INVESTIGATIONS OF
VERTEBRAL AND OTHER SKELETAL ABNORMALITIES
CAUSING LAMENESS AND
LOSS OF PERFORMANCE IN HORSES.

Collected publications on the above
and other topics submitted for
the degree of Doctor of Veterinary Science
in the University of Melbourne.

by

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PREFACE

This thesis contains a collection of publications which are submitted for examination for the degree of Doctor of Veterinary Science in the University of Melbourne. The work presented here involves a continuing investigation into the underlying causes of poor performance and gait abnormalities in horses.

Section 1 provides an introduction to the thesis by considering the concept of "wastage" or reduced performance in racehorses and highlights the role of lameness. It is clear that more sophisticated and objective techniques of assessment (eg locomotion analysis and noninvasive bone measurement) are going to be essential if the current disastrous level of economic wastage is to be effectively reduced. The ensuing sections consider the author's investigations into some of the more difficult to diagnose forms of lameness in horses.

Section 2 deals with the investigation and management of thoracolumbar conditions which pose some of the most perplexing problems faced by veterinarians today in practice. These publications attempt to shed some light into this controversial area by presenting a protocol for evaluation and diagnosis of conditions affecting the vertebral column.

Section 3 covers similar ground concerning the pelvic girdle while Section 4 considers problems affecting the stifle joint.

Section 5 deals with an emerging technique of noninvasive bone measurement, which appears to have important applications in assessing skeletal maturity and bone quality, as well as performance and exercise physiology.

Each Section is headed by a short explanatory note. Colleagues who shared in the work are recognized as co-authors and other help is acknowledged in each paper. In the case of collaborative work each section or subsection is preceded by a Statement on Share of Work to indicate my part in the planning, execution and publication of the work described.
ACKNOWLEDGEMENTS

The main theme of the candidate's scientific publications has involved aspects of fundamental and applied research in the domestic horse, *Equus caballus*. I have been fortunate in being able to specialise in a species for which I have a particular affection. However, my scientific interests have been broadly based over the last 20 years and a number of disciplines and disease conditions have been investigated. It has also been my good fortune to have had the collaboration of some excellent colleagues and co-authors in England, Sweden and Australia. It is a pleasure to acknowledge their assistance.

I wish to acknowledge a particular debt of gratitude to:­

- Richard Archer - formerly Director of the Animal Health Trust's Equine Research Station, Newmarket who was instrumental in stimulating my interest in research and publication of scientific work.

- Peter Rossdale - for his enthusiastic support and collaboration during my years working in Newmarket, U.K.

- Göran Dalin - for his assistance in developing my interest in functional anatomy and gait analysis.

- Ron McCartney - for his stimulating collaboration in my current field of research interest - noninvasive bone measurement.

- My family - firstly to Tisza my wife, who has been, and always will be, the inspiration of my life. Thanks are also due to my two daughters, Julie and Michele, for reminding me of the important things in life.
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CURRICULUM VITAE

Full Name: Leo Broof Jeffcott.
Home Address: 21 Quarbing Street, Werribee, Victoria 3030, Australia.
Date of Birth: 19 June 1942.
Place of Birth: Tiverton, Devon, England.
Nationality: British and Australian Citizenship.
Marital Status: Married with 2 daughters.

Secondary and Tertiary Education:

1961-66 Royal Veterinary College, University of London.

Postgraduate Qualifications:

1973 Part 1 Diploma in Veterinary Radiology of the Royal College of Veterinary Surgeons.
1978 F.R.C.V.S. thesis entitled "The diagnosis and treatment of some disorders of the thoracolumbar spine in the horse".

Scientific Appointments:

1967-71 Assistant Pathologist, Equine Research Station of the Animal Health Trust, Newmarket, Suffolk, U.K.
1972-77 Radiologist and Clinician, Equine Research Station.
1977-82 Head of Clinical Department, Equine Research Station.
Feb. 81 - Mar. 82 Professor of Clinical Radiology, Veterinary College, Swedish University of Agricultural Sciences, Uppsala, Sweden.
1983 - Professor of Veterinary Clinical Sciences, University of Melbourne.
1985 - Chairman of Department of Veterinary Clinical Sciences, University of Melbourne.
1985 Deputy Dean, Faculty of Veterinary Science, University of Melbourne.
1986 - Director of School of Veterinary Science's Clinic and Hospital.
Executive and Honorary Appointments:

**British Equine Veterinary Association (BEVA):**

- 1969-71 Honorary Secretary.
- 1972-74 Member of Executive Committee.
- 1974-82 Chairman, Disease Survey Section.
- 1974-75 Hon. Assistant Editor, *Equine Veterinary Journal*.
- 1978- Trustee of BEVA Trust.
- 1979-82 Vice-Chairman, Equine Research Liaison Committee.
- 1980-81 Member of Editorial Board, *Equine Veterinary Journal*.
- 1981-82 Junior Vice-President.
- 1982-83 President-Elect.
- 1982- Member of Editorial Advisory Board of *Equine Veterinary Journal*.

**British Veterinary Association (BVA):**

- 1969-71 Member of British Veterinary Association Council.
- 1977-81 Member of British Veterinary Association Council.
- 1974-80 Member of Education and Technical Development Committee.
- 1979-80 Vice-Chairman, Education and Technical Development Committee.
- 1974-79 Member of Equine Subcommittee.
- 1978-79 Chairman of the Equine Subcommittee.
- 1977 Member of Congress Scientific Programme Subcommittee.
- 1978-80 BVA representative on Bloodstock and Racehorse Industries Confederation.
- 1979-80 Member of Editorial Board of the journal "*In Practice*" (Supplement to the Veterinary Record).

**University of Melbourne:**

- 1983 - Member of Academic Board of the University, Faculty of Veterinary Science, Veterinary Clinic and Hospital Administrative Committee, School Executive, Selection Committee and Faculty Budgets Committee.
- 1984 - Member of Veterinary Research and Graduate Studies Committee, Melbourne University Veterinary Research Fund and Melbourne University Equine Research Fund.
- 1986 - Member of Board of Management of Veterinary Clinic and Hospital.
- 1987 - Member of the University's Academic Committee.

**Other Organisations:**

- 1980 Consultant to San Siro Veterinary Clinic, Milan, Italy.
- 1981- Member of Editorial Board of *British Veterinary Journal*. 
1983- Director and member of Australian Equine Research Foundation and Research Advisory Committee.
1983- Consultant to University of Sydney Postgraduate Committee.
1985- Member of Education Committee, Australian Equine Veterinary Association.
1985- Event veterinarian Equestrian Federation of Australia.

Lectureships and Awards: -

1977 Sir Frederick Hobday Memorial Lecture entitled "Back problems in the horse - a look at past, present and future progress".
1977 Thomas Irvine Memorial Chair at International Stockman's School, Agriservices Foundation, San Antonio, U.S.A.
1978 Norman Hall Medal for Research into Animal Diseases, Royal College of Veterinary Surgeons.
1978 Inaugural Bain/Fallon Memorial Lectures, Sydney, Australia.
1981 International Prize of Tierklinik Hochmoor at Equitana, Essen, Germany.
1981 Short course of lectures to Equine Practitioners Group of South African Veterinary Association.
1983 Principal speaker at 5th Bain/Fallon Memorial Lectures on "Lameness".
1983 Principal speaker at New Zealand Veterinary Association Congress, Napier.
1983 Keynote address at the AGM of the Victorian Division of the Australian Veterinary Association.
1985 Short course to New Mexico Veterinary Medical Association Annual Meeting.
1986 Principal speaker at 3 day short course for racecourse veterinarians in Kuala Lumpur at the Universiti Pertanian Malaysia.

Travel: -

1968-88 Study tours to North America on 15 occasions to attend specialist and scientific meetings. I have visited the veterinary schools of California (Davis), Florida (Gainesville), Pennsylvania (Philadelphia), Michigan (East Lansing), Missouri (Columbia), Texas (College Station), Minnesota (Minneapolis), New York (Cornell), Saskatoon (Saskatchewan) and Guelph (Ontario). Visits have also been made to Australia, New Zealand, Canada, Europe, India, South Africa and Malaysia as study tours or to attend scientific meetings.

Publications: -

1967-1988 160 scientific articles have been published on clinical medicine and pathology of the horse, equine perinatal physiology and pathology and clinical radiology in the horse; of these over 100 have appeared in refereed journals and publications. The textbook, Comparative Clinical Haematology (1977) was jointly edited with Dr. R.K. Archer.
SECTION 1

THE CONCEPT OF "WASTAGE" AND LOST PERFORMANCE IN RACEHORSES.


SECTION 1  THE CONCEPT OF "WASTAGE" AND LOST PERFORMANCE IN RACEHORSES

The reason for including the papers in this section is to set the scene for the other sections. Firstly, it includes a paper which establishes the incidence and economic wastage that occurs in British Thoroughbred racing. This is the first time that an objective assessment of the major areas of loss had been carried out. It demonstrated that in the United Kingdom in 1974 losses were incurred of least £15.2m (pounds sterling).

For horses in training, lameness was the most significant factor causing lost racing performance. The conventional means of lameness diagnosis are important in evaluating means of treatment, but are of little value in establishing objective methods of prevention. The other two review papers in this section present alternative modalities which could well be important in providing a much more objective assessment of performance potential in the racehorse.

Statement on Share of Work:

Paper 1 - In the epidemiological survey I was responsible for the overall execution, funding and organisation of the project. I also prepared the paper for publication.

Paper 2 - The review on gait analysis was prepared jointly with Göran Dalin.

Paper 3 - The review of noninvasive bone measurement was planned and written by myself with help from my postgraduate students.
General Articles

An assessment of wastage in Thoroughbred racing from conception to 4 years of age

L. B. Jeffcott
Equine Research Station of the Animal Health Trust, PO Box 5, Snailwell Road, Newmarket, Suffolk CB8 7DW

P. D. Rossdale and J. Freestone
Beaufort Cottage Stables, High Street, Newmarket, Suffolk CB8 8JS

C. J. Frank
Sunwillow Stud, Childrey, Wantage, Oxfordshire OX12 9PJ

P. F. Towers-Clark
Greatworth Manor, Banbury, Oxfordshire OX17 2DX

Summary
This paper describes a collaborative project, conducted under the auspices of the British Equine Veterinary Association’s survey section and financed by the Horserace Betting Levy Board, with the objective of collecting relevant data from breeding and racing statistics and evaluating losses (areas of wastage) that occur in the Thoroughbred racing industry. The investigation, which was carried out between 1977 and 1980, was divided into 2 parts. In Phase 1 the available statistics showed that considerable wastage existed from the time of conceiving to the appearance of the progeny on the flat, but that losses were closely consistent each year. Of the active mares in the General Stud Book for the seasons 1973 to 1979, 11.8 per cent were eliminated because no covering return was received and a further 10.1 per cent were either not covered, were covered by halfbrothers or foaled abroad. The remaining mares, which were confirmed to have been covered (ie, applicable covered returned mares) were used to base the estimates of wastage. These were failure to conceive, 22.5 per cent, aborted or had a non-surviving foal, 10.1 per cent, live progeny not named, 13.9 per cent, named animals not trained (2 to 4 years), 20.1 per cent and trained animals that did not run at 2 to 4 years, 6.2 per cent.

This gave an overall figure for wastage of 72.8 per cent. Data on the numbers of outings as well as the numbers of animals imported and exported are quoted. An estimate of the cost of these losses was made under the following categories: lost stallion fees, keep of mares, keep of unnamed foals and keep of named animals that did not run. The cumulative losses for the 1974 season and its progeny was calculated to be at least £15.2 million.

Phase 2 examined more specifically some of the areas of wastage caused by breeding losses and the reasons for an unsatisfactory number of racing appearances. The most substantial reason for not competing or competing less than the average number of times was horses showing little or no ability to race. In a survey of 762 horses, 26.5 per cent did not race up to the age of 4 years; of these just over one third were being kept as ‘store’ animals for National Hunt racing. The final part of the survey examined the veterinary reasons for wastage. In 314 horses in Newmarket, lameness was the most significant factor. There was an incidence of lameness of 53 per cent at some periods during the season and in 20 per cent of cases the lameness was sufficient to prevent racing afterwards.

Introduction
THE British and Irish Thoroughbred racing and breeding industry is a multimillion pound concern, employing thousands of people and giving interest, pleasure and enjoyment to many more. There are few who would question the status and importance of this international industry. Its success has been achieved through over 200 years experience and has involved massive expense and careful breeding selection. It is, of course, not expected that every Thoroughbred mare in the General Stud Book will produce a classic winner, but one wonders what sort of chances a random mating has of producing a live foal that will eventually see a racecourse.

There have been few detailed reports on the incidence and causes of wastage from conception to maturity in racehorses. Towers-Clark (1980) summarised the data on the English Thoroughbred from the General Stud Book 1861 to 1969, which demonstrated a steady increase in the number of mares registered, but comparatively little change in the percentage of in-foal mares or live foals during this period. Rossdale and Ricketts (1980) took Towers-Clark’s findings and extended the analysis to 1979. Laing and Leech (1975) reported on a survey of fertility in 852 Thoroughbreds and found that 69.7 per cent died within 6 weeks of birth. Rossdale (1972) drew attention to the apparent poor breeding performance of the winners of the Epsom Oaks when they retired to stud. An analysis of the percentage live single foals of 26 Oaks winners, compared with the performance of 52 mares selected at random which had
never won a race, suggested that there was a marked decline in relative performance: O’Sullivan (1980) carried out a study of the effects of dams’ age on progeny performance in which he showed that the progeny of older mares were significantly less successful than progeny of mares less than 16 years old. He suggested there might be genetic, environmental and management factors involved.

Platt (1979) carried out an extensive survey (1968 to 1973) into the incidence and causes of perinatal problems in foals on 27 studs farms. The study emphasised the importance of twin pregnancies as a source of wastage. Maternal age had an influence on the frequency of perinatal mortality, premature lactation and placental retention. Older mares also tended to have more foals with extensor and flexor limb deformities. Platt also noticed that about 60 per cent of foals born in the survey eventually raced on the flat. Of the 40 per cent that did not, some were known to have been exported and a few may have raced under National Hunt Rules, but probably the majority were of little value as potential racehorses. P. Willett (personal communication 1981) conducted a survey on 2 racehorses in Australia and the veterinary reasons for their accidents.

Losses (ie, wastage) that occur from conception to the age of 4 years had foals which eventually raced.

The project was carried out by the Record and Bloodstock and Racehorse Industries Confederation, between April 1977 and November 1980.

Table 1: Details of 20 stallions selected from the Statistical Record 1978 with the numbers of runners, winners and stakes earned by their progeny

<table>
<thead>
<tr>
<th>Stallion</th>
<th>Number of Total stakes earned (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>runners Runners</td>
<td></td>
</tr>
<tr>
<td>1 Petingo</td>
<td>25.000</td>
</tr>
<tr>
<td>2 Green God</td>
<td>30.000</td>
</tr>
<tr>
<td>3 Habitat</td>
<td>33.000</td>
</tr>
<tr>
<td>4 Deming Do</td>
<td>35.000</td>
</tr>
<tr>
<td>5 Tribal Chief</td>
<td>38.000</td>
</tr>
<tr>
<td>6 Blakeney</td>
<td>39.000</td>
</tr>
<tr>
<td>7 Crowned Prince</td>
<td>40.000</td>
</tr>
<tr>
<td>8 Huntercombe</td>
<td>42.000</td>
</tr>
<tr>
<td>9 Lord Gayle</td>
<td>44.000</td>
</tr>
<tr>
<td>10 Tudor Melody</td>
<td>46.000</td>
</tr>
<tr>
<td>11 Captains Gig</td>
<td>48.000</td>
</tr>
<tr>
<td>12 Manacle</td>
<td>50.000</td>
</tr>
<tr>
<td>13 Reform</td>
<td>52.000</td>
</tr>
<tr>
<td>14 Ridan</td>
<td>54.000</td>
</tr>
<tr>
<td>15 Roan Rocket</td>
<td>56.000</td>
</tr>
<tr>
<td>16 Laser Light</td>
<td>58.000</td>
</tr>
<tr>
<td>17 The Parson</td>
<td>60.000</td>
</tr>
<tr>
<td>18 Places of Eight</td>
<td>62.000</td>
</tr>
<tr>
<td>19 Royal Highway</td>
<td>64.000</td>
</tr>
<tr>
<td>20 Songedor</td>
<td>66.000</td>
</tr>
</tbody>
</table>

Materials and methods

PHASE 1 PROTOCOL — OVERALL ESTIMATE OF WASTAGE

STATISTICAL DATA

This part of the project involved the monitoring of the available statistics on Thoroughbred breeding and racing performance and was obtained from the computer files of the General Stud Book and the Statistical Record from Weatherby’s at Wellingborough for the seasons 1977 to 1979. Information already on file back to 1973 was also obtained. A list of the horses in training in Ireland was obtained from the Irish Turf Club over a similar period.

The data was examined under the following categories.

1. Active mares — Mares for which a stud book covering certificate counterfoil had been received
2. Returned mares — Mares for which a stud book return was received
3. Applicable covered returned mares — Excludes those mares not returned, not covered, covered by halfbreed or foaled abroad
4. Live produce — To go forward for naming
5. Produce actually named
6. Produce eligible to go into training
7. Horses that ran at any age (up to 4 years)

FINANCIAL CONSIDERATIONS

1974 was taken as the base year for this part of the survey; the mares covered in this year produced the 2-year-old runners of 1976. A total of 20 stallions were chosen from the Statistical Record based on the number of races won in 1978. The numbers selected were 1 to 5, 26 to 30, 76 to 80 and 177 to 181 (Table 1). The details of the mares covered and the resulting produce were taken from the Return of Mares for 1974. The names of resulting offspring were traced in the General Stud Book and the racing record of these progeny was extracted from Raceform for each of the years 1976, 1977 and 1978.
TABLE 2: A breakdown of the active mares in the General Stud Book and their covering returns for the seasons 1973 to 1979

<table>
<thead>
<tr>
<th>Year</th>
<th>Active mares</th>
<th>Returned mares</th>
<th>No returns</th>
<th>Not covered, covered by halfbreds, foaled abroad</th>
<th>Covered and a GSB return received*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Number %</td>
<td>Number %</td>
<td>Number %</td>
<td>Number %</td>
</tr>
<tr>
<td>1973</td>
<td>16124</td>
<td>14588 90.5</td>
<td>1536 9.5</td>
<td>1299 8.1</td>
<td>13290 82.4</td>
</tr>
<tr>
<td>1974</td>
<td>17738</td>
<td>16006 90.2</td>
<td>1733 9.8</td>
<td>1576 8.9</td>
<td>14429 81.3</td>
</tr>
<tr>
<td>1975</td>
<td>18404</td>
<td>15998 86.9</td>
<td>2407 13.1</td>
<td>1895 11.5</td>
<td>12337 75.2</td>
</tr>
<tr>
<td>1976</td>
<td>17205</td>
<td>14782 85.9</td>
<td>2423 14.1</td>
<td>1845 10.7</td>
<td>12937 75.2</td>
</tr>
<tr>
<td>1977</td>
<td>16478</td>
<td>14454 87.7</td>
<td>2023 12.3</td>
<td>1895 11.5</td>
<td>12350 77.4</td>
</tr>
<tr>
<td>1978</td>
<td>15951</td>
<td>14124 88.5</td>
<td>1827 11.4</td>
<td>1774 11.1</td>
<td>12157 76.2</td>
</tr>
<tr>
<td>1979</td>
<td>15985</td>
<td>14024 87.9</td>
<td>1931 12.1</td>
<td>1867 11.7</td>
<td>11953 78.1</td>
</tr>
<tr>
<td>1973-79</td>
<td>117,855</td>
<td>103,975 88.2</td>
<td>13880 1.8</td>
<td>11953 10.1</td>
<td>92223 78.1</td>
</tr>
</tbody>
</table>

* Applicable covered returned mares
GSB General Stud Book

TABLE 3: Outcome of covering and pregnancy of applicable covered returned mares from 1973 to 1979

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Barren</td>
<td>3037</td>
<td>3436</td>
<td>3215</td>
<td>3108</td>
<td>2747</td>
<td>2791</td>
<td>2413</td>
</tr>
<tr>
<td>Slipped</td>
<td>603</td>
<td>653</td>
<td>610</td>
<td>631</td>
<td>642</td>
<td>589</td>
<td>615</td>
</tr>
<tr>
<td>Slipped twins and dead twins</td>
<td>93</td>
<td>119</td>
<td>88</td>
<td>76</td>
<td>82</td>
<td>108</td>
<td>94</td>
</tr>
<tr>
<td>Dead foals</td>
<td>237</td>
<td>219</td>
<td>268</td>
<td>244</td>
<td>231</td>
<td>231</td>
<td>225</td>
</tr>
<tr>
<td>Died since birth</td>
<td>379</td>
<td>441</td>
<td>444</td>
<td>349</td>
<td>377</td>
<td>325</td>
<td>372</td>
</tr>
<tr>
<td>Twins</td>
<td>29</td>
<td>30</td>
<td>18</td>
<td>16</td>
<td>19</td>
<td>14</td>
<td>26</td>
</tr>
<tr>
<td>Colts</td>
<td>3680</td>
<td>4306</td>
<td>4652</td>
<td>4253</td>
<td>3969</td>
<td>4126</td>
<td>4184</td>
</tr>
<tr>
<td>Fillies</td>
<td>4487</td>
<td>4932</td>
<td>4791</td>
<td>4260</td>
<td>4221</td>
<td>4069</td>
<td>4228</td>
</tr>
<tr>
<td>Others</td>
<td>745</td>
<td>396</td>
<td>214</td>
<td>–</td>
<td>252</td>
<td>87</td>
<td>–</td>
</tr>
<tr>
<td>Accountable produce to go forward for naming</td>
<td>8941</td>
<td>9662</td>
<td>9675</td>
<td>8528</td>
<td>8481</td>
<td>8296</td>
<td>8427</td>
</tr>
</tbody>
</table>

Living twins counted as one produce
– Not recorded

Method of assessing financial losses

For the purpose of this study, it was assumed that the cumulative losses occurred in the following stages.
1. Lost stallion fees
2. Keep charges in respect of barren and uncovered mares for 12 months.
3. Keep charges in respect of foals not named for 12 months.
4. Keep charges for 2 years in respect of those foals named, but that did not run.
No allowance was made for insurance, for depreciation of interest on capital or for any other incidental expense.

PHASE 2 PROTOCOL — SPECIFIC AREAS OF LOST PRODUCTION

Phase 2 involved a more in-depth follow-up on smaller numbers of horses of the more specific areas of wastage and the veterinary reasons for their occurrence. This part of the project was subdivided into 3 sections.

Survey A — A random sampling of 400 mares covered in 1974 was provided from Weatherby's computer files and questionnaires were sent out to the owners/breeders.

Survey B — Questionnaires were sent out to trainers/breeders of 1000 named horses of the 1975 crop in order to evaluate their racing performance.

Survey C — Questionnaires were supplied to 6 training stables in Newmarket and regular visits were made to assess the health and training progress and racing statistics of 314 flat racehorses in 1980.

Results

PHASE 1 — OVERALL ESTIMATE OF WASTAGE

STATISTICAL DATA

Breeding statistics

The results of numbers of mares on file 1973-1979 and the breakdown into their various categories is summarised in Table 2. Of the active mares a General Stud Book covering return was not received in a mean 0.8 per cent cases and a further 10.1 per cent were not covered, covered by halfbreds or foaled abroad.

The results of breeding the applicable covered returned mares is shown in Table 3. These data have been summarised in Table 4 to show the percentage losses at various stages. The main reasons for the breeding losses were failure to conceive, abortion, twinning or giving birth to a dead foal (ie, stillbirth). A mean figure of 2.93 per cent of foals died after birth. The overall losses for the 1973 to 1979 seasons were calculated at 32.57 per cent.

Although there did not seem to be much variation in the results of breeding on an annual basis, there were considerable...
TABLE 4: Mean percentage losses for 1973 to 1979 incurred at various stages in applicable covered returned mares

<table>
<thead>
<tr>
<th>Category</th>
<th>Mean % applicable covered returned mares 1973-1979</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barren</td>
<td>22.50</td>
</tr>
<tr>
<td>Aborted</td>
<td>4.62</td>
</tr>
<tr>
<td>Aborted or had stillborn twins</td>
<td>0.72</td>
</tr>
<tr>
<td>Dead foal (ie, stillbirth)</td>
<td>1.80</td>
</tr>
<tr>
<td>Died since birth</td>
<td>2.93</td>
</tr>
<tr>
<td>Live produce to go forward to naming</td>
<td>67.36</td>
</tr>
</tbody>
</table>

 Differences seen according to the age of the mare. A progressive decline in live foal rate was seen from a mean figure of 75 per cent in the 4-year-old mares to 48 per cent in mares of 20 years and over (Fig 1).

An analysis of foaling dates was carried out (Fig 2) which showed a peak foaling time in mid April to May for the seasons 1977 to 1978.

Naming statistics

The numbers of live foals born and those that were actually named were obtained from the monthly Weatherby's computer files for naming/training/racing and are summarised in Table 5a.

The losses in this section were smaller than those recorded during breeding but accounted for an overall loss of 20.7 per cent of the accountable produce eligible for naming. In terms of the applicable covered returned mares this meant there was a percentage loss of 13.9 per cent over the years 1973 to 1975. Most horses were named by the time they were 2 years old, although some were not named until they were 4 years (Table 5b). These animals (ie, 12.2 per cent) were probably those kept as "store" horses for National Hunt racing.

Training and racing statistics

The training statistics were derived from monthly naming/training/racing reports for horses aged 2 to 4 years during the...
TABLE 6: Numbers of named foal crops that were actually named up to the end of 1979

<table>
<thead>
<tr>
<th>Accountable produce for naming</th>
<th>Number of horses named</th>
<th>Number of imported foal crops eligible for training</th>
<th>Total of original foal crops eligible for training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td>8941</td>
<td>7556</td>
<td>451</td>
</tr>
<tr>
<td>1974</td>
<td>9692</td>
<td>8115</td>
<td>536</td>
</tr>
<tr>
<td>1975</td>
<td>9875</td>
<td>8261</td>
<td>621</td>
</tr>
<tr>
<td>Total</td>
<td>28278</td>
<td>24032</td>
<td>1608</td>
</tr>
</tbody>
</table>

TABLE 6b: Further breakdown of the naming statistics for the 1974, 1975 and 1976 crops

<table>
<thead>
<tr>
<th>Stage of naming</th>
<th>1974 crop</th>
<th>1975 crop</th>
<th>1976 crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Named by 2 years of age</td>
<td>6005</td>
<td>5347</td>
<td></td>
</tr>
<tr>
<td>Named during ensuing 12 months</td>
<td></td>
<td>738</td>
<td>661</td>
</tr>
<tr>
<td>Named by 3 years of age</td>
<td>6825</td>
<td>6743</td>
<td>6008</td>
</tr>
<tr>
<td>Named during ensuing 12 months</td>
<td>754</td>
<td>897</td>
<td></td>
</tr>
<tr>
<td>Total named</td>
<td>7579</td>
<td>7640</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 6c: Numbers of named animals to go into training and race up to 4 years of age, based on the numbers in the original foal crop

<table>
<thead>
<tr>
<th>Category</th>
<th>1973 crop</th>
<th>1974 crop</th>
<th>1975 crop</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of original foal crop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>named and eligible for training</td>
<td>7205</td>
<td>7529</td>
<td>7640</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Number of horses ever to go into training at 2 to 4 years</td>
<td>NK</td>
<td>NK</td>
<td>4754</td>
<td>62.2</td>
<td></td>
</tr>
<tr>
<td>Number ever to race as 2-, 3- or 4-year-olds</td>
<td>NK</td>
<td>NK</td>
<td>3867</td>
<td>50.6</td>
<td></td>
</tr>
<tr>
<td>Number exported (up to 4 years of age)</td>
<td>1267</td>
<td>902</td>
<td>941</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>Number died (up to 4 years of age)</td>
<td>194</td>
<td>293</td>
<td>269</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td></td>
<td></td>
<td></td>
<td>Not known</td>
<td></td>
</tr>
</tbody>
</table>

It can be seen from these data that only 62.2 per cent of horses went into flatrace training and only 50.6 per cent actually raced as a 2-, 3- or 4-year-old. Based on the original number of applicable covered returned mares this gave an overall figure of wastage of 20.1 per cent that did not go into training and 6.2 per cent of trained horses that did not race. A detailed breakdown based on the numbers of horses still eligible for training at the end of their 4-year-old season is given in Table 7. These results also showed the considerable losses incurred by horses either not being trained or not racing.

The details of the appearances on the racecourse for the 1979 season are shown in Table 8. It shows the numbers of first outings on the racecourse for 2-, 3- and 4-year-olds, according to the time of the season. It also includes the cumulative totals and details of those making their first racecourse appearance. There were still 32 animals which raced for the first time as 4-year-olds in November 1979.

The dates (recorded half-monthly) when 2-year-olds first ran in the 1978 and 1979 seasons are shown in Fig 3 with a peak in May/June. The total number of races run by 2-year-olds in the season 1977 and 1978 showed that about 400 animals raced only once in the season and that less than 100 raced 10 times or more (Fig 4). The cumulative total of races run by 2-year-olds for the whole season was just over 2500. The more exact breakdown of the training and running details of the 1974 crop from November 1977 to November 1979 are given in Table 7. The small difference in the number of 4-year-olds compared to that shown in Table 8 is accounted for by horses that were exported.

TABLE 7: Figures for racing and training, based on the numbers of horses eligible for training at the end of the 4-year-old season

<table>
<thead>
<tr>
<th>Category</th>
<th>1973 crop</th>
<th>1974 crop</th>
<th>1975 crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of horses living and eligible for training at the end of the 4 year season</td>
<td>NK</td>
<td>NK</td>
<td>6530</td>
</tr>
<tr>
<td>Number trained as 2-, 3- or 4-year-olds</td>
<td>NK</td>
<td>NK</td>
<td>4240</td>
</tr>
<tr>
<td>Number trained at 2 years</td>
<td>NK</td>
<td>NK</td>
<td>9089</td>
</tr>
<tr>
<td>Number trained at 3 years</td>
<td>NK</td>
<td>NK</td>
<td>3339</td>
</tr>
<tr>
<td>Number trained at 4 years</td>
<td>NK</td>
<td>2345</td>
<td>2494</td>
</tr>
<tr>
<td>Number raced as 2-, 3- or 4-year-olds</td>
<td>NK</td>
<td>NK</td>
<td>4315</td>
</tr>
<tr>
<td>Number raced at 2 and 3 years</td>
<td>NK</td>
<td>NK</td>
<td>3378</td>
</tr>
<tr>
<td>Number raced at 2 years</td>
<td>NK</td>
<td>NK</td>
<td>2756</td>
</tr>
<tr>
<td>Number raced at 3 years</td>
<td>NK</td>
<td>2423</td>
<td>2500</td>
</tr>
<tr>
<td>Number raced at 4 years</td>
<td>NK</td>
<td>1211</td>
<td>1300</td>
</tr>
</tbody>
</table>

FINANCIAL CONSIDERATIONS

Baseline data

A total of 857 mares were covered by the 20 stallions selected and they produced 540 (63 per cent) live foals, of which 443 were named and 326 ran as 2-, 3- or 4-year-olds. This latter figure represents 73.6 per cent of all named foals, 60.4 per cent of all live foals and 38 per cent of the mares covered (Table 9).

In 1974 the Statistical Record recorded a total of 1175 stallions that were used at stud. However, it is unreasonable to suppose that all these stallions and mares were used for the production of Thoroughbred racehorses. The Statistical Record reveals that approximately 200 stallions are responsible for the runners in flat racing in any one season. In 1976 there were 2201 2-year-old runners so that approximately 7000 mares would be required to be covered to produce these runners. This would give an average of 35 mares per stallion.

However, some consideration must be given to those mares not covered on the assumption that a mare is rested once every flat season from October 1977 to November 1979. The numbers of horses eligible for training from the original crop and their summarised racing statistics are shown in Table 6. It was only possible to check the complete racing career of the 1975 crop but some definitive data were available for the 2- and 3-year-olds for the seasons 1973, 1974, and 1976 and 1977.
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TABLE 8: Details of first racecourse appearances of 2-, 3- and 4-year-olds for the 1979 season

<table>
<thead>
<tr>
<th></th>
<th>2-year-olds</th>
<th>3-year-olds</th>
<th>4-year-olds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st runs</td>
<td>Total</td>
<td>1st runs</td>
</tr>
<tr>
<td>To 31 March</td>
<td>101</td>
<td>101</td>
<td>290</td>
</tr>
<tr>
<td>1-16 April</td>
<td>146</td>
<td>553</td>
<td>233</td>
</tr>
<tr>
<td>17-30 April</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-16 May</td>
<td>222</td>
<td>298</td>
<td></td>
</tr>
<tr>
<td>17-31 May</td>
<td>260</td>
<td>936</td>
<td>1801</td>
</tr>
<tr>
<td>1-16 June</td>
<td>268</td>
<td>214</td>
<td></td>
</tr>
<tr>
<td>17-30 June</td>
<td>177</td>
<td>1381</td>
<td>107</td>
</tr>
<tr>
<td>1-16 July</td>
<td>176</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>17-31 July</td>
<td>141</td>
<td>1698</td>
<td>52</td>
</tr>
<tr>
<td>1-16 August</td>
<td>161</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>17-31 August</td>
<td>193</td>
<td>2052</td>
<td>56</td>
</tr>
<tr>
<td>1-16 September</td>
<td>153</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>17-30 September</td>
<td>121</td>
<td>2326</td>
<td>27</td>
</tr>
<tr>
<td>1-16 October</td>
<td>141</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>17-31 October</td>
<td>92</td>
<td>2559</td>
<td>16</td>
</tr>
<tr>
<td>1-16 November</td>
<td>43</td>
<td>2802</td>
<td>13</td>
</tr>
</tbody>
</table>

5 years. A further 1750 mares would be required to produce the total flat racehorse population. Therefore the number of mares required to produce the total flat racehorse population was assumed to be 8750 and they produced a total of 4410 foals.

The Statistical Record gives an actual total of 18,305 mares which produced live foals. Thus the balance of 9555 mares produced 5535 foals. It must be assumed that these foals were produced either for National Hunt racing or for showing purposes, being the produce of premium stallions. In any event, it is assumed for the purpose of this survey that these foals were produced by hobby breeders and that their cost is therefore absorbed within the other activities of those breeders.

In this connection, it is relevant that in 1974 in England and Ireland, there were 6456 individuals recorded as owning one mare only and a further 1605 as owning only 2 mares.
TABLE 9: Summary of the returns for the mares covered by 20 stallions in 1974

<table>
<thead>
<tr>
<th>Stallion</th>
<th>Total mares covered</th>
<th>Breeding and perinatal losses</th>
<th>Named animals that did not</th>
<th>Twins</th>
<th>Stillborn</th>
<th>Aborted</th>
<th>Barren</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petingo</td>
<td>49</td>
<td></td>
<td></td>
<td>86.11</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Green God</td>
<td>68</td>
<td></td>
<td></td>
<td>90.47</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Habitat</td>
<td>50</td>
<td></td>
<td></td>
<td>86.63</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Derring Do</td>
<td>44</td>
<td></td>
<td></td>
<td>84.26</td>
<td>2</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Tribal Chief</td>
<td>36</td>
<td></td>
<td></td>
<td>67.64</td>
<td>2</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>Blakeney</td>
<td>44</td>
<td></td>
<td></td>
<td>92.95</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Crowned Prince</td>
<td>37</td>
<td></td>
<td></td>
<td>93.76</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Huntercombe</td>
<td>43</td>
<td></td>
<td></td>
<td>80.95</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Lord Gayle</td>
<td>45</td>
<td></td>
<td></td>
<td>81.39</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tudor Melody</td>
<td>44</td>
<td></td>
<td></td>
<td>71.42</td>
<td>1</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Captains Gig</td>
<td>53</td>
<td></td>
<td></td>
<td>78.26</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Manacle</td>
<td>45</td>
<td></td>
<td></td>
<td>90.89</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Reform</td>
<td>41</td>
<td></td>
<td></td>
<td>83.33</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Ridan</td>
<td>42</td>
<td></td>
<td></td>
<td>86.84</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Roan Rocket</td>
<td>45</td>
<td></td>
<td></td>
<td>85.71</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Laser Light</td>
<td>38</td>
<td></td>
<td></td>
<td>63.33</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>The Person</td>
<td>26</td>
<td></td>
<td></td>
<td>78.26</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Pieces of Eight</td>
<td>44</td>
<td></td>
<td></td>
<td>82.92</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Royal Highway</td>
<td>47</td>
<td></td>
<td></td>
<td>71.05</td>
<td>1</td>
<td>4</td>
<td>12</td>
</tr>
</tbody>
</table>

TABLE 10: Details of the nomination fees for 1973 and losses incurred in 1973 in 20 stallions in 4 categories

<table>
<thead>
<tr>
<th>Stallions</th>
<th>Number of &quot;no foal&quot; mares</th>
<th>Nomination fee (£)</th>
<th>Lost fees (£)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petingo</td>
<td>21 from 49</td>
<td>4000</td>
<td>84,000</td>
<td>92,000</td>
</tr>
<tr>
<td>Green God</td>
<td>4 from 68</td>
<td>1500</td>
<td>6000</td>
<td>7500</td>
</tr>
<tr>
<td>Habitat</td>
<td>17 from 50</td>
<td>4000</td>
<td>68,000</td>
<td>72,000</td>
</tr>
<tr>
<td>Derring Do</td>
<td>29 from 44</td>
<td>4000</td>
<td>120,000</td>
<td>160,000</td>
</tr>
<tr>
<td>Tribal Chief</td>
<td>19 from 36</td>
<td>1100</td>
<td>20,900</td>
<td>31,900</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>81 from 247</td>
<td>(32.8%)</td>
<td>(28.8%)</td>
<td>298,900</td>
</tr>
<tr>
<td><strong>Category 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blakeney</td>
<td>10 from 44</td>
<td>1000</td>
<td>10,000</td>
<td>11,000</td>
</tr>
<tr>
<td>Crowned Prince</td>
<td>4 from 37</td>
<td>3500</td>
<td>NFNF</td>
<td>14,000</td>
</tr>
<tr>
<td>Huntercombe</td>
<td>12 from 43</td>
<td>2700</td>
<td>32,400</td>
<td>35,100</td>
</tr>
<tr>
<td>Lord Gayle</td>
<td>3 from 45</td>
<td>850</td>
<td>NFNF</td>
<td>1590</td>
</tr>
<tr>
<td>Tudor Melody</td>
<td>19 from 44</td>
<td>9800</td>
<td>186,200</td>
<td>196,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>48 from 213</td>
<td>(22.5%)</td>
<td>(22.5%)</td>
<td>245,150</td>
</tr>
<tr>
<td><strong>Category 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Captains Gig</td>
<td>17 from 53</td>
<td>750</td>
<td>12,750</td>
<td>13,500</td>
</tr>
<tr>
<td>Manacle</td>
<td>16 from 45</td>
<td>650</td>
<td>10,400</td>
<td>11,050</td>
</tr>
<tr>
<td>Reform</td>
<td>21 from 41</td>
<td>2300</td>
<td>48,300</td>
<td>50,600</td>
</tr>
<tr>
<td>Ridan</td>
<td>2 from 42</td>
<td>2300</td>
<td>27,600</td>
<td>29,900</td>
</tr>
<tr>
<td>Roan Rocket</td>
<td>1 from 45</td>
<td>1000</td>
<td>NFNF</td>
<td>1000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>57 from 226</td>
<td>(25.2%)</td>
<td>(25.2%)</td>
<td>100,050</td>
</tr>
<tr>
<td><strong>Category 4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laser Light</td>
<td>10 from 38</td>
<td>150</td>
<td>1500</td>
<td>1650</td>
</tr>
<tr>
<td>The Parson</td>
<td>26</td>
<td>300</td>
<td>live foal</td>
<td></td>
</tr>
<tr>
<td>Pieces of Eight</td>
<td>15 from 44</td>
<td>1500</td>
<td>22,500</td>
<td>24,000</td>
</tr>
<tr>
<td>Royal Highway</td>
<td>22 from 47</td>
<td>60</td>
<td>1320</td>
<td>1380</td>
</tr>
<tr>
<td>Songedor</td>
<td>8 from 16</td>
<td>400</td>
<td>3200</td>
<td>3600</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>56 from 171</td>
<td>(32.2%)</td>
<td>(32.2%)</td>
<td>28,520</td>
</tr>
</tbody>
</table>

**NFNF** No foal, no fee

**Stallion nomination fees**

An evaluation of the total lost nomination fees for the 20 stallions in the survey is shown in Table 10. The loss figure has been adjusted to take into account the individual nomination terms. The nomination price was based either on the public
auction figure or obtained from the managing agents. The total was calculated to be £672,620 or an average loss of £336.31 per stallion. The figures also showed that approximately 29 per cent of a stallion's potential income was lost in any one season. However, in order to evaluate the loss over 200 active stallions a moving average has been used to produce the following figures:

(a) In respect of the first 30 stallions the average of Categories 1 and 2 which gave an average of £54,405 or a total of £1.6 million.
(b) In respect of stallions 31 to 80 the average of Categories 2 and 3 which produced an average of £34,520 per stallion or a total of £1.7 million.
(c) In respect of stallions 81 to 200 the average of Categories 3 and 4 which is £12,857 per stallion or a total of £1.5 million.

It was calculated therefore, that the total value of nominations lost as a result of fees becoming payable but no foal being produced was £4.8 million. This figure takes into account the different terms for stallion nominations.

Keep charges

Keep charges were based on the Newmarket stud owners' rates. Although this figure was greater than the cost of keeping a mare on a private studfarm, it did take into account various other costs such as insurance, veterinary fees, etc, which are not included elsewhere in the paper.

In 1974 these charges were £2.50 a day for barren mares and £3.20 a day for foaling mares. The total cost of keeping the project figure of 1750 barren mares for one year was £1.6 million. In respect of the 7000 mares covered, the figure was divided as follows:

(a) Thirty-seven per cent of 2590 mares that produced no live foal — £2.4 million.
(b) Of the remaining 4410 mares, 39.6 per cent produced foals that did not run. The cost of 1750 of these was calculated at £3.20 a day and the total cost was £2.0 million.

Cost of keeping foals that did not run

It has been calculated above that the 7000 mares covered produced 1750 foals that did not run. Of all these, 28 per cent were not named and it is assumed that the loss in respect of these foals was confined to one year's keep (ie, 490 at £27.50 per week) — £0.7 million.

For the remaining 1260 foals that were named and did not run an additional one year's keep was calculated at £30 per week. The cost was therefore 1260 x £27.50 per week = £1.8 million and 1260 x £30.00 per week = £1.9 million.

**TABLE 11: Results of questionnaire replies of the 400 randomly selected mares covered in 1974**

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live foals named</td>
<td>180</td>
<td>48.6</td>
</tr>
<tr>
<td>Live foals named — colts</td>
<td>102</td>
<td>27.5</td>
</tr>
<tr>
<td>Live foals named — fillies</td>
<td>78</td>
<td>21.1</td>
</tr>
<tr>
<td>Live foals not named</td>
<td>41</td>
<td>11.1</td>
</tr>
<tr>
<td>Foals exported</td>
<td>6</td>
<td>1.6</td>
</tr>
<tr>
<td>No return</td>
<td>44</td>
<td>11.9</td>
</tr>
<tr>
<td>Barren</td>
<td>64</td>
<td>17.4</td>
</tr>
<tr>
<td>Sipped</td>
<td>17</td>
<td>4.6</td>
</tr>
<tr>
<td>Dead foals</td>
<td>16</td>
<td>4.3</td>
</tr>
<tr>
<td>Foals died*</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>370</td>
<td>100.0</td>
</tr>
</tbody>
</table>

* Including one dead twin

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**Total costs**

The total costs incurred in respect of the mares and their resulting foals which did not run could be summarised as follows.

(a) Lost stallion fees — £4.8 million.
(b) Cost of keeping mares not covered — £1.6 million.
(c) Cost of keeping barren mares — £2.4 million.
(d) Cost of keeping mares that produce non-runners — £2.0 million.
(e) Cost of keeping foals that were not named — £0.7 million.
(f) Cost of keeping named foals that did not run — £3.7 million.

An overall total of £15.2 million.

**PHASE 2 — SPECIFIC AREAS OF LOST PRODUCTION**

**Survey A — Breeding and perinatal losses**

Of the 400 mares selected at random by the Weatherby's computer, there were 11 born abroad, 8 mares died, 4 mares were exported before foaling, 4 mares were non-Thoroughbred, covered by non-Thoroughbred or untraceable, 2 were foreing mares imported for covering and one name was duplicated. This left 370 mares from which information on the 1974 covering season was obtained by questionnaires (Table 11).

In the case of live foals not named (11.1 per cent) and no returns (11.9 per cent), the master copy of the General Stud Book was checked at Weatherby's. With very few exceptions, which were corrected on the printout, no names had ever been registered in the case of the first category and no produce recorded in the case of no returns. Questionnaires were despatched to breeders in the case of horses registered as born but not named. From 23 replies received, 17 were shown as died or destroyed. Five were too small or kept for general riding and only one was retained as a "store" for National Hunt Racing. In the case of no returns, replies to questionnaires were invariably that the mare was barren, aborted or the foal was dead/died/destroyed. The survey confirms that no returns were an important area of wastage and fully endorsed the decision of the Thoroughbred Breeders' Association that no returns should be recorded as barren in assessing fertility figures.

**Survey B — Losses in horses in training**

The first stage in this survey was to divide the random sample of 1000 horses into their various racing categories. These ranged from those that had completed a full racing career extending over 3 seasons to those that did not race at all. The category of each horse was assessed and the accumulated number of races run listed (Table 12). It was found that 154 names from the Weatherby's computer printout were duplicated and 2 incorrectly shown. There were 65 foreign mares imported for covering and one name was shown as an unknown from which no information could be obtained. The category of each horse was assessed and the accumulated number of races run listed (Table 12). It was found that 154 names from the Weatherby's computer printout were duplicated and 2 incorrectly shown. There were 65 foreign mares imported for covering and one name was shown as an unknown from which no information could be obtained. The inclusion of the 54 horses that raced abroad but exclusion of the other 3 categories left a working base of 762 horses.

The summary of the number of horses to race at the various ages is shown in Categories A to I in Table 12, together with the number of races run. The total number of stallions involved in this group was 347, comprising every section of the Thoroughbred spectrum. The maximum number of horses sired by any one stallion was 10.
The breakdown between colts (including geldings) and fillies is shown in Table 13. The highest number of runs recorded in any category was 133 (17.45 per cent) in fillies that raced at 2 and 3 years (Category B). It is reasonable to assume that the majority of fillies that raced up to 3 years had completed the requirements of their owners and were then retired to stud. Most of the 54 horses that raced abroad completed a satisfactory race rate that was higher than those at home. There was a total of 274 horses (35.96 per cent) that raced for at least 2 seasons and a further 152 horses (19.95 per cent) raced at either 2 or 3 years.

The horses in Category A (13.78 per cent) were the most consistent performers and they ran an average 17.48 races per horse over the 3 seasons for 2 to 4 years of age. It was then necessary to find out some of the causes of wastage in the less successful categories of horses and this information was obtained from questionnaires sent out to trainers/owners. The response to this retrospective survey was excellent as it should be borne in mind that a fair proportion of horses/owners were no longer traceable.

The details were as follows. (1) Of 32 horses in Category B that ran less than 5 times over 2 seasons as 2- and 3-year-olds 21 replies (66 per cent) were received (Table 14). (2) Of 113 horses in Category E that raced only as 2-year-olds 81 replies (72 per cent) were received. (3) Of 202 horses in Category H that were named, but never raced at all as 2-, 3- or 4-year-olds, 121 replies (60 per cent) were received (Table 15). The major causes of wastage in animals that raced less than 5 times in their first 2 seasons and did not race at all as 4-year-olds were a lack of ability and unsoundness, while for animals that only raced as 2-year-olds many were exported (45.6 per cent) and a further 32.1 per cent showed little racing ability (Table 14). The most frequent reason that animals did not race at all up to the age of 4 years was because they were kept as "stores" for National Hunt racing. A total of 49 such horses were recorded out of 121 animals (40.5 per cent) in Category H. From this figure an incidence of 10.8 per cent of the total horses in the survey kept as "stores" can be calculated. The frequency of injury and unsoundness in this group was much lower and only 2 fillies were kept for breeding without racing at all.

Survey C — Veterinary reasons for losses in training

The health and training progress was surveyed in 314 horses from 6 stables during 1980 in Newmarket, Suffolk (Table 16). The reasons for losses from training were defined under the following headings:

1. Lameness — Resulting in permanent disability, a reduction

| TABLE 13: Breakdown of horses in training according to their sex and the number of races run |
|---------------------------------|---------|-----------|-----------|-----------|---------|
| Category                        | Total number | Total runs | Average runs | Total number | Total runs | Average runs |
| A — Raced for 3 seasons         | 71       | 1206      | 17.0        | 34         | 651      | 19.2        |
| B — Raced at 2 and 3 years     | 82       | 804       | 9.8         | 133        | 1217     | 9.2         |
| C — Raced at 2 and 4 years     | 2        | 12        | 6.0         | 1          | 2        | 2.0         |
| D — Raced at 3 and 4 years     | 10       | 86        | 8.6         | 8          | 103      | 12.9        |
| E — Raced at 2 years only      | 51       | 236       | 4.6         | 62         | 262      | 4.2         |
| F — Raced at 3 years only      | 14       | 43        | 3.1         | 25         | 106      | 4.2         |
| G — Raced at 4 years only      | 6        | 26        | 4.3         | 7          | 23       | 3.3         |
Animals with signs which preventing animals.

Total cases of lameness presented 51 43 64 34 23 15 3

(2) Respiratory problems — Associated with respiratory infection or upper respiratory function at exercise and resulting in an interruption of training programme or in surgical treatment (eg, laryngeal venlriculecomy).

(3) Horses retired from training or sold because of (a) limited ability in training, (b) of excellent racing performance and sold for breeding, (c) owner returned mares to stud from breeding.

(4) Convalescence or "spelling" — Animals with signs of over-

TABLE 16: Age distribution of 314 horses in training in Newmarket

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Total</th>
<th>Colt</th>
<th>Gelding</th>
<th>Filly</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>141</td>
<td>86</td>
<td>0</td>
<td>56</td>
</tr>
<tr>
<td>3</td>
<td>130</td>
<td>60</td>
<td>2</td>
<td>68</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>16</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

In performance potential, an interruption of training programme or the number of race starts.

TABLE 17: Numbers of horses in the 6 training stables with the breakdown and details of their racing performance during 1980

<table>
<thead>
<tr>
<th>Stable</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Total</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of horses of all ages</td>
<td>67</td>
<td>39</td>
<td>54</td>
<td>56</td>
<td>57</td>
<td>41</td>
<td>314</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of 2-year-olds</td>
<td>23</td>
<td>27</td>
<td>23</td>
<td>22</td>
<td>22</td>
<td>23</td>
<td>140</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number that did not start</td>
<td>9</td>
<td>6</td>
<td>7</td>
<td>10</td>
<td>6</td>
<td>9</td>
<td>46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number that won</td>
<td>4</td>
<td>8</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number that were placed</td>
<td>22</td>
<td>7</td>
<td>7</td>
<td>11</td>
<td>3</td>
<td>4</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number that started but unplaced</td>
<td>7</td>
<td>13</td>
<td>4</td>
<td>7</td>
<td>12</td>
<td>5</td>
<td>44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of starts per horse</td>
<td>2.40</td>
<td>3.10</td>
<td>4.88</td>
<td>2.38</td>
<td>2.24</td>
<td>3.57</td>
<td>3.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prize money (£)</td>
<td>7271</td>
<td>70,099</td>
<td>16,021</td>
<td>7293</td>
<td>3634</td>
<td>14,157</td>
<td>118,675</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of 3- to 6-year-olds</td>
<td>44</td>
<td>12</td>
<td>31</td>
<td>34</td>
<td>35</td>
<td>18</td>
<td>174</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number that did not start</td>
<td>2</td>
<td>10</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number that won</td>
<td>13</td>
<td>6</td>
<td>5</td>
<td>12</td>
<td>10</td>
<td>6</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number that were placed</td>
<td>22</td>
<td>6</td>
<td>15</td>
<td>16</td>
<td>14</td>
<td>11</td>
<td>84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number started but unplaced</td>
<td>8</td>
<td>4</td>
<td>11</td>
<td>14</td>
<td>15</td>
<td>4</td>
<td>56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of starts per horse</td>
<td>1.24</td>
<td>6.55</td>
<td>5.63</td>
<td>6.38</td>
<td>4.12</td>
<td>5.47</td>
<td>4.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prize money (£)</td>
<td>125,853</td>
<td>216,940</td>
<td>32,226</td>
<td>47,034</td>
<td>43,910</td>
<td>43,917</td>
<td>520,443</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Lameness was by far the most important factor in the major causes of lost racing performance in 6 stables in Newmarket during the 1980 flatracing season.

| Total cases | 51 | 43 | 64 | 34 | 23 | 31 |
| Respiratory problems | 60 | 6 | NR* | NR* | 15 | NR* |
| Retired or sold | 23 | 14 | 30 | 32 | 19 | NR |
| Turned out | 3 | NR | NR | NR | 1 | 1 |
| Colic | 14 | NR | 6 | 1 | 5 |
| Dermatological conditions | 7 | 4 | 3 | 2 | 9 | 3 |

* Stables affected with respiratory viral infection

TABLE 18: Major causes of lost racing performance in 6 stables in Newmarket during the 1980 flatracing season

<table>
<thead>
<tr>
<th>Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of horses experiencing lameness</td>
<td>36</td>
<td>25</td>
<td>37</td>
<td>27</td>
<td>16</td>
<td>22</td>
<td>163</td>
</tr>
<tr>
<td>Total cases of lameness presented</td>
<td>51</td>
<td>43</td>
<td>64</td>
<td>34</td>
<td>23</td>
<td>31</td>
<td>246</td>
</tr>
<tr>
<td>Number not starting after lameness</td>
<td>3</td>
<td>10</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>34</td>
</tr>
<tr>
<td>Number returning to race after lameness</td>
<td>33</td>
<td>15</td>
<td>31</td>
<td>21</td>
<td>11</td>
<td>18</td>
<td>129</td>
</tr>
</tbody>
</table>

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TABLE 19: Numbers of horses in training experiencing lameness during the 1980 flatracing season and the effect on racing performance

<table>
<thead>
<tr>
<th>Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of horses experiencing lameness</td>
<td>36</td>
<td>25</td>
<td>37</td>
<td>27</td>
<td>16</td>
<td>22</td>
<td>163</td>
</tr>
<tr>
<td>Total cases of lameness presented</td>
<td>51</td>
<td>43</td>
<td>64</td>
<td>34</td>
<td>23</td>
<td>31</td>
<td>246</td>
</tr>
<tr>
<td>Number not starting after lameness</td>
<td>3</td>
<td>10</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>34</td>
</tr>
<tr>
<td>Number returning to race after lameness</td>
<td>33</td>
<td>15</td>
<td>31</td>
<td>21</td>
<td>11</td>
<td>18</td>
<td>129</td>
</tr>
</tbody>
</table>

Training or poor performance that were turned out to grass for a period of rest.

(5) Colt — Signs which usually had only a temporary effect on the training programme.

(6) Dermatological conditions — Preventing animals from attending race meetings.

The training programme of all the horses was checked on a daily basis either by personal observations or from the stable staff and the veterinary records. The racing performances were collected each day from the racing press and cross-checked at the end of the season by questionnaire from each trainer. The figures for racing and prize money were calculated for the 1980 flatracing season from these data (Table 17).

The major causes of lost racing performance were lameness and respiratory infection (Table 18). Of the 314 horses surveyed, 67 (22 per cent) did not start during the season and the remainder started a total of 459 times.

The figures for racing and prize money were calculated for the 1980 flatracing season from these data (Table 17). The major causes of lost racing performance were lameness and respiratory infection (Table 18). Of the 314 horses surveyed, 67 (22 per cent) did not start during the season and the remainder started a total of 459 times. A breakdown of the reasons for not starting at all showed that 45 per cent were because of musculoskeletal conditions, 15 per cent left the stable because of poor early performance or owner dissatisfaction, 14 per cent were backward and respiratory infection (Table 18). The figures for racing and prize money were calculated for the 1980 flatracing season from these data (Table 17).
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TABLE 20: Types of injury causing lameness in 33 horses which prevented them starting during the season

<table>
<thead>
<tr>
<th>Cause of lameness</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpal damage</td>
<td>6</td>
</tr>
<tr>
<td>Foot problems and fractures</td>
<td>5</td>
</tr>
<tr>
<td>Exertional myopathy (tying up)</td>
<td>4</td>
</tr>
<tr>
<td>Cannon and splint problems</td>
<td>5</td>
</tr>
<tr>
<td>Fetlock conditions</td>
<td>3</td>
</tr>
<tr>
<td>Tendon injury</td>
<td>3</td>
</tr>
<tr>
<td>Abscess on back</td>
<td>2</td>
</tr>
<tr>
<td>Overriding dorsal spinous processes</td>
<td>1</td>
</tr>
<tr>
<td>Shoulder injury</td>
<td>1</td>
</tr>
<tr>
<td>Laceration to hindlimb</td>
<td>1</td>
</tr>
<tr>
<td>Undiagnosed</td>
<td>3</td>
</tr>
</tbody>
</table>

TABLE 21: Analysis of the major sites of lameness recorded in 164 horses during the 1980 flat racing season

<table>
<thead>
<tr>
<th>Site or diagnosis of lameness</th>
<th>Stable A</th>
<th>Stable B</th>
<th>Stable C</th>
<th>Stable D</th>
<th>Stable E</th>
<th>Stable F</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foot</td>
<td>3 4 2 3 1 0</td>
<td>2 3 1 0 0 0</td>
<td>6 5 3 2 1 0</td>
<td>10 12 9 7 5 3</td>
<td>6 10 4 2 1 0</td>
<td>67 77 33 18 11 7</td>
<td>180</td>
<td>11.4</td>
</tr>
<tr>
<td>Tendons</td>
<td>5 1 1 0 0 0</td>
<td>1 2 3 4 5 6</td>
<td>1 2 1 1 1 1</td>
<td>1 5 2 3 4 6</td>
<td>1 3 2 1 1 1</td>
<td>15 32 15 16 16 14</td>
<td>92 120 38 30 30 26</td>
<td>9.2</td>
</tr>
<tr>
<td>Tendonitis</td>
<td>1 0 0 0 0 0</td>
<td>0 0 0 1 2 3</td>
<td>0 0 0 0 1 2</td>
<td>1 0 0 0 1 2</td>
<td>0 0 0 0 0 0</td>
<td>1 0 0 0 3 6</td>
<td>0.6 0 1.2 0.6 2.4 3.7</td>
<td>0.6 0 1.2 0.6 2.4 3.7</td>
</tr>
<tr>
<td>Sore shins</td>
<td>2 2 1 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>2 2 1 0 0 0</td>
<td>1.2 0 0.6 0 0 0</td>
<td>0.6 0 0.6 0 0 0</td>
</tr>
<tr>
<td>Pastern</td>
<td>6 1 1 1 1 1</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>6 1 1 1 1 1</td>
<td>3.7 0.6 0.6 0 0 0</td>
<td>0.6 0 0.6 0 0 0</td>
</tr>
<tr>
<td>Hock</td>
<td>1 1 1 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>1 1 1 0 0 0</td>
<td>0.6 0.6 0.6 0 0 0</td>
<td>0.6 0 0.6 0 0 0</td>
</tr>
<tr>
<td>Splints</td>
<td>1 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>1 0 0 0 0 0</td>
<td>0.6 0 0 0 0 0</td>
<td>0.6 0 0 0 0 0</td>
</tr>
<tr>
<td>Shoulder injury</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
</tr>
<tr>
<td>Overriding dorsal spines</td>
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</tr>
<tr>
<td>Laceration to hindlimb</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
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<tr>
<td>Undiagnosed</td>
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<td>0 0 0 0 0 0</td>
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<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
</tr>
</tbody>
</table>

A total of 103 horses (33 per cent) showed no signs of lameness during the year and they started 459 times (ie, 4.45 races per horse). Of the 140 2-year-olds, only 34 (23 per cent) did not show any sign of lameness. Many of the 77 per cent that did go lame showed minor complaints such as sore shin and splint problems. In one stable, which had 7 with sore shins, 6 were racing by the end of the season; the remaining one developed a unilateral superficial flexor tendinitis.

The sites of lameness were chiefly involved in the forelimb (70 per cent) with 28 per cent affecting the hindlimbs (Table 21). Figures available from Stables B and C showed that of 41 horses that went lame, 32 (78 per cent) returned to racing and started a total of 71 times (ie, 2.2 races per horse). From all 6 stables 130 (79 per cent) of the 163 horses that suffered lameness did return to the track.

During 1980 several of the racing stables were badly affected by a viral respiratory disease. The clinical signs noted in most cases were a slight rise in temperature followed by lethargy and then a cough. Little seemed to affect the course of the disease and some horses coughed for a period of months while others seemed to get over the condition in a week or so. This type of virus infection affected racing performance and horses were seen to have a shallow and rapid depth of respiration and took a much longer period than normal to recover after a race or fast exercise.

Stable A kept detailed records during an outbreak of respiratory disease and monitored the body temperature of all horses morning and night as well as the number of coughs from each horse from early February to late April 1980. There was a total of 30 horses in the stable of 65 which ran a temperature. The number of horses coughing is shown in Fig 3. By 23 April there had been a reduction in the number of coughing horses and this continued to decline even though the trainer no longer kept such accurate records. During the whole period all horses in the stable coughed with the exception of a few of the older animals.

Four of the training yards in 1980 were more seriously affected with viral infection (Stables A, C, D and F) than the others. In addition to the immediate effects of infection and coughing, a number of animals had to be eased and rested from training for periods up to 6 months and still did not return to their previous racing ability. One stable had 8 horses that were lost in early training in 1981 from the longterm effects of the respiratory disease in the 1980 season.

Fig 3. Results of horses coughing and number of coughs recorded in Stable A during an outbreak of respiratory virus disease in 1980
Unlike lameness, the respiratory problems did not usually stop the horses competing. In the majority of cases the subsequent performance was poor and following this the horses were often rested. The respiratory problems that did stop horses racing were laryngeal hemiplegia (2), epistaxis (2) and unspecified breathing difficulties (6).

Colic was not seen as a major cause of loss from racing. It was difficult to gain accurate figures because a number of the colic cases were subacute and corrected themselves. A number of horses in the stables experienced mild impactive colic which resulted in missing a day or 2 of training but no more. There were no surgical cases of colic from these stables during 1980.

Skin conditions were usually caused by ringworm or urticaria, although a small number of undiagnosed complaints and skin abscesses were recorded. One horse was lost from training with a serious skin allergy, resulting in it being sold overseas. The condition could be controlled by administration of steroids, but the animal was not allowed to perform under the Rules of Racing.

**Discussion**

Surveys of mortality and morbidity form an essential basis on which to determine the need for remedial action. If conducted annually or at regular intervals, they provide information on the degree of success of remedial measures employed. Surveys of incidence are the prerequisite starting line, which consisted of mares for which a return was made.

Biological wastage may result from intrinsic or extrinsic factors acting either alone or in combination. The most important example of intrinsic wastage is from genetic causes, as an expression of inheritance or of chromosomal abnormalities. In Thoroughbred horses, selection for athleticism or Irish training yards. It is in this very substantial area of loss that we have least information to determine how far this was related to biological and how far to economic considerations such as stature of the individual, export or breeding for purposes other than racing. This aspect requires more investigation using different methods of collecting and relating information than were available to us in the present study.

The number of horses in training could be analysed according to whether or not individuals raced as 2- and/or as 3-year-olds, and on the number of times they competed. The finding that 35.0 per cent of 2-year-olds never ran and that, on average, 2-year-olds performed only 3 times per annum is regarded as significant. Three-year-olds performed rather more often although even here there were 36.6 per cent which never competed at all and on average an individual competed only 5 times in the season.

An estimate of the financial costs of wastage to the industry was made which amounted to a total of £15.2 million. This figure was based on costs in 1974 to 1976 and although it can only be considered an approximate assessment, it is clear that the exact figure for 1982 must be considerably greater than this, perhaps as high as 2 or 3 times the estimated figures. The main areas where losses need to be curtailed are stallion fees (£4.8 million), keep for barren mares (£2.4 million) and keep/training fees for horses that did not run (£3.7 million).

The needs of the racing industry have never been defined satisfactorily. It seems that there is an ad hoc control of the number of horses in training, probably related to supply and demand, which in turn is based on no more than the commercial instincts of the market. Jockey clubs and other administrators of racing do not appear to have paid much regard for establishing the optimal number of horses in training, let alone the number of times that each horse competes for the purposes of racing as a public spectacle, medium for gambling or employment.

The most substantial reason for not competing or for competing less than an average number of times appears to have been that the horses showed little or no ability. However, among the 311 horses surveyed in Newmarket, lameness was the most significant factor. Fifty-three per cent of the total number of animals experienced some period of lameness, and in 20 per cent of cases the lameness was sufficient to prevent...
the individuals from racing after the injury occurred. There is obvious scope here for a more extensive epidemiological survey of the reasons for lameness.

Wastage among breeding stock appears from this survey to be caused largely by failure to conceive or to carry a foal successfully to term. This is a well-documented area of loss among all breeds of horses (Rowlands 1981). It is not clear either from the present study or from previous investigations how far intrinsic and extrinsic factors are responsible for this wastage. Our study indicates that there is a relationship between increasing age and decreasing ability for mares to produce live foals. A more intensive investigation of this aspect might provide evidence about the causes of infertility in mares. It would be interesting to ascertain whether there are genetic reasons, as has been suggested to be the case in the relationship between winners of the Epsom Oaks and poor breeding performance (Rossdale 1972).

Acknowledgements

The authors are most grateful to the Horserace Betting Levy Board for the financial support necessary to carry out this survey. We acknowledge the timely and expert assistance of Peter Marshall and Richard Allebone of Weatherby's and Rhidian Morgan-Jones of Bloodstock and Racehorse Industries Confederation. Our thanks are also due to the 6 Newmarket trainers and their staff for allowing us access to their stables in 1980 and to our colleague Raymond Hopes for his collaboration.

Reprints of this article are available from Mrs H. Carpenter, Park Lodge, Yew Green Road, Frant, Tunbridge Wells, Kent, price £1.50

References


Résumé

Cet article produit les résultats d'une étude menée sous les auspices de la commission d'enquête de la BEVA, étude financée par le British Horserace Betting Levy Board. L'objectif de cette étude était de réunir des informations utilisables à partir des statistiques des courses et de l'élevage afin d'évaluer les pertes et les points faibles de l'industrie des courses de pur sang.

Les recherches ont été conduites entre 1977 et 1980. Les résultats sont exposés en deux parties. Dans la première, les statistiques disponibles ont montré qu'un déficit considérable se produisait entre la période de monte et l'apparition de la production sur l'hippodrome; les pertes sont du même ordre chaque année.

11.8% des poulinieres répertoriées au General Stud Book ont été écarteres de l'étude parce qu'aucun renseignement sur la monte n'a été renvoyé. En outre 10% des poulinieres furent ou bien non saillies ou bien saillies par des demi sang, d'autres mettant bas à l'étranger. On a donc retenu pour servir de base à l'estimation le reliquat, c'est-à-dire celles des poulinieres dont les résultats de saillie furent officiellement confirmés (renseignements effectivement "retournés"). Les résultats furent les suivants:

- vides (n'ayant pas conçu): 22.5%
- avortées ou ayant eu un produit qui n'a pas vécu: 10%
- production vivante non nommée: 13.9% (anonymes)
- animaux nommés qui n'ont pas été à l'entraînement entre deux et quatre ans: 20.1%
- animaux entraînés qui n'ont pas couru entre 2 et 4 ans: 6.2%

Au total le déficit s'élève à 72.8%. Les données se rapportant au nombre d'animaux importés et exportés sont fournies.

Une estimation du montant des pertes ainsi constatées a été faite sous les rubriques suivantes: pertes sur les coûts de saillie — pertes sur l'entretien des juments — pertes sur l'entretien des poulains anonymes — pertes sur l'entretien des chevaux qui n'ont pas couru.

Cumulées, les pertes pour la saison 1974 et pour ceux des animaux nés cette année là ont été estimées à plus de 15.2 millions de livres sterling.

Dans la seconde partie, on examine plus particulièrement quelques unes des sources du déficit et les raisons du nombre insuffisant des sorties en course. La raison la plus importante pour ne pas courir ou pour courir moins souvent que la moyenne ne est l'inaptitude pure et simple à la compétition. Pour 762 chevaux on constate que 26.5% d'entre eux n'ont pu courir avant l'âge de 4 ans. Parmi ceux-ci un peu plus d'un tiers fut conservé pour les programmes de courses à obstacles. La dernière partie de cette étude étudie les raisons "vétérinaire" du déficit. A Newmarket, pour 314 chevaux on a trouvé que la boiterie était le facteur le plus important. A un certain moment, on a constaté 53% de boiteries durant la saison et dans 20% des cas les boiteries ont empêché le retour à la compétition.

Zusammenfassung

Stuten (Stuten mit bekannten Deckangaben und Abfohlergebnissen) dienten zu einer Verschleisschätzung:
Keine Konzeption 22.5%
Abort oder nichtüberlebendes Fohlen 10.1%
lebendes, namenloses Fohlen 13.9%
Tiere mit Namen, aber nicht im Training zwischen 2 bis 4 Jahren 20.1%
Im Training, aber nicht im Rennen zwischen 2 bis 4 Jahren 6.2%

Das ergibt eine Verschleissrate von 72.8%. Es werden auch Angaben gemacht über die Anzahl der bestrittenen Rennen und über die Zahl importierter, beziehungsweise exportierter Pferde.

Eine Schätzung der durch diesen Verschleiss verursachten Kosten wurde in den folgenden Kategorien angenommen: verlorene Sprunggelder; Kosten der Stutenhaltung; Kosten der Haltung namenloser Fohlen; Haltungskosten für nicht in Rennen eingesetzte Pferde. Die kumulierten Verluste für die Deckssaison 1974 und für die Produktion aus dieser Saison wurden auf mindestens 15.2 Mio Pfund geschätzt.

In Phase 2 der Untersuchung wurden bestimmte Aspekte dieser Zuchtverluste spezifischer ausgewertet und die Gründe für die unbefriedigende Anzahl bestrittener Rennen erforscht. Der wichtigste Grund dafür, dass viele Pferde überhaupt nie auf die Rennbahn kommen oder nur an einer unterdurchschnittlichen Anzahl von Rennen teilnehmen, bestehend in einer fehlenden oder ungenügenden Eignung als Rennpferd. Von 762 Pferden bestritten 26.5% bis zu einem Alter von 4 Jahren überhaupt keine Rennen; davon wurde nur etwas mehr als ein Drittel für den Einsatz in Hindernisrennen "aufgespart".

Im letzten Teil der Untersuchung wurden die tierärztlichen Gründe für die Verluste unter die Lupe genommen. Bei 314 Pferden in Newmarket wurde Lähmheit als weit wichtigster Grund festgestellt. Während der Rennsaison ergaben sich Perioden mit einer Lähmheitsfrequenz von 53%, wobei 20% der lähmten Pferde auch später nicht mehr in Rennen eingesetzt werden konnten.

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Many different approaches have been attempted to assess the performance potential of horses from evaluation of the hematologic profile, hemodynamic studies, muscle physiology, techniques for cardiovascular and pulmonary function as well as biomechanics of the locomotor system. However, an integral part of the whole problem is the general lack of objective appreciation of the horse's gait and locomotor pattern. This is surprising, for movement is the final product of the activities of all the other organ systems so closely investigated. From the veterinary viewpoint, the quantitative evaluation of the gait would form the basis of a vastly improved and objective system of lameness diagnosis as well as the analysis of performance potential.

Recently, the historical background and current status of equine locomotion research have been reviewed in two comprehensive papers by Leach and Dagg.\textsuperscript{42,43} This article will concentrate on the methods used for gait analysis and consider some basic data on the different gaits of the horse. Finally, some recent studies will be briefly discussed and the likely trends for the future will be outlined.

**METHODS OF GAIT ANALYSIS**

The science of motion in animals, including man, is referred to as *kinesiology*. The subject may be subdivided into *kinematics*, the field of kinesiology dealing with the *temporal* and geometric characteristics of motion without regard to the forces associated with it, and *kinetics*, which deals with the forces that produce, arrest, or modify motion. Most methods used in equine locomotion research are modifications of techniques originally developed for the study of...
human movements. For technical details, the reader is referred to handbooks on human kinesiologic methods. \(^\text{30,75}\)

**Kinematic Methods**

There are a number of different methods available for the measurement of kinematic variables (that is, durations, distances, and joint angles). Presently, *high-speed cinematography* is the method most commonly used. The format for a gait analysis system based on this technique is summarized in Figure 1. The advantages and disadvantages of high-speed cinematography in equine gait analysis have been discussed in detail. \(^\text{21}\) In the near future, *high-speed video systems* may become less expensive and easier to handle. The major drawback of high-speed cinematography is the delay from recording to analysis; at present, video gives poorer picture resolution, which causes problems when measuring small distances or small angular movements. However, both systems have the great advantage of not requiring any equipment having to be attached to the horse. The currently available *optoelectronic systems* \(^\ast\) require the attachment of light-emitting diodes to the horse’s body and limbs, which may interfere with the normal gait of the animal, especially at higher speeds. *Electrogoniometers* measure changes in joint angles but have not yet been used very extensively in horses. They have so far mainly been used at comparatively slow speeds in studies of carpal and fetlock lameness. \(^\text{1,56,67}\) The possible disturbing effect of the equipment on the gait has not been investigated, and it is uncertain if they can be efficiently used at maximal speeds. *Accelerometers* are used to measure accelerations in different parts of the limbs and can give valuable information on the gait, especially if they are used in conjunction with other methods that measure the timing of the stride cycle. Accelerometers do require cables and other equipment to be attached to the horse, so they may interfere with normal gait. In field trials, electrogoniometers and accelerometers are impractical, so telemetry systems or portable tape recorders are required.

**Kinetic Methods**

Much attention has been paid to the forces acting between the ground and the hoof. There are two methods that have been used for this type of work—*measuring shoes* and *force plates*. The more advanced equipment measures the forces acting in the longitudinal, transverse, and vertical directions, whereas the less sophisticated systems only measure the vertical forces. The advantage of using measuring shoes is that they provide continuous recording of the forces during a number of strides and can be used on different track surfaces. Special shoes have been developed for recording vertical \(^\text{16}\) as well as horizontal forces. \(^\text{5}\) The shoes are, however, too heavy to be used at high speed without producing serious gait disturbances.

\(^\ast\) Selspot, Selcom, Partille, Sweden.
Figure 1. Diagrammatic representation of the CRACK (Cinematographic Recording and Analysis by Computer in Kinesiology) system and its potential applications in the field. (From Fredricson, I., Drevemo, S., Dulin, G., et al.: The application of high-speed cinematography for the quantitative analysis of equine locomotion. Equine Vet. J., 12:54-59, 1980; with permission.)
The force plate does not require any equipment to be mounted on the horse, but there is the inherent problem of “hitting” the force plate with this technique. At speed, only a 1 in 20 success rate has been reported, and each successful recording contains only one hoof-ground contact. In spite of this, force plates have been the method of choice in a number of studies involving the walk, trot, and gallop. The in vivo measurement of bone and tendon strain in the horse is beyond the scope of this article, but the reader is referred to some recent papers.

Electromyography

The analysis of the electrical activity of muscles by electromyography is a most useful tool in locomotion research, especially if used in combination with other kinesiologic techniques. However, the method has not been used very much in horses. Wentink used both electromyography and high-speed cinematography in his studies of hindlimb biomechanics.

Treadmill

To enable recording of horses indoors at high speeds and under standardized conditions, a special treadmill has been designed. The differences between outdoor and treadmill performance have been studied and a good comparison was obtained. After 7 years of operation, the treadmill has proved to be very safe. The horses can be easily subjected to standard forms of exercise and the reproducibility of the gait is good between sessions. The treadmill has also been extensively used for other forms of exercise physiology.

THE STRIDE CYCLE OF THE INDIVIDUAL LIMB

Temporal and Linear Variables

The stride is the basic repeated series of movements of the individual limb (Fig. 2). The stride length is the linear distance that the hoof moves during one stride cycle or the distance between two successive hoof imprints of the same foot. The stride duration is the time for one complete gait cycle or the time between any two identical events of a cycle (for example, heel contacts, see Fig. 2). The number of strides per unit time is the stride frequency.

The stride consists of two phases: the stance phase, when the foot is in contact with the ground (Fig. 2A to E), and the swing phase, when the foot is lifted and brought forward to be placed on the ground again (Fig. 2A to E).

In the analysis of the stance phase, it has been arbitrarily divided into an anterior part, the restraint stage, and a posterior part, the propulsion stage. In between these two stages is the mid-stance position, which in the forelimb is when the metacarpus is in the
Figure 2. The sequence of right forelimb movement during one stride cycle of a trotting horse. The stance phase lasts from (a) to (e) and consists of the restraint stage from (a) to (c) and the propulsion stage from (c) to (e). The swing phase lasts from (e) to (a). (a) Heel contact; (b) full contact; (c) mid stance position; (d) beginning of heel-off; (e) toe-off; (f) beginning of hoof acceleration; (g) mid swing; and (h) end of hoof deceleration.


The various stride characteristics have been shown to be repeated in a strikingly stable pattern (see Fig. 5).\cite{9,10,26} Obviously, the timing of the gait components must be very precisely controlled within the central nervous system. When a horse gallops at 18 m per second (65 kph), the following events are repeated without mishap every 425 milliseconds. The stance phase lasts about 95 milliseconds and the force exerted between the ground and the foot reaches a maximum of more than double the weight of the horse. During the vertical position (Fig. 2C) and, in the hindlimb, when the hoof is right under the hip joint.\cite{9}
330 milliseconds swing phase, the speed of the hoof relative to the ground is 0 kph at take off, but as the foot is lifted it accelerates to 65 kph (that is, the overall speed of the horse) and continues to a maximum of more than double the speed of the horse (that is, more than 130 kph). It then rapidly decelerates to almost 0 kph again to land approximately 7.6 m in front of the preceding hoof imprint.

Data on the different stride variables of racing trot, pace, and gallop are surprisingly sparse. The relation between speed and some of the basic stride variables have been described for the walk.\(^1\) trot,\(^4,11\) canter,\(^32\) and gallop.\(^32\) In 1910, Jordan reported stride lengths of 5.86 m and 6.01 m in the trot and pace, respectively.\(^35\) His extensive study of the trot and pace was based on measurements of the hoof imprints on the track surface. More detailed analyses of the linear and temporal variables of the racing trot have been carried out using high-speed cinematography.\(^9,22\) The only other reported investigations on the gallop of racing Thoroughbreds are the report of Pratt and O'Connor, which was based on three horses,\(^57\) and the study of gait fatigue by Leach and Sprigings, who analyzed the gait of 17 horses at the beginning and the end of races.\(^17\) It is obvious that much more remains to be done, especially in the analysis of the pace and gallop.

Some basic data on the stride components of the individual limb in the trot, pace, and gallop are summarized in Table 1 and Figures 3 and 4.

**Joint Kinematics**

The kinematics (that is, angular displacement) of the carpal, fetlock, and hock joints have been investigated using electrogoniometry in horses at the walk and trot.\(^67\) The same method has also been used to evaluate horses with fetlock\(^1\) and carpal\(^39\) lameness (vide infra).

At higher speeds, electrogoniometers are no longer practical and high-speed cinematography has been used.\(^17,20,24,26,29,58,63,64,70,72\) Fredricson and colleagues developed a method of three-dimensional analysis for the spatial orientation of horses' hooves at fast trot.\(^17,20,26\) The resultant joint coordination pattern (RCP) indicated the position of the hoof relative to the ground and was considered the result of the actions in the joints of the limb. The method was simplified to a two-dimensional analysis and the RCP variations were studied in eight fast-moving Standardbred trotters (Fig. 5B).\(^21,22\) In five horses, the forelimb joint kinematics were analyzed using reference points glued to the skin of the horses and the reliability of the method was studied in detail.\(^23\) The method has since been used in studies of lame horses (see Fig. 13) and in the evaluation of diagnostic toe grabs and heel calks (vide infra).\(^59\) Using high-speed cinematography, the stressful effects of underbanked curves on the fetlock and carpal joints have been analyzed qualitatively.\(^8,18\)

Similar cinematographic methods were used in the study of hindlimb biomechanics,\(^70,72\) and in combination with simultaneous force plate recordings.\(^58,63,64\) In a galloping Thoroughbred, Kingsbury
### Table 1. Linear and Temporal Stride Characteristics of the Individual Limbs in the Trot, Pace, and Gallop

<table>
<thead>
<tr>
<th>Gait</th>
<th>No. of Horses</th>
<th>Speed (m/sec)</th>
<th>Stride Length (m)</th>
<th>Stride Duration (sec)</th>
<th>Stance Phase (sec)</th>
<th>Swing Phase (sec)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trot</td>
<td>17</td>
<td>2.2–4.7*</td>
<td>1.7–3.5*</td>
<td>0.86–0.62*</td>
<td></td>
<td></td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1.2–12.7*</td>
<td>1.2–5.7*</td>
<td>1.15–0.46*</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5.8–12.6</td>
<td></td>
<td>0.544–0.425</td>
<td>0.152–0.112</td>
<td>0.402–0.316</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>11.3–12.4</td>
<td>4.85–6.09</td>
<td>0.503–0.411</td>
<td>0.127–0.101</td>
<td>0.391–0.294</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>(X 12.0)</td>
<td>(X 5.45)</td>
<td>(X 0.455)</td>
<td>(X 0.114)</td>
<td>(X 0.342)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pace</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td>0.448</td>
<td></td>
<td>73</td>
</tr>
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<td></td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td>6.77–7.04</td>
<td></td>
<td>74</td>
</tr>
<tr>
<td>Gallop</td>
<td>17</td>
<td>3.7–13.3*</td>
<td>2.1–5.8*</td>
<td>0.67–0.41*</td>
<td></td>
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<td>14</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>5.1–19.3</td>
<td>2.97–8.16</td>
<td>0.613–0.384</td>
<td>0.209–0.070</td>
<td>0.442–0.301</td>
<td>32 and</td>
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<td>J., et al:</td>
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<td></td>
<td>17</td>
<td>11.1–16.4</td>
<td>5.3–7.0</td>
<td>0.50–0.38</td>
<td></td>
<td></td>
<td>47</td>
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<td></td>
<td>3</td>
<td>15.0–17.1</td>
<td>6.66–7.38</td>
<td>0.455–0.425</td>
<td>0.112–0.098</td>
<td>0.337–0.318</td>
<td>57</td>
</tr>
</tbody>
</table>

* Estimated from published diagrams.
and colleagues analyzed the forelimb fetlock and coffin joint angles and correlated them with the vertical forces between ground and hoof.

**INTERLIMB COORDINATION: GAITS**

A *gait* can be simply defined as a limb coordination pattern used in locomotion. Horses have many different gaits. The Icelandic horse, for example, is capable of performing in six different gaits. In this article, we will deal principally with the trot, pace, canter, and gallop.

Trot and pace are *symmetric gaits* (that is, the limb movements of one side are repeated by the opposite side half a stride later). The canter and gallop are *asymmetric gaits* (that is, the limb movements of one side do not exactly repeat (those of the other side)).

**Trot and Pace**

In the *trot*, the diagonal limbs move together synchronously (that is, contralateral pairs of limbs are 50 per cent out of phase). Each pair of diagonal feet are alternatively lifted, thrust forward, and
again placed on the ground, the body being without support twice in each gait cycle (Fig. 6).

The following description of the racing trot and the definitions used are based on the work by Dreveno and colleagues. Because the contralateral pairs of limbs are 50 per cent out of phase, the step length (that is, the distance between the ground contact of one hoof and that of the succeeding contralateral hoof) is approximately half the stride length. Consequently, the step duration (that is, the time between corresponding positions of contralateral hooves, Fig. 6A to F) is normally about 50 per cent of the stride duration. The diagonal feet moving together are named after the forelimb involved (that is, the right forelimb and left hindlimb constitute the right diagonal, and vice versa). At slow speeds, the diagonal feet tend to land and take off at the same time. At faster speeds, there is a tendency for the forelimb to land and leave ground first (Fig. 6A, B, D, and E, respectively). These time differences between diagonal limbs at landing and take off are referred to as diagonal dissociation. The time that the diagonal hooves are in contact with the ground is called bipedal support (see Fig. 6B to D). Diagonal length is the distance between diagonal hooves during the bipedal support. When both diagonal feet have been lifted, there is a suspension period when the horse has no contact with the ground (see Fig. 6E to F). After this period, the hind hoof lands in front of the imprint of the ipsilateral hoof; the distance is called overreach.

Some data on the interlimb coordination in racing trot are summarized in Table 2.
In the *pace*, the forelimbs and hindlimbs on the same side work synchronously and the contralateral limbs are 50 per cent out of phase. Pace has not yet been studied in detail, but there is some important work in progress.\textsuperscript{73,74}

**Canter and Gallop**

The *gallop* is a much more complex gait than the *trot* and *pace* with many possible limb coordination patterns.\textsuperscript{34} In the horse, two
main types are identified: the canter, or "three-beat gallop" (Fig. 7), and the "four-beat gallop," normally referred to as gallop (Fig. 8). Canter is seen at lower speeds and is characterized by the stance phases of the lead hindlimb and the nonlead forelimb occurring si-

Table 2. Linear and Temporal Gait Characteristics of Interlimb Coordination from 30 Standardbred Trotters at a Speed of 12.0 Meters/Sec (Standard Deviation is 0.25)

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>FORL.</th>
<th></th>
<th></th>
<th>BEND.</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>273.0</td>
<td>271.9</td>
<td></td>
<td>275.1</td>
<td>269.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(15.7)</td>
<td>(19.1)</td>
<td></td>
<td>(22.4)</td>
<td>(20.5)</td>
<td></td>
</tr>
<tr>
<td>Step duration (msec)</td>
<td>225.4</td>
<td>229.3</td>
<td></td>
<td>229.8</td>
<td>225.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(12.2)</td>
<td>(14.9)</td>
<td></td>
<td>(18.3)</td>
<td>(18.4)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>LEFT</th>
<th></th>
<th></th>
<th>RIGHT</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagonal dissociation (msec)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landing*</td>
<td>-1.6</td>
<td>(15.1)</td>
<td></td>
<td>-6.0</td>
<td>(17.0)</td>
<td></td>
</tr>
<tr>
<td>Take off†</td>
<td>-10.8</td>
<td>(14.8)</td>
<td></td>
<td>-10.6</td>
<td>(16.6)</td>
<td></td>
</tr>
<tr>
<td>Bipedal support (msec)</td>
<td>99.3</td>
<td>(8.7)</td>
<td></td>
<td>98.5</td>
<td>(12.2)</td>
<td></td>
</tr>
<tr>
<td>Diagonal length (cm)</td>
<td>105.2</td>
<td>(18.2)</td>
<td></td>
<td>102.2</td>
<td>(21.4)</td>
<td></td>
</tr>
<tr>
<td>Overreach duration (msec)</td>
<td>122.6</td>
<td>(18.6)</td>
<td></td>
<td>119.4</td>
<td>(17.7)</td>
<td></td>
</tr>
<tr>
<td>Overreach length (cm)</td>
<td>170.9</td>
<td>(24.0)</td>
<td></td>
<td>166.9</td>
<td>(21.6)</td>
<td></td>
</tr>
<tr>
<td>Suspension time (msec)</td>
<td>99.0</td>
<td>(18.8)</td>
<td></td>
<td>98.9</td>
<td>(14.8)</td>
<td></td>
</tr>
</tbody>
</table>

* - sign indicates that the fore hoof lands first.
† - sign indicates that the fore hoof takes off first.

multaneously (see Fig. 7B to E). In the gallop, the lead hindlimb normally lands and takes off in advance of the diagonal nonlead forelimb (see Fig. 8B and E).

The main features of the canter and gallop are shown in Figures 7 and 8. The nomenclature used is that proposed by Leach, Ormrod, and Clayton. The gait cycle of gallop has been divided into the stride stance phase, which begins with the landing of the nonlead hindlimb and ends when the lead forelimb leaves the ground (see Figs. 7A to F and 8A to H), and the suspension phase, when there is no limb contact with the ground (see Figs. 7F to H and 8A to H). During the stride stance phase, one or more limbs are in contact with the ground. The time during which more than one limb is on the ground is the overlap (see Figs. 7B to E and 8B, D, and F).

There are great differences between the gallop at slow and at fast speeds. In a study of 48 horses at speeds between 5.1 and 19.3 per second, overlap was the variable most affected by speed. Other data on the canter and gallop are summarized in Table 3 and in Figures 3, 4, 7, and 8.

**FORCES BETWEEN GROUND AND HOOF**

The size and pattern of the forces acting between the ground and the hoof vary considerably with body weight, gait, and speed. In draught horses, the load also plays an important role. There are a number of reports dealing with this aspect of gait analysis, but
because of the lack of standardization they are not easily summarized. 

However, the peak vertical forces for different gaits are as follows:

Walk—0.5 to 0.7 body weight (bwt)\(^{63,69}\)

Trot—0.9 to 1.3 bwt at speeds up to 8 m per second\(^{78,63,69}\)

Gallp—1.75 bwt at 14 m per second\(^{89}\)

At the slow trot, the peak vertical force for the hindlimb is 10 to 15 per cent less than that for the forelimb (Fig. 9).\(^{33,69}\) In trot, the timing of the forelimb vertical peak occurs almost at the midpoint of the stance phase (45 to 50 per cent),\(^{58,63,69}\) in the hindlimb, it is a little earlier (40 to 45 per cent).\(^{69}\)

The horizontal force acting in the direction of the horse’s movement exerts a decelerating action during the initial part of the stance phase and then changes into an accelerating force. In the trot, this change in direction occurs after 40 to 45 per cent of the stance phase in the forelimb.\(^{58,63}\)

When the hoof lands, a vertical force of high amplitude and very short duration may be seen (see Fig. 9). This is equivalent to the so-
Table 3. *Temporal Gait Characteristics of Interlimb Coordination in the Canter and Gallop*

<table>
<thead>
<tr>
<th>NO. OF HORSES</th>
<th>SPEED (m/sec)</th>
<th>STRIDE STANCE PHASE (SEC)</th>
<th>OVERLAP (SEC)</th>
<th>SUSPENSION (SEC)</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>15.0–17.1</td>
<td>0.317–0.310</td>
<td>0.130–0.080</td>
<td>0.125–0.115</td>
<td>57</td>
</tr>
<tr>
<td>48</td>
<td>5.1–19.3</td>
<td>0.473–0.268</td>
<td>0.295–0.038</td>
<td>0.169–0.083</td>
<td>32 (Hellander, J., et al.: unpublished data)</td>
</tr>
</tbody>
</table>
called “heel strike” described in human athletes, which is seen in the diagrams of several equine investigations. The “heel strike” amplitude may be of great importance in the development of musculoskeletal injuries. It is increased with speed and is affected by the characteristics of the track surface and foundation.

**SOME PRACTICAL APPLICATIONS**

There are many areas that require further investigation in equine locomotion. Leach and Crawford have identified some of them and have suggested a plan of action. It includes further studies on the characteristics of normal locomotion as well as the different factors that influence locomotion such as conformation, shoeing, different
kinds of equipment, racetrack design, mechanical track characteristics, lameness, and fatigue.

**Racetrack Design**

The geometric design (that is, ergonomics) of harness racetracks and the effects of improperly banked turns on the trotting action of Standardbreds have been studied in detail (Fig. 10). Under-banked turns are extremely important in contributing to gait asymmetry and lameness.

Another most important factor is the mechanical properties of the track surface and foundation. They significantly contribute to performance and initiation of lameness. Cheney and colleagues studied the correlation between track characteristics and the prevalence of lameness at five racetracks in California. They concluded that tracks with a pliant, soft base and a loose cushion could drastically reduce the dynamic impact on a running Thoroughbred and thereby minimize the occurrence of lameness. The amplitude of the "heel strike" is also reduced on softer surfaces. Further investigations into

![Figure 10](image_url)

Figure 10. Action of a trotter going through an insufficiently banked curve at racing speed in a counterclockwise direction. The horse leans inwards as the hindquarters and sulky skid outward. Left forelimb is placed well under the body and lands on the lateral side of the heel (a); medial deviation of fetlock and carpal areas throughout the stance phase (b); right (outer) forelimb lands with both heels simultaneously (c); and no significant deviation of the fetlock and carpus (d). (From Fredricson, I., Dalin, G., Dreveno, S., et al.: Ergonomic aspects of poor racetrack design. Equine Vet. J., 7:63–65, 1975, with permission.)
the assessment of "heel strike" could be of major importance, especially in the development of better track foundations and surfaces.

In a recent study, four Thoroughbreds were recorded at three speeds each (8 to 19 m per second) on both wood-fiber and turf tracks.\(^28\) No significant differences were noted in the temporal variables between the two tracks. However, the striking gait-pattern stability was disrupted only when a horse was galloped on asphalt. On turf, the stride durations were significantly longer than on the more rigid asphalt (Fig. 11).

**Lameness**

The number of studies on the gait of lame horses is surprisingly few. Those reports that are available have used either electrogoniometry, high-speed cinematography, or force plates, but overall only a small number of horses have been investigated and no standard method of examination has yet emerged.

Joint kinematics have been studied by electrogoniometry in both fetlock\(^1\) and carpal\(^29\) lameness and a reduced range of movement was demonstrated in the affected joints.

The gait changes in horses with unilaterally induced back pain were analyzed using high-speed cinematography by Jeffcott and colleagues.\(^30\) The most striking feature here was an inability to perform at fast speeds, but no substantial signs of lameness nor any significant alterations in the stride characteristics were found. This was a useful model as it appeared to closely resemble the clinical effects of thoracolumbar injury in the field.\(^35\)

![Figure 11. Alteration in stride duration (milliseconds) with increasing speed (m per sec) in a Thoroughbred galloping on turf (□) and on asphalt (△). (From Fredriesson, L., Hellander, J., Hjertén, G., et al.: Galoppaktion II: Basala Gångartsvariabler i relation till banunderlag. Svensk Vet. Tidn. [Suppl. 3], 35:83–88, 1983; with permission.)](image-url)
The effects of phenylbutazone administration on the gait of a Standardbred trotter with a proximal sesamoid fracture was studied using high-speed cinematography and the treadmill described above. The gait was analyzed before, during, and after medication and the significant asymmetries of the horse's trot disappeared during medication (Fig. 12). Similar methods have been used in the study of the joint kinematics in forelimb lameness (Fig. 13).

The diagnostic use of toe grabs and heel calks has been evaluated by measuring the changes in the movements of the distal joints in the forelimbs and hindlimbs of Standardbreds. From high-speed cinematographic recordings, it was shown that toe grabs gave an increase of the maximum pastern/coffin joint angle both in the forelimbs and hindlimbs. The heel calks gave an increased dorsiflexion of the fetlock joints of forelimbs and hindlimbs. It was suggested that toe grabs were the more valuable type of provocative in distal lameness.

In their studies on the effects on gait from clinical and experimental digital flexor tendon injuries, Silver and colleagues combined force-plate measurements with high-speed cinematography for the assessment of lameness and recovery. From these objective measurements, they concluded that the force plate was able to distinguish between those horses whose performance was almost the same as before injury and those that had "compensated" and therefore ap-

![Figure 12. Height curves of the tuber spinae scapulae (tss) and tuber coxae (tc) in a Standardbred trotter with lameness due to a proximal sesamoid fracture in the right forelimb. The horse was recorded by high-speed cinematography when trotting on a treadmill at 7.6 m per sec before (- - -) and during (— — —) administration of phenylbutazone. The stance-phase duration (milliseconds) of the four limbs is also given before and during medication. During the administration of the analgesic agent, a normalization of the vertical movements was observed and the marked diagonal dissociation on the right diagonal disappeared. (Diagram courtesy of Dr. Stig Dreveno, Department of Anatomy and Histology, Faculty of Veterinary Medicine, Swedish University of Agricultural Sciences.)](image)
Figure 13. Carpal versus elbow joint angles of a Warmblood-type horse with a left carpal osteoarthritis. The horse was recorded by high-speed cinematography on a treadmill at 6.0 m per sec before (- - -) and during (———) administration of phenylbutazone. During medication, an increased and normalized range of movement was seen. Heel contact before and during medication (a) and (a'); mid-stance position (b) and (b'), heel-lift (c) and (c'); heel contact after one full stride cycle (d) and (d'); stance phase (a–c); and swing phase (c–d).

peared “clinically sound.” There was also a good correlation between force-plate data and subsequent pathology.

Finally, the force plate has been used to investigate horses with either experimentally induced or naturally occurring carpal and fetlock joint osteoarthritis, and a significant decrease in weight-bearing on the affected limb was found.289

Gait Fatigue

From the viewpoint of exercise physiology, the effects of fatigue on the gait of the horse are of paramount importance. The gait changes produced by fatigue are also thought to predispose to certain musculoskeletal injuries.4760 If these changes could be better understood and identified, they could be of great value in the assessment of individuals and their training programs.41

Little work has been done in this area as yet, however. In racing Thoroughbreds, the changes due to fatigue include increased stride duration and shorter stride lengths.47 There have not been any studies reported yet on the effects of fatigue on the gait of trotters and pacers.
The Development of Gait in Young Horses

Little is known about the development of gait and its correlation to growth in young horses. In adult Standardbred trotters, gait asymmetries are frequently present even in sound horses. To study the development of gait asymmetries in young Standardbreds, 10 horses were recorded by high-speed cinematography at the ages of 8, 12, and 18 months. In the trot, asymmetries were most pronounced at the age of 18 months and included differences between the left and right diagonals and between contralateral limbs. It was concluded that locomotor asymmetries are inherent to some extent.

Jumping Performance

Locomotion analyses could be of great value in the assessment of jumping performance and in the training work of showjumpers. The techniques of a number of international Grand Prix horses when negotiating different obstacles have been studied by high-speed cinematography. Recently, more detailed analyses of the temporal and linear stride characteristics during take off and landing have been carried out in event-horses jumping a steeplechase fence and in horses competing in Grand Prix jumping.

CONCLUSIONS

From the material presented in this article, there can be little doubt of the importance of gait analysis in exercise physiology, racetrack ergonomics, and lameness prophylaxis. It also provides an exciting concept for the objective assessment of performance potential in racehorses. However, the reader should not be carried away with enthusiasm without taking careful stock of the real situation in equine kinesiology. It is true that there are a large number of references in the literature, but viewed critically they fall a long way short of giving a clear overview of the subject. This is a pity because one would have thought that Muybridge's outstanding and pain-staking early work would have set the scene and been a fine example to later investigators. In fact, we find the following:

1. Insufficient data are available on the physiology of locomotion and the gaits of horses.
2. A standard nomenclature for the parameters of gait has been lacking.
3. Comparison between different workers is difficult because no standardized system of recording is ever used.
4. Many workers have investigated only very small numbers and have not recorded such fundamental data as numbers, ages, body weights, height, and speed of the animals.

As a result, many of the published papers on gait analysis, even in international journals, have only limited scientific value. What is urgently needed is the following:
1. International collaboration between investigators to coordinate ongoing programs of research along the lines suggested by Leach and Crawford.11
2. Standardization of the recording techniques utilized as well as the methods of exercise. This will probably involve setting up special locomotion laboratories equipped with a treadmill and computerized analytical recording systems.
3. Much more "normal material" should be investigated for the different types and gaits of horses at different speeds and on various track types.
5. Reviewers and scrutinizers of papers on gait analysis should be much more critical about material presented for publication.

Despite the time, effort, and expense of implementing these recommendations, they will undoubtedly pay handsome dividends! The field of equine kinesiology will then be able to live up to the expectations that it was given 10 or so years ago and prove to be an invaluable tool in equestrian sport and equine veterinary science.

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Non-invasive measurement of bone: A review of clinical and research applications in the horse

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Summary
The current methods for non-invasive measurement of bone quality are reviewed. In the horse this has traditionally involved the use of radiography, but there are now two other modalities available for the critical evaluation of cortical bone quality and strength. These utilise single photon absorptiometry and ultrasound velocity. Photon absorptiometry gives a direct measurement of bone mineral content, by using a monoenergetic radionuclide source, and transverse ultrasound velocity in bone gives a measure of bone stiffness or elasticity. They can both be used conveniently on the metacarpus of the conscious horse. Both ultrasound velocity and bone mineral content can be used as accurate indicators of skeletal maturity. In addition, the effects of disease on bone and certain types of lameness can be monitored accurately. Preliminary data show an association with exercise in young and mature horses. There also appears to be considerable scope for in vivo research of bone changes in horses produced by immobilisation, weightlessness, exercise and nutrition.

Introduction
In human medicine the clinical applications for assessment of bone quality are well established, particularly in the evaluation of osteoporosis and metabolic bone disease (Griffiths and Zimmerman 1978; Cheney and Shore 1982). The application of some of these techniques to the horse would also seem to have great potential, particularly for the accurate assessment of skeletal maturity and to monitor the effects on bone of exercise and training methods. It has been demonstrated clearly in man that increased mechanical loading of the skeleton leads to increased bone mass and strength (Nisdon and Westin 1971; Williams, Wagner, Wassich and Heitbrun 1984).

The whole field of exercise physiology and sports medicine in horses is currently making substantial headway, particularly in the areas of cardiovascular and muscle physiology. However, little attention has yet been focused on the in vivo response of bone to the stresses of racing and other forms of equestrian sport, although preliminary studies on racehorses are now underway in Australia, Italy, Japan and the USA. The purpose of this paper is to review the current situation in assessing bone quality non-invasively and to draw attention to its possibilities in equine practice as well as in research.

The concept of bone quality
For the purposes of this article ‘bone’ refers to that mineralised body tissue which originates from endochondral (ie, long bones) or intramembranous (ie, vertebrae and skull) ossification. Bone is generally considered to be a two phase system or mineralised composite (Currey 1984; Lees and Davidson 1977). It has a primary organic matrix of fibrous Type I collagen onto which hydroxyapatite, a crystalline calcium phosphate, is deposited. The presence of mineral gives bone its hardness and stiffness. The other major component of bone is water which is intimately incorporated in the structure of the other two components by adhering to the surfaces of the molecules and crystallites, or lying free and filling pores and vesicles.

The major role of bone is in the structural (ie, mechanical) support of the body and to withstand the stresses of locomotion. This is particularly important in the horse which, historically, has relied upon its locomotory ability to escape predators. Man has used the horse for transport, as a source of power and in warfare; but today the horse is also involved in racing, jumping and other competitive athletic events which place further stresses on this structural support. As in other species, bone is an active system with considerable regenerative and remodelling capacity. The modelling and remodelling activity of bone is responsive to hormonal and nutritional factors as well as being affected by the mechanical strain history and by various drugs. Osteopenia means too little mineralised bone (Mazen 1979). Osteoporosis which is often used synonymously, is when there is deficient mineral and collagen. Osteomalacia is reduced mineral due to inadequate osteoid mineralisation.

In the horse bone quality involves provision of the minimal amount of bone distributed in such a way as to maximise overall bone strength. This is especially important in the distal limbs in order to withstand stresses and enhance locomotory ability. The mechanical properties of cortical and trabecular bone have been investigated extensively. For example, the density of compact bone has been found to be positively

This paper is based on a talk given at the Eighth Ham-Fallon Memorial Lectures, Sutters Paradise, Australia 1986.
correlated with both breaking strength and the modulus of elasticity (Wright and Hayes 1976; Schryver 1978). The mineral density, or percentage ash, has been correlated with the breaking strength of whole bones as well as to single osteons (Vose and Kubala 1959; Ascensi and Bonucci 1968; Currey 1969a, b).

An assessment of the ‘quality’ of bone must involve different facets of its material components and the geometric structure. The basis of non-invasive bone measurement is to characterise as precisely as possible these important features. In particular, it involves an assessment of total bone strength in terms of:

a) stiffness or elasticity;
b) mineral density; and
c) geometric configuration.

There are inherent difficulties in the accurate estimation of elasticity and density because of the anisotropic and non-homogeneous nature of bone. Nevertheless, some valuable information can be gained because non-invasive techniques can be used sequentially.

Methods of non-invasive bone measurement

Non-invasive measurement of bone mineral content in man has been considered of diagnostic importance for over 50 years. A variety of different techniques (Table 1) have been used successfully to quantify aspects of bone density both clinically (eg, osteoporosis) and experimentally (eg, immobilisation and spaceflight). The current trend is to develop sophisticated methods for bone measurement involving quantitative computed tomography (QCT), magnetic resonance imaging (MRI) and nuclear medicine (NM). These modalities, described here briefly, generally tend to be beyond the present scope of equine veterinary medicine, principally because of the costs involved. However, there is considerable scope for investigation of the pathophysiology of equine bone using modestly priced equipment.

Sites

There are essentially two types of bone that can be investigated: cortical and trabecular. The measurement of cortical bone, which is dense and compact, gives a good indication of long bone strength. Trabecular bone has a faster turnover and more rapidly reflects generalised changes in the skeletal system. The measurement of trabecular bone is therefore considered most important for early detection of metabolic bone changes (eg, osteoporosis).

It is important to be able to measure long bone strength and density in the horse because osteoporosis and metabolic bone disease are relatively uncommon. There are good indications for using the third metacarpus for the assessment of cortical bone quality in the horse. These include its biomechanical role and importance as a site of injury. The metacarpus also lends itself extremely well to these investigations because of its accessibility and minimal soft tissue covering. Preliminary investigation of the tarsus (calcaneus) is under way for the assessment of trabecular bone (Scotti and Jeffcott 1988). Other sites might include the coxofemoral vertebral, as has been used in sheep and cattle (Siemon, Moodie and Robertson 1974; Zetterholm and Dalen 1978), or the distal metacarpal metaphysis (J. C. Cleland and L. B. Jeffcott, unpublished data).

Radiography

Plain radiography – has been the traditional means of assessing skeletal maturity in the horse. This has principally involved assessment of growth plate closure, particularly that of the distal radial physis. Closure times have been correlated to unsoundness in young racehorses (Mason and Beurke 1973; Gabel, Spencer and Pipers 1977), but the technique is not precise. The assessment of cortical density is imprecise because a change of greater than 40 per cent in bone mineral content is required for visual evaluation by radiography (Lachman 1955). However, the situation can be improved, to some extent, by using the techniques of radiographic densitometry and radiogrammetry.

Table 1: Summary of methods currently available for non-invasive measurement of bone

<table>
<thead>
<tr>
<th>Modality</th>
<th>Specific technique</th>
<th>Bone data determined</th>
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</thead>
<tbody>
<tr>
<td>Radiography</td>
<td>Plain radiography</td>
<td>Visual image analysis</td>
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<tr>
<td></td>
<td>Radiographic photodensitometry</td>
<td>Optical density</td>
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<tr>
<td></td>
<td>Radiogrammetry</td>
<td>Cortical dimensions</td>
</tr>
<tr>
<td>Photon absorptiometry</td>
<td>Single ($^{125}$I, $^{241}$Am)</td>
<td>Bone mineral content</td>
</tr>
<tr>
<td></td>
<td>Dual ($^{153}$Gd)</td>
<td>Bone mineral content</td>
</tr>
<tr>
<td>Ultrasound velocity</td>
<td>Transmission</td>
<td>Cortical bone density</td>
</tr>
<tr>
<td></td>
<td>Pulse echo</td>
<td>Cross sectional area of cortex</td>
</tr>
<tr>
<td>COMBINED ultrasound</td>
<td>Transmission ultrasound + single photon</td>
<td>Bone mineral density</td>
</tr>
<tr>
<td></td>
<td>absorbptiometry</td>
<td>Compact bone density</td>
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<tr>
<td></td>
<td></td>
<td>Modulus of elasticity</td>
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<tr>
<td>Compton/Coherent scatter</td>
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<tr>
<td>Quantitative computed tomography</td>
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<tr>
<td>Magnetic resonance imaging</td>
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<td>Plasma</td>
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<tr>
<td></td>
<td>Osteocalcin, calcium phosphorus, PTH,</td>
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<td>Calcitonin</td>
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</tr>
<tr>
<td></td>
<td>Hydroxyproline, cyclic adenosine monophosphate</td>
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</tr>
<tr>
<td>Urine</td>
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</tbody>
</table>
be detected. A computerised system had been devised by Price et al (1983) which improves clinical reproducibility to within 3.5 per cent for the human forearm. Meakim, Ott, Asquith and Feuster (1981) have estimated the bone mineral content of the equine third metacarpus in this way by determining a radiographic bone aluminium equivalent (RBAE). However, this work was done principally on excised bones and needs to be repeated in field studies to ensure its applicability as an in vivo technique.

Radiogrammetry – involves the measurement from a radiograph of cortical thickness, medullary cavity width and overall bone diameter. It has been used successfully in man by Ekman, Ljungquist and Stein (1970) and was investigated by Meakim et al (1981) in their study of 17 equine metacarpal bones. It may have clinical potential providing that a careful and standard radiographic technique is employed. However, a knowledge of the geometry of the normal metacarpus (Piotrowski, Sullivan and Colahan 1983) is essential.

Photon Absorptiometry

Bone mineral content (BMC) is of importance because the extent of mineralisation is closely correlated to bone strength (Currey 1984b). As a non-invasive technique in human medicine, photon absorptiometry has been a major breakthrough in helping to diagnose and monitor the problem of osteopenosis.

Single photon absorptiometry – was developed by Cameron and Sorenson (1963) in the USA. The principle of the technique is to scan a bone with a narrow beam of low-energy photons from a monoenergetic radium-225 source and to measure the degree of attenuation of the beam by bone, relative to its attenuation by tissue, by means of a scintillation detector system. A direct relationship is established between the number of extra photons absorbed and the bone mineral content. The amount of mineral (mB) per unit area in the path of the photon beam is calculated by the formula (Sorenson and Cameron 1967):

$$m_B = \frac{P_B \ln (I_0/I)}{(\mu_B \rho_B + \mu_S \rho_S)} \text{ g/cm}^2$$

where: $\mu$ microscopic density (g/cm$^2$) for bone ($\rho_B$) and soft tissue ($\rho_S$); $\mu$ mass absorption coefficient (cm$^2$/g) for bone mineral ($\mu_B$) and soft tissue ($\mu_S$):

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**Fig. 1.** Method of radiographic photodensitometry by comparing the optical density of the cortical bone on a radiograph with that of a known thickness of a standard material (e.g., aluminium step wedge).

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**Fig. 2.** Diagramatic representation of single photon absorptiometry in the horse using an $^{241}$Am source.

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**Fig. 3.** Method used to scan the third metacarpus in the standing horse by single photon absorptiometry.

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The mass of mineral per unit length of bone, M$_B$ (g/cm), is then obtained by adding the masses per unit area which are measured at equally spaced intervals across the bone.

Equipment for single photon absorptiometry uses an iodine isotope ($^{131}$I) which is available commercially for the measurement of cortical bone in humans. However, specific adaptations for veterinary use are necessary. A prototype (Figs 2 and 3) has been developed for scanning the metacarpus of the horse (Norland Large Animal Scanning System, Model 2781, Norland Corporation, Fort Atkinson, Wisconsin). This system uses americium ($^{241}$Am) as the source of monoenergetic (60 keV) photons or y-rays. The radiation dose for a full examination of both legs is very low (<2 mrad) and the beam is very fine (approximately 0.3 mm). The accuracy and reproducibility of the estimate of BMC by scanning is around 2 per cent, which is much better than by direct radiography or radiographic densitometry. The limb containing the bone being scanned must be surrounded by a soft tissue equivalent material, so that the surfaces facing the source and detector are flat and reasonably parallel. Both the photon source and the radiation counting device move in unison to scan the bone transversely. The transmitted intensity of the beam is reduced as it traverses the bone and a logarithmic plot of counts per second shows a typical absorption curve (Fig 4).

One major disadvantage of single photon absorptiometry is that it provides the mineral content per unit length of bone scanned (i.e., BMC g/cm), and takes no account of differences...
in bone size. In other words, single photon absorptiometry measures the mineral content in a 1 cm thick slab or cross section of the bone. Thus, it is really only useful in monitoring sequential changes in an individual where changes in the cross-sectional area of the bone can be considered negligible.

For the assessment of trabecular bone mineral content, single photon absorptiometry can be used with $^{153}$Tb as the source of choice. Most sites have differing proportions of cortical and trabecular bone. The tarsus is a potential site which is currently being investigated (Scotti and Jeffcott 1986).

Dual photon absorptiometry - is a newer technique which can quantify more accurately bone mineral content, particularly where there is variable thickness of overlying soft tissue. It is considerably more expensive than single photon absorptiometry, but provides a more sensitive indicator of general skeletal mass (Kinner and Pors Nielsen 1980; Riggs et al 1981). The technique uses high purity and high activity gadolinium ($^{153}$Gd) which is a dual energy source of photons at approximately 44 and 100 keV. Scans of the human spine are made in a rectilinear fashion and the results are expressed as g/cm. It takes 15 to 45 mins to perform a scan of the spine depending on the activity of the source and the precision required. The precision of measurement is considered to be 2 to 3 per cent and the radiation dose is relatively low at 10 to 20 mrem. However, this method still suffers from not taking into account the third dimension of the bone volume and again sites are mostly a combination of cortical and trabecular bone. Work in the horse using dual photon absorptiometry has been confined so far to excised bones (Lawrence and Ott 1985; McCarthy, Jeffcott and McCartney 1988).

Ultrasound velocity

The measurement of ultrasound velocity in bone is a recent development and not, at present, clinically applied. It is used to measure bone quality because the velocity of sound is directly related to the modulus of elasticity (or stiffness) and density of bone provided the extensional (ie, longitudinal) wave velocity is measured (Katz 1980):

$$E = \rho C^2$$

where $E$ = modulus of elasticity;
$p$ = compact bone density or specific gravity;
$C$ = velocity of ultrasound.

A study on human cadaver bone has shown correlations between ultrasound velocity, density and the modulus of elasticity as measured by three point bending (Ahendsohn and Hyatt 1970). Lees, Ahern and McCartney (1983) reported that ultrasound velocity in bone is dependent on its density, water content and probably its porosity, as well as the direction of the ultrasound path and the orientation of fibres in the bone matrix.

The modulus of elasticity is the property of a material which relates to its bending strength and stiffness and ultimately to its fracture threshold (Pratt 1980). Preliminary studies, measuring the transverse ultrasound velocity through the metacarpal shaft of the horse to give an indication of strength, have been encouraging (Pratt 1980; Rabin et al 1983; Hasegawa, Masumitsu, Ueda and Tomisaka 1985; Jeffcott and McCartney 1985).

Transmission ultrasound velocity - This method involves passing an ultrasound beam through the bone from a transmitting to a receiving transducer (Fig 5). The velocity ($C$)
of the ultrasound (m/sec) can be derived from the distance the two transducers (D) are apart and the time of flight of the sound (t). Corrections need to be applied to compensate for overlying soft tissues. If it is assumed that the some pathway is directly from one transducer to the other, the velocity determined is referred to as 'apparent velocity' (C):

$$C = \frac{D}{t} \text{ m/sec}$$

C may be correct for a uniform section of cortical bone, but is inaccurate for the metacarpal shaft which is not uniform, but cylindrical with an outer cortex ($C \sim 3000$ m/sec) surrounding a medullary cavity ($C \sim 1800$ m/sec). In this situation, the shortest pathway for the sound will be entirely via the cortex as shown in Fig. 7. It is possible to estimate the true pathway and correct C, to give a 'true' transverse cortical bone ultrasound velocity ($C_T$) (McCarron and Jeffcott 1987). Not only can the cortical pathway be determined, but by measuring a later pulse which travels directly through the medulla (Fig. 7), the ratio of the medulla to cortex can also be estimated. From this information the cortical cross sectional area (CSA) of the shaft can be derived.

**Pulse echo ultrasound velocity** - This is another technique which can be used to measure the velocity of ultrasound in cortical bone. The time difference between reflections of a pulse of ultrasound from the inner and outer surfaces of the cortex of the bone is measured on an oscilloscope (Craven, Constantini, Greenfield and Stern 1973; Greenfield *et al* 1981). A measurement of the thickness of cortex through which the pulse has travelled is made from a radiograph taken in a standardised fashion. Given the time difference ($t_x$) and the cortical thickness ($d$), the velocity of ultrasound ($C$) can be estimated:

$$C = \frac{2d}{t_x} \text{ m/sec}$$

Pulse echo ultrasonography also holds promise in the measurement of the soft tissue thickness overlying the bone, which is one of the problems encountered with the transmission method described earlier, particularly when oedema is present.

**Combined ultrasound velocity and photon absorptionmetry**

The BMC measured by photon absorptionmetry can be used to derive the bone mineral density (BMD) if the cortical cross sectional area is known. The ultrasound velocity technique provides an estimate of this area and thus:

$$\text{BMD} = \frac{\text{BMCA}}{\text{CSA}} \text{ g/cm}^2$$

The estimation of BMD provides a volumetric estimate of mineral content and allows for animals of different size to be compared and changes in growth to be objectively assessed. Using a bone model (Greenfield *et al* 1981) for cortical bone involving the microscopic collagen density ($p_c = 1.0 \text{ g/cm}^3$) and microscopic bone mineral density ($p_o = 3.2 \text{ g/cm}^3$), the compact bone density or specific gravity (CBD) can be estimated:

$$\text{CBD} = p_c + (1 - p_o/p_c) \times \text{BMD} \text{ g/cm}^2$$

**Fig. 6. Method of ultrasound velocity measurement in the third metacarpus in vivo**

**Fig. 7. Simplified diagram of pathways of ultrasound through the metacarpal shaft (from McCarron and Jeffcott 1987)**

**Fig. 8. Diagram of typical ultrasound traces seen on oscilloscope to determine time of flight measurements for apparent transverse and transverse cortical bone ultrasound velocity**
Furthermore, a modulus of elasticity (E) can be derived using the Helmholtz equation:

$$E = 	ext{BDI} \times C^2 \quad \text{N/m}^2$$

where C is the ultrasound velocity.

The strength of a bone is related to its geometry, and the elastic strength of the material of which it is composed. BMD and BDI are measures of the degree of the bone's mineralisation and E of its elastic stiffness. In this way the mechanical properties of the whole bone can be evaluated in vivo.

**Coherent Compton scattering**

A direct estimate of trabecular bone density in the human calcaneus has been developed (Shukla et al 1986) and is based on the original concept of Pumalainen, Urmahanta, Alhava and Ollkonen (1976). This technique uses the ratio of coherent to Compton-scattered photons arising from the irradiation of a small volume of bone by an x-ray source (147Am). The method, which focuses on this small volume within the structure, can measure mineral density in either cortical or trabecular bone and is considered to be superior to single photon absorptiometry because it estimates bone mineral density (i.e. g/cm³). It requires a high purity germanium detector which detects scatter at an angle of 90° from the source which is housed in a specially designed jig. The method is accurate, not particularly expensive and seems to have considerable potential for diagnosis of osteoporosis in man. However, the site measured must remain stationary for approximately 10 mins and this may limit its use in the horse.

**Quantitative computed tomography**

Quantitative computed tomography (QCT) is particularly useful for non-invasive bone measurement because of its ability to provide a quantitative assessment as well as an image. QCT measurements are achieved by using a minimal calibration phantom included in each scan. It can be used to measure trabecular or cortical bone, the region being chosen on the CT image. The equipment is highly sophisticated, requires careful technical support and operational experience to achieve consistent results. QCT techniques may use either a single energy photon beam (SE-QCT) or dual energy (DE-QCT), in which each slice is sampled twice at different kVp levels. DE-QCT requires extra processing and various methods are being developed. Because DE-QCT techniques can correct for marrow fat it is considered better than SE-QCT, although the radiation dose is higher and there is decreased precision. In human medicine, QCT is considered superior to dual photon absorptiometry (Gennat 1985). Despite its general use in a small number of institutes in the USA, there are very few data on the assessment of bone quality in the horse by QCT.

**Magnetic resonance imaging**

This recently developed modality relies on detecting differences in tissue content and structure by measuring the nuclear resonance of the material at different points in space, when the material is enclosed in a very high uniform magnetic field and excited by radio frequency fields. The majority of resonance detected with present techniques is related to the hydrogen atoms. Cortical bone does not emit strong or distinctive signals, but trabecular bone and bone marrow, in which there is both fat and other soft tissues give significant signals. This new, sophisticated and very expensive modality is yet to be evaluated for its use in bone biology, but is considered by many to have great promise, in particular in discriminating between cortical bone or highly mineralised tissue and fat or other soft tissues (Young 1984).

**Nuclear Medicine**

Nuclear medicine uses physiological tracers, referred to as radiopharmaceuticals, to measure remodelling of bone. Specific radiopharmaceuticals have been developed which allow images of bone changes (scintigraphy) to be made following their injection into the bloodstream and subsequent uptake at injured or altered sites due to some physiological change. The bone images are generally produced minutes or hours after administration of the radiopharmaceutical by a large volume collimated detector called a gamma camera. The images, which take a few minutes to produce, are of a coarse appearance, but have distinct value because of the physiological basis of the uptake. The equipment is expensive, the radiopharmaceutical and the animals require special handling and thus the technique is only suitable for well equipped suitably staffed and licensed centres. The techniques have been applied in the horse with very promising results (Eibl 1977; Baum and Devos 1980).

A slightly different technique for regional bone mineral densitometry in rats has been described (Leblanc, Evans, Jhirn and Johnson 1984). An 125I source was used with a gamma camera and a system to magnify the image of the bone for high resolution. Precision of better than 5 per cent was obtained and the method demonstrated the heterogeneity of bone mineral loss in oophorectomised and bone grafted rats.

**Neutron activation**

Neutrons from either a neutron generator or a radioactive neutron source are used to induce radioactivity in the calcium atoms of the bone matrix. The calcium content can be estimated by detecting the radiation emitted by the radioactive calcium (Cohn 1981). The method is simple, could be adapted to the horse, but does require immobilisation for some minutes. The equipment is sophisticated and requires specialist attention.

**Biochemical tests**

Although the biochemical basis for bone remodelling is somewhat obscure, several substances appear to be involved and may serve as clinically useful biochemical markers of the state of osteoporosis (Orwell and Belsey 1984). Alkaline phosphatase (AP) is an enzyme considered essential in mineralisation, and concentrations in serum can reflect osteoblastic activity. It is a useful, but somewhat insensitive, marker of bone turnover unless the bone-specific isozyme can be assayed.

Hydroxyproline (Hyp) is produced during the formation of bone collagen and is released during the process of bone resorption by osteoclasts. It is not biologically recycled and cannot therefore be used in the formation of new bone collagen. Ultimately it is excreted in the urine and therefore is of some value as a marker of bone turnover. However, the situation is complicated by necessity to adjust the diet of patients to overcome the dietary contribution to levels in urine.

Osteocalcin (or bone Gla protein) may be a more sensitive indicator of the mineralisation process because is released into the circulation during bone formation (Mellick, Farrugia...
and Quelch 1985). It has definite advantages over AP and HP because it is specific for bone and can be measured easily by radioimmunoassay.

Serum calcium and phosphorus are of no use as screening tests in the diagnosis of osteopenia because the size of serum calcium and phosphorus pools bear no direct relationship to bone mineral content. However, they may be invaluable in the identification of certain conditions which may be responsible for osteopenia.

Other markers, including parathyroid hormone (PTH), urine cyclic adenosine monophosphate (cAMP), vitamin D and calcium, have been used (Orsow and Belcex 1984) but they all have limited usefulness in clinical terms.

**Applications of bone quality measurement in horses**

The main indications for evaluation of bone quality in horses are listed in Table 2.

**Skeletal maturity**

Data from post mortem material from 50 normal horses showed marked increases of BMC and apparent transverse ultrasound velocity from birth and during the first few months of life. The values began to plateau after two years. Peak values were noted at six years of age and this was followed by a slight fall with advancing years (Jeffcott, Buckingham and McCartney 1987). There were no significant differences between males and females or left and right limbs.

Results in a small group of Standardbred foals (n = 5) studied from weaning (five months) to onset of training (16 months) showed a similar pattern to that of the exported bones (Buckingham and Jeffcott 1987). BMC increased progressively, but this was largely caused by increase in bone size due to growth. The BMD was calculated and found to remain constant, as did the modulus of elasticity.

**Training and exercise**

The traditional method of training Thoroughbred racehorses was investigated at two stables in the Melbourne area (Jeffcott, Buckingham and McCartney 1987). Apparent transverse ultrasound velocity was measured sequentially (n = 201) at monthly intervals from 18 months to three years. All horses showed a progressive increase over the period.

**TABLE 2: List of clinical and research applications for non-invasive bone measurement in the horse.**

<table>
<thead>
<tr>
<th>Applications for non-invasive measurement of bone</th>
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<tbody>
<tr>
<td>Skeletal maturity:</td>
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<tr>
<td>(a) age, sex, breed and size</td>
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<tr>
<td>(b) problems associated with growth (osteochondrosis)</td>
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<tr>
<td>Assessment of training methods:</td>
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<tr>
<td>(a) weaning, breaking, training and racing</td>
</tr>
<tr>
<td>(b) conventional vs interval training on treadmill</td>
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<tr>
<td>Lameness:</td>
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<tr>
<td>(a) Acute injuries — alteration in viscoelastic properties of bone</td>
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<td>(b) Chronic lameness — reduced weight bearing</td>
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<tr>
<td>Bone metabolism and osteopenia:</td>
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<tr>
<td>(a) weightlessness by florarion</td>
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<td>(b) immobilisation of distal limb by cast</td>
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<tr>
<td>Calcium phosphorous metabolism and generalised bone disease:</td>
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<tr>
<td>(a) dietary effects on bone</td>
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<tr>
<td>(b) assessment of osteoporosis</td>
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Examined from 2730 to 2882 m/sec. Values appeared to increase more steeply with increasing work. If the training programme was halted for some reason, apparent velocity readings remained static or even declined. This was noticed particularly in horses that developed shin soreness.

The effects of more standardised forms of exercise in mature horses have also been investigated (Jeffcott, Buckingham and McCartney 1987). No changes in apparent transversal velocities of BMC were detected in two horses given an eight week programme of relatively slow work in a sand lungen ring. A group of six racehorses given a 12 week programme of strenuous interval training on a treadmill showed a significant increase in ultrasound velocity at the end of the exercise programme. However, no significant changes in BMC or BMD were noted. These preliminary results are encouraging and have been confirmed in more detail by McCarthy and Jeffcott (1987).

**Lameness**

Sudden decrease in ultrasound velocity has been used to diagnose stress fractures in racehorses in the USA (Pratt 1980; Hohin et al. 1983). Alterations of similar magnitude have been seen in other conditions (e.g. splints, severe tendon strain, carpal fractures) (Jeffcott and McCartney 1985). However, there is an important complication in interpretation of apparent velocity which invokes the presence of subcutaneous edema of the metacarpal shaft. Even 1 to 2 mm of increased soft tissue thickness can lower the apparent velocity reading by 50 to 100 m/sec. Provided the thickness of additional soft tissue is known it can be corrected for, but this is not yet a practical proposition in the field.

A significant fall in apparent velocity is noted in young horses that develop shin soreness (Jeffcott et al. 1987). Values do not increase again until the animals return to training. No changes in BMC with acute lameness have been seen. However, in chronic moderate to severe lameness changes in both apparent velocity and BMC occur. The type of lameness does not seem to be of major importance as the changes result from partial weight bearing and disuse for periods of a month or more (Jeffcott et al. 1986).

**Induced Osteopenia**

The experimental production of reduced bone density is an important feature of these investigations because it provides a useful pathophysiological model of bone change. A sequential method of flotation of horses to reduce body weight by 50 per cent has been achieved (Hutchins, Clunie and Brownlow 1980; V. C. Spens, unpublished data). The combination of non-invasive measurements and quantitative histomorphometry demonstrates the degree of osteopenia. A similar effect can also be obtained in one foal by applying a full length fibreglass cast for eight weeks (S. H. W. Buckingham and L. B. Jeffcott, unpublished data).

Another method of inducing bone weakness has been reported by Lee, Burnard and Churchill (1987) by inducing a state of osteochondrosis in rabbits. A lathrogen reduced the elastic modulus of growing bone by inhibition of collagen crosslinking in the bone matrix and consequently reducing the mineralisation of the matrix.

**Effects of diet and metabolic bone disease**

Growing animals have high calcium requirements to provide mineralisation for a rapidly expanding skeletal mass, and therefore have high levels of gastrointestinal calcium absorp-
tation. Older animals require less calcium in their diet and their calcium absorption is less efficient. Valuable baseline data have been established for skeletal maturation in horses during the post weaning period (Buckingham and Jeffcott 1987). The stage is set for investigation of the effect of variation in calcium and phosphorus content of the diet on bone quality and skeletal maturation.

In man, bone mineral measurements, by the use of absorptionmetry and CT, have been used to predict relative fracture risks at certain skeletal sites, to assess accurately the severity of bone loss in conditions resulting in osteoporosis, and to monitor the effectiveness of therapy (Waldner 1985). Bone scintigraphy allows assessment of total skeletal bone turnover in similar patients.

There has been very little of this type of work done in relation to metabolic bone disorders of the horse. The application of these techniques to clinical disorders such as osteochondrosis, rickets and nutritional secondary hyperparathyroidism will be extremely interesting.

Potential for non-invasive bone measurements

It is clear that non-invasive measurements of bone quality can provide valuable information for assessing skeletal maturity and in studying the effects of exercise and lameness. At this stage one exciting facet of the research is the creation and monitoring of experimental situations to study, and even manipulate, changes in the physical properties of bone. The combined use of ultrasound velocity and single photon absorptiometry now enables the following measurements to be made non-invasively:

- Apparent transverse velocity of ultrasound (Ct, m/sec);
- Transverse cortical bone ultrasound velocity (Ct, m/sec);
- Cross sectional area of metacarpal cortex (CSA cm²);
- Bone mineral content (BMC g/cm²);
- Bone mineral density (BMD g/cm³);
- Compact bone density (CBD g/cm³); and
- Transverse modulus of elasticity (E, GN/m²).

The correlation of all these parameters with ash and chemical analyses on cadaver specimens is being carried out. Preliminary results look very encouraging (Jeffcott and McCartney 1985, Jeffcott et al 1986; McCartney and Jeffcott 1987; McCarthy et al 1988). However, crucial to the whole project will be the comparison of in vivo findings with histomorphometric analyses after bone labelling, thus allowing more accurate appreciation of bone changes, and rate of turnover, in different situations.

Despite the wealth of knowledge that is being accumulated, there are undoubtedly some major problems to overcome. For acceptable precision and repeatability of the methods, considerable experience with the equipment and procedures is necessary. With ultrasound velocity measurement there is always the problem of subcutaneous oedema or swelling affecting the readings. The selection of the site and positioning for photon absorptiometry, as well as the avoidance of limb movement, can be difficult. Electrical and computer problems can also occur. We believe, at this stage, that the use of commercial equipment which only measures apparent transverse velocity of ultrasound is misleading because interpretation of results can be very difficult. They will become more valuable as knowledge of bone pathophysiology increases.

One direction that our research is taking is to investigate different types of exercise in different age groups of horses and also to attempt to create a model of sole shins for detailed study of the changes involved. In regard to metabolic bone disease and the effects of dietary change (calcium/phosphorus metabolism in particular), a better means of examining trabecular bone is required. This might be achieved by a combination of ultrasound and photon absorptiometry using a 125I source, or by the Compton/coherent scattering technique of Shukla et al (1986).

In conclusion, the preliminary work done so far, clearly demonstrates that single photon absorptiometry and ultrasound velocity measurement, used alone and in combination, are potentially useful clinical and research tools for the non-invasive investigation of bone quality in the horse.

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SECTION 2

VERTEBRAL CONDITIONS.

2.1 REVIEWS AND BIBLIOGRAPHY.
2.2 DIAGNOSIS OF VERTEBRAL DAMAGE.
2.3 CLINICAL AND EXPERIMENTAL CONDITIONS.
2.4 MANAGEMENT AND TREATMENT.
SECTION 2 VERTEBRAL CONDITIONS

A particular interest in the equine vertebral column was developed because of the special facilities in the Clinical Department of the Equine Research Station, UK, and the dearth of scientific information concerning equine spinal and thoracolumbar disorders.

The functional anatomy of the back has been investigated with comments on its biomechanics and natural rigidity during locomotion. A technique for clinical and radiographic examination of the horse's back was devised which formed the basis of an epidemiological survey of 443 horses presented with a history of thoracolumbar disorder. A wide range of conditions were found to be capable of producing back problems, although the most frequent causes was diagnosed as injury to the epaxial muscles and ligaments. Less commonly encountered were vertebral malformations, fractures and degenerative spondylosis. The most frequent lesion involving the vertebral column was associated with crowding and overriding of the spinous processes in the caudal thoracic region (ie "kissing spines"). The overall prognosis for these horses with chronic back injuries was usually favourable (ie 57% recovery rate) irrespective of the specific diagnosis or the means of therapy given.

More recently a model of back pain was established by injection of multiple small doses of concentrated lactic acid into the longissimus dorsi muscles. The effects of this procedure were assessed on a treadmill to provide standard regimes of exercise. The horses were filmed by high speed cinematography and a quantitative assessment of the characteristics of the gait made. The results were interesting because alterations in gait variables were minimal, but there was a dramatic reduction in performance potential, which is such an important feature of field cases with back pain.
SECTION 2 VERTEBRAL CONDITIONS

2.1 REVIEWS AND BIBLIOGRAPHY


This section incorporates a number of review papers on problems associated with the horse's back. A paper presented as the Fourth Sir Fredrick Hobday Memorial Lecture considers many of the difficulties associated with establishing meaningful criteria for diagnosis and treatment.

Statement on Share of Work:

Papers 4-7 - All these papers were planned and prepared by myself and I played the major role in publishing the two collaborative papers.
Disorders of the Equine Thoracolumbar Spine—A Review

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M.R.C.V.S.

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Animal Health Trust, Balston Lodge,
Newmarket, Suffolk, England

Introduction

In 1976, Lupton* remarked that back injuries "are among the most common and least understood of equine affections." This statement is largely true today, judging from the limited amount of information available on the etiology and pathogenesis of conditions affecting the horse's back. The only published report on incidence from general practice1 recorded 0.9% of back injuries in a series of 6,588 horses presented with musculoskeletal damage. However, no breakdown of these cases into specific diagnoses was made.

Over the last 20 years there has been a tremendous increase in the popularity of competitive equine sports throughout the world, and associated with this a noticeable rise in the incidence of back problems has occurred.* In this review it is proposed to cover some of the historical literature on back problems, before considering the various causes of deformity and injury to the thoracolumbar spine. The important differential diagnoses of disorders of the spine will then be considered before giving a brief account of the methods currently in use for treatment of back injuries in horses.

Historical Aspects

Few firm facts, detailed descriptions, or pathological studies occur among the lengthy accounts of back disorders in the old farriery and veterinary textbooks. Diagnosis was based mostly on clinical observation, and opinions were many and varied.

These early writers were often excellent horsemen and were particularly
knowledgeable on aspects of conformation. In relation to the incidence of spinal damage, Youatt believed that the short-backed horse showed less tendency to back problems and could be expected to carry more weight. Also it possessed greater endurance but did not have much potential for speed. The long-backed horse was built for speed but was much more prone to weakness when ridden. In well-conformed animals he thought there should be a gentle ventral curve immediately behind the withers, followed by a straight line to the lumbar region. An increase in this curvature (lordosis, saddlebacked, swaybacked) would increase the tendency to weakness and strain (Fig 1). Dorsal curvature (ruch back), however, was considered to be a more severe defect, which seriously impaired usefulness and performance (Fig 2).

One condition, to which reference was almost invariably made, was that of strain of the back, also called strained back-sinew, sway'd back, or strain of the loins. This was apparently common in heavy draught horses and was usually caused by injury or overexertion. It reputedly involved "strain of the back muscles, injury to the spinal marrow and even discolouration of the pelvis." In severe cases there was marked lameness with back pain and the animal was said to be chinked.

Fractures of the spine were referred to by some of these authors but did not seem to have been particularly common. A general stiffness of the back was attributed to ankylosis of the bones of the back which was thought to be common in old and hard worked horses. Youatt referred to this condition as broken-backed or chinked in the chine.

A problem Lupton referred to as rick or chink of the back was particularly common in draught and harness horses. One fairly dramatic clinical sign observed in some of these cases was that of so-called kidney-dropping (Fig 3). The animal would suddenly squat on its haunches when coming to a halt. There would be no obvious pain exhibited although a temporary loss of skin sensation in the hind legs apparently occurred. The animal could soon get up again on its own and be apparently sound until the signs recurred. The method of examination in horses with a rick or chinked back was by palpation of the thoracic and lumbar dorsal spinous processes, in order to locate an area of pain in the lower back region (Fig 4). It was suggested that in addition

![A Hollow-Backed Horse](image-url)
to the vertebral damage there was injury to the spinal cord. Consequently clinical signs were prone to recur, and these animals carried a poor prognosis. Ricked back was not always diagnosed with such dramatic symptoms, and in some horses clinical signs were confined to stiffness of the spine with an associated poor or difficult temperament.

Lupton described a condition often encountered in riding horses where there was considerable pain noted on mounting. This was followed by a tendency to violent kicking and rearing. He ascribed the damage to subluxation of the vertebrae of the back together with ligamentous strain. Another reported cause of back trouble was that associated with damage to and aggravation of skin lesions (stiffness, warbles, etc.) due to poorly fitting tack. Saddle galls were apparently considerably more frequent in ladies horses, presumably because of the custom of riding sidesaddle in those days.

The involvement of temperament or simply bad habits mimicking the clinical signs of back problems in some horses has been alluded to in some of the older texts, although no definite ideas on their pathogenesis or control were put forward.

Radiological Examination of the Thoracolumbar Spine

Horses with back pain present a complicated clinical picture, and specific diagnosis has been hampered by a lack of a radiographic technique suitable for the thoracolumbar spine; in the past this has been limited to the cervical region. Schebitz and Wilkins examined the summits of the dorsal spinous processes in the region of the withers from T1 to T11. Since this, a number of reports on radiography of the thoracolumbar spine have appeared, but powerful equipment is necessary to provide exposures of up to 150 kV and 500 mAs. Secondary radiation is a major problem of x-raying a thick subject, but this may be reduced by:

1. Mounting the x-ray tube on an overhead gantry and linking it to a cassette holder on the far side of the animal. The source of x-rays can then be automatically directed to the center of the cassette and the beam size carefully collimated to the size of the film.
2. Enabling high ratio and crosshatch grids to be
used with confidence thus effectively reducing scatter.

3. Employing the fastest possible system of intensifying screens and film to keep exposures to a minimum.

4. Filtering ("dodging") part of the primary beam to help compensate for the marked variation in thickness of the horse's spine.

5. Putting additional lead on the back of the cassette to prevent back scatter for exposures of 100 kV or more.

It is not possible to take radiographs of diagnostic quality of the sacroiliac regions in the standing position. The animal is placed on its back under general anesthesia and the cassette inserted beneath the pelvis. Even in very large horses, weighing 700 kg or more, exposures above 150 kV are not required, although up to 500 mAs have been used on some occasions.

Congenital Deformities of the Thoracolumbar Vertebral Column

Congenital malformations of the thoracolumbar vertebral column are uncommon. The deformity most frequently encountered is scoliosis (lateral deviation of the spine). The degree of spinal deviation is quite variable, but most affected foals that are born alive generally adapt themselves to the condition within a few weeks of life. Severe cases are not usually viable and are frequently associated with other limb deformities.

Rooney and Prickett reported on congenital lordosis (dipped or swayback) in 2 yearling fillies. The spinal curvature began in the cranial thoracic region, T₃-T₇, and was associated with marked hypoplasia of the caudal intervertebral articular processes. There was overextension at 1 or more of these articulations, resulting in dipping and undue curvature of the thoracic spine. Kyphosis (round back) in 3 Thoroughbred weanlings has been recorded by Rooney, but no reference to other vertebral deformities has been found.

Soft Tissue Injuries and Myopathies Affecting the Back

Muscle Damage—One group of conditions that has received considerable attention is that of the so-called exertional myopathies (i.e., azoturia and the tying-up syn-
dromes). Azoturia (or paralytic myoglobinuria) is considered to be the severe form of this condition and is not usually confused with a back problem. Typically it occurs in animals that are in good bodily condition, after 1 or 2 days rest but kept on a high grain ration. Soon after exercise is recommenced, the animal shows profuse sweating with pain and "boarding" of the muscles of the quarters. In severe cases the animal may become recumbent and even die. The clinical signs are associated with renal damage and the passage of deep brown or black colored urine (i.e., myoglobinuria).

Tying-up or self-tie involves muscular damage without obvious renal involvement and symptoms of thoracolumbar injury are sometimes exhibited. The condition usually occurs after active muscular exertion and most commonly involves the iliopeas, quadriceps, and glutal groups of muscles. With increasing speed and duration of work, affected animals do not stretch out fully, the back is kept rigid, and the horse walks as if suffering from back pain. There may be obvious, often unilateral hindlimb lameness, as well as general stiffness or restriction of gait after exercise. There is frequently resentment to hard pressure and palpation over the loins. Pain may also be produced by palpating the iliopsoas muscles on rectal examination. The clinical signs are usually of fairly short duration, lasting only a few hours. Once an animal has been affected it seems to be subject to recurrence.

The pathogenesis of this condition is unknown although an increase of glycogen storage in the skeletal muscles, especially those of the hindquarters, is suspected to be involved. The condition is common in excitable and nervous animals and seems to be more often encountered in fillies than colts or geldings. Horses on high oat or grain diet are more susceptible, and horses being rested while kept on a high plane of nutrition are at particular risk. There is apparently excessive lactic acid production when the affected muscles are suddenly exercised. The lactic acid concentration, combined with a possible vascular insufficiency in the rested muscles, results in an excessive accumulation of metabolites leading to local muscle damage. There is some evidence that vitamin E and selenium deficiency may be involved in the etiology, and some workers have reported a good response to administration of these compounds both for treatment and prevention.
The presence of the acute muscle damage, whatever the cause, may be confirmed by enzyme estimation. From a practical viewpoint tests should be performed both pre and postexercise, and the most useful enzymes for analysis are creatine kinase (CPK)\(^{31,33}\) and aspartate amino transferase (AAT or SGOT). The clinical signs are particularly important because there is little difference in the pattern of enzyme release between azoturia, tying-up, myositis, tetanus, muscular trauma, and the effects of physical exercise in untrained animals.\(^{64}\)

A condition which presents a rather similar clinical picture to tying-up is the so-called *myositis* of the psoas and longissimus dorsi muscles.\(^{3,8}\) This condition is essentially muscle strain resulting from trauma or severe exertion, and it may occur as a sequel to exertional myopathy. Owners frequently mistake this condition for *kidney trouble or chill in the kidneys*.\(^{3,11}\) The animal is presented with signs of a stiff, acutely painful back, which persists for several days or weeks. There tends to be some restriction in the hindlimb gait, and there may be raised AAT levels but probably only during the active stage of lameness.\(^{3}\) At rest the lumbar spine appears slightly arched and stiff and the hindlimbs are brought further forward under the abdomen than normal. Biopsy of the muscle may help identification of the character of the pathological process.\(^{31}\) Myositis usually responds to rest and anti-inflammatory therapy.

*Muscular* strain may also apparently result from active degenerative disease of bones or joints.\(^{31}\) For example, lesions of the vertebral bodies and dorsal spines of the back, and subluxation of the sacroiliac articulations may lead to secondary inflammation of the back muscles. Hammond and Raker\(^{2}\) also suggest that myositis may be produced by ill-fitting tack and faulty action or gait.

A more severe form of muscular damage involves the rupture of the psoas muscles following violent slipping backwards of the hindlegs.\(^{28}\) The animal stands with both hind legs adducted and if made to move adopts a straddling gait, shags its hind toes, and can only advance, turn, or move backwards with difficulty. The diagnosis is confirmed by rectal examination of the ruptured muscle which is painful on palpation.

*Ligamentous Damage* Sacroiliac strain or subluxation of the sacroiliac joint has been described by Rooney, Delaney, and Mayo\(^{46}\) and Adams.\(^{2}\) No reports of damage to the supraspinous or other ligamentous structures of the back have been found. The sacroiliac articulation is one of the strongest joints in the body; it is a diarthrosis formed between the auricular surfaces of the sacrum and ilium.\(^{33}\) In the normal adult horse, no significant movement occurs at this joint, and stability is provided by the tough ventral, dorsal, and lateral sacroiliac ligaments.\(^{2}\)

Severe injury to the sacroiliac ligaments caused by slipping, bad falls, or twisting of the sacroiliac joint may result in lameness. Pain is often severe and is apparently due to reflex muscular spasm, which occurs until healing of the damaged ligaments has taken place.\(^{3}\) Jackson\(^{12}\) confirms the stability of this joint in man and suggests that strain in the horse is very unlikely to occur unless accompanied by a major disruptive injury. Rooney\(^{46}\) described 2 cases of bilateral, partial sacroiliac luxation in harness horses, which clinically resembled the kidney droppers referred to by Lupton.\(^{35}\)

The clinical signs of sacroiliac strain vary considerably.\(^{1}\) In the acute stage pain may be produced by pressure above the tuber coxae or sacroiliac region, and crepitation can sometimes be detected by palpation over the affected joint(s). Marked lameness in 1 or both hind limbs is usually evident initially. In the less severely affected or the more chronic cases the animal is stiff in the back, reluctant to jump, and has a rather short hindlimb stride. Often 1 or both hind toes are dragged. Some asymmetry of the hindquarters may be seen, usually with 1 tuber sacrale displaced dorsally. Adams\(^{2}\) lists the following as differential diagnoses: iliac thrombosis, azoturia, fractured ilium, myositis of the lumbar muscles, trochanteric bursitis, possible hormonal causes, and overlapping of the summits of the dorsal spinous processes. Treatment for the condition is by prolonged rest to allow for healing of the damaged ligamentous structures. A return to complete stability of the joint does not always take place, and recurrence is fairly common.\(^{1}\)

There are few references to studies on the intervertebral disc of horses. However, it is known that these discs do degenerate, particularly with age, but they are not known to herniate into the vertebral canal or cause pain by pressure on nerve roots. Toucedo\(^{29}\) has referred to disc degeneration associated with spondylitis in racehorses.

**Lesions of the Thoracolumbar Vertebræ**

*Fractures and Dislocations—Multiple fractures of the dorsal spinous processes, T₄-T₁₄, are seen in horses which fall over backwards.\(^{11,26}\) The tips of the spinous summits are fractured and displaced laterally. Recovery is usually satisfactory after the initial pain and local reaction have subsided. There is no permanent effect on the animal’s performance, but a persistent depression or swelling over the withers may require a special saddle to be fitted. Occasionally, fractures of individual thoracic dorsal spines occur; these are associated with pain and lowered performance, but they generally heal satisfactorily.\(^{33}\) Fractures of the transverse and spinous processes of the lumbar vertebrae occur, but these also heal rapidly and merit no special consideration.\(^{28}\)

Fractures involving the vertebral bodies are uncommon and of a much more serious nature. Rooney\(^{46}\) states
that they are usually compression-type fractures and are more frequently seen at the 11th, 12th, and 13th thoracic vertebrae. Jeffcott and Whitwell showed that there were 3 main areas of the back that were prone to fracture: the vertebral bodies at each end of the thoracolumbar spine (i.e., T1, T12, and L1, L5) and those around the mid-point of the back (T10). The greatest amount of dorsoventral and lateral movement of the vertebral column occurs from T11, T12, which is approximately where the rider’s weight is exerted.

A clinical description of vertebral fractures resulting from steeplechasing accidents has been provided by Sumner. He pointed out some of the difficulties in making a diagnosis on the racecourse and emphasized the variability of the horse’s reaction to pain. Some animals may exhibit typical signs of a broken back only to regain full use of their hindquarters within 30 minutes or so; others do not become recumbent or paraplegic immediately, even after suffering a severe comminuted vertebral fracture. In a series of 125 fatal accidents incurred during racing, there were 15 thoracolumbar fractures which occurred in hurdlers and ‘chasers following a bad fall. The main clinical signs were paraplegia with loss of sensory and motor power in the hindquarters. Only 2 managed to walk after the accident. 1 became recumbent within the hour and the other the next day. In most cases more than 1 vertebra were fractured. Gross fracture of the vertebral body was unusual; more often the dorsal spine fractured together with the neural arch resulting in damage to the underlying spinal cord. The lumbar vertebrae T1, T12, were most frequently affected, although fractures from T5, S1 were seen.

Fractures of the sacrum may result when horses rear over backwards. This type of fracture may cause temporary difficulty in defecation and micturition, but healing takes place without any loss of usefulness, although the contour at the root of the tail may be permanently depressed.

The occurrence of vertebral displacement or subluxation has been referred to by Herrod-Taylor as causing back problems in horses. Strömberg demonstrated “hot spots” in 2 cases with back pain; however, subluxated vertebrae. There is not general agreement, however, that any displacement of vertebral in the thoracolumbar spine is actually possible. Cowhouse has not seen dislocation of the horse’s back without a vertebral fracture also being present.

Sacrooccipital luxation has been described by Prick-ett and is usually in association with fracture of a spinous process. The clinical signs are usually indistinguishable from neuritis of the cauda equina.

Osteoarthritis of the Spine and Ossifying Spondylitis—Much has been written on this subject although no satisfactory or complete explanation of etiology yet exists. Chronic arthritis of the limb joints in adult horses is common, and there is an increasing incidence with age. However, the clinical signs associated with osteoarthritis of the thoracolumbar spine have not been well documented.

Sticher and Goss, who examined the spines of 245 horse skeletons, found ankylosis of intervertebral joints, vertebral bodies, and even dorsal spines although the clinical significance of these findings was not ascertained. It may well be that these pathological changes do not have any harmful effects but actually give increased stability to a part of the vertebral column that is kept rigid during locomotion. In the lumbar region false joint formation followed by fusion of the transverse processes commonly occurs in domestic horses, mules, and in feral animals, such as zebra and Przewalski horses. Smythe points out that once ankylosis is complete there are no clinical signs of back trouble. He suggests that the bony lesions are formed directly from inflammatory changes affecting the vertebrae and that during this active stage there may be pain and consequent reduction in performance.

Hare made an exhaustive study of 146 cases of chronic arthritis and concluded that the pathogenesis was not usually associated with infective or bacterial etiology. Two aged draught horses suffering from chronic arthritis of various limb joints also showed evidence of ossifying spondylitis. There were 19 other animals with similar joint lesions which did not show spondylitis. It is assumed, therefore, that these were incidental lesions and not of any serious clinical importance. There are a few reports of infective spondylitis which caused serious clinical signs, and these involved tuberculosis, Brucella abortus, and Corynebacterium and Actinomyces species.

Mitchell described a condition he called janked back or partial paraplegia which formed part of the general osteoarthritic problem. These horses exhibited an unsteady gait behind, difficulty in turning, and inability to back. There was sometimes crossing of the hindlegs with dragging of the toes and intermittent tremors of the muscles on the quarters. Because of this last sign, differentiation from shivering was sometimes difficult. Osteophyte formation at the intervertebral foramina was found at post mortem, as well as osteoarthritic of the vertebral column and some limb joints. Neuritis of the sciatic nerves with a secondary inflammatory reaction and patchy development of fibrosis in the nerve bundles was also noted. The significance of these findings was somewhat debatable as they were probably the normal paenian or lamellar corpuscles found in the thickened region of the sciatic nerve as it passes behind the hip.

Overlapping (or Overriding) of the Dorsal Spinous Processes—Back pain and lameness was reported by Roberts due to pressure between the summits of the dorsal spinous processes of the thoracic and lumbar spine. The
history and clinical signs were variable in these cases, and alteration of behavior and temperament was quite common. There was sometimes a history of injury to the back, but signs were not always seen immediately. The condition was more commonly encountered in hunters and jumpers.

Palpation of the midline of the back in these horses usually caused pain, and there was reduced flexibility of the spine noted. There could be resentment to saddling, mounting, and grooming and reduction in general performance. Some degree of hindlimb lameness associated with stiffness and restriction of gait was sometimes seen, and poor jumping ability could also occur. The diagnosis of this condition, which has since been referred to as overriding of the dorsal spine, can be based on the clinical picture but must be confirmed by radiography. A further diagnostic aid can be provided by the injection of local anesthetic into the affected interspinous spaces. Roberts also described the surgical treatment of the condition which involved resection of the affected dorsal spines.

Overriding of the dorsal spines is similar to a condition in man referred to as kissing spines or lumbar interspinous bursitis. The clinical signs in man are localized pain with tenderness in the low back, and treatment is by steroid injection or surgical excision.

**Differential Diagnosis**

*Conditions Which Can Cause a Loss of Hindlimb Coordination* The occurrence of incoordination without other clinical signs in young male Thoroughbreds is relatively common and is referred to as wobbler disease. The clinical signs result from spinal compression frequently associated with stenosis of the vertebral canal in the cervical spine. Detailed descriptions of the syndrome are given by Rooney, Whitwell, and Beech. The etiology of the condition is not completely understood, but affected animals cannot be raced and are generally unfit for stud purposes. In many cases the vertebral stenosis can be demonstrated by radiographic examination.

Another cause of hindlimb ataxia is that due to fracture of the cervical spine with associated damage to the spinal cord. The clinical signs also involve neck pain and stiffness. Tumors of the spinal cord have been recorded occasionally. In the United States, a condition of myelitis-encephalitis has been recorded with a rather similar clinical picture to wobbler disease, but hypermetria, limb dragging, forelimb incoordination, stumbling, and initially a unilateral lameness may also be seen. The pathological picture is one of destructive, inflammatory lesions involving the blood vessels of both grey and white matter, particularly the grey matter.

Lesions are frequently multifocal and occasionally localized to 1 area of the lumbar cord. The condition is currently thought to be a protozoan myeloencephalitis. A rather similar condition of unknown etiology has recently been described, which is termed equine degenerative myeloencephalopathy (EDM). The onset of ataxia occurs from birth to 24 months, skeletal cervical damage is absent, and in most cases the disease is progressive. Degenerative lesions are present in the grey and white matter of the lumbar, thoracic, cervical spinal cord, and in the brain stem.

Other causes of hindlimb incoordination include equine herpesvirus (EHV-1) infection, ingestion of Sudan grass or sorghum, nematodiasis associated with larval migration in the thoracolumbar spinal cord, and vertebrectomy fracture. All these conditions show other clinical signs that should help in differentiation from wobbler disease.

Another neurological condition of the spine is that of neuritis of the cauda equina. The clinical signs are principally paralysis of the tail, bladder, rectum, and anus. There is desensitization of the perineum often with muscle atrophy over the gluteal regions. A region of hyperesthesia may be present at the periphery of the desensitized zone, and affected animals may be seen rubbing their hindquarters against the walls, manger, or other solid objects. The onset of the disease is usually insidious, and the etiology is obscure. There are various predisposing causes that have been suggested including trauma and previous infections. Greenwood et al. consider that the reaction may reflect a hypersensitivity response secondary to local infection. Several of the cranial nerves may be affected as well as the cauda equina, and in severe cases hindlimb ataxia may develop. The condition is progressive, and euthanasia usually becomes necessary. At post mortem the affected cord and nerve roots are thickened, hemorrhagic, and edematous. Histologically, there is severe inflammation with demyelination, degeneration, and cellular infiltration followed by proliferation of the perineurium and local fibrosis.

*Conditions Causing Hindlimb Lameness* A number of conditions, which affect the hindlimb action, should be considered in differential diagnosis of back injuries. These include lameness in the hind due to spavin and osteochondrosis desiccans. "Hip or pelvic lameness" need to be differentiated in some cases as well as partial upward fixation of the patellae and osteochondrosis of the stifle.

Hindlimb lameness caused by thrombus formation in the iliac arteries (iliac thrombosis) is rare in the U.K. and U.S.A. but seems to be much more common in South Africa. The clinical signs vary with the size of the thrombus and degree of occlusion of the blood vessels. The condition is usually unilateral, and lameness is seen soon after exercise begins. There may be profuse sweating, pain, and anxiety if the exercise is continued. Many of the signs resemble softtend and myositis, but the affected limb appears
cooler and pulsation of the femoral artery will be less than in the opposite limb. If the thrombosis is bilateral, the horse may have difficulty in supporting the hindquarters. Rectal examination reveals decreased pulsation of the affected side occasionally with fremitus. After exercise there is a reduced filling time of the femoral vein on the affected side. The pathogenesis of the condition is not known. Adams considers that the thrombus formation results from larval damage due to *Strongylus vulgaris*, but Azrie  disagrees and suggests that hormonal factors and trauma to the aorta or iliac artery may be involved.

Skin Lesions: Local areas of pain and irritation in the skin around the saddle region can give rise to signs of back trouble. Various subcutaneous or epidermal skin lesions may be implicated, but the most common are associated with poorly fitting tack producing saddle and girth sores. Saddle soreness of this type is particularly important in horses used for endurance and long distance rides. Other chronic skin conditions, such as stitfnesses, carbuncles, and skin tumors (usually equine sarcomas) may also cause trouble.

Methods of Treatment

Conservative Methods: There are a number of conservative methods available to treat disorders of the back of the horse. Many of the earlier workers advocated rest as the simplest and most effective remedy for back trouble. Lupton recommends "upon the earliest indication being perceived of the spine having been injured, the horse should be allowed to lie down for at least six hours. The animal should be placed in a roomy loose box; it should have the hair cut off close over the seat of injury and the place should be constantly moistened by means of cloths dipped in a lotion, composed of tincture of arnica two ounces and water one pint. This remedy with softened food of the most supporting kind, should constitute the treatment for the first month of recovery."

Physiotherapy: Good results have been reported in the use of various methods of physiotherapy, such as faradic stimulation of muscles, manipulation of the spine, shortwave diathermy, and ultrasonics. Deep massage by cyclo-therapy has also been used particularly in the United States and more recently therapy by swimming horses has been advocated.

Medical Methods: In the older literature much store was placed on frequent bleeding of the animal, the application of cold charges, and the promotion of sweating. After the initial symptoms of strained back had improved, the use of mild blisters or embrocations were recommended, apparently with beneficial effects. Ryder advocated "a fresh sheep skin, with the fleshy side in, should be laid across the strained parts. As soon as by this treatment the animal's strength is gradually restored, he should be sent to grass until completely recovered." However, the author did not enlighten his readers with the exact mechanism of action of this line of therapy. Anti-inflammatory and/or analgesic drugs such as phenylbutazone and corticosteroids are often prescribed for chronic back problems. Anti-inflammatory drugs injected into painful areas in the back and between the interspinous spaces have also had beneficial effects.

Surgical Methods: For crowding and overriding of the dorsal spinous processes in the thoracolumbar spine, surgical resection of part of the process was described by Roberts to relieve pain and thereby eliminate the associated lameness. He performed the technique on 29 cases with apparently encouraging results. A slight modification of this method has recently been described by Jeffcott and Hickman, which also seems to be successful.

Acupuncture: In Japan the technique of acupuncture in horses has been used with apparent success for muscular problems of the back. Long Japanese needles (5-15 cm) are used: 10-20 needles are used for 1 to 2 minutes each and the needles must be continuously stimulated. The treatment which takes about half an hour is repeated 2 to 3 times in a week, and faradic therapy may also be given at this time. The pain usually lasts about 48 hours to disappear. Some preliminary work on acupuncture has also been carried out in the United States, and a good response to treatment was reported in cases of dorsolumbar myositis. These workers concluded that the technique did work but that correct diagnosis and proper judgement of treatment application were essential for effective acupuncture therapy.

References

Disorders of the Thoracolumbar Spine
The Fourth Sir Frederick Hobday Memorial Lecture

Back Problems in the Horse—A look at past, present and future progress

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SUMMARY

The horse is predisposed to back injury by virtue of the type of work and intensity of competition to which it is subjected nowadays. This paper reviews some of the inherent difficulties in establishing meaningful criteria for the diagnosis and treatment of these injuries. It highlights some of the large gaps in knowledge, particularly in relation to the causative factors involved and the biomechanics of the equine spine. One controversial area in diagnosis and treatment concerns the possible subluxation of vertebral dorsal spinous processes and their subsequent reposition by means of manipulation. From an anatomical standpoint movement or subluxation of these structures would seem to be impossible without causing drastic disruption of the vertebral column.

Many of the back problems presented are associated with soft tissue damage to the muscles and ligaments of the thoracolumbar spine. In spite of this there is considerable value in radiography of these cases because the elimination of bony damage can be a helpful aid to prognosis. There is an extensive range of different techniques available for treatment of back injuries although there is a dearth of controlled studies to assess their efficiency objectively. The simple recourse to a period of rest is often beneficial and there is good evidence that spontaneous recovery occurs in many cases.

INTRODUCTION

There is no doubt of the importance of back injuries in horses and their implications on performance for both horse and rider. The various conditions affecting the thoracolumbar (TL) spine are associated with a complex, often confusing clinical picture. The situation is exacerbated by the great diversity of views and opinions which exist concerning the aetiology, pathogenesis and methods of treatment available. This lecture provides an opportunity to make a plea for common sense in a field which is characterised by many unproven concepts and hypotheses. However, I do not seek to impose my ideas on this topical and controversial subject to the exclusion of other workers, because I believe it will only be by liaison, discussion and concentrated collaborative effort that any notable innovations or advances will be made.

Every equine clinician will, from time to time, be faced with an animal exhibiting signs of a back injury which results in a reduction of its performance. The overall problem is therefore clear, but the relevant scientific knowledge available and the means with which we are currently equipped to tackle the problem are much more difficult to specify (Table 1). Initially, we should

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<th>TABLE 1</th>
<th>LIMITING FACTORS IN THE EVALUATION OF BACK PROBLEMS IN THE HORSE</th>
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<tbody>
<tr>
<td>1.</td>
<td>Lack of knowledge of the natural history of disorders of the thoracolumbar (TL) spine.</td>
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<td>2.</td>
<td>Difficulties in establishing a specific diagnosis due to:</td>
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<td></td>
<td>(a) the size and temperament of the animal;</td>
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<td></td>
<td>(b) difficulty in palpation of the structures involved in the TL spine;</td>
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<td></td>
<td>(c) no accurate definitions of &quot;back pain&quot;;</td>
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<td>(d) the diagnosis of soft tissue injuries must be largely empirical.</td>
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<td>3.</td>
<td>There is insufficient research currently being undertaken and a paucity of information of the biomechanics of the TL spine during locomotion.</td>
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<td>4.</td>
<td>The dearth of controlled studies on therapy and outcome of spinal disorders in horses.</td>
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<td>5.</td>
<td>The lack of common ground between the veterinary and chiropractic professions.</td>
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<td>6.</td>
<td>No definitive pathological studies on TL disorders have yet been performed.</td>
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try to establish the incidence of TL disorders in working and competitive horses, identify the broad categories of diagnosis and determine the likely prognosis. Based on this kind of epidemiological information it will then be possible to develop productive lines of research. It is my aim in this paper to consider briefly all these points to try and present an overall view of chronic back injuries and their management. I feel that this is a subject in which Sir Frederick Hobday himself would have been interested and very much involved if he were alive today. I hope that you will consider my lecture to be a suitable tribute to this great clinician and surgeon.

CRITERIA OF BACK PAIN IN THE HORSE

The assessment and measurement of pain in animals has always been fraught with difficulty and establishing the precise site of pain in horses with back trouble is no exception. The whole situation is often made more complicated because the major clinical sign in some TL conditions is not so much due to pain but to a loss of performance. On the other hand there must be many horses that apparently perform satisfactorily in spite of some low grade back pain.

To add to this confusion there are some animals that appear to be naturally sensitive or "thin-skinned" and resent being pulped along the back. The evasive response produced can be wrongly interpreted by both owners and clinicians as a sign of pain resulting from an underlying spinal lesion. Another rather similar and well-known condition is that referred to as a "cold-back". In these cases there is persistent hyper-sensitivity over the back with stiffness and dipping of the spine as the rider gets into the saddle. There are usually no other demonstrable clinical signs and no radiological changes are to be found in the TL spine. The initial stiffness on being saddled or mounted wears off within a few minutes and thereafter no effect on performance is noted. Whether this condition is actually painful, or associated with some previous back pain, or is merely a matter of temperament is not clear.

Many of the difficulties in clinical diagnosis would be solved if some meaningful criteria for the assessment of back pain could be established and an objective system of quantifying it formulated. In man back pain is considered to be as much a problem of pain as a problem of the back (Dixon, 1976). The primary origin for the input results from the irritation of dorsal nerve roots and the branches of the spinal nerves. The role of peripheral nerve lesions in back pain in the horse has not been evaluated, but a careful study should certainly be contemplated for the future.

The back, like most tissues of the body, is equipped with a specific system of nerve endings that are particularly sensitive to tissue dysfunction. They are referred to as nociceptive receptors (Wyke, 1976) and are represented in the back by plexiform and freely-ending arrangements of unmyelinated nerve fibres. These are distributed throughout the skin and subcutaneous tissues, adipose tissues, fasciae and ligaments, periosteum, dura mater, adventitia of blood vessels and fibrous capsules of intervertebral articulations and sacroiliac joints (Wyke, 1970). In normal circumstances this receptor system is relatively inactive, but it is activated when mechanical or other damaging forces are applied to the tissues containing the unmyelinated nerve endings. Primary back pain therefore results from trauma or by the irritation of the nociceptive receptor nerve endings. There are various other pain responses recognised in man which include secondary, referred and psychosomatic back ache (Wyke, 1976) but their importance in the horse is as yet unproven.

Another important factor to be considered is the marked variation in the response and sensitivity to pain which exists so that meaningful measurement of "pain threshold", even in man, is unrealistic in our present state of knowledge. Individual patients vary in the intensity of their experience of pain from day to day and even at different times during the day (Wyke, 1976). The involvement of temperament as a contributory factor in the horse is felt to be important. It appears that the lowered performance is sometimes due to the animal attempting to "save its back" even though the clinical signs of pain had abated some time previously.

BIOMECHANICS OF THE THORACOLUMBAR SPINE

The biomechanics of the equine TL spine have been considered to some extent (Tucker, 1964a, b; Rooney, 1969) but it still requires much greater study if the pathogenesis of the various TL disorders are to be properly understood. The old analogy, of the vertebral column being constructed like an inverted parabolic cantilever bridge, is no longer considered biomechanically sound (Gray, 1944; Slipper, 1946). The modern point of view is represented by the "bow and string" theory which was originally propounded by Strasser (1913). The trunk of the skeleton (ie, the vertebral column, the pelvis and their muscles) may be considered as the bow which is kept under tension from the string, formed by the sternum, abdominal muscles and linea alba (Fig 1). This type of construction involves the extrinsic muscles of the limbs as well as the epaxial musculature of the spine itself. It does not exercise a force in the cranio-caudal direction on the 2 supporting piers (ie, fore and hind legs). The retractors of the foreleg and retractors of the hindleg act like the abdominal muscles and head the bow. The retractors of the foreleg and protractors of the hindleg try to stretch it like the epaxial muscles of the back. The horse, like other ungulates, has a very flat shaped bow: there is a slight curve in the thoracic region, but the lumbar and sacral regions are horizontal. At the cranial end of the bow is an attached beam supported at one end only (the head). This beam receives additional support from the

![Fig 1a. "String and bow" arrangement of vertebral column (after Slipper, 1946).](image-url)
cervical muscles and ligaments, particularly the splenius and nuchal ligament. The tail represents a similar beam, but is of much less biomechanical importance.

The flexibility of the body axis is provided in part by the elasticity of the intervertebral discs, the interspinous and other intervertebral ligaments, and the nuchal ligament. However, a much more significant part is played by the tone of the epaxial spinal musculature. The stress of the string and bow can thus be adapted to any given posture and to any locomotor phase; a situation which could never be attained by the action of the discs and ligaments alone. The horse’s back does not normally sag under the load of a mounting rider and, in fact, the slight dorsal curvature increases the elastic stress of the body-axis (Slipper, 1946). The relative inflexibility of the horse’s spine is well known, especially in the caudal thoracic and lumbar regions. False joint formation followed by fusion of the transverse processes in the lumbar region commonly occurs in domestic horses, mules and in feral animals, such as zebra and Przewalski horses (Stecher, 1962). Ankylosis of intervertebral joints, vertebral bodies and even dorsal spines has also been reported by Stecher and Goss (1961), although the possible clinical significance of these findings was not ascertained. It may well be that such lesions did not have any pathological or harmful effects, but actually gave increased stability to a part of the vertebral column that is kept rigid during locomotion.

The greatest amount of movement that occurs within the vertebral column is probably produced during the act of jumping. There is maximum ventroflexion (ie, basquilling) of the spine after take-off and up to the mid point of the jump followed by dorsiflexion (ie, dipping) just before landing. In order to demonstrate this a horse was photographed with a shutter speed 1/1000 second at 4 frames per second while jumping (Fig 2). It can be seen quite clearly and confirms that the majority of movement occurs in the cervical region with the TL spine remaining more or less rigid.

**COMMON CAUSES OF BACK TROUBLE**

Conditions affecting the horse’s back can be conveniently divided into 3 main categories, congenital deformity, soft tissue injury and lesions of the TL vertebrae (Jeffcott, 1978). In a series of 443 horses referred back cases (Jeffcott, 1977), which were examined clinically and radiographically (Table II), the incidence of diagnoses made is shown in Fig 3. There were 3 conditions most commonly encountered in these cases, namely, the non-specific soft tissue injury to the back, overriding of the dorsal spinous processes and sacroiliac strain.

In the condition of override dorsal spines, radiological changes were not always related to the

![Diagram of horse muscles](image)

**TABLE II**

<table>
<thead>
<tr>
<th>CONDITIONS WHICH MAY CAUSE BACK PROBLEMS IN THE HORSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>General category</td>
</tr>
<tr>
<td>Deformity of vertebral column</td>
</tr>
<tr>
<td>Soft tissue injury</td>
</tr>
<tr>
<td>Fractures</td>
</tr>
<tr>
<td>Other bony damage</td>
</tr>
<tr>
<td>Other causes of lameness or loss of performance</td>
</tr>
<tr>
<td>Management problems</td>
</tr>
<tr>
<td>Miscellaneous conditions</td>
</tr>
</tbody>
</table>
clinical signs exhibited. The pain was probably referable to an interspinous pseudoarthrosis and this agrees with the findings of von Salis and Huskamp (1978). There may be a tendency to attach too much clinical significance to this condition although it undoubtedly predisposes animals to periods of back pain and discomfort. There are some horses, which show radiographic evidence of chronic overriding, that perform perfectly satisfactorily (Jeffcott, 1979). The clinical signs when they do occur are sometimes only temporary and in many instances resort to surgical resection for alleviation of the overriding is unnecessary.

No cases of herniation or disc protrusion were seen in this series. This is not to say that equine intervertebral discs do not degenerate with age, but because of their make-up and the anatomical arrangement of the TL spine herniation is unlikely. There were also no cases diagnosed with temporary displacement or malalignment of vertebrae. In only 1 brood mare was a vertebral subluxation of the fifth lumbar vertebra (L5) detected radiologically and this was considered to be a longstanding condition.

PREDISPOSING FACTORS TO BACK INJURY

There is undoubtedly a growing awareness of the importance of disorders of the TL spine. This may be partly due to today's popularity of showjumping and eventing as well as the increasing number and intensity of competitions currently taking place. In my experience the type and use to which horses are put and their conformation can have an important bearing on the injury incurred. Specific spinal malformations, such as lordosis, tend to predispose to back injury by weakening the bow arrangement of the TL spine. This will put extra strain on the "string" or epaxial muscles of the back and result in intermittent soft tissue injury. The majority of horses do not have specific conformational defects, but those which are short backed with reduced flexibility of the spine tend to exhibit more vertebral lesions. The longer backed animals, which have relatively more suppleness and spinal flexibility, seem to be more prone to muscular or ligamentous strain. Large framed animals with comparatively weak-keeping quarters are more susceptible to sacroiliac strain. Age is not nearly such an important factor in equine back disorders (Jeffcott, 1977) as it is in man (Anderson, 1976). Ossifying spondylitis appears more frequently in mares and overriding of the dorsal spinous processes is most often seen in short backed Thoroughbred geldings.

There does seem to be an association with the type of back injury and type of work involved. The 443 horses in my series (Jeffcott, 1977) could be subdivided into 3 main groups, as follows:

**Group A** Horses jumped at speed
- Hurdlers
- Steeplechasers
- Point-to-pointers
- Hunters

**Group C** Non-jumping horses

<table>
<thead>
<tr>
<th>Category</th>
<th>Total</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cases</td>
<td>443</td>
<td>157</td>
<td>180</td>
<td>106</td>
</tr>
<tr>
<td>Overriding of the dorsal spinous processes</td>
<td>170 (100)</td>
<td>55 (35%)</td>
<td>86 (48%)</td>
<td>29 (27%)</td>
</tr>
<tr>
<td>Musculoligamentous injuries</td>
<td>118 (100)</td>
<td>44 (28%)</td>
<td>48 (27%)</td>
<td>26 (25%)</td>
</tr>
<tr>
<td>Chronic sacroiliac strain</td>
<td>67 (100)</td>
<td>33 (21%)</td>
<td>21 (12%)</td>
<td>13 (12%)</td>
</tr>
</tbody>
</table>

(Figures in brackets denote percentage of total cases in each of the 3 categories)
For the 3 most common causes of back injury the incidence according to the type of jumping is depicted in Table III. Sacroiliac strain was most prevalent in horses jumping at speed, whereas overriding was most common in the competitive jumping group Group B. The incidence of soft tissue damage was much the same in both Groups A and B and there was little difference in any of the 3 diagnoses in the non-jumping horses.

Another feature which seems to have a bearing on incidence is the seat of the injury itself. By plotting this out in a simplified site diagram (Fig 4) it can be seen that bone damage tends to be centred around the mid-point of the back while the soft tissue injuries are more often seen in the proximal and distal parts of the TL spine. This could be helpful from a practical point of view, if no special or radiographic facilities are available. For example, one of the commonest complaints is the acute onset of noticeable discomfort in the animal's back behind the saddle region; this would most likely be due to soft tissue damage and could be treated accordingly. In general practice it should be possible therefore to facilitate diagnosis of TL disorders by carrying out a thorough clinical examination and utilising the ancillary aids available (ie, assessment of muscle enzyme levels, a short course of an anti-inflammatory drug and the local anaesthesia of the interspinous spaces).

**LINES OF THERAPY**

As regards methods of treatment, the simple recourse to a period of rest usually proves to be all that is necessary in most kinds of TL disorder. In some animals certain types of physiotherapy can be beneficial and in others the periodic use of anti-inflammatory medication is indicated (Jeffcott, 1977). In Table IV there is listed the range of methods in current use. However, the assessment of any therapy for back injuries is difficult because of the tendency for spontaneous recovery to occur. In a series of 375 horses referred to the Equine Research Station (Table V) with a back problem some

62 per cent had received some form of therapy prior to examination. In this group the response to treatment was obviously judged to be unsatisfactory or the horses would not have been referred for radiological examination. They showed either no response at all, only partial improvement or a temporary relief of the back condition.

One method of treatment which is becoming increasingly popular is that of chiropractic manipulation (Herrod-Taylor, 1967). This technique involves reposition or replacement of structures in the spine which should, anatomically speaking, be unable to become displaced without serious disruption to the vertebral column. From both clinical and post-mortem examinations it would seem to the author to be impossible to create any appreciable movement between the vertebral bodies and their spinous processes or at the sacroiliac articulations in the living animal. The apparent subluxation of spinal processes may perhaps be due to a "spastic scoliosis" resulting from damage and increased tone or spasm of all or part of the back muscles. In any event this line of therapy seems to be based on a misconception, a problem which is further accentuated by the lack of common ground between the veterinary and chiropractic professions, each side having a very different appreciation of the likely diagnosis. However, the technique should not be dismissed out of hand as it is believed by some to produce useful clinical improvement (Watson, 1975; Ashby, 1975; Seckington, 1975).

The mode of action of these manipulative procedures is equivocal, they may work by relaxing or reducing muscle tension or spasm. This would eliminate pain and increase the suppleness of the spine and improve the animal's performance. The situation in man is rather similar where there is also a paucity of critical studies of
the effects of manipulation. One controlled trial involving 6 hospitals showed no obvious differences between the recovery rate of patients manipulated and those given other treatments (Doran and Newell, 1974). Glover, Morris and Khosla (1974) compared in a single-blind trial of 84 patients, the effect of manipulation with that of detuned (ie, simulated) shortwave therapy. Many of those who were manipulated were given immediate relief but after a few days there was no obvious difference between the groups. From discussions with owners of horses in my series, I received a rather similar impression that the response to manipulation was often dramatic but short-lived. Further work on this subject is certainly necessary before any definite conclusions can be made.

OUTCOME AND PROGNOSIS

Although there are still great difficulties in evaluating the diagnosis and response to treatment some attempt at establishing an assessment for prognosis of the various TL conditions of horses should be made. In a series of 190 horses (Jeffcott, 1977) with a chronic back complaint from which clinical follow-up information was obtained, some 57 per cent recovered completely irrespective of the diagnosis and treatment given and in only 17 per cent was no improvement shown at all. These results are depicted graphically in Fig 5. The most common regimen of treatment for all 190 cases was rest or no specific therapy at all, and in only 11 per cent was physiotherapy reported. This was chiefly in the form of faradic treatment although swimming was successfully used in a few horses. There were few horses in the series that died or necessitated destruction for a TL disorder and even fewer were available for post-mortem examination.

The highest recovery rate was in those where no specific diagnosis was made (78 per cent), whilst the lowest was in the spondylitis group (9 per cent). As might have been expected there was a good recovery (73 per cent) and comparatively low recurrence rate (25 per cent) in the group of soft tissue injuries (ie, muscular and ligamentous damage to the back). The most recurrences were in the spondylitis group (91 per cent) despite their receiving a higher rate of anti-inflammatory medication and few returned to full work.

For horses with sacroiliac strain the full recovery rate (45 per cent) was considerably less than that recorded for other soft tissue injuries, but it was also lower than that reported for the overriding dorsal spinous process cases (57 per cent). The likelihood of continuance or recurrence of clinical signs was higher for sacroiliac strain (45 per cent) than for overriding (37 per cent) but a greater percentage of anti-inflammatory medication was used in this latter group (25 per cent).

Surgical resection of part of the summit for alleviation of overriding of the dorsal spinous processes has been described by Roberts (1968) and Jeffcott and Hickman (1975). A comparison of the outcome of surgical and conservative (ie, rest and physiotherapy) treatment is shown in Fig 6. The overall recovery rates of the 2 groups of overriding cases was very similar. The surgical cases, which generally comprised the more severely affected horses, tended to make better progress and a greater percentage returned to full work in this group. Nevertheless, it must not be forgotten that the surgical cases all received 4 to 6 months rest by way of convalescence, and this was the principal modus of treatment used in the medical group. It would therefore appear from these results that surgical treatment for overriding dorsal spinous processes does not provide any major advantage over conservative lines of therapy.

CONCLUSIONS

In the last 5 years or so we have learnt something of the natural history of TL disorders and have made some progress in the rationalisation of diagnosis, particularly of the bony conditions. The establishment of a routine system for radiography of the TL spine is essential for accurate diagnosis (Jeffcott, 1975; 1977). However, there were some serious limitations associated with the radiographic quality that could be achieved particularly in the cranial lumbar region, and the fact that in many instances it was only practical to take radiography in one plane (ie, lateral view). Furthermore, in the conditions of overriding dorsal spinous processes the radiological changes were not always directly related to the clinical signs exhibited, and were probably secondary to an interspinous pseudarthrosis. Radiography was, nevertheless, most valuable in differential diagnosis of TL disorders by the elimination of serious
vertebral lesions. This was of particular value as many horses were referred for examination of suspected bony damage. The negative radiographic picture considerably improved the prognosis of the case and reassured the owner even if a definitive diagnosis was not made. It would appear that horses are predisposed to TL injury according to certain types of conformation, the use to which they are put and fitness of the animal. As occurs in man there is a tendency to spontaneous recovery of back problems and some 57 per cent of all cases made a complete recovery.

The technique of physiotherapy, including chiropractic manipulation, appears subjectively to be of therapeutic benefit in some cases, but controlled trials are necessary to gain a more objective assessment. Surgical resection of overriding spinous processes should only be carried out on selected cases and where the diagnosis has been confirmed by radiological examination and local anaesthesia of interspinous spaces. Further studies on the biomechanics and pathology of TL injuries are essential.

I shall end this lecture with a quotation from Mohammed, who must have been something of an equine practitioner about 3000 years ago, when he wrote "Cure for your mares—their bellies are your treasure, their backs your safety, and God will help their owners".

REFERENCES


RÉSUMÉ
Le cheval est prédisposé aux lésions dorso lombaires par le type de travail qu'il accomplit et par l'intensité des efforts qu'on lui impose. Cet article passe en revue les difficultés qu'il y a de retenir des critères significatifs pour le diagnostic de telles lésions et pour leur traitement. Il met en lumière quelques unes des inconnues dans ce domaine et notamment celles qui ont trait aux facteurs responsables et à la mécanique vertébrale du cheval. L'une des questions controversées quant au diagnostic et au traitement, est la possibilité de subluxations des apophyses vertébrales transverses et la possibilité de leur correction par manipulation. D'un point de vue anatomique des déplacements ou des subluxations de ces apophyses paraissent ne pouvoir exister sans entraîner simultanément des ruptures considérables de l'axe vertébral.

Bien des troubles dorso lombaires sont associés à des lésions des tissus mous, musculaires ou ligamentaires. Cependant la radiographie de cette région demeure utile puisqu'elle permet d'éliminer l'existence de lésions osseuses et contribue ainsi au pronostic. Il existe de nombreuses techniques pour le traitement des affections dorso lombaires mais la preuve expérimentale et objective de leur efficacité reste encore à produire.

Le simple recours à une période de repos est souvent bénéfique et il y a de nombreux exemples de guérison spontanée.

ZUSAMMENFASSUNG

Commissioned Articles

Natural rigidity of the horse's backbone

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Summary

The functional anatomy of the thoracolumbar (TL) spine is considered in relation to the horse's ability to perform at speed and to jump. The morphological features quite clearly show the relative inflexibility of the equine back and this was confirmed by some experimental studies. Fresh post mortem specimens from 5 Thoroughbreds were used to estimate the limits of dorsoventral movement of the TL spine from mid-thoracic to the cranial lumbar (T10-L2). The individual spinous processes could be moved a mean 1.1-6.0 mm on maximum ventroflexion and 0.8-3.8 mm on dorsiflexion. The overall flexibility of the back was found to be 53.1 mm. Caudal to the mid-point of the back (T10) there was virtually no lateral or rotatory movement of the spine possible.

The pathogenesis of some of the common causes of back trouble are discussed including the so-called vertebral subluxation and its treatment by chiropractic manipulation. From an anatomical viewpoint, this condition appears to be a misnomer and may simply be attributable to muscular imbalance leading to a spastic scoliosis.

Introduction

BACK problems are well recognised as an important cause of loss of performance in competitive horses (Jeffcott 1979). However, in many instances, there is considerable diversity of opinion about the underlying aetiology and pathogenesis. This paper reviews the salient features of the functional anatomy of the horse's thoracolumbar spine in an attempt to put this somewhat controversial matter into perspective for the equine clinician.

Terminology

The terms thoracolumbar (TL) spine and back are taken to be synonymous and to refer to the thoracolumbar vertebral column, its associated ligaments and epaxial musculature. Dorsiflexion refers to the dorsally concave curvature or extension of the back (ie, dipping or lordosis). Vento-flexion refers to the dorsally convex curvature or flexion of the back (ie, arching or kyphosis).

Fig 1. Diagrammatic representation of the vertebrae of the horse.
Functional anatomy of the horse's back

The backbone consists of a chain of approximately 54 median, unpaired, irregular bones with a vertebral formula of C7, T16, L6, S5, C7-21. All the vertebrae have an essentially similar morphology (Fig 1) but variations in size of the body and various processes occur according to their position (Sisson and Grossman 1975). The usual number of thoracic vertebrae is 18 but 17 and 19 are quite commonly encountered (Stecher 1962). Thoracic vertebrae vary considerably especially in the length and inclination of the dorsal spinous processes (Fig 2). The dorsal spinous processes except on T1 are large, narrow and tend to be directed caudally. They reach their maximum height at T4 to T6 and then diminish in size to T11 or T16. There is the most noticeable caudal inclination at T2 and this decreases from T6 to T11 which is termed the antecinal vertebra. In the mid-back region (e. T11-T14) the dorsal tips of the spinous processes are usually rather hook-shaped. The intervertebral foramina are variable in size and commonly show local osteophyte formation with resultant narrowing of the affected foramen. This condition, unless it is part of a generalised osteoarthritis of the spine, does not cause local damage to the spinal nerves or any associated clinical signs.

The domestic horse and zebra all have 6 lumbar vertebrae but the donkey has only 5. The number of sacral vertebrae is normally 5, but 4 and 6 occur and, in old horses, the first coccygeal may be fused to the last sacral. The transverse processes of the lumbar vertebrae are flattened, elongated plates which increase in length to L4 or L5 and then diminish to L6. The medial part of the sixth process is thick and articulates with the wing of the sacrum. Lateral facets and lateral joints between these processes are commonly found in apparently healthy horses (Stecher 1962). Stecher and Goss (1961) suggest that further stability of the lower lumbar spine may also occur following ankylosis of these lateral joints.

The horse, like all other ungulates, has a comparatively rigid spine during locomotion. The greatest amount of
The principal muscles of the horse's back may be conveniently divided into 3 main groups (Fig 4):

**Superficial layer**
- cutaneous muscle
- trapezius muscle (across withers)

**Deeper layer**
- serratus dorsalis cranialis
- serratus dorsalis caudalis
- longissimus dorsi
- multifidus dorsi
- iliocostalis dorsalis
- intertransversales lumborum

**Sublumbar and middle gluteal muscles**
- psoas minor
- psoas major
- iliopsoas
- iliacus
- quadratus lumborum
- middle gluteal

The most important muscle in the back is the longissimus dorsi. It is made up of a large number of relatively small segments and is the most powerful extensor of the back and joints. Acting singly it flexes the spine laterally and by its cervical attachment assists in extending the neck. However, the primary role of these muscles, as has been shown in the cat, is to control the stiffness of the back during walking rather than to induce movements (Carlson, Halbertsma and Zomlefer 1979). The muscle originates on the tubera, crest and adjacent part of the ventral surface of the ilium, the first 3 sacral spines and the lumbar and thoracic spines and the supraspinous ligament. It inserts on the lumbar transverse and articual processes, the thoracic transverse processes, the spinous and transverse processes of the last 4 cervical vertebrae and the lateral surfaces of the ribs.

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**Fig 4.** Diagrammatic representation of the epaxial muscles of the equine thoracolumbar spine (excluding the superficial layer of muscles). The multifidus dorsi forms a series of segmental muscles lying alongside the spinous processes from T1 to S5.
The middle gluteal is a very large muscle which covers the gluteal surface of the ilium. There is a large "gluteal tongue" in the horse which originates on the aponoeurosis of the longissimus dorsi as far forward as L2. The body of the muscle originates from the gluteal surface of the ilium and the sacroiliac region. It has its insertion on and around the epaxial of the spine abduct the limb. The connection of the gluteal tongue to the animal's propulsion and also gives it much of its ability to kick and rear.

Flexibility and range of possible movement

The biomechanics of the vertebral column, although very complex, are of vital importance because they form the basis of all the body's movements. The construction and function of the spine have been studied, principally in terms of statics, by D'Arcy Thompson (1942), Gray (1944) and Slijper (1946) but our overall knowledge is still very limited.

The concept of the backbone being constructed like a "bow and string" is now generally accepted (Baudoux 1975). The horse has a very flat shaped bow which is made up of the vertebral column, its epaxial muscles and ligaments. The whole structure is kept rigid and under tension from the string formed by the sternum, abdominal muscles, linea alba and the muscles of the limbs (Slijper 1946).

A comparative biomechanical analysis of the TL vertebral column was made by Tucker (1964a, b) and Rooney (1969) has described some of the theoretical dynamic forces which are involved in the equine spine. For the analysis of movement of the horse's spine the original work of Muybridge (1899) and that of Hildebrand (1959) has still to be relied upon.

Range of movement of the horse's back during exercise

The limited amount of flexibility in the vertebral column is chiefly provided by the tone of the epaxial spinal musculature supplemented by the elasticity of the intervertebral discs, interspinous and other intervertebral ligaments and the nuchal ligament. The tension in the string and bow can be easily adapted to accommodate to any given posture and to any locomotory phase; a situation which could never be attained by the action of the discs and ligaments alone. The horse's TL spine is capable of withstanding the considerable weight of a rider without experiencing any demonstrable dorsiflexion (ie, ventral curvature). There is also the slight dorsal curvature of the mid-back which tends to increase the elastic tension in the body-axis and prevent the back sagging (Slijper 1946). Another feature of the backbone which has received some attention is the importance of the length and the angle of the dorsal spinous processes (Slijper 1946; Tucker 1964b; Baudoux 1974; Gambaryan 1974). The dorsal spines together with their supporting ligaments and muscles prevent the body-axis from being bent too far in a dorsal direction (ie, they limit ventroflexion). Their inclination, however, does not depend on the demands of the string and bow construction or else their heights would tend to increase to the mid-point of the back, whereas the converse is true. Slijper (1946) states that the direction of the dorsal spines depends on the special demands of the muscles and ligaments inserted on them and therefore the most favourable direction is perpendicular to that of the muscular and ligamentous forces acting on them.

During locomotion there are a great many forces acting on the vertebral column. The horse is built essentially for endurance; it can run at about 30 km/h for 30 km and its rate of travel declines only slowly as distances increase over 50 km. At the gallop a horse covers 5.79 to 7.62 m/stride and completes 2.25 strides per sec at 56 km/h (Hildebrand 1959). It uses the transverse gallop (Muybridge 1899) as opposed to the leaping gallop of the cheetah which is better designed for high speed over short distances. The TL spine of the horse is kept virtually rigid during locomotion; the small movements that may be seen take place in the lumbarosacral joint (Hildebrand 1959).

The weight of the body lies mainly over the forelegs leaving the hindlegs as the main source of propulsion. The greatest dynamic forces are applied to the vertebral column when the animal is moving at high speed, galloping and jumping. With the head thrust well forward the hindlegs will be further relieved of their share of the load. At the walk the body is supported by up to 3 of the 4 legs. This is the most stable pace since the projection of the centre of gravity lies within the triangle of support (Slijper 1946). At more rapid paces a stable pattern of locomotion is only guaranteed if the sequence of limb movements conforms to the diagonal pattern.

The greatest amount of movement that occurs within the vertebral column is probably produced during jumping (Fig 5). There is maximum ventroflexion of the spine after take off and up to the mid-point of the jump followed by dorsiflexion of the spine just before landing.

Movement of the TL spine under experimental conditions

The absolute limits of movement of the TL spine of 5 horses
were tested at post mortem to confirm the rigidity of the equine spine to dorsoventral, lateral and rotary movement.

Range of dorsoventral movement

The spines from 5 horses were subjected to maximum dorso- and ventroflexion at post mortem (Fig 6). After euthanasia both the fore- and hindlimbs, the rib cage (distal to the vertebral articulations) and the cervical vertebrae were removed. The epaxial muscles were dissected away and the remaining TL vertebral column supported at the cranial and caudal extremities. Each spine was then fixed so that it resembled, as closely as possible, the natural standing position. The region examined was from T10 to L4 and measurements of the interspinous spaces (ie, standardised by always taking the narrowest distance between the 2 spinous summits) were made from lateral radiographs. A 10 kg weight suspended from the mid-point of the back was sufficient to achieve maximum dorsoflexion in this preparation. Maximum ventroflexion was produced by raising the vertebral body of T12 from beneath until no weight was being taken by the supports at either end.

The results (Table 1) of the interspinous measurements and the changes obtained by forced dorsi- and ventroflexion show that even under these artificial conditions there was very little dorsoventral flexibility of the back. The extent of movement between the dorsal spinous processes was calculated by the addition of the increase in the spaces produced by ventroflexion, and the decrease during dorsoflexion. This range of possible movement (or flexibility of the spine) gradually decreased cranio-caudally from approximately 10.0 mm at T10-T11 to only 3.5 mm at T14-L1. The interspinous spaces were therefore reduced to their minimum in the middle of the back from T12 to T13 (Fig 7). The overall increase from T10-L2 on ventroflexion was 31.0 mm and on dorsoflexion was 22.1 mm. Thus the total range of movement in the dorsoventral directions of the equine back was only 53.1 mm under these experimental conditions.

Range of lateral movement and flexibility

Three of the TL spines were fixed at the sacral end and the cranial thoracic extremity was pulled sideways as far as possible. There was virtually no lateral deviation of the lumbar and caudal thoracic region. Lateral bending of the spine began from about T14 and from this point forwards gradually increased (Fig 8).

No appreciable movement in the intercentral or interneural articulations was produced caudal to T4 by applying rotatory force to these specimens. In addition, it was not possible to elicit any movement or produce displacement of any of the individual dorsal spines or vertebral bodies by manual

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TABLE 1: Measurement of interspinous spaces (mm) in the normal standing position and on maximum ventro- and dorsoflexion of the thoracolumbar spine of 5 Thoroughbred horses

<table>
<thead>
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<tbody>
<tr>
<td>Normal position</td>
<td>4.8</td>
<td>5.5</td>
<td>5.4</td>
<td>3.8</td>
<td>3.4</td>
<td>4.1</td>
<td>8.2</td>
<td>8.2</td>
<td>4.8</td>
<td>11.0</td>
</tr>
<tr>
<td>Ventroflexion</td>
<td>10.8</td>
<td>9.5</td>
<td>9.5</td>
<td>7.0</td>
<td>6.3</td>
<td>6.7</td>
<td>10.4</td>
<td>10.4</td>
<td>7.5</td>
<td>12.1</td>
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<tr>
<td>Dorsoflexion</td>
<td>1.0</td>
<td>2.2</td>
<td>2.6</td>
<td>1.9</td>
<td>1.8</td>
<td>1.9</td>
<td>5.7</td>
<td>6.4</td>
<td>4.0</td>
<td>8.1</td>
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<tr>
<td>Increase in space on ventroflexion</td>
<td>6.0</td>
<td>4.0</td>
<td>4.1</td>
<td>3.2</td>
<td>2.9</td>
<td>2.6</td>
<td>2.2</td>
<td>2.2</td>
<td>2.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Decrease in space on dorsoflexion</td>
<td>3.8</td>
<td>3.3</td>
<td>1.3</td>
<td>1.9</td>
<td>1.8</td>
<td>2.2</td>
<td>2.5</td>
<td>1.8</td>
<td>0.8</td>
<td>2.9</td>
</tr>
<tr>
<td>Total range of movement possible</td>
<td>9.8</td>
<td>7.3</td>
<td>6.4</td>
<td>5.1</td>
<td>4.6</td>
<td>4.8</td>
<td>4.7</td>
<td>4.0</td>
<td>3.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>
pressure applied to the spinous summits or the vertebral bodies.

Discussion

A review of the functional anatomy and measurement of the limits of spinal movement amply confirm the relative inflexibility of the equine TL spine. Without this rigidity the horse would be incapable of achieving any useful locomotor performance at speed, let alone be able to jump with a 70 kg rider sitting on the middle of the back.

It is generally accepted that soft tissue injuries (ie, muscular and ligamentous damage) are responsible for the majority of back problems in horses and that recovery rates are good (Jeffcott 1979). There is no evidence reported that damage to the intervertebral discs, involving degeneration or prolapse, plays an important role. This is hardly surprising considering the thin fibrocartilaginous make-up of the equine disc, the strong vertebral longitudinal ligaments and the restriction of spinal movement compared to that seen in man and the dog. Local damage or pinching of thoracic and lumbar spinal nerves as a cause of chronic “backache” has not been thoroughly investigated. However, it is unlikely to be as important a factor, as in man, because the incidence of spondylolisthesis and disc lesions are much less common. Most of the radiographic damage found in the horse’s TL spine is centred around the mid point (ie, T13-14) and the commonest condition encountered is that referred to as overriding of the dorsal spinous processes (Jeffcott 1980). The interspinous spaces are narrowest in the mid-back (Fig 7) and if the amount of movement during dorsiflexion exceeds this (ie, approx 4 mm) there will be repeated impingement of the spinous summits leading to local pressure and periosteal reaction on the opposing edges. This can result in pain, discomfort and loss of performance. The final outcome is the production of a pseudoarthrosis between the summits usually with a remission of clinical signs.

During locomotion the maximum dorsoventral movement of the TL spine occurs at the lumbosacral junction (Hildebrand 1959; Gambaryan 1974) and virtually no movement takes place at the sacroiliac articulations. There is much greater mobility between the lumbar and sacral vertebrae than between individual lumbar vertebrae. This is reflected by the increased size of the spinous processes and the fact that the lumbar spines slope forward and the sacral spines backward. This may constitute a site of weakness because, in addition to increased mobility, there is no supraspinous ligament crossing the gap between L1 and S1 to strengthen the vertebral column. In both galloping and trotting racehorses this region is a common site of pain, perhaps resulting from muscle strain due to overextension of the lumbosacral spine (ie, ventroflexion).

The pain associated with TL conditions is often difficult to define accurately, especially in longstanding cases, and many horses are referred for loss of performance rather than actual back pain. Animals in this category are often said to have one or more vertebrae subluxated or “put out” of alignment particularly in the caudal lumbar region (L7-L1) (Herrod-Taylor 1967; Watson 1975, personal communication). It is claimed that these vertebrae can be “put back” into their correct position by means of a manipulative technique which involves sharp pressure being applied to the dorsal tip of each affected summit. From an anatomical point of view this claim is unacceptable because, either naturally or by manual manipulation, movement of individual vertebrae or their spinous processes is contrary to all that has been considered here. It seems more realistic to explain this malalignment of the dorsal midline of the back as some alterations in postural tone between the right and left epaxial musculature. The increased tone or spasm caused by local muscle injury of the longissimus dorsi could produce a slight curvature of the horse’s spine (ie, spastic scoliosis). This situation would lead to abnormal biomechanical stress on the TL spine (ie, the bow) and so effect normal locomotor pattern and performance.

It is of interest that, in man, muscle imbalance has been
suggested as the root cause of several orthopedic deformities, such as idiopathic scoliosis (MacEwen 1973) and clubfoot, although the situation in the horse is not strictly analogous. Ober (1974) explains how a dynamic dysfunction of the stabilizing system of the spine results in the static appearance of scoliosis:

"The reflex contractions of the spinal column muscles compensate for the bending of the spinal column. This is a characteristic behaviour of the spine stabilizing system during human movement. As a result, even small compensatory differences between the right and left sides cause permanent, asymmetric, dynamic over-loadings on the soft tissues. These over-loadings are cumulative and after some time result in the partial loss of elasticity in the soft tissues on one side of the spine. This loss results in modification of the previously neutral position of the intervertebral linkage, and scoliosis appears."

The results of chiropractic manipulation of horses with back problems are reported to be dramatic and instantaneous although the incidence of recurrence of symptoms is, apparently, high (Herrod-Taylor 1967; Watson 1975, personal communication). The technique is now routinely performed in most European countries, the United States, Australia and South Africa but no critical or controlled trials of the efficacy or mode of action of the technique have yet been published. It is possible that the sharp pressure applied to one or more of the spinous summits and muscles in the affected area creates a reflex contraction in the back muscle of the contra-lateral side. This would produce a state of transient muscle tension thereby eliminating the previous postural imbalance. Both sides would have equal muscle tone again and so be able to relax; the spastic scoliosis disappearing and the horse's performance instantly improved. However, this is only a tentative theory and the whole matter needs further investigation before it can be satisfactorily resolved.

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Tucker, R. (1964b) Contributions to the biomechanics of the vertebral column II. Rotatory system induced in the thoracolumbar curvature by the epaxial musculature. Acta theriol. 9, 171-192.

Résumé

L'anatomie fonctionnelle du rachis thoraco lombaire est étudiée dans ses relations avec les aptitudes du cheval à la vitesse, et au saut.

Les caractères morphologiques montrent clairement la non flexibilité du rachis dorsal. Ceci fut confirmé par des études expérimentales.

Des rachis frais prélevés sur 5 Pur Sangs servirent à estimer les limites des mouvements dorsaux ventraux de l'axe dorsal lombaire entre D 10 et L 2. Chaque apophyse épinière pouvait être déplacée de 1,1 à 6 mm en ventroflexion maximale, et de 0,8 à 3,8 mm en dorsoflexion maximale. La flexibilité totale du dos étaït d'environ 53,1 mm. A partir de D 13 vers l'arrière, on constate la quasi-impossibilité d'un mouvement latéral ou rotatoire du rachis.

On discute de la pathologie de quelques unes des causes habituelles des douleurs dorsaux lombaires. En particulier on discute de la soi-disant luxation vertébrale et de son traitement par chirurgie. D'un point de vue anatomique, il semble que la dénomination soit impropre puisqu'il ne pourrait s'agir que d'une scoliose spastique résultant d'un déséquilibre musculaire.

Zusammenfassung

Die funktionelle Anatomie der thorakolumbalen Wirbel säule wird in Abhängigkeit von der Leistungsfähigkeit (Geschwindigkeit und Springvermögen) besprochen. Die morphologischen Gegebenheiten zeigen, dass der Pfederücken verhältnismässig starr ist, was auch durch experimentelle Studien bestätigt werden konnte. Frische Autopsiepraparate von 5 Vollblüttern wurden verwendet, um die Grenzen der
dorsovertebralen Bewegung der thorakolumbalen Wirbelsäule von T10 bis L2 abzuschätzen. Die einzelnen Dornfortsätze konnten bei maximaler Ventroflexion durchschnittlich um 1,1-6,0 mm nach unten, und bei Dorsiflexion um 0,8-3,8 mm nach oben bewegt werden. Für die Gesamtflexibilität des Rückens wurde ein Wert von 53,1 mm gefunden. Hinter dem Mittelpunkt des Rückens (T13) konnte praktisch keine laterale oder rotatorische Beweglichkeit der Wirbelsäule festgestellt werden.

Die Pathogenese einiger üblicher Ursachen von Rückenleiden wird besprochen, einschließlich der sogenannten Wirbelgelenkssubluxation und ihrer chiropraktischen Behandlung. Von einem anatomischen Gesichtspunkt aus gesehen, wird dieser Zustand falsch bezeichnet; er dürfte einer muskulären Ungleichheit zuzuschreiben sein, die zu spastischer Skoliose führt.

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Bibliography of thoracolumbar conditions in the horse

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Introduction

In spite of the prevalence of thoracolumbar injuries in horses, the back has been a neglected area in veterinary medicine and research. This may be partly because of the complexity of clinical signs exhibited and the lack of basic understanding of the pathogenesis of these problems. Nevertheless, there have been quite a number of investigations carried out and reports made, but no attempt to collate the information in any way, or to use it as a basis to plan future research or collaborative investigations, has been made.

The purpose of this bibliography is to provide as comprehensive a list as possible of investigations pertaining to the back of the horse, derived from equine veterinary periodicals and abstracting journals such as Index Veterinarius, Veterinary Bulletin and Current Contents for the last five years. It is unlikely that the list is definitive, but it is hoped that it covers most of the current literature. The references have been listed under eight headings:

- Historical and reviews
- Functional anatomy
- Biomechanics and kinesiology
- Clinical conditions

However, this format is used for convenience and many articles contain information on more than one topic.

It can be seen that some useful progress has been made in the last 10 years on the clinical examination and aspects of radiology, but little has yet been done to evaluate pathogenesis or to formulate a rational means of therapy. There have recently been some exciting developments in investigating the biomechanics of thoracolumbar movement, but this needs to be followed up by the application of this type of study to clinical cases. The feasibility of using an experimental model of back pain could also have important possibilities for a more objective assessment of clinical signs and comparison of different types of treatment. Probably the most worrying areas from the practitioner's point of view are the difficulty of recommending a particular line of treatment and in evaluating prognosis of the more chronic cases. Although various types of physical therapy are currently being used, no control trials have yet been carried out.

Historical and reviews

RYDE, J. (1871) The veterinary surgeon's manual — complete guide to the cure of all disorders incident to horses, cattle, sheep and dogs. Thomas Tegg, London.

Functional anatomy


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**Biomechanics and kinesiology**


Ronne, J. R. (1969) *Biomechanics of lameness in horses.* Williams & Wilkins, Baltimore, Maryland, USA.


Tucker, R. (1946) Contributions to the biomechanics of the vertebral column. II. Rotary system induced in the thoracolumbar curvature by the epaxial musculature. *Acta. theriol.* 9, 171-192.

**Clinical conditions**


**Pathology**


Radiology


Treatment and outcome


Differential diagnosis


SECTION 2.2 DIAGNOSIS OF VERTEBRAL DAMAGE


Statement on Share of Work:

Papers 8-10 - In the first three papers in this Section I was responsible for the planning and execution of all the work and the preparation for publication.

Paper 11 - I played a major role in the planning and execution of this collaborative project which involved clinical, endoscopic, radiological and pathological components. I was chiefly responsible for the preparation of the manuscript for publication.

Paper 12 - I was responsible for the planning and organisation of the project and played the major role in preparation of the manuscript for publication.
Diagnosis of Back Problems in the Horse

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Newmarket, Suffolk, England

The tremendous increase in popularity of competitive equestrian sports over the last 20 years has been accompanied by a noticeable rise in the prevalence of spinal injuries in horses. However, definitive diagnosis of injuries to the back of the horse is made difficult by the often complex clinical picture and by the frequent lack of adequate radiographic facilities for the mid and caudal regions of the thoracolumbar (TL) spine. Nevertheless, if a careful and systematic approach is made, a presumptive diagnosis frequently can be made without resorting to radiography. This paper is a synopsis of previously published work on the equine TL spine. It describes a practical scheme (Table I) for the evaluation of a horse with a potential back problem.

Clinical Signs

The clinical signs of TL disorders are many and varied, but the most consistent feature is a loss of performance, particularly the ability to jump well. Obtaining a complete history (including information concerning management, tack, performance, and temperament) back to the time of the animal's acquisition is extremely helpful in deciding whether or not one is dealing with a genuine back problem. It is all too common for owners to suspect an underlying disorder in the TL spine when the condition is simply caused by problems of schooling or equitation.

There seems to be a correlation between nervous or temperamental animals and the incidence of back trouble. One consistent feature of a long-standing back problem is a history of some deterioration in the animal's behavior or temperament (e.g., a normally good-natured animal becomes sour and fractious to handle and work). This may be insidious in onset and it may be some time before the owner fully appreciates that the change has taken place.

A history of back pain is not always reported, particularly in long-standing cases, although acute soreness in the back muscles is often associated with a history of a fall or some traumatic incident. In more severe cases, difficulty in straddling to urinate or defecate is noted, and there may be a reluctance to lie down in the box stall or to roll. Resentment to putting on a blanket, grooming, and picking up one or both hindlimbs is sometimes reported, and the farrier may remark on the difficulty of shoeing the animal. Failure
TABLE I
A SIMPLIFIED PROTOCOL FOR EXAMINATION OF A HORSE WITH A POTENTIAL BACK PROBLEM

1. Case history
   a. Assessment of management factors (experience of owners, etc.)
   b. Temperament and ability to perform
   c. Time of onset and duration of clinical signs
   d. Response to any treatment given

2. Clinical examination
   a. At rest: visual inspection, palpation, manipulation
   b. At exercise: in hand, lunging, and ridden

3. Radiological examination
   a. Lateral views of thoracolumbar (T1 to L4, or L5) and sacroccygeal (S1 to C1) regions performed in standing position
   b. Radiography of lumbosacral (L4 to S1) spine carried out under general anesthesia in ventrodorsal plane

4. Laboratory examination
   a. Hematological analysis: CBC
   b. Biochemical analysis, including muscle enzymes (AAT and CK), before and after exercise test

5. Other aids
   a. Local anesthesia of interspinous spaces
   b. Short-term effect of antiinflammatory, antiarthritic drug on performance
   c. Back-slap test for evidence of cervical vertebral stenosis causing mild to severe hindlimb incoordination

---

to move sideways in the box stall in one direction occurs occasionally, and a history of resentment to any weight on the back, with a tendency to collapse behind, is sometimes reported. Saddling up may become a problem, particularly when the girth is actually tightened. The animal may buck when first mounted, although this is usually a result of temperament rather than of back pain. Reluctance to move backwards or run backwards when being ridden may be reported.

The signs at exercise may be reported as uni- or bilateral hindlimb lameness or as a loss of enthusiasm for work and an inability to stride out at fast paces. The owner will often mention some stiffness in the hindlimb action and a loss of suppleness of the back when the horse is ridden, although the action when the horse is loose in the paddock appears satisfactory. There may be a disinclination to jump, particularly the combination type fences. Jumping with a somewhat fixed hollow back is frequently seen. The horse may seem to lose its fluidity and timing during jumping and become tense and tend to rush over the fences. Head shaking is occasionally noted as well as an increased tendency to tail swishing.

Clinical Examination at Rest
Visual Inspection

The examination should begin in the loose box stall with a general appraisal of the animal and its conformation. This is particularly relevant because some conformational types predispose to TL disorders. For example, short-coupled Thoroughbreds show a higher incidence of bone damage than the longer and more flexible-backed horses, which in turn are more prone to muscle strain in the lumbar region (Figure 1). It is important to note the general body condition of the animal and to differentiate poor condition (i.e., cachexia) from specific atrophy of the longissimus dorsi muscle, gluteal masses, and thigh muscles. The presence of any lumps, scars, or saddle marks on the back and any undue curvature of the spine must also be noted, because they may have some bearing on the underlying condition. Assessment of the animal's temperament and its response to gentle palpation of the back, loins, and quarters can also be carried out at this time.

A more detailed examination of the back is best performed with the horse restrained in stocks. The dorsal midline of the back is viewed from above (e.g., by standing on a chair behind the rear quarters) to determine if it is straight and correctly aligned when the horse is standing squarely on all four limbs. Any lateral curvature of the spine is suggestive of a degree of muscle spasm on one side (spastic scoliosis). If the animal has a history of a bad fall, suggesting a degree of sacroiliac strain, examination for any apparent asymmetry of the pelvis or muscle atrophy over the gluteal area should always be carried out. The presence of a so-called jumpers lump may be seen in some horses, although it is not necessarily associated with overt clinical signs. This feature is associated with a prominence of the lumbar dorsal spinous processes or the tuber sacralis caused by lack of muscle of the longissimus dorsi and gluteals (Figure 2).

Palpation of the Thoracolumbar Spine

A test is made of the horse's reaction to gently running a hand along its back from the withers to the base of the tail. It is very difficult to palpate more than the tips of the dorsal spinous processes, although in most normal horses it is possible to identify the interspinous spaces. It should be possible to detect spasm of the longissimus dorsi muscles or any protrusion or displacement of the summits of the dorsal spinous processes. Thin-skinned or hypersensitive horses will cringe when this is done, but unless there is a dramatic response (e.g., kicking out, rearing, or grunting), this should not be considered to be of clinical significance. The tips of the sacral spinous processes should be palpated, particularly in horses used for harness racing. Pain may be palpable over the tendinous insertion of the longissimus dorsi muscle onto the spines of S1 and S2. The tail and croup region should be examined
for any flaccidity or perineal paralysis, which may be a sign of early cauda equina neuritis.

When there has been a history of serious trauma, a rectal examination should be made to determine the presence of damage to the pelvic canal, sublumbar muscles, and/or sacroiliac region. Rectal examination is rarely of much positive assistance in vertebral fractures of the caudal thoracic or lumbar spine.

**Manipulation of the Thoracolumbar Spine**

By alternative pinching of the midline in the caudal thoracic and the sacral regions, it should be possible to make the animal flex (i.e., ventroflex or arch) and extend (i.e., dorsiflex or dip) its spine. Reluctance to perform this maneuver and rigidity of the back are often significant findings, as they may reflect some underlying pain due to soft tissue or bony lesion of the TL spine. Pain or discomfort is often accompanied by spasm of the longissimus dorsi muscles on one or both sides of the back. Areas of pain are located as precisely as possible for comparison with any bony abnormalities noted on radiological examination. If there has been active damage to the muscles or ligaments in the sacroiliac region, pressure exerted above each tuber coxa and in the midline at L4 to L5 usually produces pain or discomfort.

Skin sensitivity over the back and loins has proved to be an unreliable test because it is so variable between individuals. However, firm stroking of the longissimus dorsi muscles with a pencil to produce muscular contraction and lateral flexion of the thoracic and lumbar spine is a useful technique. There should normally be no marked resentment to this test unless there is some painful muscle involvement. If some chronic bony or muscular problem is present in the mid back, a reluctance or difficulty in lateral flexion in one or both directions is often seen.

**Examination at Exercise In Hand**

On a loose rein, the animal is first walked and then trotted in hand in a straight line to detect any obvious abnormalities in gait. Many horses with
Diagnosis of Thoracolumbar Conditions

The signs of injury or damage to the horse's spine can be difficult to predict precisely because they vary greatly between individual cases. However, some of the common clinical signs of seven of the most common causes of back trouble are listed in Table II. These signs will not be seen in every instance, but they do provide a guide for the practitioner. A list of conditions that may directly cause back pain and discomfort in horses is shown in Table III. Some of the problems that should be considered in differential diagnosis are listed in Table IV.

Noticeable signs of hindlimb lameness are not usually a feature of TL disorders, and only rarely is some degree of forelimb lameness present. Probably the most common differential diagnosis of a back problem is mild to moderate hock or stifle damage. This is particularly true if the condition is bilateral, because stiffness and shortening of the stride are clearly detectable. Osteoarthritis of the hock (i.e., spavin) and partial upward fixation of the patella can both produce a gait with a lack of impulsion of the hindlimbs that is very similar to the gait of a TL disorder. Many other conditions must also be considered, from dental disease to mild compressive spinal cord damage. The problems that actually affect a horse's back can be grouped into the following categories: congenital deformities, soft tissue injuries, and lesions of the TL vertebrae. It is also quite common for more than one site or type of injury to exist at the same time. The three conditions most commonly encountered by the author were nonspecific soft tissue injury to the back, overextending of the dorsal spinous processes (i.e., hinging spines), and chronic sacroiliac strain (Table V). No cases of disc herniation or disc protrusion were seen. This is not to say that equine intervertebral discs do not degenerate with age, but because of their makeup and the anatomical arrangement of the TL spine, herniation is not feasible. The author also did not diagnose any cases as having temporary displacement or malalignment of vertebrae.

The condition of congenital lordosis (i.e., dipped back or swayback) is associated with hypoplasia of the intervertebral articular processes (Figure 4). Degrees of acquired lordosis and kyphosis (i.e., arched or roach back) are occasionally seen in adult horses; these conditions will usually predispose to weakness of the TL spine (Figure 5). Diagnosis can be confirmed by radiography revealing abnormal curvature of the vertebral column, usually in the

Figure 7A

Figure 7B

Figure 7 - (A) Five-year-old Thoroughbred dressage mare with well-muscled and symmetrical quarters. (B) Seven-year-old steeplechase with clinical signs of chronic left-sided sacroiliac strain.
chronic back trouble show restricted hindlimb action with poor hock flexion and a tendency to drag the toes of one or both hindlimbs. If there is moderate to severe pain, a wide, straddling hindlimb gait is usually seen, but in horses with a low-grade problem (e.g., chronic sacroiliac strain) there will be a very close action behind (i.e., plaiting). Next, the animal is turned as short as possible in both directions to make it flex the spine laterally and use its hocks. If back pain is present, turning is often difficult and there is a loss of suppleness, resulting in jerky movements and spasm of the back muscles. On backing there is sometimes an initial reluctance to move; when the horse does move, its head is raised, its back is arched more than usual, and some spasms of the back muscles occurs. Another sign of discomfort is the dragging of the forelimb toes on moving backwards. Horses with chronic sacroiliac damage will often resent being backed up or down a slope. Severe lameness of one or both hindlimbs is not usually a feature of a TL disorder: Mild, shifting lameness or simply an unlevelness of action of one hindlimb is much more commonly seen. Flexion tests (e.g., spavin test) rarely have any effect on the gait, but they are very useful in distinguishing hock or stifle problems.

Lunging Exercise
A session of 10 to 15 minutes of exercise on the lunge rein is spent critically assessing the horse’s gait. This also provides an opportunity to see any improvement or deterioration in the action as the horse warms up. Horses with stiff backs often show exaggerated contractions of the longissimus dorsi muscles with each stride, although this is also seen in horses that are very unfit. Animals with restricted hindlimb gait often show poor tracking of the hindfeet (i.e., placement of the hindfeet behind the imprint of the ipsilateral forefoot) and a tendency to drag or plait with the hindhoes. The head carriage may be elevated and the animal may look uncomfortable in its work. A poor action is usually best seen at a trot, and some horses will only lunge at a collected canter. There is often some visible difficulty when the horse changes pace, or an inability to lead on the correct leg may be seen. The action behind may appear to lack impulsion, and swishing of the tail is often a feature. However, tail swishing is not always indicative of back pain.

Ridden Exercise
It is useful to see the horse saddled up and to note if there is any pain or resentment to tightening the girth or mounting. An animal with a cold back will dip the back (i.e., dorsiflex) when mounted, but this does not necessarily imply that there is an underlying spinal problem. The horse should be ridden, if possible by its regular rider, and an assessment should be made of the action at the walk, trot, and canter. If the horse is a jumper, it should also jump over the kinds of fences that usually cause the most trouble (i.e., combination-type fences).

After the animal has cooled down, it should be exercised in hand again to see if there is any change in the action. This is particularly useful in horses with a low-grade exertional myopathy (i.e., mild azoturia or tying-up), because they may show increased stiffness of the hock and hindquarters.

Radiographic Examination of the Thoracolumbar Vertebral Column
Technique
Powerful equipment is necessary for radiographic examination of the horse’s vertebral column, because exposures of up to 150 kV and 500 mAs may be required in large horses.\(^1\) One of the major problems encountered in radiographs of such a thick subject is the inevitable production of secondary radiation. However, there are a number of ways to minimize scatter.

The tube can be mounted on an overhead gantry system and linked to a cassette holder on the far side of the animal. The primary beam can then be automatically directed to the center of the cassette and the beam size can be carefully collimated to the size of the film (Figure 3). This system makes it possible to use with confidence high ratio and crosshatch grids to effectively reduce scatter. The fastest possible system of intensifying screens and film (e.g., rare earth screens) should be employed so that exposures are kept to a minimum. Considerable improvement in radiographic quality can be obtained by filtering (dodging) part of the primary beam to help compensate for the marked variation in thickness of the horse’s spine.

It is not possible to take radiographs of diagnostic quality of the caudal lumbar (L₄ to L₆) and

![Figure 3—Technique of making a radiograph of a horse’s back (T₁ to L₁₄) in the standing position.](attachment.png)
sacroiliac regions with the horse standing. The animal must be anesthetized and placed on its back so that the cassette can be inserted beneath the pelvis for a ventrodorsal view. Even in very large horses (i.e., weighing 700 kg or more), exposures above 150 kV are not required, although up to 500 mAs have been used on some occasions. To limit scattered radiation, it is necessary to use crossed, high-ratio grids and to put additional lead on the back of the cassette to prevent backscatter.

Normal Radiographic Anatomy

The TL spine of the newborn foal has a more pronounced curvature (i.e., dorsally convex) in the mid thoracic region than does the adult animal. The dorsal spinous processes appear short in relation to the length of the vertebral bodies, and in the mid thoracic region they are blunt ended or spatula shaped, with wide interspinous spaces. The vertebral bodies have well-defined cranial and caudal epiphyses, but all the other ossification centers in the vertebral bodies and neural arch have fused before birth.

During the first few months of life the TL spine straightens out to some extent. In the mid and caudal TL spine there is some alteration in shape of the summits as well as a general lengthening and reduction in size of the interspinous spaces. At about 12 months of age, calcification of separate ossification centers on the summits of the cranial spinous processes occurs, and these persist without fusion into old age (i.e., 15 years or older). The tallest point of the TL vertebral column is at the withers, usually T12. Areas of periosseal irregularity are frequently seen in the mid portion of the thoracic spine, but these are of no clinical significance. The spine beneath the saddle region, T10 to T17, is considerably shorter and more upright; the antilical vertebra is usually T10. Caudal to this, the spinous processes are increasingly slanted forward and the interspinous spaces are considerably narrowed. The summits are variable in shape, but they have cranially directed, often beak-shaped tips.

In the adult the TL spine lies horizontal when the animal stands squarely on a level surface. The ventral portions of the vertebral bodies are clearly visible radiographically as far back as T15, because they form the roof of the thoracic cavity. It is difficult to view the articulations of the ribs and the articular and the transverse processes. Behind the

<table>
<thead>
<tr>
<th>Condition of TL Spine</th>
<th>Deformity (undue spinal curvature)</th>
<th>Fracture</th>
<th>Soft tissue injury</th>
<th>Ossifying spondylosis</th>
<th>Overriding of dorsal spinous processes</th>
<th>Sacroiliac strain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>History of fall or accident</td>
<td>Lowered performance on flat</td>
<td>Lowered performance on perpendicular</td>
<td>Back pain with acute onset</td>
<td>Clinical evidence of arthritis</td>
<td>Reduced flexibility of TL spine</td>
</tr>
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<td>Back pain with acute onset</td>
<td>Clinical evidence of arthritis</td>
<td>Reduced flexibility of TL spine</td>
</tr>
</tbody>
</table>

Table II

Major Clinical Signs Exhibited by Horses Suffering from Various Causes of Back Trouble

<table>
<thead>
<tr>
<th>Signs</th>
<th>Fracture</th>
<th>Soft tissue injury</th>
<th>Ossifying spondylosis</th>
<th>Overriding of dorsal spinous processes</th>
<th>Sacroiliac strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deformity (undue spinal curvature)</td>
<td>- - ± + - - - +</td>
<td>± + - - - + - - - +</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
</tr>
<tr>
<td>Fracture</td>
<td>+ - ++ NA ± + - +</td>
<td>+ - - - + - - - +</td>
<td>+ + - - - +</td>
<td>+ + - - - +</td>
<td>+ + - - - +</td>
</tr>
<tr>
<td>Dorsal spinous processes</td>
<td>- - - - + ± - - - +</td>
<td>- - - - + - - - +</td>
<td>- - - - +</td>
<td>- - - - +</td>
<td>- - - - +</td>
</tr>
<tr>
<td>Soft tissue injury</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
</tr>
<tr>
<td>(muscle or ligament strain)</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
</tr>
<tr>
<td>Ossifying spondylosis</td>
<td>+ + + + - - - +</td>
<td>+ + - - - +</td>
<td>+ + - - - +</td>
<td>+ + - - - +</td>
<td>+ + - - - +</td>
</tr>
<tr>
<td>Overriding of dorsal spinous processes</td>
<td>- + ± ++ + - + + + - - + + + - + + + - + +</td>
<td>- + ± ++ + - + + + - - + + + - + + + - + +</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sacroiliac strain</td>
<td>++ - - ± ± + - ±</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
<td>± ± + - ± - ± - - +</td>
</tr>
</tbody>
</table>
**TABLE III**

Conditions that May Directly Cause Back Problems in Horses

<table>
<thead>
<tr>
<th>General Category</th>
<th>Specific Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deformity of spinal column</td>
<td>Undue curvature of the spine (scoliosis, lordosis, kyphosis)</td>
</tr>
<tr>
<td></td>
<td>Synostosis (congenital vertebral fusion)</td>
</tr>
<tr>
<td>Soft tissue injury</td>
<td>Muscle strain of longissimus dorsi and/or sublumbar muscles</td>
</tr>
<tr>
<td></td>
<td>Strain or damage to supraspinous ligament of the back</td>
</tr>
<tr>
<td></td>
<td>Tying-up (sifast, myositis) or cramming of back muscles</td>
</tr>
<tr>
<td></td>
<td>Sacroiliac strain or instability</td>
</tr>
<tr>
<td>Fractures</td>
<td>Dorsal spinous processes (single or multiple overriding fractures)</td>
</tr>
<tr>
<td></td>
<td>Vertebrae bodies and neural arch</td>
</tr>
<tr>
<td>Other bone damage</td>
<td>Ossifying spondylolisthesis</td>
</tr>
<tr>
<td></td>
<td>Crowding and overriding of the dorsal spinous processes (rising spinous)</td>
</tr>
<tr>
<td></td>
<td>Osteoarthritis and fusion of the dorsal spinous, transverse, and articular processes</td>
</tr>
<tr>
<td>Miscellaneous conditions</td>
<td>Skin lesions (sifasts and warbles beneath saddle area)</td>
</tr>
</tbody>
</table>

**TABLE IV**

Conditions to be Considered in Differential Diagnosis of a Thoracolumbar Disorder

<table>
<thead>
<tr>
<th>General Category</th>
<th>Specific Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperament problems</td>
<td>Apparent hypersensitivity of back resulting from previous TL injury</td>
</tr>
<tr>
<td></td>
<td>Poor schooling and equitation</td>
</tr>
<tr>
<td>Hindlimb lameness problems</td>
<td>Originating from pelvic region</td>
</tr>
<tr>
<td></td>
<td>Stifle problem (e.g., partial fixation of the patella)</td>
</tr>
<tr>
<td></td>
<td>Hock lesion (e.g., spavin)</td>
</tr>
<tr>
<td>Hindlimb coordination (mild ataxia)</td>
<td>Spinal cord damage in cervical or TL spine</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Headshaking and dental problems</td>
</tr>
<tr>
<td></td>
<td>General debility and stiffness (e.g., laminitis)</td>
</tr>
</tbody>
</table>

Diagnosis of Back Problems S139

**TABLE V**

Diagnoses in Horses with Potential Thoracolumbar Disorders*

<table>
<thead>
<tr>
<th>General Category</th>
<th>Specific Diagnosis</th>
<th>No. of Diagnoses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conformational defects</td>
<td>Congenital or acquired</td>
<td>29</td>
</tr>
<tr>
<td>Soft tissue damage</td>
<td>Muscular damage/ligamentous strain</td>
<td>269</td>
</tr>
<tr>
<td></td>
<td>Tying-up (sifast, myositis)</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Sacroiliac strain</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td>Sublumbar/spinal abscess</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Cauda equina neuritis</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Surgical complications</td>
<td>6</td>
</tr>
<tr>
<td>Vertebral lesions</td>
<td>Fractures of vertebral bodies</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Fractures of dorsal spinous processes</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Other fractures</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Ossifying spondylolisthesis</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Overriding dorsal spinous processes</td>
<td>234</td>
</tr>
<tr>
<td></td>
<td>Displaced lumbar vertebra</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Other bone degeneration/osteomyelitis</td>
<td>3</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Temperament</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Dental problems</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Wobblcr/cervical vertebral stenosis</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Stifle lameness</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Hock lameness</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Hip lameness</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Upper forelimb lameness</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Lower limb lameness</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>10</td>
</tr>
<tr>
<td>No diagnosis made/no abnormalities detected</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>953</td>
<td></td>
</tr>
</tbody>
</table>

*This was a series of 825 horses referred for investigation of potential TL disorders.

stocky, short-coupled type of horse. The reduction or obliteration of the interspinous spaces, chiefly in the region from T₇ to T₉, is associated with pressure points between adjacent spines with overriding local periostel reaction and focal areas of radiolucency. The tips sometimes overlap one another and become misshapen presumably because of the continued pressure from the adjacent spines. There are few variations noted in the normal radiographic anatomy apart from the changes associated with the crowding of the dorsal spinous processes in the mid back region. Other incidental findings (e.g., abnormal spinal curvature, vertebral fracture, displacement, or ossifying spondylolisthesis) are rarely encountered.

**Laboratory Findings**

A full hematological and biochemical profile, including the determination and fractionation of the plasma proteins, should always be carried out. This is chiefly an eliminative procedure to identify...
other causes of decreased performance (e.g., anemia, systemic parasitism, intercurrent infection, etc.). The determination of the serum enzymes, aminoaspartate transferase (AA1 or SGOT) and creatine kinase (CK), in association with a standard exercise test can be helpful in diagnosing an exertional myopathy (i.e., azoturia or tying-up) or some other serious muscle damage to the back. A blood sample is taken at rest and the animal is lunged in a sand ring for 10 to 15 minutes. Postexercise blood samples are taken immediately and 18 to 24 hours later. Active muscle damage is indicated by a two- to fivefold increase above resting levels.

Other Aids to Diagnosis

A useful and simple test in longer-standing cases is to administer a short course (two to three days) of an antiinflammatory/antiarthritic drug (e.g., phenylbutazone), because this will often help differentiate soft tissue and bone injuries. If some chronic skeletal bone damage exists, temporary abatement in the clinical signs will usually occur.

Another technique can be used when crowding or overriding of the summits of the dorsal spinous processes (kissing spines) is suspected. This involves the assessment of the animal’s performance before and after the injection of a local anesthetic in the interspinous spaces of the mid or distal back. This should always be done in association with a careful radiological examination, because the placement of the needles is critical.

The possibility of cervical cord compression should be considered in horses showing signs that
cranial thoracic region (T₃ to T₆) in lordosis and in the cranial lumbar region (L₁ to L₃) in kyphosis.

The objective assessment of back pain is frequently difficult. For example, some animals, particularly young Thoroughbreds, are naturally sensitive or thin-skinned over the back and loin area. On palpation, an exaggerated dorsiflexion response can easily be misinterpreted as pain. However, no associated signs of a demonstrable bone or soft tissue lesion can be found and there is no effect on the animal's performance. Cold back is another, somewhat similar and well-known syndrome. In these horses there is a persistent hypersensitivity over the back, with stiffness and dipping of the spine on being saddled or mounted (Figure 6). There are usually no other clinical signs, and no radiological damage can be found in the TL spine. The initial signs of rigidity on being saddled or mounted are usually a reluctance to ventroflex the spine. In most long-standing cases there is no demonstrable pain in the lumbar or pelvic regions. The only radiographic finding is an increased joint space of the sacroiliac articulations on one or both sides and some arthrosis at the caudal aspect of the joint in long-standing cases.

Radiological changes are not always related to the clinical signs exhibited in cases of overriding dorsal spinous processes. The pain is probably referable to an interspinous pseudoarthrosis. However, there may be a tendency to place too much clinical significance on the condition. It undoubtedly predisposes animals to periods of back pain and discomfort, but the clinical signs occur only temporarily, and surgical resection as a means of therapy is in many instances unnecessary. Furthermore, some horses show radiographic evidence of chronic overriding and nevertheless apparently perform satisfactorily.

Spondylitic lesions affecting the vertebral bodies of the mid to caudal thoracic region are rarely seen in working horses. However, when they do occur, they have serious clinical effects, and there is usually little that can be done in the way of permanent treatment to keep the animal in work. Osteoarthritic lesions of the transverse and articular processes of the lumbosacral vertebral in the distal back are much more common, especially in older horses. However, they appear to cause little inconvenience to jumpers, because this part of the spine is kept particularly rigid.

Summary

The diagnosis of chronic back pain in horses is seldom straightforward, and it is frequently achieved more by the elimination of conditions with similar signs than on the basis of positive findings. A detailed clinical history must be considered and the animal must be examined at rest and during exercise. Routine radiography of the TL spine from T₃ to L₃ should be done, with examination of the lumbosacral and sacroccygeal regions when appropriate. The technique for the radiographic examination of the withers and back (T₅ to L₃ or L₄) is best carried out with the horse standing, but general anesthesia and dorsal recumbency are required for the lumbosacral and sacroiliac regions. A number of ancillary aids to diagnosis can be employed, including examination of serum enzymes (CK and AAT) after exercise, local anesthesia of caudal thoracic interspinous spaces, and administration of a short course of an antiinflammatory drug.

There is a wide range of lesions capable of producing back problems, and more than one condition may be present at one time. The three most common causes of back problems are muscular or ligamentous injury, overriding of the dorsal spinous processes, and sacroiliac strain. The type, use, and conformation of the horse have an important bearing on the category of injury involved. Most of
the vertebral damage is concentrated at the midpoint of the back, and the soft tissue injuries tend to occur at either side of the caudal withers and cranial lumbar regions.

BIBLIOGRAPHY
Radiographic Examination of the Equine Vertebral Column

L. B. Jeffcott

A method is described for routine radiography of the horse's thoracolumbar (TL) spine from T2 to L3 in the standing position. Stocks were used for restraint, and the x-ray tube, which was mounted on an overhead gantry, was linked automatically to a cassette holder on the far side of the animal. A crosshatch grid with an ultra-fast system of screens and film was employed to provide adequate radiographic quality. An aluminum wedge filter (dodger) was used to help compensate for the marked variation in spine thickness. For radiography of the caudal lumbar spine and lumbosacral region, it was necessary to anesthetize the horse and make radiographs in the ventrodorsal position. Exposures of up to 150 kV and 400 mAs were required for heavy horses weighing up to 750 kg. Scatter radiation was kept to a minimum by using crossed high-ratio grids and by putting additional lead on the back of the cassette to prevent back scatter.

(Key words: equine, musculoskeletal system, radiography)

Horses that have chronic injuries of the thoracolumbar (TL) spine often exhibit a complicated clinical picture (5). Furthermore, specific diagnosis has been hampered by the lack of a suitable radiographic technic for the TL spine. One author (7) states that because of technical problems, radiography of the equine vertebral column is currently limited to the cervical region. Apart from one article (8) and two preliminary reports (2, 3), no reference to radiographic examination of the back has been found. The summits of the dorsal spinous processes were examined in two normal horses (9), but only in the cranial thoracic region (T3–T10).

This paper describes a system for the routine examination of the TL spine in the standing position from T2 to L3 and for the caudal lumbar and sacral spine under general anesthesia.

RADIOGRAPHIC FACILITIES AND EQUIPMENT

The equipment used in this study was a Siemens Triplex Optimatic 1023 with the tube mounted on a 3D overhead suspension. The tube was linked to an image intensifier, to the front of which a cassette holder could be attached if required. With this arrangement, the central ray was automatically directed to the center of the cassette. High-ratio grids could be used to assist in reducing scatter. A plan of the radiographic unit at the Equine Research Station and its facilities is shown in Figure 1.

For the examination of all conscious horses, stocks were used routinely. The stocks were movable and could be taken away to allow access of an anesthetized animal on a forklift truck. For the first 3 years of the study, a 200 kV/1000 mA tube with a conventional-speed rotating anode (2000 rpm) was used. Because of a manufacturing fault, this tube was replaced with a 150 kV/1250 mA high-speed rotating anode (8000 rpm) tube. Both tubes had broad and fine focal spots which measured 2.2/1.1 mm and 1.2/0.6 mm, respectively. The replacement...
tube produced a noticeable increase in radiographic quality for conscious horses, as the greater mA rating allowed for much shorter exposures. The reduction in focal spot size increased geometric sharpness.

TECHNIC FOR EXAMINATION OF THE THORACOLUMBAR AND SACROCOCCYGEAL SPINE

Examination of the TL spine from T2 to L3–4 was always performed in the standing position with the horse in stocks (Fig. 2). To avoid distortion and malposition of skeletal structures, the horse stood squarely on all four limbs on a level surface. The loaded cassette was placed in a holder on the front of the image intensifier and parallel to the longitudinal axis of the spine.

It was necessary to make up a spine-radiograph mosaic of T2–L3, not only because of the large area examined and the fact that the largest film size available is 35 × 43 cm (14 × 17 inches), but also because of the great variation in radiodensity of different levels of the vertebral column. The sacrococcygeal spine was not examined in all horses. The exposure values had to be varied for the different levels (Table 1).

The following routine helped to produce radiographs of standard quality.

Intensifying Screens and Film

Two systems were employed for routine examinations; both were designed to give as much speed and latitude as possible. In the first instance, ultra-

<table>
<thead>
<tr>
<th>Region</th>
<th>System A</th>
<th>System B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kV</td>
<td>mAs</td>
</tr>
<tr>
<td>Withers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorsal spines (T2–T12)</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>Vertebral bodies (T7–T13)</td>
<td>80</td>
<td>160</td>
</tr>
<tr>
<td>Mid-back</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorsal spines (T12–T18)</td>
<td>80</td>
<td>160</td>
</tr>
<tr>
<td>Vertebral bodies (T12–T17)</td>
<td>85</td>
<td>200</td>
</tr>
<tr>
<td>Lower back and iliums</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorsal spines (T17–L4)</td>
<td>90</td>
<td>200</td>
</tr>
<tr>
<td>Vertebral bodies (T17–L3–4)</td>
<td>120</td>
<td>250</td>
</tr>
<tr>
<td>Croup and sacral region</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorsal spines and vertebral bodies (S2–Cy4)</td>
<td>80</td>
<td>200</td>
</tr>
</tbody>
</table>


† System B: 150 kV/1250 mA tube with high-speed anode, Lanex rare earth screens, and Kodak Ortho-G film.

The rare earth screens appeared to have much the same range of speed as the Lightning-Plus screens, but they gave a better range of contrast. The differences observed in exposures between Systems A and B (Table 1) were due principally to the change in the x-ray tube and not to the intensifying screens and film used.

Films were processed using an automatic processor.

Grids and Cassettes

The grid employed was a crosshatch-parallel Lysholm with an 8:1 grid ratio and 75 strips/cm. The cassettes were lead-backed, but an extra sheet of lead was placed behind the cassette to prevent back scatter when settings greater than 100 kV were used.

Movement, Image Distortion, and Unsharpness

Movement of the horse was reduced when neces-

---

Table 1. Approximate Exposure Values for Radiography of Thoracolumbar Spine Using the Dodger-T Filter for 450–500 kg Horse

---

8 DuPont Cronex, Lightning-Plus, Photo Products Department, X-ray Division, Hawkbeden Road, St. Neots, Huntingdonshire, England.

* Kodak RP/R 54.

7 Lanex, Kodak Ltd., Swallowdale Lane, Hemel Hempstead, Hertfordshire, England.

6 Elema-Schonander, Sweden.
A ventrodorsal projection with the horse under general anesthesia and in dorsal recumbency was necessary for this part of the examination (Fig. 4). This was done to ensure restriction of movement, to enable accurate positioning, and to reduce the thickness of the part to be radiographed. Little information could be gained from a lateral view of the sacroiliac and pelvic region.

For this technic, the horse was premedicated with 0.05 mg/kg acepromazine maleate given intramuscularly or intravenously. Anesthesia was induced with 1 g/100 kg thiopentone and maintained with halothane and oxygen using a modified Fisher-Jennings circle absorber. The legs were hobbled and the horse picked up by an overhead hoist, placed on a forklift truck with a 213 x 131 cm (7 x 4.5 ft) wooden palette, and transported from the anesthetic/recovery box to the radiographic examination room.

The range of exposures required for the caudal lumbar and sacroiliac regions is given in Table 2. The same fast film, screens, and automatic processing were used, but the following additional items were found to be necessary:
1) A cassette tunnel was placed beneath the horse. The tunnel was made of 2-cm marine ply and raised above the surface of the palette;
2) Crossed high-ratio grids were used to limit scatter. These were Lysholm focused 105 cm, 12:1 grid ratio, 100 strips/cm²;
3) A lead cone (24 x 30 cm at 100 cm) was used to limit the beam in horses weighing more than 600 kg;
4) A lead intensifying screen (0.005 cm) was placed in front of the grids to help remove low-intensity scatter and improve radiographic quality;
5) An FFD of 130 cm was used.

DISCUSSION

The power available with the Triplex Optimatic 1023 radiodiagnostic equipment gave adequate penetration of a mass as thick as the TL spine of even the heavier horses (>500 kg body weight). One of the major objectives of the study, therefore, was to try to find ways of reducing the secondary radiation and thereby improve radiographic quality. This was achieved to a large extent by collimating the primary x-ray beam to an absolute minimum and using either a large lead cone or aluminum wedge filter.
The fastest available system of screens and film, i.e., rare earth, was employed as was a crosshatch type of grid. The results obtained have been encouraging (4, 6), but it is thought that there are still some limitations associated with the technic. For instance, it is still necessary to take a minimum of six radiographs to include all of the structures in the TL spine in order to make up a composite picture of the vertebral column from T2 to L3. The best results for this part of the back were obtained with the animal standing squarely on all four feet. For the region caudal to L4, it was mandatory that the horse be in dorsal recumbency. The quality and contrast could still be improved upon, particularly in the caudal lumbar region. Another drawback was the fact that radiographs taken with the animal either standing or under general anesthesia were limited to one plane, i.e., lateral or ventrodorsal.

From the point of view of radiation safety, the system used here is to be commended in spite of the large exposures that were required for adequate penetration of the vertebral column. With the horse in stocks, only two people were involved: an attendant at the head and the radiographer. Neither of them stood near the primary beam (Fig. 2). For the lumbosacral spine, the animal being radiographed was under general anesthesia. All personnel could conveniently leave the room when an exposure was being made.

**Table 2. Approximate Exposure Values for Radiography of the Caudal Lumbar and Sacroiliac Regions According to Body Weight of the Horse**

<table>
<thead>
<tr>
<th>Weight (kg)</th>
<th>kV</th>
<th>mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>120</td>
<td>250</td>
</tr>
<tr>
<td>400</td>
<td>125</td>
<td>320</td>
</tr>
<tr>
<td>500</td>
<td>135</td>
<td>320</td>
</tr>
<tr>
<td>600</td>
<td>140</td>
<td>400</td>
</tr>
<tr>
<td>700</td>
<td>150</td>
<td>400</td>
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</tbody>
</table>

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Animal Health Trust
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Snailwell Road
Newmarket, Suffolk CB8 7DW
England
REFERENCES

Radiographic Features of the Normal Equine Thoracolumbar Spine

L. B. Jeffcott

The normal radiographic anatomy of the equine thoracolumbar (TL) spine is described from birth to maturity. Closure of the vertebral epiphyses was found to take place from 30 to 38 months of age. In a series of 110 normal horses, there were few incidental radiologic abnormalities seen apart from changes associated with crowding and overriding of the dorsal spinous processes. Sixty-six percent of horses were free from any detectable radiologic lesion, and an additional 12 percent showed only impingement of the dorsal tips of one or more summits. The remainder (22 percent) exhibited some evidence of overriding of the dorsal spinous processes, but in only 3 percent were the changes pronounced. This reduction or obliteration of the normal interspinous spaces occurred chiefly in the midthoracic spine from T13 to T16 and was associated with pressure points between adjacent spines with local periosteal reaction and focal areas of radiolucency. The tips of the processes sometimes overlapped one another and became misshapen, presumably as a result of continued pressure from the adjacent impinging spines.

(Key words: equine, musculoskeletal system, radiography)

There have been no detailed descriptions to date of the normal radiographic anatomy of the equine thoracolumbar (TL) spine. It was thought that some attempt at remedying this situation should be made to form a basis for radiologic interpretation of horses exhibiting clinical signs of back trouble. This study was performed on a series of horses free of radiographic signs of back disease using the technic described in a previous paper (2).

MATERIALS AND METHODS

Thoracic and Cranial Lumbar Region

The results presented here are based on the examination of 110 normal horses of various breeds whose ages ranged from newborn to 27 years (Table 1). They included seven male Thoroughbreds which were available for examination every 3 to 6 months over a 2-year period from 20 months of age to the end of their third year. None of these horses had any known history of back injury, ataxia, or hind limb lameness. The technic of radiographic examination in the standing position has been described (2).

Caudal Lumbar and Sacral Region

In this part of the study, information about radiographic anatomy was obtained from 149 horses referred for lower back or upper hind limb injury that showed no radiologic abnormalities. Full clinical details are available elsewhere (1). The technic for radiography under general anesthesia has been described (2). All the animals examined were fasted overnight.

RESULTS AND DISCUSSION

Thoracic and Cranial Lumbar Spine

At Birth and During Foalhood

The TL spine of the newborn foal (Fig. 1) had a more pronounced curvature in the midthoracic region than the adult animal; it was dorsally convex. The dorsal spinous processes appeared rather short in relation to the length of the vertebral bodies, and there were no detectable centers of ossification on the summits from T2 to T7. In the midthoracic regions the spinous processes were rather blunt-ended or "spatula-shaped," and there were wide interspinous spaces. The vertebral bodies had well-defined cranial and caudal epiphyses, but all of the other

Table 1. Ages and Types of Horses Used to Study the Radiographic Anatomy of the Thoracolumbar Spine

<table>
<thead>
<tr>
<th>Type</th>
<th>No. of animals</th>
<th>Age (yr)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>&lt;1</td>
</tr>
<tr>
<td>Thoroughbred</td>
<td>70</td>
<td>16</td>
</tr>
<tr>
<td>Parthbred</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Thoroughbred</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>animals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ponies</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>110</td>
<td>7</td>
</tr>
</tbody>
</table>

From the Equine Research Station of the Animal Health Trust, P.O. Box 6, Balaton Lodge, Snaillwell Road, Newmarket, Suffolk CB8 7DW, England, where Dr. Jeffcott is Head of the Clinical Department.

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ossification centers in the vertebral bodies and neural arch had fused before birth.

During the first few months of life, the dorsal curvature of the TL spine was straightened to some extent, and the spinous processes underwent changes in shape. In the cranial thoracic region, the processes lengthened and showed a pronounced curvature at about their midpoint (Fig. 2). The dorsal tips also broadened at the site of insertion of the nuchal ligament. In the mid- and caudal TL spine there was some alteration in shape of the summits as well as a general lengthening and reduction in size of the interspinous spaces (Figs. 3, 4). The vertebral epiphyses remained evident during the first year of life.

**Yearlings and Adults**

At about 12 months of age, calcification occurred in the separate ossification centers on the summits of the cranial spinous processes (Fig. 5). The spines straightened and developed a fairly pronounced backward slant. The tallest point of the TL vertebral column was at the withers, usually the spine of T6. The nuchal ligament attached to the summits of T2–T7 and the supraspinous bursa could usually be demonstrated above the spine of T2 and T3 (Fig. 6).

The interspinous spaces at the withers were generally large, and the separate centers of ossification on the dorsal tips of T2–T6 persisted even into old age, 15 years or older. The cranial border of the spines was thinner than the caudal border; the latter was often seen as a double line radiographically, as there was usually a slight ridge or groove on the caudal edges. Areas of periosteal irregularity in the midportion of the thoracic spines were frequently seen, but they did not appear to have any clinical significance. The spines beneath the saddle region, T11–T17, were considerably shorter and more upright (Fig. 7). The antclinal vertebra was usually T15, and caudal to this the spines increasingly slanted forward. The interspinous spaces were narrower in this region; in some horses, impingement of adjacent spines occurred. The summits were variable in shape but had a cranially directed, often beak-shaped, tip. There was also some variation in shape according to breed. In the Thoroughbred, the
Fig 3. (Top) Radiograph and (bottom) explanatory diagram of the mid- and caudal thoracic spine in a 1-month-old Thoroughbred foal.

Fig 4. (Top) Radiograph and (bottom) explanatory diagram of the caudal thoracic and lumbar spine in a 4-month-old Thoroughbred foal.

Fig 5. (Top) Radiograph and (bottom) explanatory diagram of the cranial thoracic region with early ossification of the separate ossification centers on the spinous summits in a yearling Thoroughbred.

Fig 6. (Top) Radiograph and (bottom) explanatory diagram of the cranial thoracic spine (withers) in a 3-year-old pony showing the insertion of the nuchal ligament inserting onto the summits of T2-T8.
summits tended to be beak-shaped with narrower interspinous spaces, while in ponies and other breeds, they were more blunt-ended and were spaced wider apart (Fig. 8). In the adult, the TL spine was almost completely horizontal with the animal standing squarely on all four feet. The ventral portions of the vertebral bodies as far back as T16 were clearly visible radiographically as they formed the roof of the thoracic cavity. It was much more difficult to view the articulations with the ribs and the articular and transverse processes. Behind the line of the diaphragm, the lumbar vertebrae as far back as L3 could usually be defined together with the articular and transverse processes (Fig. 9). Closure of the vertebral epiphyses took place at 3 to 3½ years. In the seven Thoroughbreds in training examined over a 2-year period, closure began at about 30 months of age and was almost complete by 38 months.

Other Radiologic Findings

There were few variations from the normal radiographic anatomy in these 110 horses apart from some changes associated with crowding of the dorsal spinous processes in the cranial (withers) and caudal thoracic (midback) regions. No evidence was found of abnormal spinal curvature, vertebral fracture, vertebral displacement, or ossifying spondylosis.

A fairly common and presumably incidental finding in the withers was a degree of spur formation on the dorsal tip of T3 or T4 near the insertion of the nuchal ligament (Fig. 10). This was not usually associated with any impingement or radiologic evidence of damage on the opposing surface of the preceding spine.

In the midback, the width of the interspinous space was variable, and a certain amount of impingement or overriding of the spinous summits was seen. It was more frequent in the Thoroughbred animals and much less so in the ponies (Table 2). It did not seem to be particularly related to age (Table 3) but rather to conformation and was present more often in the stocky, short-coupled type of horse. As a guide to the degree of the radiographic changes, a system of grading them was evolved (see Table 4). Sixty-nine horses (66 percent) did not show any evidence of crowding of the dorsal spinous processes; in a further 13 (12 percent) there was only impingement of the dorsal tips of one or more summits in-
Table 2. Radiographic Evidence of Overriding Dorsal Spinous Processes According to Type (or Breed) of Horse

<table>
<thead>
<tr>
<th>Type of horse</th>
<th>No. of horses</th>
<th>Grade of overriding dorsal spinous processes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Thoroughbred or Partbred</td>
<td>67 (100%)</td>
<td>37 (55%)</td>
</tr>
<tr>
<td>Non-Thoroughbred</td>
<td>15 (100%)</td>
<td>10 (67%)</td>
</tr>
<tr>
<td>Pony</td>
<td>23 (100%)</td>
<td>22 (96%)</td>
</tr>
</tbody>
</table>

Table 3. Radiographic Evidence According to Age of Crowding and Impingement of Dorsal Spinous Processes in 105 Horses That Showed No Sign of Back Trouble

<table>
<thead>
<tr>
<th>Age group (yr)</th>
<th>No. of horses</th>
<th>Grade of overriding dorsal spinous processes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>0-2</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>3-5</td>
<td>26</td>
<td>17</td>
</tr>
<tr>
<td>6-9</td>
<td>33</td>
<td>22</td>
</tr>
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<td>10-14</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>105 (100%)</td>
<td>69 (66%)</td>
</tr>
</tbody>
</table>
Table 4. System for Grading Radiographic Evidence of Overriding Dorsal Spinous Processes

<table>
<thead>
<tr>
<th>Grade</th>
<th>Radiographic evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No impingement of the spinous processes</td>
</tr>
<tr>
<td>1</td>
<td>Impingement of summits only</td>
</tr>
<tr>
<td>2</td>
<td>Impingement with signs of mild overriding, i.e., crowding</td>
</tr>
<tr>
<td>3</td>
<td>Overriding of spinous processes associated with periosteal reaction at sites of impingement</td>
</tr>
<tr>
<td>4</td>
<td>Severe overriding with periosteal reaction, pseudarthrosis, and misshapen dorsal summits</td>
</tr>
<tr>
<td>5</td>
<td>Fusion of adjacent dorsal spinous processes</td>
</tr>
</tbody>
</table>

More pronounced radiologic changes (Grade 4) were seen only in 3 percent of the horses. The reduction or obliteration of the interspinous spaces chiefly in the region from T13 to T18 was associated with pressure points between adjacent spines with overriding local periosteal reaction and focal areas of radiolucency. The tips sometimes overlapped one another and became misshapen, presumably as a result of continued pressure from the adjacent spines. The clinical features of this condition and its effect on performance are considered in another publication (3).

Of the seven male Thoroughbreds examined regularly from the onset of training to the end of their 3-year-old racing career, only one showed any sign of crowding or overriding of the dorsal spinous processes (Table 5). In this colt there was overriding of the caudal thoracic summits, T12 to T17 (Fig. 12), before it had done any work, although no clinical signs became evident and the colt performed satisfactorily. The changes progressed from Grade 3 to Grade 4 over the next 6 months during the early stages of training. During the ensuing autumn and winter, there was a reduction in the degree of periosteal reaction between opposing spines and a slight widening of the interspinous spaces. The colt was then regraded to Grade 3.

CAUDAL LUMBAR AND SACROCOCCYGEAL SPINE

The main radiographic features demonstrable in the lumbosacral spine and pelvic region are illustrated in Figures 13 and 14. Although the animals
Table 5. Results of Periodic Examination of the Thoracolumbar Spines of Seven Thoroughbreds in Training

<table>
<thead>
<tr>
<th>Animal</th>
<th>20 months</th>
<th>26 months</th>
<th>32 months</th>
<th>38 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0*</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>NE</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* Examined at 36 months.
NE = Not examined.

examined were fasted overnight before the induction of general anesthesia, this made little difference to the fecal content of the large bowel. The head of the cecum and the pelvic flexure of the large colon sometimes obscured part of the lumbosacral spine, but it was usually possible by manipulation per rectum to move these structures to some extent and assist radiographic interpretation. There was considerable variation in the extent and frequency of caudal transverse process fusion, and it was not usually possible to see the lateral tips of these processes because of superimposed bowel shadows.

The lumbosacral articulation was generally quite clearly outlined, but it was usually difficult to de-
lineate the sacroiliac joint space. Careful positioning of the horse in dorsal recumbency was essential to avoid lateral curvature or deviation of the caudal lumbar spine and sacrum, as this could be confused with a radiologic abnormality. This was particularly important in horses suspected of having sacroiliac strain which sometimes showed as malalignment of the sacrum in relation to the pelvic symphysis. The dorsal spinous processes of the sacral vertebrae showed up well, although the outline of the sacrum itself was often difficult to discern. In the pelvis, the centers of ossification at the tubera coxae and tubera ischii were usually closed by 2 years of age. This was also true of the femoral head physis, but the pelvic symphysis did not begin to fuse until 2 years and was not completely fused until the end of the fifth or sixth year. In a few animals, there was incomplete fusion of the pelvic symphyses at 8 or 9 years.

In the standing position it was possible to take lateral radiographs of the sacral dorsal spines and bodies from S2 or S3 caudally (Fig. 15). This view was not taken routinely, but only when some sacral or coccygeal damage was suspected.

Fig. 15 (Top) Lateral radiograph and (bottom) explanatory diagram of the sacrococcygeal spine taken in the standing position of a 5-year-old castrated male Thoroughbred.
The slap test for laryngeal adductory function in horses with suspected cervical spinal cord damage

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Equine Research Station of the Animal Health Trust, PO Box 5, Balaton Lodge, Snailwell Road, Newmarket, Suffolk CB8 7DW

Summary

The paper describes the assessment and practical implications of a laryngeal adductory reflex in a series of 30 ataxic and 64 non-ataxic horses. The reflex was evoked by slapping the saddle region just caudal to the withers. In normal horses this produced a flickering adductory movement of the contralateral arytenoid cartilage which was observed endoscopically. Abolition of the laryngeal response was encountered in 3 situations:

1. Disruption of the afferent impulse occurred in those horses in which there was significant spinal cord pathology affecting the pathway from the cranial thoracic region to the medulla.
2. Disruption of the efferent impulse was manifest when damage to the adductory component of the recurrent laryngeal nerve prevented normal adduction.
3. The reflex was abolished in tense or frightened horses, possibly due to interference from higher centres.

The laryngeal adductory reflex was considered to be a useful diagnostic and prognostic aid in the assessment of ataxia and spinal cord lesions in the horse.

Introduction

The endoscopic diagnosis of most cases of laryngeal paralysis amounts to recognition of an adductor paralysis and adductor function is not assessed. Yet in any one case of laryngeal paralysis there is a chance that adductor paralysis may be more advanced than adductor paralysis and, for the diagnosis of partial paralysis in particular, there is a definite advantage to be gained from assessing both adductor and adductor function. The horse's ability to abduct its larynx can usually be assessed by laryngoscopy during quiet respiration, immediately after a swallowing reflex or immediately after a gallop, at which times varying degrees of abduction take place. Adduction however, normally occurs only during phonation, swallowing or coughing and laryngoscopy is either difficult or anatomically impossible during these transient episodes. Some convenient method was needed to make a horse adduct its larynx on demand. In searching for such a method, one of us (W.R.C.) found that by slapping the saddle area of a normal horse a laryngeal adductor reflex was initiated in the contralateral arytenoid cartilage. In horses suffering from left-sided laryngeal paralysis the response from the left arytenoid cartilage was often found to be absent or weak. However, it was not until the reflex was tested in a horse which also had a spinal cord lesion that wider clinical implications were appreciated: this chance examination revealed that the adductory reflex was absent on both sides.

Since these initial observations, the slap test has been carried out routinely on cases with suspected idiopathic laryngeal paralysis, incoordination and "wobbler" syndrome. The purpose of this paper is to report on the evaluation of the laryngeal adductory reflex in 94 horses and to emphasise its application as a clinical diagnostic aid in the assessment of spinal cord disease.

Materials and methods

Horses

A total of 94 horses referred to the Equine Research Station were subjected to a clinical and endoscopic examination between December 1977 and February 1980 (Table 1). The cases were divided into 2 categories. Group A consisted of 30 horses which exhibited clinical signs of ataxia; in 5 of these the signs were only mild or suggestive of ataxia. In some horses in this group ataxia was accompanied by other clinical signs. Group B comprised 64 non-ataxic horses referred for a respiratory problem, suspected cervical vertebral damage or lameness.

Technique of the slap test

The animals were examined in stocks and restrained with a twitch. The endoscope, a flexible fibreoptic gastroscope (Olympus, Key-Med, Southend), was passed into the left or right ventral nasal meatus and the larynx observed. Movements of the arytenoid cartilages and vocal cords were evaluated during quiet respiration. The saddle area on one side was then given a series of 3 or 4 slaps of moderate intensity by an assistant and the laryngeal adductory reflex was assessed simultaneously. The same procedure was then repeated on the opposite side of the thorax. Back slapping was performed several times on each side of the thorax and more than one observer assessed the response endoscopically.

A normal response involved a slight adductory flicker of the contralateral arytenoid cartilage as a result of each slap (Fig 1).

Radiographic examination

Lateral radiographs of the caudal skull, cervical and cranial thoracic spine (C7-T1) were taken in the standing position in all horses in Group A and in 15 horses in Group B. No other views were taken and no attempts at myelography were made.

The equipment used was a Siemens Triplex Optimatic 1023 machine with a tube capable of 150 kV and 1250 mA mounted
TABLE 1: Details of horses in the series

<table>
<thead>
<tr>
<th>Category</th>
<th>No of animals examined</th>
<th>Slap test</th>
<th>Radiography</th>
<th>Post mortem</th>
<th>Sex</th>
<th>Age range</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) Obvious signs of ataxia</td>
<td>25</td>
<td>25</td>
<td>12</td>
<td>24</td>
<td>1</td>
<td>4m-10y</td>
<td>18</td>
</tr>
<tr>
<td>(ii) Suspected ataxia</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>11m-12y</td>
<td>4</td>
</tr>
<tr>
<td>Group B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-ataxic animals</td>
<td>64</td>
<td>15</td>
<td>1</td>
<td>48</td>
<td>16</td>
<td>12m-12y</td>
<td>32</td>
</tr>
<tr>
<td>Total</td>
<td>94</td>
<td>43</td>
<td>13</td>
<td>76</td>
<td>18</td>
<td>—</td>
<td>54</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sex</th>
<th>Thoroughbred</th>
<th>Non-Thoroughbred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>45</td>
<td>54</td>
</tr>
<tr>
<td>Female</td>
<td>52</td>
<td>40</td>
</tr>
</tbody>
</table>

on an overhead gantry and linked to a cassette holder (Jeffcott 1980). Rare earth intensifying screens (Kodak, Lanex) and film (Kodak (G1)) were used with a 8:1 crosshatch Lysholm grid at a focus to film distance of approximately 100 cm.

The films were read at one session without reference to the clinical signs or slap test results. Each set of radiographs was assessed simply for evidence of bony lesions causing stenosis of the vertebral canal (+), the absence of such lesions (-) or an inconclusive result (±).

Post mortem examination

A post mortem examination was carried out in 12 horses in Group A and in one horse in Group B. This included gross and histological examination of the cervical spinal cord and brain in all cases and the thoracolumbar cord in those cases where convincing macroscopic evidence of a focal cervical cord lesion was not detected grossly at autopsy. Intervertebral articulations and vertebral morphology were assessed before and after cleaning by boiling.

Results

Technical considerations

The normal flickering adductory response from the contralateral arytenoid cartilage was observed initially but it was noted that as slapping progressed the response tended to become weaker or even disappear. It was found preferable therefore to slap in short bursts of 3 or 4 slaps.

In tense or excited horses fixed bilateral abduction of the larynx occurred and this precluded assessment of the reflex. Some horses relaxed after the endoscope had been in situ for a few minutes and in some instances removal of the twitch tended to encourage relaxation of the larynx. It was only necessary to resort to chemical restraint in 3 animals; acepromazine maleate was administered intramuscularly or intravenously at a dose rate of 0.05 mg/kg body weight. This did not appear to affect the reflex.

The degree of adductory movement elicited varied among horses showing a normal response. Some horses reacted to gentle slapping while in others the reflex was only observed after a more vigorous stimulus. For this reason the optimal strength of the slap administered had to be determined for each individual horse and varied according to the type and size of the animal. If too soft a slap was used no response was elicited even in normal horses. If the slap was too forceful the horse adducted both arytenoid cartilages simultaneously which was regarded as a fear response.

Effects of laryngeal paralysis

In many horses suffering from laryngeal paralysis, whether "idiopathic" left-sided laryngeal paralysis, or paralysis caused by other pathological processes (eg, guttural pouch mycosis) the laryngeal response to the slap test was absent or weak on the paralysed side of the larynx. For this reason the laryngeal function of each horse had to be assessed endoscopically and taken into consideration before the results of the slap test could be used to evaluate the integrity of the cervical spinal cord.

Group A (ataxic horses)

The results of the slap test, radiographic findings and post mortem findings are presented in Tables 2, 3 and 4 respectively. Of the 25 horses with definite clinical evidence of ataxia, the interpretation of the test was inconclusive in the 2 youngest animals (aged 4 months and 7 months) due to
RESULTS OF ASSESSMENT OF THE LARYNGEAL ADDUCTORY REFLEX IN 94 HORSES

<table>
<thead>
<tr>
<th>Category</th>
<th>Signs of laryngeal paralysis</th>
<th>No of animals</th>
<th>Normal</th>
<th>Slap response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Abnormal</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Unilateral</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Inconclusive</td>
</tr>
<tr>
<td>Group A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(25) Obvious signs of ataxia</td>
<td>Present</td>
<td>11</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>14</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>(5) Suspected ataxia</td>
<td>Present</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Group B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(64) Non ataxic</td>
<td>Present</td>
<td>41</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>23</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>94</td>
<td>34</td>
<td>18</td>
</tr>
</tbody>
</table>

RESULTS OF RADIOGRAPHIC FINDINGS IN THE CERVICAL SPINE OF 43 HORSES

<table>
<thead>
<tr>
<th>Category</th>
<th>Radiographic findings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No of animals</td>
</tr>
<tr>
<td>Group A</td>
<td></td>
</tr>
<tr>
<td>Obvious signs of ataxia</td>
<td>25</td>
</tr>
<tr>
<td>Suspected ataxia</td>
<td>3</td>
</tr>
<tr>
<td>Group B</td>
<td></td>
</tr>
<tr>
<td>Non ataxic animals</td>
<td>15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>No of animals</th>
<th>Radiographic findings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obvious signs of ataxia</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>Suspected ataxia</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Non ataxic animals</td>
<td>15</td>
<td>3</td>
</tr>
</tbody>
</table>

- positive evidence of bony lesions causing vertebral canal stenosis
- equivocal results
- no significant radiological damage

Tenderness and fixed laryngeal abduction. Autopsy of one of these showed ataxia to have been caused by a focal, bilateral spinal cord compression at the level of the articulation between the third and fourth cervical vertebrae (C3-C4). In the remaining 23 horses only 3 had a normal response to the slap test. Two of the 3 were examined at post mortem and caudal lumbar spinal cord lesions were found with no significant lesions in the cervical spinal cord. In the third case a lumbar spinal cord lesion was suspected but the horse was not obtained for autopsy.

Seventeen horses with definite ataxia had no response to the slap test. One of these cases improved clinically over the ensuing 12 months and the adductory reflex became normal after that period. Seven of the other 16 cases were autopsied; focal cervical cord lesions were found to be present in all 7, affecting the cord bilaterally. A unilateral response to the slap test was observed in 3 horses which had no endoscopic signs of laryngeal paralysis; 2 of them were autopsied and, in both, predominantly unilateral cervical spinal cord lesions were confirmed (Fig 2). In the third case a unilateral lesion was suspected from the radiographs.

Five horses with suspected hindlimb incoordination were also examined; only one had a normal response to the slap test. Laryngoscopy indicated that 2 of the animals had left laryngeal adductory paralysis. In one the left arytenoid adductory response was absent; in the other it was normal but the adductory response was absent on the right side. The remaining 2 horses had normal larynges but both had unilateral adductory responses.

The radiological results (Table 3) showed positive evidence of bony lesions causing stenosis of the vertebral canal in only 12 of the 25 horses with obvious ataxia and in only one of the 3 horses with suspected ataxia.

Group B (non-ataxic horses)

Forty-one of the 64 horses in this group had laryngeal paralysis and of these only 10 had a normal response to the slap test (ie, had no adductory paralysis, Table 2). Twenty-nine horses had a unilateral response (ie, had laryngeal adductory muscle paralysis interrupting the reflex arc). Inexplicably one non-ataxic horse had no response to slapping despite a relaxed larynx. In one horse the slap test was inconclusive because of laryngeal tenseness. Twenty-three horses did not show any endoscopically demonstrable laryngeal paralysis and 20 of them had a normal slap response. In the remaining 3 cases the interpretation of the test was inconclusive because of laryngeal tenseness.

The radiological results in the Group B horses were equivocal as 3 of the 15 animals examined showed radiographic evidence of some vertebral canal stenosis without any signs or history of incoordination.

Correlation of results of the slap test with the pathological findings in 12 ataxic horses (Group A)

<table>
<thead>
<tr>
<th>Slap test result</th>
<th>No of horses</th>
<th>Cause of ataxia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>1</td>
<td>Focal myelitis of lumbar cord</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Focal haemorrhage into lumbar cord</td>
</tr>
<tr>
<td>No response</td>
<td>3</td>
<td>Focal (bilateral) cervical cord compression at C3-4 articulation</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Focal (bilateral) cervical cord compression at C5-6 articulation</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Focal (bilateral) cervical cord compression at C6-7 articulation</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Equine degenerative myeloneuropathy</td>
</tr>
<tr>
<td>Unilateral</td>
<td>1</td>
<td>Focal mainly unilateral ischaemic myelopathy: malacia and cavitation at level of C6-7 articulation</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Focal mainly unilateral cord compression by unilateral arthropathy of C6-7 diarthrodial joint, and bulging intervertebral disc</td>
</tr>
<tr>
<td>Inconclusive</td>
<td>1</td>
<td>Focal (bilateral) cord compression at C3-4 articulation</td>
</tr>
</tbody>
</table>
No lesion was detected in the cervical spinal cord or brain of the one non-ataxic horse which was autopsied; its slap test had been normal.

Discussion

The presence of a laryngeal adductory reflex has been demonstrated in normal horses by slapping the saddle region with the hand. The subjective evaluation of the test was overcome, to some extent, by the use of 2 or 3 independent observers. This also ensured that the endoscopic examination lasted longer, allowing some tense horses to relax. Repeat examinations were often of value and this was especially so in cases where the response was apparently abnormal.

The importance of noting the functional capabilities of each horse's larynx when interpreting the results of the slap test has been outlined. Although no such case occurred in this survey, operators should also be alert to the presence of any other pathological entities which could provide mechanical/anatomical reasons for an abnormal response to the slap test (eg. acquired or congenital deformities involving the larynx and neoplasia).

The laryngeal response to back-slapping is contralateral, hence there must be a cross-over point somewhere in the central nervous system. A study of the unilateral cord lesions found in 2 of the ataxic horses with unilateral responses throws some light on the location of the pathways involved. In both cases there was a normal left laryngeal adductory response to a slap on the right saddle patch but no response to a slap on the left. Both animals were shown to have predominantly right-sided cervical spinal cord lesions at the level of the C5-C7 articulation with both dorsal funiculi affected to about the same extent (Fig. 2). Thus it would appear that in each case the absence of movement of the right side of the larynx was caused by inability of the impulse to pass the lesions in the right side of the cord; the afferent impulse crossed over at the level of the thoracic cord segment on entry rather than ascending in the cord on the same side as the slap stimulus and crossing somewhere in the medulla (Fig. 1).

The precise pathways involved in the slap reflex are not known. The afferent arm of the reflex appeared to originate from the ribcage but it has not been possible to define the exact cranial or caudal limit. Slapping the neck, lateral abdominal wall or the lateral aspect of the thigh failed to stimulate a reflex in normal horses. Nor is it known what receptors are being stimulated by the slapping action or what modality is involved. No laryngeal response was observed when the saddle patch was stimulated with the point of a needle. The efferent arm of the reflex almost certainly involves the nucleus ambiguous in the medulla, the vagus and recurrent laryngeal nerves. It was noted that the slap reflex was often abolished in horses with laryngeal paralysis. However, 8 horses with some degree of laryngeal paralysis had a normal response to the slap test. In these horses the laryngeal paralysis would appear to have selectively affected the adductor more than the adductor muscles of the larynx. In this study it has not been possible to define the central relays and pathways involved in the slap reflex. From Fig 2 it would appear that the impulse may travel to the medulla in tract(s) in the lateral funiculus of the spinal cord. When cases involving medullary lesions can be examined clinically and afterwards at post mortem further light may be shed on the pathway of the reflex in the brain. It seems probable that a lesion in the medulla could also abolish the laryngeal reflex.

The ability of the cervical spinal cord to recover functionally from acute compressive cord lesions was demonstrated by one case in this study. An Anglo-Arab yearling with a traumatic fourth cervical vertebral fracture became acutely incoordi­nated with no response to back-slapping. When examined 3 months later the horse was clinically normal and had a normal slap response. In another case a 2-year-old crossbred gelding had obvious hindlimb ataxia, an abnormal slap test response and equivocal radiographic signs of vertebral canal stenosis. The horse was re-examined a year later when the ataxia had disappeared and the response to the slap test was normal, although the radiographic findings were unchanged.

The slap test was useful in detecting laryngeal adductor muscle paralysis but its role in the evaluation of cervical spinal cord disease was of much greater practical importance. It was found that the test can provide valuable confirmatory evidence of the presence of a lesion in the cervical spinal cord in horses exhibiting obvious forelimb incoordination. In those cases where only hindlimb ataxia was present it was of value in differentiating cervical from thoracolumbar spinal cord damage. The usefulness of the reflex in assessing medullary or thoracic spinal cord damage has yet to be investigated; no suitable cases were examined in this study. It is noteworthy that in this series of cases the slap test was found to be considerably more reliable as a diagnostic aid than radiography.
Acknowledgements

It is a pleasure to acknowledge the skilled assistance of Mr Bill Foster and Miss Janet Butler. The cost of the investigations was supported by the Horserace Betting Levy Board and Mr T. R. C. Greet was in receipt of a Horserace Betting Levy Board Training Scholarship.

Reference


Résumé

Cet article décrit les modalités d’observation et les conséquences pratiques d’un réflexe laryngé d’adduction chez 30 chevaux atactiques et 64 chevaux non atactiques. Le réflexe était déclenché en frappant du plat de la main, la région sous la selle immédiatement en arrière du garrot. Chez des chevaux normaux, il en résulte un mouvement d’adduction brutal du cartilage arytenoïde opposé, tel qu’on l’observe par endoscopie. La suppression de ce réflexe fut observée dans 3 cas :

1. — Par non transmission des stimulus chez les animaux atteints d’une affection de la moelle épinière telle que les voies de transmission allant de la région thoracique antérieure à la moelle épinière, se trouvaient interrompues.

2. — L’interruption de l’influx nerveux efférent était évidente lors de lésion du nerf récurrent laryngé empêchant l’adduction normale.

3 — Le réflexe était supprimé chez les chevaux tendus ou effrayés, en raison d’une éventuelle interférence des centres supérieurs.

Le réflexe d’adduction laryngé est ici considéré comme pouvant aider en diagnostic et au pronostic des ataxies et des lésions de la moelle épinière chez le cheval.

Zusammenfassung

Dieser Artikel beschreibt die Interpretation und die praktische Bedeutung des laryngealen Adduktionenreflexes bei 30 ataktischen und 64 nicht-ataktischen Pferden. Der Reflex wurde ausgelöst durch einen Schlag auf die Sattellage knapp hinter dem Widerrist. Bei normalen Pferden bewirkte dieser Schlag eine flatternde, adduktorische Bewegung des contralateralen Arytheneoids, die endoskopisch zu sehen war. Der Reflex spielte nicht, wenn einer der folgenden Zustände vorhanden war:

1. Unterbrechung des afferenten Impulses trat bei Pferden auf mit signifikanten Rückenmarksveränderungen zwischen der cranialen Brustregion und der Medulla.

2. Eine Unterbrechung des efferenten Impulses manifestierte sich bei Schäden am n.recurrens, die eine normale Adduktion verunmöglichen.

3. Der Reflex spielte nicht bei "gespannten" oder verängstigten Tieren, wohl wegen einer Interferenz durch höhere Zentren.

Der adduktorische Larynxreflex wird als nützliche diagnostische und prognostische Hilfe zur Beurteilung von Ataxien und Rückenmarksveränderungen des Pferdes angesehen.

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Use of iohexol for myelography in the horse

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Summary
The use of iohexol as a contrast agent for myelography is reported in two groups of horses. Group 1 (n = 6) were used only for myelography and to assess the clinical and pathological effects of intrathecal administration of iohexol. A volume of 20 ml at a concentration of 300 or 350 mg iodine/ml gave satisfactory myelographic detail with no serious clinical or neurological side effects. Only a minimal inflammatory response could be demonstrated in cerebrospinal fluid at four and 14 days after injection. At post mortem examination 14 days after myelography there was no evidence of meningitis or any other pathological change detected. Group 2 (n = 19) comprised a series of clinical cases of suspected cervical vertebral malformation. The only untoward sequelae recorded involved two horses in which iohexol was diluted with sterile water prior in intrathecal injection. A progressive necrotising meningitis developed in both cases which necessitated euthanasia. It was concluded that the major advantages of iohexol for use in the horse were its diagnostic quality, safety and low cost.

Introduction
Spinal cord damage associated with ataxia (e.g., wobbler syndrome) is an important problem in young horses (Mayhew et al. 1978). This is often caused by cervical cord compression which can only be accurately diagnosed by radiography which includes myelography (Rantanen, Gavin, Barbee and Sande 1981). The water soluble non-ionic contrast agent metrizamide (Omnipaque; Winthrop) has been extensively used for myelography in the USA (Stowater, Kneller and Frechlich 1978; Beech 1979; Rantanen et al. 1981). However, a number of complications, such as prolonged recoveries, muscle fasciculations, involuntary movements and anaphylactic shock have been described (Beech 1979; Nyland et al. 1980; Conrad 1984). Another drawback in the use of medical grade metrizamide is its high cost. In order to reduce this cost some workers have advocated using analytical grade metrizamide (Rantanen et al. 1981). This is made up into solution using a buffered diluent immediately prior to administration and injected via 0.2 μm milipore filter.

The introduction of iohexol (Omnipaque; Winthrop), a triiodinated, non-ionic, water soluble contrast medium, has been reported in man to have less side effects and to be safer than metrizamide (Jindgren 1980; Bryan et al. 1982). The cost of iohexol in Australia is approximately one eighth that of medical grade metrizamide.

This paper reports on the results of iohexol in a safety trial in six horses and as a contrast agent for equine myelography in a further 19 clinical cases.

Materials and methods

Animals
A total of 25 horses were used. Group 1 comprised five Thoroughbreds and one hack whose ages ranged from one-and-a-half to six years and body weights from 340 kg to 540 kg. These animals were considered to be clinically normal and showed no abnormal neurological signs. Group 2 consisted of 19 horses referred to the Veterinary Clinical Centre for evaluation of suspected cervical vertebral malformation (i.e., wobbler syndrome). This group consisted of 17 Thoroughbreds (eight months to six years old); one Warmblood gelding (18 months) and one Clydesdale cross mare (15 years). A thorough physical and neurological examination (Mayhew and McKay 1982) was performed prior to myelography.

Myelographic technique

General anaesthesia was induced with glyceryl guaiacolate (Grafen; Parnell Laboratories) and a bolus of thiopentone sodium (Pentothal; CEVA Chemicals Australia) without any premedication. Anaesthesia was maintained with halothane and oxygen via a semi-closed circuit anaesthetic machine (Penmedic; New Zealand Technikon Industries).

The animal was positioned in right lateral recumbency with the head elevated by placing an inclined board under the head and neck (Rantanen et al. 1981). The region over the poll was then clipped and surgically prepared before cysternal puncture through the atlanto-occipital space (de Lahunta 1975). This was performed using a 19 gauge 8.75 cm spinal tap needle with a stylet. A volume of 20 ml of cerebrospinal fluid (CSF) was withdrawn before slow injection of iohexol. An aliquot of CSF was submitted for clinical pathological and cytological examinations. These included total leucocyte and differential counts, and determination of total protein and creatine kinase.

Group 1 horses were given 20 ml of iohexol at a concentration of 300 mg iodine/ml (Omnipaque 300) or 350 mg iodine/ml (Omnipaque 350). This volume was chosen empirically and found to give satisfactory results. No differences in radiographic quality of the myelograms were noted between the two concentrations and no other volume was subsequently used.

Group 2 horses were given the same total dose of iohexol. In the first two animals the iohexol (350 mg iodine/ml) was diluted with sterile water to a volume of 50 ml just before administration, after the withdrawal of 50 ml of CSF. In all...
the other horses a volume of 20 ml undiluted 350 mg iodine/ml was given.

The head was kept elevated for 4 mins before replacing it in lateral recumbency for radiography in neutral, flexed and hyperextended positions (Rantanen et al 1981).

Radiography

The equipment used was a Toshiba Model KXO-1250 (150A), Tokyo Shibaura Electric Company, Japan and myelograms were produced after the short scale technique of Rantanen et al (1981). Typical exposure factors for a 500 kg horse varied from 58 kVp: 500 mAs: 0.25 sec for the cranial cervical region to 82 kVp: 500 mAs: 0.4 sec for the caudal cervical area using a rare-earth screen film system (Lanex regular; Kodak) and a stationary 6:1, 105 lines/inch parallel cross-hatched grid at a focus to film distance of 150 cm.

The radiographic routine was to take survey films centred on the third (C3) and fifth (C5) cervical vertebral bodies. Then the contrast agent was administered and the previous radiographs repeated, as well as flexed views centred on C3 and C4 and a hyperextended view centred on C4 (Rantanen et al 1981).

Follow-up examinations

The horses were recovered in a paddock stall and were monitored daily over the following 14 days for any untoward clinical and neurological effects.

On Day 4 after the myelogram had been performed all six horses in Group 1 were given a short anaesthetic using a mixture of thiopentone/glycerol guaiacolate given intravenously and a second CSF sample was collected for analysis. Between Days 10 and 14 all six horses were euthanased and a final CSF sample collected immediately before a detailed post mortem examination. The brains, spinal cords and trigeminal ganglia were removed and fixed in 10 per cent buffered formalin. Selected sections were removed, paraffin embedded, sectioned at 6 μm and stained with haematoxalin and eosin, and placed for light microscopic examination.

Results

Group 1

All six horses recovered uneventfully after the myelographic procedure and did not show evidence of muscle fasciculations or head tremors. Two out of the six appeared slightly depressed for 36 to 48 hr.

The CSF analysis before myelography was compared with that taken four days later and at the time of euthanasia (Table 1). In all cases the fluid was clear and colourless. There were slight increases in the white cell count and total protein after the injection of the iohexol. Values for both these parameters had decreased at the time of autopsy. The creatine kinase levels at all times were below 12 IU/litre. At post mortem

TABLE 1: Results of clinical pathological investigations of CSF from horses in Group 1 before and after administration of iohexol for myelographic examination

<table>
<thead>
<tr>
<th>Variable</th>
<th>0</th>
<th>4</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>White cell count (X10⁶/litre)</td>
<td>5 (1.15)*</td>
<td>25 (2.5.40)</td>
<td>7 (0.25)</td>
</tr>
<tr>
<td>Total protein (g/litre)</td>
<td>60 (35.86)</td>
<td>85 (60.120)</td>
<td>70 (58.94)</td>
</tr>
<tr>
<td>Creatine kinase (IU/litre)</td>
<td>4 (0.7)</td>
<td>6 (0.9)</td>
<td>4 (0.5)</td>
</tr>
</tbody>
</table>

*Range

Fig. 1. Myelogram of mid-cervical region (C3 to C7) of two-year-old Thoroughbred filly (415 kg) in the neutral position after injection of 20 ml iohexol (Humphrey 350).

The only serious clinical effects of iohexol observed were seen in the two horses in which the iohexol was diluted to 50 ml with sterile water before intrathecal injection. Radiographic quality was satisfactory and both animals recovered normally from anaelesia. However, three days after myelography they both had obvious cervical stiffness and were observed to guard their necks when approached. One horse became recumbent 16
h later and developed signs of opisthotonus and progressive central nervous system deterioration, and required euthanasia. The other horse showed a more slowly developing neurological syndrome. On Day 4 CSF was turbid, xanthochromic, had a white cell count of 350 × 10^6/litre, a total protein of 165 g/litre and a creatinine kinase level of 148 in/litre. It was treated intensively with non-steroidal anti-inflammatory drugs and antibiotics, but had to be euthanased eight days after myelography.

At post mortem both horses had a severe meningitis characterised by the infiltration of leptomeninges and nerve roots by neutrophils, with many macrophages which had phagocytosed erythrocytes, some lymphocytes and fibrin exudation (Figs 4 and 5). The inflammatory changes extended the length of the spinal cord and involved the brain. A diagnosis of acute severe haemorrhagic necrotising leptomeningitis was made. Bacteriological culture failed to yield any aerobical micro-organisms.

The myelograms of the horses in Group 2 demonstrated the site of cervical vertebral malformation to be either a static (Fig 6) or a dynamic compression (Fig 7). There were 10 dynamic and nine static lesions demonstrated in three horses lesions were demonstrated at more than one site. Post mortem examination of eight horses confirmed the myelographic findings of spinal cord compression. The anatomical distribution of the myelographic lesions is presented in Fig 8. Two cases failed to exhibit any compressive lesions, one of which was of an occipitocervical axial malformation in a two-year-old Thoroughbred which showed no sign of vertebral stenosis (Fig 9).

Discussion

Cervical vertebral malformation (cervical stenotic myelopathy and cervical vertebral stenosis), trauma, equine protozoal myelopathy, equine degenerative myelencephalopathy and equine herpesvirus myelitis are the most frequently reported causes of pelvic and thoracic limb ataxia (Reed et al 1981). Differentiation of these diseases is based on careful clinical examination (Mayhew et al 1978), the response to the slap test (Greet, Jeffcott, Whitwell and Cook 1980), radiography and myelography (Rantanen et al 1981), paired serum samples for herpesvirus serology (Greenwood and Simson 1980) and post mortem examination (Whitwell 1980).

Cervical vertebral malformation is reported to account for 42 out of 100 horses presented for ataxia at Washington State University (Reed et al 1981). A safe and diagnostic myelographic technique is essential for the accurate diagnosis, particularly since a practical method for surgical correction of the dynamic cervical vertebral malformation has now been described (Wagner et al 1979).

The contrast agent metrizamide has been most extensively used for myelography in the horse at a concentration of 180 mg/iodine/ml. Recently iopamidol (Nipamid; Merck) has also been reported as a safe contrast agent for myelography in horses (May et al 1986). Iohexol is another water soluble non-ionic iotonic contrast medium which has been developed by Nyegaard in Norway. Laboratory investigations and clinical trials have indicated that iohexol appears to be superior to metrizamide for intrathecal injection (Lindgren 1980; Bryan et al 1982). Double blind clinical trials on the comparison between iohexol and metrizamide for human lumbar myelography would indicate that iohexol is significantly less morbid and is a superior contrast agent to metrizamide (Gabrielsson et al 1984).

Although two different concentrations of iohexol were used...
in Group 1 horses, there did not appear to be any difference in the quality of the radiographs obtained. However, in two horses in Group 2 in which iodexol (250 mg iodine/ml) was diluted with sterile water serious complications were experienced. These two animals were the first in this series to be given iodexol for myelography. The reason the dose was diluted in this way was to produce a similar concentration of iodine (175 mg iodine/ml) as had previously been described with metrizamide (Rantanan et al 1981). It was assumed that the effect of diluting the iodexol with sterile water produced a chemical reaction which led to a severe necrotising meningitis in these two horses. It appears therefore that dilution of iodexol is contraindicated. However, the results using undiluted indicated it to be a safe and reliable contrast agent for clinical use.

Acknowledgements

The authors thank Josie Wilson, Cheryl Evans and Frank Oddi for expert technical assistance and the veterinary practitioners who referred cases to the Veterinary Clinical Centre for myelography.

References


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SECTION 2.3 CLINICAL AND EXPERIMENTAL CONDITIONS


Statement on Share of Work:

Paper 13 - I carried out all the work for the first paper, Jeffcott (1980), which formed a major part of my Fellowship thesis for the Royal College of Veterinary Surgeons. This paper won the "Open Award" for best paper published in Equine Veterinary Journal in 1982.

Paper 14 - Katherine Whitwell and I played approximately equal roles in this project, although I prepared the manuscript for publication.

Paper 15 - This paper was jointly carried out with colleagues in the Locomotion Laboratory of the Swedish University of Agricultural Sciences, Uppsala, Sweden. I planned and oversaw the whole project and prepared the manuscript for publication.
Disorders of the thoracolumbar spine of the horse — a survey of 443 cases

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Summary
The survey comprised 443 horses, referred to the clinical department of the Equine Research Station, with a history of a thoracolumbar (TL) complaint. A wide range of lesions were capable of producing back problems and more than one condition or site of injury was found in 75 animals (17 per cent). There were 103 horses (19.7 per cent) with no evidence of damage to the TL spine or its associated structures. In 66 of these cases, clinical signs were attributed to a variety of hindlimb lamenesses and, in 37, no specific diagnosis could be made.

Soft tissue injury was diagnosed in 203 cases (38.5 per cent), the most frequent sites being the longissimus dorsi muscles and/or the supraspinous ligament in the caudal withers and cranial lumbar regions. Chronic sacroiliac strain or mild sacroiliac instability was also a frequent cause of low back trouble in competitive horses. Other conditions included tying-up, subluxation of a lumbar vertebra and neuritis of the cauda equina.

Fifteen cases (2.9 per cent) of vertebral malformations were found including scoliosis, lordosis and kyphosis. Vertebral lesions accounted for 202 (38.6 per cent) of the diagnoses. The most common condition was associated with crowding and overriding of the dorsal spinous processes in the caudal thoracic and cranial lumbar regions. This was most often diagnosed in competitive jumping horses (173 cases) and caused a loss of suppleness and spinal flexibility resulting in lowered performance and bouts of back pain. There was a comparatively low incidence of fractures (13 cases) and degenerative spondylosis (14 cases).

Introduction
The literature on thoracolumbar (TL) disorders has recently been reviewed (Jeffcott 1979a). Previous papers have described a method for the clinical examination of horses with a potential back problem (Jeffcott 1975 and 1979b), the technique for routine radiography (Jeffcott 1979c) and the normal radiographic anatomy of the equine TL spine (Jeffcott 1979d). This paper reports on the data analysis of 443 horses with suspected TL injury referred, for clinical and radiological investigation, to the clinical department of the Equine Research Station (ERS) between 1972 and 1977 inclusive.

Case material
The details of age, sex, type, use and body weight (bwt) of the 443 horses included in the survey are shown in Fig 1. In each case, a full case history was obtained from the owner or trainer and the attending veterinarian and a physical examination at rest and during exercise was performed. Serum enzymes, including aminoaspartate transferase (AST) and creatinine kinase (CK) were measured. The TL spine was subjected to radiography in the standing position for the withers and back (ie, T1 to L4) and in dorsal recumbency under general anaesthesia for the spine caudal to the fourth lumbar vertebra, to enable the dorsoventral plane to be radiographed.
TABLE 1: Analysis of the diagnoses made in 443 horses referred with a suspected back injury

<table>
<thead>
<tr>
<th>Category</th>
<th>No</th>
<th>%</th>
<th>Specific diagnosis</th>
<th>No</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft tissue injuries</td>
<td>203</td>
<td>38.8</td>
<td>Muscular damage/ligamentous strain</td>
<td>117</td>
<td>22.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tying-up (soft, myositis)</td>
<td>7</td>
<td>1.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sacroiliac strain</td>
<td>69</td>
<td>13.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Displaced lumbar vertebra</td>
<td>1</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Neuritis of the cauda equina</td>
<td>3</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sublumbar or spinal abscess</td>
<td>2</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Surgical complications</td>
<td>4</td>
<td>0.76</td>
</tr>
<tr>
<td>Thoraco-lumbar lesion</td>
<td>453</td>
<td>100</td>
<td>No diagnosis made</td>
<td>37</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Conformational defects  15 2.9

| Vertebral lesions      | 202| 38.6| Scoliosis                          | 1  | 0.19 |
|                        |    |    | Lordosis                           | 1  | 0.21 |
|                        |    |    | Other                               | 3  | 0.63 |

miscellaneous conditions  66 12.6

| Non-thoraco-lumbar lesion | 66 | 12.6| Stifle and hock lameness           | 20 | 3.82 |
|                           |    |    | Lower limb lameness                | 11 | 2.10 |
|                           |    |    | Temperamental involvement          | 24 | 4.59 |
|                           |    |    | Dental and other miscellaneous conditions | 11 | 2.10 |
|                           |    |    | No diagnosis made                  | 37 | 7.07 |
| Total                    | 523| 100|                                      |    |     |

Results

The diagnoses (Table 1) made in the survey were categorised as follows.

- (1) Soft tissue injuries.
- (2) Conformational defects.
- (3) Vertebral lesions.
- (4) Miscellaneous conditions.
- (5) Undiagnosed.

Two conditions were diagnosed in 70 cases and 5 horses showed evidence of 3 different lesions (Table 2). There were, therefore, a greater number (80) of specific diagnoses than animals referred for investigation.

SOFT TISSUE INJURIES

There were 203 cases diagnosed as soft tissue injuries (Table 1).

TABLE 2: Details of the multiple diagnoses made on 75 horses referred with a back problem

<table>
<thead>
<tr>
<th>Additional conditions found</th>
<th>Muscular/ligamentous injury</th>
<th>Sacroiliac strain</th>
<th>Overriding dorsal spinous processes</th>
<th>Hind limb or lower limb lameness</th>
<th>Temperamental involvement</th>
<th>Other conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscular/ligamentous injury</td>
<td>—</td>
<td>10</td>
<td>2</td>
<td>18</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Conformational defects</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Sacroiliac strain</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Fractures</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Spondylosis</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Overriding dorsal spinous processes</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Hindlimb or lower limb lameness</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Temperamental involvement</td>
<td>—</td>
<td>—</td>
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</tr>
</tbody>
</table>

MUSCLE STRAIN

Muscular injury, principally involving the longissimus dorsi complex, usually occurred during ridden exercise, a slip, fall or poorly executed jump causing uni- or bilateral strain. All types and ages of horses were affected and the damage was at a fairly advanced stage by the time of referral.

Clinical signs

Consistent findings were acute onset, poor performance and a change in temperament. The back was kept rigid and the hindlimb gait noticeably restricted. There was marked reduction in the flexibility of the TL spine and, in some cases, lateral curvature was observed due to increased muscle tone or spasm of one or other longissimus dorsi muscle (ie, spastic scoliosis). Initially, some slight swelling with heat might be detected and in the acute stage some increase in the
blood levels of the muscle enzymes after exercise occurred, although changes were small and transient (ie, 2 or 3 fold increase in resting levels).

**EXERTIONAL MYOPATHY (TYING-UP)**

There were no horses referred which exhibited the classic clinical picture of azoturia but 7 animals suffered from the less severe and somewhat atypical form of tying-up. All were in good or excellent bodily condition and showed stiffness and evidence of pain in their backs with restriction of the hindlimb gait after varying amounts of exercise. The intensity of the clinical signs was usually related to the workload. The signs were frequently recurrent and the diagnosis was confirmed from the history, clinical signs, the negative results on radiography and elevated serum muscle enzymes after exercise.

**LIGAMENTOUS DAMAGE**

The supraspinous ligament was a common site of injury occurring most often in younger subjects with long, flexible TL spines. This structure runs down the middle of the back and is firmly attached to the summits of the thoracic and lumbar dorsal spinous processes. It includes the multiple tendon insertions from various parts of the longissimus dorsi and is, therefore, subject to strain in the same way as the muscles. Some degree of muscle strain was, therefore, probably also involved. Strain probably constituted the “rick” or “chink in the chine” referred to in the old veterinary textbooks (Lupton 1876).

**Clinical signs**

Clinical signs were essentially similar to muscle strain but usually persisted for longer and the prognosis was less favourable. The cranial lumbar region was the most common site of injury and usually some thickening occurred in the midline over one or more summits. Lateral flexibility, in one or both directions, of the TL spine was reduced. Pain on palpation was a common sign even in the more longstanding cases. Radiological examination usually revealed the soft tissue thickening and, occasionally, a focal increase of radiodensity in the ligament. Detached flakes from the spinous summits were readily demonstrated and slight periosteal roughening on the dorsal surfaces was common. In one case a biopsy taken from the ligament showed diffuse mild degenerative change and fibrosis on histological examination.

The case of a 2-year-old Thoroughbred colt is cited as an example. This horse had damaged its back coming out of the starting gate too rapidly and had torn the insertion of the supraspinous ligament from the top of the dorsal spines in the caudal withers. A painful swollen area was found in the mid-thoracic region and a flake of bone had become detached from the summit of T6. The colt’s performance was severely affected and its hindlimb action became very restricted. After 6

---

**Fig 2.** Sacroiliac strain (SIS). This figure illustrates a common type of conformation for this condition; a diagrammatic representation of a normal and asymmetric pelvis and the caudal views of 6 horses with differing causes of asymmetry of the quarters.

- [Image of TB gelding with SIS]
- [Diagram of normal and sacroiliac strain]
- [Images of left and right SIS, fractured ilium, and tuber coxae]
- [Description of musculoskeletal injuries and asymmetries]
months test it improved markedly; the flake of bone was just discernible; radiographically but no local periosteal reaction was evident.

In general, the prognosis for strain or injury to the supraspinous ligament was considered guarded, largely because of the likelihood of recurrence. A number of horses recovered but subsequently developed signs of "cold back", which did not affect their performance.

CHRONIC SACROILIAC STRAIN

These cases usually presented with a history of severe pain in the pelvic or sacroiliac region associated with marked hindlimb lameness. The subacute and chronic strain were often presented as a back problem and the condition was particularly prevalent in large animals (162.6 to 172.7 cm) with long backs and weak-looking quarters (Fig 2). A fall or similar incident was often reported although signs were not always recognised for some time afterwards. The animal's performance was affected, particularly at slower paces or during dressage. An intermittent, sometimes shifting, hindlimb lameness associated with stiffness and rigidity of the spine in one direction was reported.

Clinical signs

The tail was sometimes held across the midline usually to the affected side. Most cases showed some degree of asymmetry of the hindquarters due to a malalignment or apparent tilting of the pelvis in addition to some muscle wastage on one quarter (Fig 2).

In the acute stages pain could be evinced by applying pressure to the midline just in front of the tuber sacrale, by pressing down over the tuber coxae or by flexing the affected leg. Once the condition was chronic, no pain in the lumbo-sacral region could be elicited and hyperflexion of the hindlimbs was not resented. However, there was often a reduction in flexibility of the TL spine with resentment or reluctance to dorsiflex (ie, dip the back).

At exercise there was often some stiffness in the back with dragging of one or both toes and a tendency to "plait" (ie, the foot of the affected limb swings inward in the anterior phase of the stride and is placed almost in front of the opposite hindfoot).

Few cases showed obvious hindlimb lameness, but dropping of the affected quarter was sometimes noted. A flexion (spavin) test rarely produced any effect on hindlimb action. When ridden, cases showed evidence of stiffness of the hindlimb action with an apparent lack of impulsion from the quarters. In many longstanding cases, jumping was not seriously impaired and continued exercise did not seem to exacerbate the clinical signs. Many of these animals responded temporarily to administration of therapeutic doses of an anti-inflammatory drug, such as phenylbutazone.

There were few radiographic features detectable apart from evidence of increased joint space of the sacroiliac articulation and slight rotation of the pelvis or sacrum. In one case showing right hindlimb lameness there were signs of some early osteoarthritic change at the caudal edge of the joint (Fig 3).

Post mortem material

Only 2 cases became available for post mortem examination but both showed similar findings; there was no obvious stretching of the sacroiliac ligaments but noticeable new bone proliferation was present at the caudal aspect of the sacral wing (Fig 4). This large spur of new bone was covered in cartilage and articulated with a similar, but smaller, spur on the opposing auricular surface of the ilium. The sacrolumbar articulation, hip joints and remainder of the caudal vertebral column showed no remarkable pathological abnormality.

UNCLASSIFIED CONDITIONS

One case showed evidence of vertebral displacement or subluxation unaccompanied by vertebral fracture or deformity. This was a 13-year-old Thoroughbred broodmare exhibiting signs similar to sacroiliac strain. Some lateral displacement of the fifth lumbar vertebra was demonstrated radiographically (Fig 5) and the mare showed gradual improvement during the 8 months following referral with no treatment being administered.
Two cases of neuritis of the cauda equina were presented and showed progressive perineal paralysis and wastage of the quarters with negative radiographical results. The perineum was desmataised and there was atrophy of the gluteal muscles. At post mortem examination the spinal cord and nerve roots were found to be thickened, haemorrhagic and oedematous. Histologically there was severe inflammation with demyelination, degeneration and cellular infiltration, followed by proliferation of the perineurium and local fibrosis. A third case was suspected but not confirmed in a 5-year-old Thoroughbred with a history of making a bad jump in a hurdle race followed by a sudden onset of perineal paralysis which improved over the next month only to recur after a bout of colic. No radiological evidence of damage to the sacrum was found, the paralysis again disappeared and the animal made an apparently complete recovery.

CONFORMATIONAL DEFECTS

The 15 cases referred with conformational defects showed evidence of scoliosis, lordosis or kyphosis (Fig 6) and the details of the clinical findings are summarised in Table 3.

Scoliosis

Scoliosis (lateral curvature of the spine) was not always obvious visually as is illustrated in the case of a Thoroughbred foal in which the diagnosis was made on an S-shaped bend of the caudal thoracic vertebral column seen on a ventrodorsal radiograph (Fig 7). This foal showed a rather stilted hindlimb action with inflexibility of the back at exercise in the paddock. A congenital cystic condition of the maxilla was also found and the foal was destroyed at age 6 months because its prospects as a racehorse were severely limited.

Another case showing only a mild degree of scoliosis was an 8-month-old Arab colt with synostosis (congenital fusion of the vertebral bodies) of 2 lumbar vertebrae (L2 and L3). These abnormalities were accompanied by changes in the neural arch and spinal processes (Fig 8). The colt showed a poor straddling hindlimb gait with obvious inflexibility of the back. A reduction in general manoeuvrability was observed and the colt had difficulty in rising from the recumbent position. The degree of scoliosis and of the lumbar spine kyphosis was considered to be secondary to the synostosis.

Lordosis

Severe lordosis (ventral curvature of the spine—dipped or sway-back) of the mid-thoracic region was observed in a 6-month-old Thoroughbred filly with a clinical picture similar to that described for scoliosis. The central curvature in the mid-back was so marked that obliteration of the interspinous spaces between the dorsal spines had occurred and secondary overriding lesions were already present. The animal was destroyed and post mortem examination confirmed the changes seen radiographically.

Six adult horses had demonstrable lordosis of the mid- to dorsal thoracic region. It was not usually clear whether these deformities were congenital or acquired but they were much less marked than that seen in the foal described above. They were generally associated with bouts of soft tissue damage to the back or overall poor performance at ridden and jumping exercise. In most the radiological changes were slight, but in the more severe types some crowding and overriding of the dorsal spines occurred. The ventral curvature of the TL spine seemed to predispose these animals to back trouble,
Normal Conformation

Congenital Lordosis

Congenital Scoliosis

Kyphosis in a Yearling

Lordosis in an adult

Fig 6. Examples of conformational defects of the thoracolumbar spine

presumably by the extra stress put on the epaxial structures of the vertebral column.

**Kyphosis**

Kyphosis (dorsal curvature of the spine—routh back) was most frequently seen in young animals exhibiting varying degrees of bilateral stifle damage (e.g., epiphysitis or osteochondrosis dissecans). Improvement only occurred if the underlying cause was resolved.

**VERTEBRAL LESIONS**

Two hundred and two cases of vertebral lesions were found (Table 1).

**VERTEBRAL FRACTURE**

The clinical details of 13 cases of fracture of the vertebral column (from T1 to CyI) are shown in Table 4.

Fractures of the thoracic dorsal spinous processes were readily diagnosed as there was often a history of a traumatic incident with local pain, heat and swelling. Multiple fractures of the spinous summits in the withers resulted from horses rearing and falling over backwards. The tips of the summits were fractured and displaced laterally but once the pain and local reaction had subsided a satisfactory recovery ensued. A residual depression on the withers required a special saddle to be made. In 2 cases there was an incomplete fracture of an individual spinous process. They both had back pain and the diagnosis was confirmed by radiography. After a period of rest they made an uneventful recovery.

**DEGENERATIVE (OSSIFYING) SPONDYLOSIS**

Radiological evidence of spondylosis was usually associated with serious clinical consequences and in only 3 cases was it detected as an incidental finding; in a 5-year-old mare with suspected tuberculosis of the cervical spine, a 7-year-old mare with Marie's disease (hypertrophic pulmonary osteoarthropathy) and a 16-year-old mare with chronic forelimb lameness.

Spondylosis was seen in the more mature animals (6 to 20 years) and there was a much higher proportion (64 per cent) of mares affected than in other TL disorders (Table 5). In some of the cases there was a history of a serious fall, but in others the early signs of back pain were diagnosed as exertional myopathy (tying-up).

**Clinical signs**

Palpation of the spine was strongly resented and there was reduced spinal flexibility. Ventroflexion and dorsiflexion of the back sometimes produced a violent reaction with kicking and efforts to prevent any palpation or manipulation being repeated. There was usually no difficulty taking the weight of a rider, but transient resentment to tightening the girth and on mounting were sometimes noticed. At exercise marked rigidity of the spine was a feature which was associated with poor performance at fast paces and during jumping. The clinical signs often remained static for long periods and in one case, an 8-year-old mare, no significant improvement occurred for 4 years.
**TABLE 3: Clinical details of 15 cases showing defects of conformation**

<table>
<thead>
<tr>
<th>No</th>
<th>Type</th>
<th>Use</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TB</td>
<td>At stud</td>
<td>S</td>
<td>6m</td>
<td>Congenital scoliosis of caudal thoracic spine; colt was destroyed</td>
</tr>
<tr>
<td>2</td>
<td>Arab</td>
<td>At stud</td>
<td>S</td>
<td>8m</td>
<td>Congenital synostosis (L7-L8) with associated scoliosis and kyphosis of lumbar spine</td>
</tr>
<tr>
<td>3</td>
<td>TB</td>
<td>At stud</td>
<td>M</td>
<td>6m</td>
<td>Congenital lordosis of mid and caudal thoracic spine associated with overriding dorsal spinous processes; filly was destroyed</td>
</tr>
<tr>
<td>4</td>
<td>TB</td>
<td>Hurdler</td>
<td>G</td>
<td>5</td>
<td>Lordosis of mid thoracic spine with associated kyphosis; showed poor performance at speed and over jumps</td>
</tr>
<tr>
<td>5</td>
<td>TB</td>
<td>Hurdler</td>
<td>G</td>
<td>6</td>
<td>Lordosis of mid thoracic spine associated with overriding dorsal spinous processes; gelding showed periodic back trouble</td>
</tr>
<tr>
<td>6</td>
<td>TB</td>
<td>Chaser</td>
<td>G</td>
<td>6</td>
<td>Mild lordosis associated with intermittent poor performance</td>
</tr>
<tr>
<td>7</td>
<td>Hunter</td>
<td>Showjumper</td>
<td>G</td>
<td>11</td>
<td>Mild lordosis associated with damage to the supraspinous ligament of the mid back</td>
</tr>
<tr>
<td>8</td>
<td>TB</td>
<td>Hurdler</td>
<td>M</td>
<td>5</td>
<td>Mild lordosis associated with soft tissue damage to the back</td>
</tr>
<tr>
<td>9</td>
<td>TBX (bred)</td>
<td>Eventer</td>
<td>G</td>
<td>11</td>
<td>Mild lordosis associated with soft tissue damage to the back</td>
</tr>
<tr>
<td>10</td>
<td>TB</td>
<td>Flatracer</td>
<td>S</td>
<td>2</td>
<td>Kyphosis noted without obvious clinical signs</td>
</tr>
<tr>
<td>11</td>
<td>TB</td>
<td>At stud</td>
<td>S</td>
<td>1</td>
<td>Kyphosis noted without obvious clinical signs; improved without treatment</td>
</tr>
<tr>
<td>12</td>
<td>Anglo Arab</td>
<td>At stud</td>
<td>S</td>
<td>1</td>
<td>Kyphosis associated with severe osteochondrosis dissecans of both stifles; colt was destroyed</td>
</tr>
<tr>
<td>13</td>
<td>TB</td>
<td>Flatracer</td>
<td>G</td>
<td>3</td>
<td>Kyphosis associated with soft tissue damage to the stifle</td>
</tr>
<tr>
<td>14</td>
<td>TB</td>
<td>Hack</td>
<td>G</td>
<td>4</td>
<td>Poor performance possibly associated with animal’s general poor conformation</td>
</tr>
<tr>
<td>15</td>
<td>TB</td>
<td>Eventer</td>
<td>M</td>
<td>6</td>
<td>Poor conformation of back and quarters resulting in strain of the supraspinous ligament</td>
</tr>
</tbody>
</table>

TB—Thoroughbred; TBX—part-bred; S—colt or stallion; M—filly or mare; G—gelding.
TABLE 4: Clinical details of 13 cases of fracture of the vertebral column

<table>
<thead>
<tr>
<th>No</th>
<th>Type Use</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Site</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TB/Connemara Hack/hunting</td>
<td>G</td>
<td>7</td>
<td>T₁</td>
<td>History of stiff neck and difficulty turning and jumping; satisfactory clinical improvement</td>
</tr>
<tr>
<td>2</td>
<td>Pony Showjumping</td>
<td>G</td>
<td>7</td>
<td>T₆-T₁₀</td>
<td>History of poor jumping performance and lameness; no recent history of accident</td>
</tr>
<tr>
<td>3</td>
<td>TBX (¼-bred) Hack</td>
<td>M</td>
<td>4</td>
<td>T₆-T₁₀</td>
<td>Reared and fell over backwards going into horse box; satisfactory clinical improvement</td>
</tr>
<tr>
<td>4</td>
<td>Anglo-Arab Show hack</td>
<td>M</td>
<td>7</td>
<td>T₆-T₁₀</td>
<td>Accident coming out of horse box, fell onto its back; satisfactory clinical improvement</td>
</tr>
<tr>
<td>5</td>
<td>TB Steeplechasing</td>
<td>G</td>
<td>3</td>
<td>T₆-T₁₀</td>
<td>Broke loose from lunge rein, reared up and fell on withers; satisfactory clinical improvement</td>
</tr>
<tr>
<td>6</td>
<td>TB Steeplechasing</td>
<td>G</td>
<td>10</td>
<td>T₆-T₁₀</td>
<td>Chronic fractures of withers; also had sacroiliac strain and some overriding dorsal spinous processes</td>
</tr>
<tr>
<td>7</td>
<td>TB Flat racing</td>
<td>S</td>
<td>2</td>
<td>T₈</td>
<td>Difficulty breaking in; tended to rein back and rear up; satisfactory clinical improvement</td>
</tr>
<tr>
<td>8</td>
<td>TB/pony Showjumping</td>
<td>G</td>
<td>6</td>
<td>T₉</td>
<td>Presented with back pain and poor jumping performance; satisfactory clinical improvement</td>
</tr>
</tbody>
</table>

Vertebral bodies

<table>
<thead>
<tr>
<th>No</th>
<th>Type Use</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Site(s) involved</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TB At stud</td>
<td>M</td>
<td>1½</td>
<td>T₁₂-T₁₄</td>
<td>Accident in paddock, became paraplegic immediately; was destroyed</td>
</tr>
<tr>
<td>2</td>
<td>TB Flat racing</td>
<td>M</td>
<td>3</td>
<td>T₁₆</td>
<td>Sudden onset of back pain and ataxia; rested 6 months and improved satisfactorily</td>
</tr>
<tr>
<td>3</td>
<td>TB Point-to-pointing</td>
<td>G</td>
<td>8</td>
<td>L₁</td>
<td>Pulled up after bed jump, in pain initially severely ataxic; was destroyed</td>
</tr>
<tr>
<td>4</td>
<td>TBX Hunting</td>
<td>M</td>
<td>8</td>
<td>L₂-L₄</td>
<td>Bed jump out hunting, walked 2 miles home then became paraplegic; was destroyed</td>
</tr>
<tr>
<td>5</td>
<td>TB Show hunter</td>
<td>G</td>
<td>7</td>
<td>C₇</td>
<td>Reared up and went over backwards, damaged base of tail; satisfactory clinical improvement</td>
</tr>
</tbody>
</table>

TB—Thoroughbred; TBX—part-bred; S—colt or stallion; M—filly or mare; G—gelding

Tube agglutination and Coomb's microglobulin tests showed that there was no relation in these 14 cases of spondylosis to Brucella abortus infection.

Radiological changes

Radiographically the lesions varied in site and extent but were concentrated at the mid-point of the back (Fig 9a). There were flange or spur-like osteophytes arising from the ventral and ventrolateral borders of the vertebral bodies (Fig 9b). At some sites the osteophytes fused to form a bridge of new bone across the intercentral joint space but at others the spurs did not fuse even after prolonged periods. They did not usually change in character or size for many months or years and clinical signs did not appear to improve until complete fusion had taken place.

The presence of a generalised osteoarthritis of the spine was seen only once in an aged pony mare which had been retired from active work for some years before it was destroyed. In this case there was also new bone deposition around the thoracic and lumbar intervertebral foramina with resultant narrowing of the lumen at some sites. These findings were not

TABLE 5: Clinical details of 14 cases of ossifying spondylosis

<table>
<thead>
<tr>
<th>No</th>
<th>Type Use</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Site(s) involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TBX Hack/hunting</td>
<td>Mare</td>
<td>9</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>2</td>
<td>TBX Showjumping</td>
<td>Mare</td>
<td>9</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>3</td>
<td>Anglo-Arab Hack/jumping</td>
<td>Mare</td>
<td>9</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>4</td>
<td>Pony Hack</td>
<td>Mare</td>
<td>20</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>5</td>
<td>TB Hunting</td>
<td>Mare</td>
<td>6</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>6</td>
<td>TB Eventing</td>
<td>Mare</td>
<td>8</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>7</td>
<td>TBX Showjumping</td>
<td>Mare</td>
<td>7</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>8</td>
<td>Pony Hack</td>
<td>Geld</td>
<td>10</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>9</td>
<td>Pony Hack</td>
<td>Mare</td>
<td>7</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>10</td>
<td>TBX Eventing</td>
<td>Geld</td>
<td>11</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>11</td>
<td>Anglo-Arab Showjumping</td>
<td>Geld</td>
<td>8</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>12</td>
<td>TBX Showjumping</td>
<td>Geld</td>
<td>7</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>13</td>
<td>TBX Eventing</td>
<td>Geld</td>
<td>10</td>
<td>T₈-T₁₄</td>
</tr>
<tr>
<td>14</td>
<td>Hunter-type Hunting</td>
<td>Mare</td>
<td>8</td>
<td>T₈-T₁₄</td>
</tr>
</tbody>
</table>

TB—Thoroughbred; TBX—part-bred.
Fig 9a. The distribution of lesions in the thoracolumbar spine of 14 horses with ossifying spinal lesions.

Fig 9b. Post mortem specimen of ossifying spinal lesion in an aged pony gelding.

associated with demonstrable clinical signs. Mitchell (1933) described similar changes at the lumbosacral intervertebral foramina which he thought caused pressure on the sciatic nerves and led to the condition of shivering. However, these osteophytic lesions can be found in apparently normal horses without evidence of back pain or shivering.

CROWDING AND OVERRIDING OF THE DORSAL SPINOSUS PROCESSES

The distribution of age, type, use, sex and bwt of horses suffering from crowding and overriding of spinous summits in mid or caudal TL spine is shown in Fig 10. The impingement of the dorsal spinous processes, chiefly beneath the saddle area, T1 to T15, appeared to predispose horses to back pain. They usually presented with a chronic history frequently having received empirical treatment for back trouble. The condition was prevalent in young adult horses of middle to heavy bwt used for jumping or dressage and in Thoroughbred or parthbred animals with short backs.

Clinical signs

The onset of signs was often insidious, although a history of trauma to the back from a fall was sometimes reported. Many horses were referred for loss of performance associated with increasing stiffness in the back and an abnormality of the hindlimb gait. One of the first signs noted by owners was a change in the animal’s temperament or resentment to grooming, saddling or rugging-up. There was sometimes reluctance...
to lie down or roll or to move over in the box. Some were disinclined to have their hind feet picked up for cleaning or shoeing.

In some animals a degree of hindlimb lameness was reported but it was frequently difficult to identify with certainty the site or even the limb involved. At exercise affected horses did not always track up well with their hind limbs and tended to go on 2 tracks behind. Signs of toe-dragging and plaiting of the hind feet were not usually seen but poor jumping performance was nearly always a feature, particularly at the combination-type fences. Overt signs of back pain were not always exhibited although on manipulation there was invariably resentment to dorsiflexion with noticeable rigidity of the TL spine. In severe and chronic cases a degree of wastage of the longissimus dorsi muscles was sometimes apparent. There were 18 cases in which back pain was associated with some secondary muscular or ligamentous damage and another 18 showed signs of sacroiliac strain as well as overriding of the dorsal spinous processes.

Radiological changes

Pressure points between opposing spines with local periosteal reaction, small bony cysts and false joint formation were found radiographically. The tips of the summits sometimes overlapped one another and often became misshapen because of friction. The severity of the lesions varied considerably and in many the clinical signs exhibited were not directly related to the amount of damage seen radiographically. Radiological changes of this type were also seen in some horses with apparently normal backs (Jeffcott 1979d). However, the incidence was lower and the lesions were generally less severe.

In order to quantify the radiological findings a system of grading the changes was introduced (Fig 11a and b). A comparison was made of the "overriding" cases with the "normal" group, the cases of hindlimb lameness and the other causes of back trouble (Fig 12). The region of the vertebral column principally affected was the caudal thoracic region, T11 to T13 (Fig 13). The formation of false joints (pseudoarthrosis) between opposing spines was very common but fusion of the summits occurred in only one case, at T13 to T14 in a pony.

Possible pathogenesis of the condition

The source of pain in these cases of overriding dorsal spinous processes was often not clearly understood. Local anaesthesia of the interspinous spaces resulted in marked improvement of the performance in some horses and eliminated the back pain, whereas this technique did not appear to improve horses with ligamentous or muscular injuries. There was presumably some discomfort at exercise produced by the impingement of the spinous processes associated with the local periosteal reaction and the secondary pseudoarthrosis (Von Salis and Huskamp 1978) or bursitis). Repeated maximal dorsiflexion of the spine during fast exercise or jumping might well have activated or exacerbated some of the chronic lesions. However, as in man (Wyke 1976), considerable differences in the threshold of back pain could be expected, with some animals apparently being able to perform satisfactorily in spite of the condition. A comparable condition to overriding has been described in man (Hazlett 1964) from which the pain is said to derive from a lumbar spine bursitis.

The predilection site of the condition is the mid-back where the weight of the rider is exerted and the interspinous spaces are narrowest. This may explain why the condition was much more common in Thoroughbreds than in other breeds, which tended to have wider interspinous spaces (Jeffcott 1979d). It would appear, therefore, that the underlying cause of the condition involves the conformation of the
Grade 0 - No impingement of dorsal processes spinous

Grade 1 - Impingement of summits

Grade 2 - Impingement with mild overriding (crowding)

Grade 3 - Overriding associated with periosteal reaction on opposing spinous processes

Grade 4 - Severe overriding with periosteal reaction, pseudoarthrosis and misshapen summits

Grade 5 - Fusion of adjacent spinous summits

Fig 11B. Depicts the line drawings from the radiographs of these cases

Fig 11C. Comparison of the degree of overriding in horses with a thoracolumbar disorder, overriding of the dorsal spinous processes or hindlimb lameness, and the group of normal horses

Fig 12. Comparison of the degree of overriding in horses with a thoracolumbar disorder, overriding of the dorsal spinous processes or hindlimb lameness, and the group of normal horses

Fig 13. The location and frequency of the interspinous spaces involved in 100 cases of overriding of the dorsal spinous processes

vertebreal column while the clinical signs are more associated with the type of work performed. Animals at rest or those kept in very light work will not show overt back pain but will probably exhibit a somewhat rigid TL spine. Animals that are predisposed to maximal spinal flexion and extension (ie, during jumping) will be prone to back pain if the impinging spines are jarred and the pseudoarthrosis traumatised. Most cases should, therefore, respond to periods of rest to allow this painful reaction to subside but recurrence of the clinical signs may take place.

OTHER BONY DEGENERATION

There were only 2 cases in this category. The first was a 3-month-old Thoroughbred foal that had a large draining
sinus on its right withers. Radiographs revealed osteomyelitis involving the mid-portion of the spinous process of T₄ (Fig 14). The condition improved with treatment for 2 months and then gradually deteriorated until destruction of the animal became necessary.

The second was a 5-year-old gelding showjumper which had recently begun serious schooling and jumping work. It showed discomfort in the back and reluctance to jump. The only radiographic finding was an area of osteolysis on the cranial edge of T₅ (Fig 15). The exact significance of this lesion was uncertain and, so far, no follow-up information on the case has been forthcoming.

**MISCELLANEOUS CONDITIONS NOT SPECIFICALLY INVOLVING THE TL SPINE**

There were 66 horses in the series in which no evidence of actual damage to the TL spine or its associated structures could be found (Table 1). In 20 of them some stifle or hock problem was diagnosed and in a further 11 the clinical signs were attributed to lameness originating below the hock or carpus (eg, laminitis, navicular disease and ringbone). In the 9 cases in which the stifle was involved, 7 were ascribed to intermittent or partial fixation of the patella. In the 11 horses with a hock lesion this was due to either low grade osteoarthritis or local ligamentous damage.

There were 24 cases in which all or part of the clinical signs were attributed to the animal's temperament. In 15 of these horses some other more tangible lesion was also present (Table 2) but in 9 cases no other demonstrable sign of back injury could be found. The history usually suggested a previous TL problem which had apparently resolved but the animal's performance had not improved or there was still resentment to palpation or taking weight on its back.

Another cause of lowered performance which was confused with a TL disorder was that associated with a dental problem (4 cases), while 3 of the remaining cases involved damage to the cervical spine. In addition one case each of fractured 17th rib, arthritis of the hip, stringhalt and warble-type lesion on the back behind the saddle were recorded.

**UNDIAGNOSED**

There were 37 cases referred as having a back complaint in which no definitive diagnosis could be established at all (Table 1). These horses usually exhibited some loss of performance with discomfort in the back or signs of having a "cold back". No specific clinical or radiological abnormality could be found for the presenting clinical signs. They may possibly have been associated with some low grade tissue damage, undiagnosed peripheral nerve root lesions or simply due to problems of temperament or equitation.
Discussion

This series of 443 cases appears to be the first attempt to categorize the major causes of back complaints in the horse. A wide range of conditions was found to be involved, although diagnosis was often complicated by the imprecise clinical picture and the individual variation in the amount of pain exhibited by different animals. The most consistent feature noted was, undoubtedly, a loss of performance, particularly jumping performance. The value of good radiographic technique was not only helpful in pointing the presence of vertebral lesions but was also most valuable as a prognostic aid, by being able to eliminate the possibility of serious bone damage.

The incidence of epaxial soft tissue injury was 38.8 per cent, which is high, especially as the majority of cases examined were referred principally for examination of suspected vertebral damage.

The problems of diagnosis, necessitating a careful clinical approach, in horses with potential back problems, were emphasized by:

1. The relatively large number of cases encountered that were not attributable to actual damage to the TL spine;
2. The range of possible conditions;
3. The fact that more than one condition or site of injury could be involved at the same time;
4. The limits imposed by the need to evaluate, objectively, the degree of pain and its exact location.

In some cases, the TL condition was responsible for a loss of performance without any demonstrable pain response (e.g., chronic sacroiliac strain). However, some animals were naturally sensitive or "thin-skinned" over the back and palpation resulted in an exaggerated response to dorsiflexion which could be misinterpreted as pain. Cases suffering from the syndrome commonly referred to, colloquially, as a "cold back" were found to be persistently hypersensitive over the back with "stiffness" and 'dipping of the spine on being mounted. There were usually no other demonstrable clinical signs and no radiological changes were to be found in the TL spine. The initial signs of stiffness on being saddled or mounted wore off within a few minutes and, thereafter, no effect in performance was noted. Whether this condition was actually painful or associated with previous back pain, or was merely a matter of temperament, was not clear.

Definitive diagnosis is often difficult even with recourse to sophisticated radiographic back-up but when it is based purely on a clinical examination it must be largely a subjective assessment of the situation. This inevitably leads to the wide variation in veterinary and lay opinions and speculation of the various pathogeneses of equine back problems.

The condition referred to as chronic sacroiliac strain is an important cause of back trouble on hindlimb performance. The clinical signs, biomechanics and post mortem findings have been discussed previously (Adams 1969; Rooney, Delaney and Mayo 1969). The major clinical sign in many of the chronic cases in this series was a lack of impulsion from one or both hindlimbs at slower paces. However, if the animal was made to jump or exercise at speed the tone of the gluteal and sublumbar muscles would be much increased and the animal's performance improved. The inference being, perhaps, that at slower more relaxed paces there was a mild instability at the sacroiliac joint which in time would lead to slight laxity and great movement of the joint surfaces. The post mortem findings in the 2 cases seen here suggest that there has been some increased mobility of the joint. For the horse to get maximum impulsion from the hindquarters there should be no appreciable movement taking place at the sacroiliac joint.

It is hoped that this study may stimulate interest and further investigation into the general field and pathogenesis of equine back problems so that a rational basis for therapy can be established.

References


Résument

Il s'agit d'une étude portant sur 443 chevaux confiés au département clinique de la Station de Recherche Equine de Newmarket avec des conoméromatiques de lésions thoracolombarie (TL). La gamme des lésions pouvant engendrer des troubles dorso-lombaires est vaste et 75 animaux, soit 17%, furent trouvés porteurs de deux ou de plusieurs lésions distinctes. En revanche, 103 chevaux (19,7%) se révélèrent indemnes de lésions vertébrales ou paravertébrales thoraco-lombaires. Pour 66 de ces animaux, les signes cliniques furent attribués à diverses sortes de boiteries postérieures. Pour les 37 autres, on ne put produire un diagnostic spécifique.

Des lésions des sites sous furent diagnostiquées dans 203 cas (38,8%), le site le plus fréquent étant le long dorsal, et, ou le ligament sus-épineux dans la région thoracique antérieure. Les autres affections identifiées furent le syndrome tying up (myoglobinurie fruste), la sub-luxation d'une vertèbre lombaire et la névrite de la queue de cheval (cauda equina).

Quinze cas de malformations vertébrales furent identifiés (2,9%) y compris des cas de lordose, scoliose et cyphose. Des lésions vertébrales furent diagnostiquées dans 38,6% des cas, soit 202 animaux. Le cas le plus fréquent était le rapprochement ou le chevauchement des apophyses épineuses dorsales dans la région thoracique postérieure et dans la région lombaire antérieure. Ce diagnostic fut le plus souvent posté
chez les chevaux de concours hippique (173 cas), et l'on constatait une perte de souplesse et de flexibilité rachidienne. Il en résultait des performances amoindries et des signes de douleur dorsale. Les fractures furent peu nombreuses (13 cas), et les spondylites dégénératives au nombre de 14.

Zusammenfassung

Diese Übersichtsuntersuchung umfasst 443 Pferde, die in die Klinik der Pferdeforschungsstation wegen Rückenschmerzen eingewiesen wurden. Eine grosse Anzahl von Veränderungen kann Rückenprobleme schaffen und mehr als eine Krankheit oder mehr als eine veränderte Stelle wurde bei 75 Tieren festgestellt (17,0%), 103 Pferde (19,7%) wiesen keine nachweisbaren Schäden der thorakolumbalen Wirbelsäule auf. Bei 66 dieser Fälle, konnten die klinischen Zeichen einer Nachhandlahmheit verschiedener Art zugeschrieben werden, bei 37 Pferden konnte keine spezifische Diagnose gestellt werden.

Wichteilschäden diagnostizierte man bei 203 Fällen (38,8%), meistens im m. longissimus dorsi und/oder im supraspinalen Band des hinteren Widerrists und der vorderen Lumbalregion. Chronische sacroiliacale Zerrungen oder milde sacroiliacale Unstabilität waren ebenfalls häufige Ursachen hinterer Rückenleiden von Leistungspferden. Andere diagnostizierte Krankheiten schlossen Tying-up, Subluxation von Lendenwirbeln und Neuritis caudae equinae ein.

Fünfzehn (2.9%) Fälle von Wirbelmissbildungen umschlossen Skoliose, Lordose und Kyphose. Wirbelschäden machten 38,6% (202 Fälle) der Diagnosen aus. Am häufigsten konnte eine enge Stellung oder ein Ubereinandergreifen der Dornfortsätze der hinteren Brust- und vorderen Lumbalregion festgestellt werden. Dieser Zustand fand sich besonders oft bei Springpferden (173 Fälle) und verursachte einen Verlust der Losgelassenheit und der Wirbelbeweglichkeit, was schlechtere Leistungen und Anfälle von Ruckenschmerzen hervorgerufen hat. Es fand sich nur eine vergleichsweise tiefe Frequenz von Frakturen (13 Fällen) und von degenerativer Spondylose (14 Fälle).

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EQUINE NEUROPATHOLOGY PANEL

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I.G. MAYHEW
I. LIU
FRACTURES OF THE THORACOLUMBAR SPINE OF THE HORSE

L. B. JEFFCOTT and KATHERINE E. WHITWELL

Introduction

The importance and clinical diagnosis of fractures of the thoracolumbar spine, "broken back," have been discussed in fairly general terms and some of the neuropathologic signs have been considered by de Lahunta. Two individual cases, one in an adult and the other in a young foal, have also been published. The most detailed study which has appeared so far is that of Vaughan and Mason, who described 15 cases of thoracolumbar fracture in a series of 125 horses which suffered fatal racing accidents, chiefly as a result of trauma to the spine during jumping.

There is a fairly complex relationship between the neurologic signs and possible bone damage to the vertebral column (Table I) and diagnosis of thoracolumbar fracture is not always a simple matter. This may be further complicated at equestrian events by an anxious lay audience who expect almost instant decisions after only a limited and cursory examination as to whether the animal should be immediately destroyed. The purpose of this communication is to report on a series of 22 cases of fracture involving the thoracolumbar spine. This will include consideration of the incidence and site of these fractures, the factors which may predispose to spinal fracture and consideration of the problems in clinical diagnosis with particular emphasis on radiologic examination.

Incidence and Sites of Fracture

It is not possible to give an exact figure for the incidence of thoracolumbar fractures, but in a series of 377 horses referred specifically for consideration of neurologic signs, vertebral fractures were diagnosed in 47 cases. This suggests an incidence of approximately 12.5%. Table I presents a classification of CNS signs, bone lesions and both cervical and thoracolumbar fractures. A detailed description of the findings in each case is given in the Appendix.

<table>
<thead>
<tr>
<th>CNS SIGNS WITH BONY LESIONS</th>
<th>CNS SIGNS WITHOUT BONY LESIONS</th>
<th>BONY LESIONS WITHOUT CNS SIGNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trauma</td>
<td>Vertebral fracture (complete/partial)</td>
<td>Edema, hemorrhage into spinal cord</td>
</tr>
<tr>
<td>Infection</td>
<td>Osteomyelitis with pathologic vertebral fracture</td>
<td>Spinal abscess</td>
</tr>
<tr>
<td>Congenital Deformity</td>
<td>Defects of vertebral column (e.g., meningiocele, spina bifida)</td>
<td>Congenital defects of CNS with normal vertebral canal</td>
</tr>
<tr>
<td>Neoplasia</td>
<td>Metastasis to vertebral column (e.g., lymphosarcoma)</td>
<td>Primary spinal cord tumor (e.g., glioma)</td>
</tr>
<tr>
<td>Stenosis of Vertebral Canal</td>
<td>Dorsalventral or lateral bony protruberance into vertebral canal (e.g., wobbler disease)</td>
<td>Stenosis caused by soft tissue (e.g., disc, synovial cyst)</td>
</tr>
<tr>
<td>Other</td>
<td>Focal or diffuse myelitis (e.g., protozoal myeloencephalitis)</td>
<td>Cauda equina neuritis</td>
</tr>
</tbody>
</table>

TABLE I. THE RELATIONSHIP OF NEUROLOGIC SIGNS AND BONE DAMAGE IN THE VERTEBRAL COLUMN
TABLE II. A SURVEY OF FRACTURES OF THE AXIAL SKELETON OF THE HORSE

<table>
<thead>
<tr>
<th>Region Involved</th>
<th>Number</th>
<th>CNS Signs Present</th>
<th>fracture Direct Cause Of Death</th>
</tr>
</thead>
<tbody>
<tr>
<td>AXIAL SKELETON (From a series of 2,170 cases examined) 65</td>
<td>32</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Skull (23)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cranial base of skull</td>
<td>11</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>Nasofrontal region</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cervical Spine (16)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atlanto-occipital/C1-C2 (incl. dislocation)</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C3-C7</td>
<td>9</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>C7+ osteomyelitis</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Thoracic Spine (17)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertebral bodies/neural arch and articular processes</td>
<td>10</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Dorsal spinous processes</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lumbar Spine (5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertebral bodies/transverse and articular processes</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Dorsal spinous processes</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sacrococcygeal Spine (4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sacrum</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Coccygeal vertebrae</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

back complaints, this was less than 3%. From a total of 2,170 horses referred to the Equine Research Station for radiologic or postmortem examination, 65 fractures of the skull and vertebral column were recorded. Approximately one third of these (22 cases) involved the thoracolumbar spine (Table II). There were 15 fractures of the vertebral bodies, neural arch and/or articular processes, of which almost all were associated with serious neurologic signs and resulted in death or humane destruction. Fractures confined to the dorsal spinous processes were seen only in the thoracic spine, were not associated with neurologic signs and carried a good prognosis.

Fig. 1. Location of 52 vertebral fractures from 32 cases involving the thoracolumbar spine. This histogram includes material from Vaughan and Mason (1976), Moyer and Rooney (1971) and Mason (1971). In many cases more than one vertebra was fractured.
The sites of the various vertebral body fractures in this series and in a further 17 cases from the literature have been plotted in the form of a histogram (Fig. 1). Three main areas of the back seem prone to fracture. The vertebral bodies at each end of the thoracolumbar spine (i.e., the first three thoracic and all the lumbar vertebrae and around the mid point of the back [T₁₂]). The greatest amount of dorsoventral movement of the vertebral column occurs from T₁₁-T₁₃ which is more or less where the most of the rider's weight will be exerted. The fractures of the dorsal spines without involvement of the vertebral bodies show a markedly different distribution (Fig. 2). In seven cases examined radiologically, all were confined to the withers region; T₆ (which is usually the highest point of the withers) was most commonly fractured.

**Predisposing factors**

The type of animal and use to which it is put are the most obvious predisposing factors. Thoracolumbar fracture must be considered an occupational hazard in those horses used for jumping at speed (i.e., steeplechasers, hurdlers, eventers and hunters), but it is rarely seen in flat racing horses or show jumpers. The type of fence will undoubtedly have a bearing, as well as the fitness and/or tiredness of the horse. Jumps where the landing is at a lower level than the take-off are particularly hazardous, as well as the large spreads or water jumps. In many instances the animal makes its mistake in the air and lands badly, thereby greatly increasing the loading on certain parts of the back.

The possibility of previous trauma to the thoracolumbar spine may also be an important predisposing factor in some cases of fracture. There may have been some chronic ligamentous or intervertebral disc damage, or even a small spondylitic lesion produced in response to earlier spinal injury. A number of vertebral and pelvic fractures have been seen with evidence of fairly chronic pathologic change near the site of fracture. Congenital lesions of the vertebral column, such as vertebral fusion (synostosis) or scoliosis, may
result in thoracolumbar fracture during parturition if much traction is required during delivery.

In our series, fractures of the thoracolumbar spine are more prevalent in adult horses, foals and young animals being only occasionally affected. With young animals there is often a history of the animal's careering into a solid object in the paddock. (Thunderstorms can play a part in fractures of this type by causing horses to panic.) Such cases usually involve the cranial thoracic or mid back regions of the spine.

Spinal fractures appear to be slightly more common in females compared to fractures of the skull and cervical spine. There is the possibility of an increased susceptibility in heavily lactating brood mares which may be associated with some osteoporosis of the spine.

Clinical Signs

The clinical features of thoracolumbar fracture may be divided into two categories, those which involve fracture of the dorsal spinous processes only, and those in which there is damage to the vertebral canal and body. It is this latter group that frequently results in serious neurologic deficit and which may be more difficult to diagnose and locate exactly.

Fractures of the thoracic dorsal spine do not usually present much difficulty in diagnosis. There is usually a history of some traumatic incident followed by heat and swelling over an acutely painful area of the back. Multiple fractures of the spinous summits in the withers are sometimes seen in young horses which have reared up and fallen over backwards. The tips of the summits and the centers of ossification are fractured and displaced laterally (Fig. 3). After the initial pain and local reaction has subsided, these animals make satisfactory recoveries. A residual depression on the withers can often be seen or palpated. There is not usually any permanent effect on the animal's performance, but a persistent deformity of the withers may require a special saddle.

When a thoracolumbar vertebral fracture involves the vertebral canal, the rapidity of onset of neurologic signs and their severity depends largely upon the rapidity and extent to which the fracture fragments displace and cause damage to the spinal cord. Strong ligaments bind the vertebrae together and are supported by dense muscle masses and their tendons. These have a natural splinting effect on the fractured vertebrae, the effectiveness of which depends upon the position of the fracture lines and the amount of mobility to which the site is subjected after fracture.

Immediate Onset of Paraplegia

Fractures characterized by immediate paraplegia often occur when trauma is sudden and severe (e.g., hitting a tree at a full gallop, a heavy fall when jumping a large obstacle at speed). Fracture-displacement is likely to be immediate and can cause either complete transection of the spinal cord or, where the dura remains intact, a local pulping of the cord.

Onset of Paraplegia After a Short Delay

This syndrome will occur when the initial fracture trauma is less severe than the previous category, the fragments displacing when the horse
continues to move at speed. An example of this was a 3-year-old colt which, in the words of a racecourse veterinarian, "collapsed at the end of a two mile Novices' Hurdle race on the run in after the last hurdle, and was unable to rise." When turned over, the horse raised itself halfway and then collapsed again, throwing its head onto and into the ground with tremendous force. It appeared to be in fearful pain and there was no alternative but humane destruction. At necropsy, severely comminuted fractures of the first two lumbar vertebrae were present.
Onset of Paraplegia After a Longer Delay

This type of case occurs when the traumatic incident which caused the fracture is followed immediately by a period of immobility or of slow walking exercise without a rider. The incident may not even involve the horse’s falling to the ground. As there is little or no evidence of locomotor incoordination, presumably there is little or no fracture displacement. The horses do, however, exhibit pain — probably as a result of periosteal tearing, subperiosteal and intramuscular hematoma formation, and even nerve root compression. They may adopt a characteristic posture with spinal rigidity, sweating, and a straddling hindlimb stance. Because such horses appear stiff and uncomfortable and have a tendency to lie down, they are sometimes reported to show signs of colic. Once they become recumbent, fragment displacement easily occurs with resultant paraplegia or paresis. A fairly typical history of this type of case involved an 8-year-old mare injured while out hunting. She made a bad jump and “left her hindlimbs behind” in the ditch. The rider was thrown but caught the mare and walked with her two miles to where the mare was examined by a veterinarian. He diagnosed some abdominal pain associated with strain of the back. It was not until the evening that the mare went down in the box, became paraplegic and was eventually euthanatized. Overriding fractures of the vertebral bodies of L2 and L3 which extended up through the neural arch to the dorsal spine of L3 were found at necropsy.

No Paraplegia

Where, as outlined above, the conditions after a thoracolumbar fracture are favorable for there to be no immediate fragment displacement, and where this state can be maintained, there is some hope that recovery might ensue. Two cases will illustrate the possible outcome of such fractures.

An 8-year-old Thoroughbred gelding was pulled up during a Point-to-Point race, having made a mistake at a jump. Although it was reported to have a bout of mild colic and discomfort that night, the only clinical sign was a marked posterior incoordination. When examined a few days later, there had been no improvement in the ataxia; it was willing to trot, and no pain response could be elicited along the back — he was, in fact, showing the clinical signs of a severe “wobbler.” It was destroyed ten days after the race. The first lumbar vertebra was fractured into three main fragments but there was minimal displacement. Hemorrhage was slight and very local to the fracture lines. There was an epidural hemorrhage around the spinal cord within L1, and a surprisingly severe focus of recent damage to the cord, involving both grey and white matter.

A second example was a 2-year-old Thoroughbred filly which had a hairline fracture of the vertebral body of T16. It showed some signs of back pain and hind limb incoordination but completely recovered within six months.

Diagnosis

a) Clinical Examination

Both Palmer and Rooney discuss methods of making a clinical assessment of the site in cases of cord trauma.
Rooney suggests that a period of 24 hours' delay is necessary for the signs of spinal shock to abate. Many horses with sudden paraplegia are destroyed before this period. Horses with thoracolumbar fractures and paraplegia retain the ability to move the neck, lift the head and voluntarily move the forelegs. A clinical examination should include an assessment of the voluntary and reflex responses to pinpricks (skin, panniculus, perineum), the degree of tone in the limbs, the state of the bladder and rectum, the presence of sweating and a rectal examination. The latter technique is frequently of more value in differential diagnosis than in identifying the location of a fracture, even in the more posterior lumbar vertebrae. Pelvic fractures and severe sacroiliac strain can be differentiated in this way.

b) Radiologic Examination

Radiography in these cases is not always possible because the animal cannot be moved and portable equipment is not sufficiently powerful except in very small or young animals. If adequate facilities are available, it should be possible to pinpoint the site and assess the degree of damage to the vertebral canal. However, in some cases, it will not be possible to demonstrate incomplete fracture on X-ray.

The severe fractures are invariably crush-type fractures with some displacement and overriding of the fragments resulting in stenosis of the vertebral canal (Fig. 4). A case which demonstrates the inability to show up incomplete fractures by plain radiography was seen in the 8-year-old Thoroughbred gelding cited above. The animal was presented with sudden onset of ataxia after pulling up in a hurdle race. Radiography of the cervical spine did not reveal any lesions compatible with vertebral stenosis and no radiologic damage in the thoracolumbar spine was detected. The gelding was destroyed on clinical grounds and an incomplete fracture of the ventral vertebral body of L1 extending out through the transverse processes instead of going up through the neural arch was found (Fig. 5).

Further diagnostic aids are required to elucidate some of these cases of neurologic deficit and possible damage to the vertebral column. A very useful technique would be the application of computerized axial tomography (CAT) or EMI-scanning of the cervical and thoracolumbar spine of the horse (Fig. 6). This would give a view of the craniocaudal section of the vertebral canal instead of a plain lateral or ventrodorsal view. It would also be possible to take serial transverse cuts through the articular and transverse processes of the vertebral bodies to detect minor or incomplete fractures.

c) Clinical Pathology

A routine hematologic analysis may be helpful in differential diagnosis. Animals with vertebral fracture will often show some degree of hemoconcentration and leucocytosis. In acute ataxia or paraplegia resulting from cervical spinal cord compression, there is usually a normal hemogram. Spinal abscess which may present with acute onset of paraplegia will show a noticeable circulating neutrophilia.

The estimation of the muscle enzymes, amino aspartate transferase (AAT or GOT) and creatine kinase (CPK), is also worthwhile, as it will differentiate cases of peracute azoturia (paralytic myoglobinuria). Such horses can become recumbent and the condition may closely resemble thoracolumbar fracture. Urine analysis for hemoglobinuria and myoglobinuria is also important in such cases.
Fractured dorsal spine of T13.

Overriding fracture of vertebral body of T14.

Epiphyses of vertebral body.

Fig. 4. Radiograph with explanatory diagram of a crush fracture of vertebral body of T14 in a 1½-year-old Thoroughbred filly.
Fig. 5. Tracing from postmortem radiographs of an 8-year-old gelding with an incomplete fracture of the vertebral body of L1 extending dorsally and laterally into the transverse processes.
Fig. 6. EMI-Scanning (computerized axial tomography) of cervical spine of an aged hunter-type gelding, (a) at the level of mid C3 and (b) at the C3-C4 articulation.
d) CSF Analysis

Although we have had no experience of obtaining CSF from lumbosacral puncture, this would seem a logical technique to apply in suspected cases of thoracolumbar fracture. However, this may be very difficult and hazardous due to the hemorrhage or swelling of the spinal cord. In fact, the inability to collect a sample could be useful diagnostic information. In cases of spinal abscess, one would expect an increased leucocyte count in the CSF.

Treatment and Prognosis

Once fracture displacement and paraplegia have occurred, the prognosis becomes very poor and usually hopeless. The initial pain can be controlled fairly well by analgesics, eating and drinking becoming fairly normal. However, the problems of pressure sores, retention of urine and feces, hypostatic edema of lungs, and general nursing are considerable. Attempts by the horse to get up, and by attendants in turning the horse over, are likely to result in further displacement of fractures and trauma to the cord. Ideally, the spine should be immobilized as far as possible. Thus, where paresis alone occurs, there is some chance of recovery if the animal can be confined for a period of weeks and halter-tied to prevent its lying down. The use of slings might be considered. Where a fracture line has been demonstrated, radiographic monitoring would be helpful in assessing the progress of such a case.

Acknowledgement

We are most grateful to the Director and staff of E M I Central Research Laboratories, Hayes, Middlesex, U.K., for their assistance with the production of the C A T scans (Fig. 6a and b).
REFERENCES

Effect of induced back pain on gait and performance of trotting horses

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Summary
Back pain was induced in Standardbred horses by multiple intramuscular injections of a concentrated lactic acid solution into the left longissimus dorsi muscle. The investigation was divided into 2 parts. In Stage 1, 2 trotters were exercised on a treadmill and filmed by high-speed cinematography before and after the induction of back pain. No signs of hindlimb lameness were evident and no quantitative changes in the components of the gait resulted, but a noticeable reduction was seen in performance capacity. Stage 2 involved a more intensive clinical and cinematic study of 3 horses. In these animals some changes were detected in the stride pattern, but no obvious gait disturbance was produced. The principal effect was stiffness in the thoracolumbar spine and an inability to perform at fast paces.

Introduction
RECENT reports have highlighted the importance of thoracolumbar disorders in competitive horses and the difficulties in establishing specific diagnoses (Jeffcott 1979a, 1980a). One of the most consistent features in a horse with a chronic back problem is a loss of performance, rather than overt back pain. The evaluation of this type of case is essentially based on a subjective clinical opinion (Jeffcott 1979b), supported by radiological examination (Jeffcott 1979c, d). No attempt has yet been made to develop a more objective method of examination by quantitatively analysing the components of the animal's gait and performance under controlled or standardised conditions.

A model for the induction of back pain (ie, myositis) in horses by injecting lactic acid into the back muscles has been described by Kilian et al (1974). Using this model, the aim of the present investigation was to quantitate changes in gait and performance of Standardbred trotters with induced back pain, using a computerised analytical system based on high-speed cinematography.

Materials and methods
A preliminary trial by quantitative gait analysis (Stage 1) was made using 2 horses. This was followed by a more evaluated clinical and kinematic study (Stage 2), involving 3 different animals. The horses were exercised on a treadmill (Sikob AB, S-191 78 Sollentuna, Sweden) before and after the induction of back pain. Their locomotor performance was evaluated by high-speed cinematography (Fredricson et al 1980). This system is referred to as CRACK (Cinematographic Recording and Analysis by Computer in Kinetiology).

Stage 1
Both the animals used were Standardbred trotters. They showed no signs of lameness or other significant clinical abnormalities at the time of study. They were accustomed to being exercised on the treadmill. Horse A, a 4-year-old mare, was worked and photographed on the treadmill, before back pain induction, at speeds of up to 10 m/sec. Two 10 ml injections of 85 per cent lactic acid solution were made about 10 cm apart in the left longissimus dorsi muscle between T7 and L1. The next day the exercise and cinematography were repeated.

Horse B, a 7-year-old gelding, was given 2 sessions of exercise at 7 m/sec before induction of back pain. A series of 10 injections of lactic acid (2 ml) were made at 10 cm intervals down the left longissimus dorsi. Exercise and recordings were made the next day at 7 and 9 m/sec. Both horses were filmed in 2 projections simultaneously (ie, left lateral view and from behind) (Fig 1) and 5 complete strides were analysed by the CRACK system.

Stage 2
All 3 horses were Standardbreds in good physical condition, which had been trained to exercise on the treadmill before the experiment. Horse C was a 5-year-old mare approximately 150 cm in height. After the initial programme of exercise a mild degree of right forelimb lameness was seen. This was associated with slight thickening on the caudal aspect of the fetlock joint and was attributed to some previous damage to the insertion of the suspensory ligament on to the lateral proximal sesamoid. Flexion of the joint transiently exacerbated the degree of lameness, but did not noticeably affect the performance on the treadmill.

Horse D was a 6-year-old gelding approximately 160 cm in height, which showed no signs of lameness on exercise or after flexion tests on all 4 limbs. Horse E was an 8-year-old mare approximately 148 cm in height. This animal showed a slight lameness of the left forelimb on exercise which was not increased by flexion of the distal limb and did not affect the performance on the treadmill.

The horses were all unraced but Horses C and D had been in training and were qualified to run. Horse E had been used quite extensively on the treadmill.

Procedure
A series of 10 intramuscular injections of 2 ml 85 per cent lactic acid solution were made with 18 gauge 4 cm disposable needles approximately 6 cm to the left of the midline of the back and at 10 cm intervals down the longissimus dorsi from T7 to

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Cinematographic recordings (ie, control filming) of exercise on the treadmill were made on 2 occasions before lactic acid administration and then 24 to 72 hours after injection. The horses were filmed at 9 strides at speeds from 5 to 11 m/sec in 2 views (ie, left lateral and from above) (Fig 1). The feed was examined for any significant differences using Student's t test. After lactic acid injection each stride component was compared with that on the control film taken 2 days before the injection of lactic acid and the significance of each variation calculated using Student's t test.

Blood samples were taken at rest for estimation of haematological and biochemical parameters, including serum enzymes, aspartate aminotransferase, creatine kinase and serum total protein and bilirubin. Further blood samples were taken immediately after the control period of exercise and 12 to 18 h later to assess any changes in aspartate aminotransferase and creatine kinase. Blood was also collected at intervals after the lactic acid injection and subsequent exercise periods. Heart rates were recorded before and during exercise and muscle biopsies taken from the longissimus dorsi before and after lactic acid injection (Lindholm and Piehl 1974).

Results

STAGE 1

Both horses A and B showed evidence of pain to palpation of the injected back muscles, but no hindlimb lameness was observed. Quantitative analysis of the gait, based on the method of Ovedson, Dalin, Fredricson and Hjerrin (1988a) and Ovedson, Fredricson, Dalin and Bjorn (1988b), included examination of the stride and its stance and swing phases, and some diagonal and ipsilateral limb variables. No measurable differences were noted, after back pain induction, in the basic stride characteristics (Table 1). However, there was a notable decrease in performance of both animals; they were unable to attain the same top speeds which they had previously achieved during the control period of exercise.

STAGE 2

Clinical signs

The day after lactic acid injection all 3 horses showed a marked pain response with some heat and swelling on palpation of the left longissimus dorsi muscle. On the second day after injection a small quantity of exudate was present at the injection sites.

The animals did not appear to be unduly distressed and no increase in body temperature was recorded. There were no signs of lameness, but horses C and D showed a noticeable stiffness of the back, particularly when turning short to the left. This feature was not as pronounced in horse E.

On the treadmill the 3 horses showed difficulty in attaining their top speeds. They tended to go into transitional gait (ie, gait between a trot and a gallop which occurs when horses are forced beyond their trotting capacity (usually more than 12 m/sec)) or break into a gallop more frequently than before the induction of back pain. All 3 horses had achieved speeds of 9 m/sec or greater before injection. Horse E was not able to trot faster than

<table>
<thead>
<tr>
<th>Stride variables</th>
<th>7 m sec</th>
<th>9 m sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride duration</td>
<td>LF 509</td>
<td>576</td>
</tr>
<tr>
<td>(msec)</td>
<td>LH 502</td>
<td>574</td>
</tr>
<tr>
<td></td>
<td>RH 502</td>
<td>574</td>
</tr>
<tr>
<td>Stance duration</td>
<td>LF 106</td>
<td>159</td>
</tr>
<tr>
<td>(msec)</td>
<td>LH 106</td>
<td>159</td>
</tr>
<tr>
<td></td>
<td>RF 106</td>
<td>159</td>
</tr>
<tr>
<td></td>
<td>RH 106</td>
<td>159</td>
</tr>
<tr>
<td>Stride length</td>
<td>LF 303</td>
<td>402</td>
</tr>
<tr>
<td>(cm)</td>
<td>LH 304</td>
<td>401</td>
</tr>
<tr>
<td></td>
<td>RF 304</td>
<td>401</td>
</tr>
<tr>
<td></td>
<td>RH 303</td>
<td>401</td>
</tr>
<tr>
<td>Diagonal dissociation</td>
<td>5 11</td>
<td>15 19</td>
</tr>
<tr>
<td>at landing (msec)</td>
<td>R 30</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>L 301</td>
<td>287</td>
</tr>
<tr>
<td></td>
<td>R 259</td>
<td>286</td>
</tr>
<tr>
<td>Hindlimb duration</td>
<td>LF 267</td>
<td>278</td>
</tr>
<tr>
<td></td>
<td>RF 267</td>
<td>278</td>
</tr>
<tr>
<td></td>
<td>RH 267</td>
<td>278</td>
</tr>
<tr>
<td>Forelimb duration</td>
<td>LF 206</td>
<td>255</td>
</tr>
<tr>
<td></td>
<td>RF 206</td>
<td>255</td>
</tr>
<tr>
<td></td>
<td>RH 206</td>
<td>255</td>
</tr>
<tr>
<td>Hindlimb length</td>
<td>LF 186</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td>RF 186</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td>RH 186</td>
<td>221</td>
</tr>
<tr>
<td>Forelimb length</td>
<td>LF 186</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td>RF 186</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td>RH 186</td>
<td>221</td>
</tr>
</tbody>
</table>

TABLE 1: CRACK analysis of the stride components for Horse B filmed before and after induction of back pain at 7 and 9 m/sec

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FIG. 1. Diagram showing a horse on the treadmill and the position of the camera used for high speed cinematographic recording. In stage 1, camera 1 and 2 were used to give a lateral view and a view directly from behind the horse. In stage 2, camera 1 and 2 were used to give a lateral view and a view from above the horse on the treadmill.

L left R right F fore H hind
7 m/sec and even at this pace there was a tendency to go into transitional gait. In Horses C and D there was exaggerated adduction of the left hindlimb on the treadmill, which had not been noticed before lactic acid injection. There were no significant differences in the horses’ heart rates either at rest or during exercise. The signs of back pain and stiffness quickly disappeared and, by 72 hours after injection, the animals had almost returned to normal. No analgesic or anti-inflammatory therapy was administered.

Cinematic analysis

Qualitative evaluation of the films taken with the camera above the horses showed some apparent stiffness of the spine, and that a greater muscular effort of the longissimus dorsi and gluteal muscles was required to maintain performance. There was also a tendency to show more of a roll (ie, lateral movement of the thoracolumbar spine) with each stride than before the onset of back pain. A slight convexity of the spine to the right was noticed after injection in Horses C and D. However, in Horse E there was slight convexity to the left associated with some unevenness of the hindlimb gait.

The computerised analysis of the gait from the lateral view filming (Drevemo et al 1988b) did not show any consistently significant changes (Tables 2 and 3) and no apparent alteration in stride length was seen (Fig 2). There were some minor differences noted in a few of the stride components between the 2 control filming sessions. However, these features were more common and of higher significance after the induction of back pain. In 2 of the horses (Horses C and E) the right hindstep, after lactic acid injection, was longer at 7 m/sec whereas in the other (Horse D) the left hindstep was shorter. In all horses this was associated with a shorter propulsion stage on the propelling limb (Table 2).

There were several other individual features of minor significance produced after back pain induction (Tables 2 and 3). Horse C showed a shorter stance phase on the left hind and reduced propulsion on both hindlimbs. Horse D had a shorter swing duration and stride length as well as shorter diagonal length on both diagonals. In Horse E the restraint phase was shorter on the right hind although on the left hind it was longer and there was a shorter propulsion phase.

![Fig 2. Relation of stride length (cm) to velocity (m/sec) in Horse C before and after induction of back pain](image)

### TABLE 2: A comparison of the CRACR results of the single limb variables of 5 strides at 7 m/sec to detect any significant differences (Student’s t test) before and after injection of lactic acid in the 3 horses in Stage 2

<table>
<thead>
<tr>
<th>Stride variables</th>
<th>Horse C</th>
<th>Horse D</th>
<th>Horse E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before injection</td>
<td>After injection</td>
<td>Before injection</td>
</tr>
<tr>
<td>Stride length (cm)</td>
<td>LF -1.25</td>
<td>-1.55</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>RF -0.83</td>
<td>-1.09</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>RH -0.43</td>
<td>-1.45</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>LH -0.61</td>
<td>-1.14</td>
<td>0.69</td>
</tr>
<tr>
<td>Stance duration (msec)</td>
<td>LF -1.37</td>
<td>-4.71***</td>
<td>-2.93*</td>
</tr>
<tr>
<td></td>
<td>RF -4.47**</td>
<td>-4.71**</td>
<td>-0.73</td>
</tr>
<tr>
<td></td>
<td>RH -1.55</td>
<td>4.00**</td>
<td>3.13*</td>
</tr>
<tr>
<td></td>
<td>LH -2.45*</td>
<td>1.37</td>
<td>-1.23</td>
</tr>
<tr>
<td>Restraint duration (msec)</td>
<td>LF -0.32</td>
<td>6.00***</td>
<td>1.77</td>
</tr>
<tr>
<td></td>
<td>RF 1.26</td>
<td>2.65*</td>
<td>1.77</td>
</tr>
<tr>
<td></td>
<td>RH 0.00</td>
<td>5.00**</td>
<td>-0.34</td>
</tr>
<tr>
<td></td>
<td>LH 1.50</td>
<td>2.65*</td>
<td>1.77</td>
</tr>
<tr>
<td>Propulsion duration (msec)</td>
<td>LF -0.68</td>
<td>1.35</td>
<td>-0.27</td>
</tr>
<tr>
<td></td>
<td>RF -0.86</td>
<td>-0.27</td>
<td>-0.82</td>
</tr>
<tr>
<td></td>
<td>RH -1.79</td>
<td>-3.22*</td>
<td>-2.45*</td>
</tr>
<tr>
<td></td>
<td>LH -2.77**</td>
<td>-2.52*</td>
<td>-0.45</td>
</tr>
<tr>
<td>Swing duration (msec)</td>
<td>LF 1.84</td>
<td>1.29</td>
<td>-1.18</td>
</tr>
<tr>
<td></td>
<td>RF 1.17</td>
<td>1.15</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>RH -0.80</td>
<td>1.61</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>LH 1.81</td>
<td>1.30</td>
<td>-0.21</td>
</tr>
</tbody>
</table>

*Before injection Significant differences noted between the 2 control recordings before back pain induction. Student’s t test results give a negative value if the second reading was greater than that in the first recording
*After injection Significant differences noted between the variables taken before and after back pain induction
  *P<0.05
  **P<0.01
  ***P<0.001
When the diagonal, ipsilateral, contralateral and single limb variables were compared before and after back pain induction for the same horse no significant differences in the locomotor cycle were noted.

**Clinical pathology findings**

The haematological and biochemical findings are summarised in Table 4. The results of the blood counts showed only a haemoconcentration associated with exercise and a mild leucocytosis after the injection of lactic acid. The most noticeable changes were seen in the muscle enzymes, creatine kinase and aspartate aminotransferase, which showed elevations in the samples taken after exercise following the induction of back pain. The changes reflected the clinical picture of the induced myositis. There was also some increase in the serum bilirubin level after the lactic acid injection which persisted after the clinical signs of pain had disappeared.

The muscle biopsies of all 3 horses were normal before the injection of lactic acid. At 24 hours after injection Horses C and E showed areas of necrosis of muscle fibres with local infiltration of many macrophages and a few polymorphs. Those areas were surrounded by muscle fibres showing lesser degrees of degeneration with some normal fibres at their periphery. The biopsy taken after injection from Horse D did not show any abnormal histological changes.

**Discussion**

The procedure of using multiple small injections of concentrated lactic acid solution provided a useful model of back pain in the horse. The clinical signs here were not as dramatic as those reported by Kilian et al. (1974), who produced a clinical picture more akin to the naturally occurring tying-up syndrome (ie, myositis). This was probably caused by the larger volumes of lactic acid injected (10 ml instead of 2 ml), the higher total dosage used (60 ml instead of 20 ml) and the fact that both longissimus dorsi muscles were injected. These horses showed a significant shortening of the hindsteps which was measured by walking the animals over freshly raked sand. They were not so much lame as in severe pain and they took much longer to recover if not treated with anti-inflammatory medication. The purpose of the work by Kilian et al. (1974) was to produce a model of myositis to test the therapeutic efficacy of a non-steroidal anti-inflammatory agent.

In this study, the onset of back pain after injection was rapid, although not associated with any serious distress to the animal.

### Table 3: A comparison of the CRACK results of the contralateral, ipsilateral and diagonal variables to detect any significant differences (Student's t test) before and after injection of lactic acid in the 2 horses in Stage 2.

<table>
<thead>
<tr>
<th>Stride variables</th>
<th>Horse C</th>
<th>Horse D</th>
<th>Horse E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before injection</td>
<td>After injection</td>
<td>Before injection</td>
</tr>
<tr>
<td></td>
<td>24 hours</td>
<td>72 hours</td>
<td>24 hours</td>
</tr>
<tr>
<td>Diagonal dissociation</td>
<td>L</td>
<td>2.80*</td>
<td>7.30***</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-7.65***</td>
<td>-0.12</td>
</tr>
<tr>
<td>Diagonal dissociation</td>
<td>L</td>
<td>-0.56</td>
<td>4.47**</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>2.53*</td>
<td>2.76*</td>
</tr>
<tr>
<td>Diagonal length</td>
<td>L</td>
<td>1.65</td>
<td>7.01***</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>5.96***</td>
<td>1.10</td>
</tr>
<tr>
<td>Forestep</td>
<td>R</td>
<td>0.93</td>
<td>3.96**</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>-3.10*</td>
<td>0.83</td>
</tr>
<tr>
<td>Hindstep duration</td>
<td>L</td>
<td>-0.33</td>
<td>2.79**</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-1.07</td>
<td>4.94**</td>
</tr>
<tr>
<td>Diagonal length</td>
<td>R</td>
<td>0.79</td>
<td>-2.63*</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>-2.14</td>
<td>-0.10</td>
</tr>
<tr>
<td>Hindstep length</td>
<td>L</td>
<td>-0.08</td>
<td>2.45*</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.77</td>
<td>-3.56**</td>
</tr>
<tr>
<td>Overreach length</td>
<td>L</td>
<td>-1.87</td>
<td>-4.52**</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-3.87**</td>
<td>-8.24***</td>
</tr>
</tbody>
</table>

*P<0.05
**P<0.01
***P<0.001
The clinical signs were similar to those recorded in field cases of acute muscle injury to the back (Jeffcott 1980a). There was pronounced resentment to palpation and increased rigidity of the thoracolumbar spine. No signs of hindlimb lameness nor any gross alteration in the components of the stride occurred even though the induced back pain was unilateral. The CRACK analysis was performed here on 5 strides which may account for some of the minor differences noted between the 2 control recordings. Dreveno et al (1980a) analysed an average of 8 strides for optimum consistency of gait analysis.

After pain induction, some weakness of the left hindlimb in 2 of the horses (Horses C and E) was noted, with less propulsion from this limb resulting in a compensatory shortening of the right hind step. In the other animal (Horse D) similar changes were seen, but affecting the opposite limbs. There was reasonably good stability of the cycle of locomotion after back pain induction suggesting that the pain had no effect on the central nervous system control of locomotion. The most striking feature, after lactic acid injection, was the inability of the horses to perform at fast speeds, which is another important sign noted in field cases of back pain (Jeffcott 1979a).

The muscle damage produced by lactic acid, in both this study and that of Kilian et al (1974), appeared to be a typical myositis. This was confirmed histologically in 2 of our horses. The result in the third horse was negative probably because the biopsy had been taken just beyond the limit of muscle damage produced by the comparatively small (2 ml) injection dose of lactic acid.

The field and scope of equine locomotion research is rapidly growing in importance (Leach and Dagg 1982) and the CRACK system has an essential role in the critical assessment of performance and in the evaluation of lameness (Fredriesson et al 1980). This study clearly demonstrated the value of employing such a quantitative analytical system to give a degree of objectivity to a clinical area that has previously been entirely subjective (Jeffcott 1979a). Another condition that would benefit from this kind of objective cinematic investigation is chronic saccroiliac strain (ie, sacroiliac arthritis or instability). The clinical signs are frequently inapparent and involve a loss of hindlimb propulsion leading to poor performance, particularly in harness racehorses (Roevey 1977) and 3-day eventers (Jeffcott 1979a). For the future, CRACK analysis might provide a much needed means of evaluating the efficacy of the many lines of therapy currently being used to treat horses with chronic back problems (Jeffcott 1979a, 1980b).

Acknowledgements

We are indebted to the skilled technical assistance of Björn Hellman for the photography and to Stina Fredriesson for her help with film reading. We also wish to thank Professor Lennart Johansson for carrying out the histological examination on the muscle biopsies and the Department of Clinical Chemistry for performing the haematological analyses.

References


Résumé

On a provoqué des douleurs dorsales chez des chevaux trotteurs, par injections intramusculaires multiples d'une solution concentrée d'acide lactique dans le muscle long dorsal gauche. Les recherches ont été conduites en deux parties: dans la première phase deux trotteurs étaient exercés sur un tapis roulant et filmés par une caméra ultra rapide avant et après l'induction de la douleur dorsale. Aucun signe de boiterie postérieure ne fut constaté et aucun changement quantitatif dans les composants de l'allure ne fut remarqué, mais on nota une diminution marquée de la capacité sportive.

La deuxième partie comporta une analyse clinique et kinétique plus intensive sur 3 chevaux. Chez ces animaux, quelques modifications furent constatées dans les foulées sans altérations évidentes de l'allure. L'effet principal constaté fut une réduction de la colonne thoraco lombaire et une inaptitude à développer des allures rapides.

Zusammenfassung


Accepted for publication 25.9.81
SECTION 2.4  MANAGEMENT AND TREATMENT


Statement on Share of Work:

Paper 16 - I played the major role in planning and execution of this paper on surgical treatment for back problems. I also prepared the manuscript for publication.

Paper 17 - This paper on management and therapy prepared from clinical experience over a number of years working with back problems. The paper was presented to an international conference on lameness in 1983.
The Treatment of Horses with Chronic Back Pain by Resecting the Summits of the Impinging Dorsal Spinous Processes

L. B. Jeffcott and J. Hickman

Equine Research Station of the Animal Health Trust, Newmarket, Suffolk and Department of Clinical Veterinary Medicine, University of Cambridge

INTRODUCTION

There are a number of conservative methods for treating disorders of the back in the horse. They include methods of physiotherapy such as faradic stimulation of muscles (Fraser, 1961), manipulation of the spine (Herrod-Taylor, 1967) and the use of thermotherapy, including shortwave diathermy and ultrasonics. More recently therapy by swimming horses has been advocated (Hartley, 1973; Swanstrom and Lindy, 1973). Roberts (1968) described the surgical resection of part of the dorsal spinous processes to relieve pain and thereby eliminate the associated lameness.

This paper reports the results of employing a modification of the surgical technique described by Roberts (1968), for the treatment of horses suffering from impaction and overriding of the dorsal spinous processes in the mid-back region. The clinical signs of this condition, its diagnosis and a technique for radiography of the thoracolumbar spine has been described (Jeffcott, 1975).

MATERIALS

During the last two years 14 horses with chronic back pain attributed to impaction and overriding of the dorsal spines were considered suitable cases for surgery. They were all Thoroughbred or hunter types used for jumping and dressage and their ages ranged from three to nine years (Table 1). The diagnoses were based on clinical and radiological evaluation, and confirmed in eight cases by the injection of local anaesthetic or corticosteroid into the affected interspinous spaces (Jeffcott, 1975).

Follow-up examinations, including radiography, have been carried out on all but two cases, and clinical reports have been received on all horses after they have been put back into work.

METHOD

(a) Preparation

Radiographic examination of the thoracolumbar spine was carried out prior to surgery. The spinous processes to be resected were identified by a series of lead markers which were placed along the back (fig. 1). The hair was clipped around the surgical site except for four narrow strips (each of which corresponded to the position of a lead marker) to the left of the midline. This procedure enabled each individual dorsal spine to be easily identified when the horse was in lateral recumbency. A tracing was made of the affected dorsal spinous processes from a lateral radiograph, and a sterilized copy was attached to the drapes above the line of incision.

Each horse was starved for at least 18 hours before the operation and premedicated about 45 minutes prior to surgery with acepromazine administered intramuscularly at a dose rate of 0.035 mg/kg. General anaesthesia was induced with thiopentone sodium and maintained

Based on a paper presented at the British Equine Veterinary Association's Annual Congress, Southampton, 1974.
with halothane and oxygen using a modified Fisher-Jennings circle absorber. The horse was then placed in right lateral recumbency on hydro-float pads and positioned with its back close to the edge of the operating table. The site was cleansed with an antibacterial skin cleanser and spirit solution followed by the application of an antiseptic. The flank and hind legs were secured in extension to limit ventroflexion of the spine and to reduce tension on the supraspinous ligament. The front legs were raised slightly using an overhead hoist, to relieve pressure on the right shoulder region.

(b) Surgical technique

A midline skin incision was made directly over the summits of the spines to be resected. The skin edges were retracted and haemorrhage controlled with artery forceps or diathermy. The supraspinous ligament was identified, divided longitudinally and dissected from the summits of the dorsal spines. The insertions of \textit{longissimus dorsi} muscles were dissected from the lateral edges of the dorsal spines with a Jones periosteal elevator. The left \textit{longissimus dorsi} muscle was retracted upwards (i.e. laterally) with a Patons retractor and the interspinous ligaments and any false joint capsules were severed. This effectively exposed the dorsal spines and the left side was resected with its ventroflexion and hind legs secured in extension. This improved initial but trainer never satisfied. Has run three times.

<table>
<thead>
<tr>
<th>Case Ref.</th>
<th>Type of Animal</th>
<th>Age</th>
<th>Sex</th>
<th>Summits resected</th>
<th>Clinical assessment following surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>C73/65</td>
<td>Hack/Hunter</td>
<td>8 y.o.</td>
<td>Geling</td>
<td>T4; T11; T17</td>
<td>Previously unrideable; showed marked clinical improvement and no recurrence</td>
</tr>
<tr>
<td>C73/100</td>
<td>Steeplechaser</td>
<td>6</td>
<td>Geling</td>
<td>T4; T11; T15; T16</td>
<td>Improved initially but trainer never satisfied. Has run three times</td>
</tr>
<tr>
<td>C73/105</td>
<td>Steeplechaser</td>
<td>9</td>
<td>Geling</td>
<td>T12; T14; T16; T18</td>
<td>Has done very well since the operation and run 14 times; won once</td>
</tr>
<tr>
<td>C73/159</td>
<td>Hurdler</td>
<td>6</td>
<td>Geling</td>
<td>T14; T17</td>
<td>Has run three times since operation</td>
</tr>
<tr>
<td>C73/177</td>
<td>Hurdler</td>
<td>4</td>
<td>Geling</td>
<td>T14; T17</td>
<td>Required second operation but now back in work and considerably improved</td>
</tr>
<tr>
<td>C73/190</td>
<td>Hurdler</td>
<td>3</td>
<td>Colt</td>
<td>T14; T17</td>
<td>Back condition improved but horse has not reached full potential. Trainer not completely happy but horse has since run four times, winning once</td>
</tr>
<tr>
<td>C73/200</td>
<td>Hack/Hunter</td>
<td>6</td>
<td>Geling</td>
<td>T14; T17</td>
<td>Marked clinical improvement and no recurrence of back trouble</td>
</tr>
<tr>
<td>C73/217</td>
<td>Showjumper</td>
<td>8</td>
<td>Mare</td>
<td>T14; T17</td>
<td>Ditto</td>
</tr>
<tr>
<td>C74/1</td>
<td>Showjumper/Eventer</td>
<td>9</td>
<td>Mare</td>
<td>T14; T17</td>
<td>Ditto</td>
</tr>
<tr>
<td>C74/13</td>
<td>Steeplechaser</td>
<td>9</td>
<td>Geling</td>
<td>T14; T16</td>
<td>Has run twice since operation and has much improved form</td>
</tr>
<tr>
<td>C74/83</td>
<td>Showjumper</td>
<td>6</td>
<td>Geling</td>
<td>T18</td>
<td>No recurrence of back trouble, performing well</td>
</tr>
<tr>
<td>C74/128</td>
<td>Hack/Hunter</td>
<td>8</td>
<td>Geling</td>
<td>T16</td>
<td>Ditto</td>
</tr>
<tr>
<td>C74/196</td>
<td>Hurdler</td>
<td>4</td>
<td>Geling</td>
<td>T14; T17; T18</td>
<td>Ditto</td>
</tr>
</tbody>
</table>

3 Jobst Institute Inc., Toledo, Ohio, U.S.A.
4 Dow Bros., and Meyer & Phelps Ltd.
5 Procin (Burroughs Wellcome & Co.).
incision was then sprayed with an antiseptic® and a waterproof porous wound dressing® applied. The whole area was further protected with a large pad of gamgee which was stuck to the skin with Vi-Drape adhesive®.

In two of the cases the cranial and caudal edges of the overriding dorsal spines were removed with Liston’s bone cutting forceps.

(c) Post-Operative care

Each horse received 3000 units of tetanus antitoxin and a three or four day course of intramuscular penicillin® to prevent post-operative infection. The skin sutures were removed one, which developed a slight post-anaesthetic radial paralysis of its right front limb. With massage and gentle walking exercise it rapidly improved and was normal within three days.

The gamgee pad was removed on the same evening or the day after surgery, and the airstrip dressing on the third or fourth post-operative day. If any excessive exudation or suppuration from the wound developed, an antiseptic was applied. The skin wounds healed by first intention in all but three cases. In two, a small pocket of infection developed with resulting wound breakdown, but it quickly responded to topical applications of the appropriate antibiotic selected with regard to the organisms present. In the remaining case a number of small stitch abscesses developed in the supraspinous ligament, although no specific pathogen was isolated. After the sutures were removed the wound healed rapidly with no further complications.

The skin sutures were removed at 10-14 days. At this time some subcutaneous swelling was still present, but within two months it was difficult to detect the skin incision and a firm union of the split supraspinous ligament was established in all cases. In the second or third post-operative day the horses were given 15-20 minutes walking exercise daily which was gradually increased over the next month to 45-60 minutes. Inevitably there was some pain and discomfort immediately following surgery, but in only one case was it necessary to administer an analgesic.

All cases were radiographed a few days after operation to ascertain the spacing of the dorsal spines achieved (fig. 2). The horses were returned home a few days after removal of the skin stitches and were then turned out in a small paddock for the next four months or kept stabled but with the daily walking exercise continued. At the end of this period they were gradually brought back into full work. A final radiological examination was carried out at this time, in all but two cases, to see if there was evidence of any periosteal reaction.

RESULTS AND DISCUSSION

Although this is a relatively small series the results have been encouraging (Table I). All the horses following operation have gone back into full work and except for three have shown considerable improvement in their form or performance. These were racehorses and their trainers consider they had not made complete recoveries. In one of them, only the edges of the overriding spines had been resected.

A hurde-r (C74/101) had three dorsal spines resected initially and made a good recovery followed by a satisfactory convalescent period. However five months later, when the horse was backed and returned to work, poor hindlimb action and performance were still present. Some pain in the mid-back region was elicited on deep palpation, and dorsiflexion (dipping) of the thoracolumbar spine was resented and limited. Radiographic examination revealed a spur of new bone on the caudal aspect of the spine of T11, which appeared to be pressing on the cranial edge of T12 (fig. 3). Ten ml of local anaesthetic® was injected round the lesion. Within a few minutes back pain was eliminated and the horse’s action markedly improved. It was decided to resect the spur of new bone together with 1.0 cm of the dorsal spine. The same surgical approach was employed and apart from the presence of a limited amount of fibrous tissue reaction in the space between T12 and T11, no untoward effects of the previous operation were seen.

The supraspinous ligament had healed well and was firmly adherent to the summits of the dorsal spines of T11 and T12. No particular difficulties were encountered in removing the spur with the oscillating bone saw, and radiographs taken four months later showed that no further proliferation of new bone had occurred. Within six months the gelding was back in work and apparently fully recovered. It ran its first hurdle race a month later and although unplaced finished the course without difficulty.

This horse proved a useful test case as it confirmed that pressure between the dorsal spines can give rise to back pain and loss of performance. However, the radiographic evidence of the degree of periosteal reaction and the extent of overriding of spines does not always equate with the severity of the clinical signs. The extent of damage affecting the dorsal spines of a clinical case is demonstrated in fig. 4 and, for comparison, radiographs of identical spines of a normal Thoroughbred yearling are added. The surgical technique employed for these cases was somewhat simpler than that described by Roberts (1968) although apparently both methods have produced satisfactory results. In
1. Overriding dorsal spines before first operation.

2. Spacing achieved immediately after surgery.


4. Removal of spur new bone from T11.

**SUMMARY**

This paper describes the surgical treatment of 14 horses exhibiting chronic back pain attributed to impaction and overriding of the dorsal spines in the thoracolumbar region. The technique involved the resection of the summits of one or more dorsal spines following midline division of the supraspinous ligament. All the horses returned to full work after a convalescent period of at least four months, and 12 of them showed considerable improvement in their form and performance. A post-surgical complication encountered in one case was the development of new bone on the edge of a resected spine. This lesion, which pressed on the dorsal spine immediately caudal to it, was removed subsequently at a second operation and no further sequelae occurred.

**RESUME**

Cet article décrit le traitement chirurgical de 14 chevaux présentant des douleurs chroniques dorso lombaires attribuées au tassement ou au chevauchement des apophyses épineuses dans la région dorso lombaire. La technique comporte la résection du sommet d'une ou de plusieurs apophyses épineuses après avoir divisé médialement le ligament supraspinal.
Tous les chevaux reprirent le travail après une période de convalescence d'au moins quatre mois et douze jours avec une amélioration sensible de leur forme et de leurs performances. Une complication post chirurgicale fut constatée pour un cas: apparition d'une prolifération osseuse à l'extrémité d'une apophyse réséquée. Cette prolifération fut supprimée au cours d'une seconde intervention sans séquelle ultérieure.

ZUSAMMENFASSUNG


ACKNOWLEDGEMENTS

We are particularly indebted to Mrs. Mavis Whitehead for her skilled technical and surgical assistance and most grateful to Miss P. M. Ellis and Lt-Col. J. A. Langley for anaesthetising the cases.

REFERENCES


AN EVALUATION OF THERAPY FOR BACK PROBLEMS IN HORSES

L.B. Jeffcott

The previous paper outlined some of the inherent difficulties involved in making accurate diagnosis of thoracolumbar (TL) conditions in horses. This contribution reviews some of the more commonly used methods of therapy and expresses some personal opinions on their efficacy. This whole area is fraught with difficulty and confusion due to the problems of diagnosis and the fact that there are very few, if any, controlled therapeutic trials that have yet been performed. As a result there is a general lack of objectivity in many of the claims made about success of different forms of treatment. The final part of the paper considers the prognosis and outcome of a series of horses with back problems that were subsequently followed up.

METHODS OF THERAPY

The range of techniques currently available for treating TL disorders in horses is extensive (Table 1). However, many horses are given a combination of these methods at the same time or concurrently (e.g. medical treatment plus some form of physiotherapy). There is no doubt that sometimes some of the methods listed are used simply as a placebo. Another facet of this business is that at times one form of therapy seems to become fashionable with owners and trainers. A few years ago it was to request surgery, then swimming became very popular followed by manipulative therapy. It looks now as if the trend for the future may well be in natural medicine (i.e. acupuncture and laser techniques). It should also be noted that much of this type of treatment is performed by non veterinarians; some are qualified physiotherapists but a considerable proportion are not.

Table 1 – List of techniques known to be used for treatment of back problems in horses.

| REST: | - box rest followed by period at pasture |
| MANAGEMENT: | - replace saddle; use sheepskin numnah |
| | - change stable and work routine |
| | - attempt reschooling |
| | - attention to rider’s equitation |
| MEDICAL TREATMENT: | - NSAI drugs by oral, parenteral or local injection |
| | - Sclerosing agents injected locally |
| PHYSIOTHERAPY: | - Heat therapy – infra-red or heat lamp |
| | - poultice, charges or counter-irritation |
| | - shortwave diathermy |
| | - solarium |
| | - Ultrasonic therapy |
| | - Faradism |
| | - Cyclotherapy (Niagara, Equissage) |
| | - Swimming and hydrotherapy |
| | - Graduated exercise programme often combined with other forms of physiotherapy |
| MANIPULATIVE THERAPY: | - Osteopathy/chiropractic in the standing animal or under general anaesthetic |
“NATURAL MEDICINE”:
- Acupuncture – conventional
- laser beam therapy
- Radionics “Black box”
- Homeopathy
- Iridiology

SURGERY:
- Compounded fracture of withers

REST
This simple recourse to a period of rest usually proves to be all that is necessary in most kinds of TL complaint. In some animals certain types of physiotherapy may be beneficial and in others the periodic use of anti-inflammatory medication is indicated. However, the assessment of any line of therapy for back injuries is difficult because of the tendency for spontaneous recovery to occur. Many of the earlier veterinary practitioners and farriers advocated rest as the simplest and most effective remedy for back troubles. For example, Lupton (1876) recommended:

“upon the earliest indication being perceived of the spine having been injured, the horse should be instantly thrown up for a least six months. The animal should be placed in a roomy loose box; it should have the hair cut off close over the seat of injury and the place should be constantly moistened by means of cloths dipped in a lotion, composed of tincture of arnica two ounces and water one pint. This remedy with softened food of the most supporting kind, should constitute the treatment for the first month of recovery.”

In earlier times store was also placed on the frequent bleeding of the animal, the application of cold charges, and the promotion of sweating. After the initial signs of strained back had improved, the use of mild blisters or embrocations were recommended, apparently with beneficial effects.

For horses with musculoligamentous damage, I usually recommend a period of rest in a loose box until the signs of acute pain have subsided. After this the animal can be turned out in a small paddock or yard for a period ranging from one to twelve months depending on the site and extent of the injury present. Often no other specific therapy is necessary, but a gradual return to exercise is always advisable. The application of heat by way of an infra-red lamp is sometimes reported to be of benefit in the acute stages of muscle strain or for other soft tissue injury to the back.

MANAGEMENT
The general management of a horse with a potential back problem is very important. Many “backy” horses have a temperament or psychological component to the clinical picture particularly those with a so-called “cold back” and the use of a sheep skin numnah is frequently found to be beneficial. Another practice is to give the animal a short period of lunging after it has been tacked up and before it is mounted.

A change of stable routine and work often seems to be beneficial and this can involve a reschooling or changing the type of exercise for a period in an attempt to renew enthusiasm for work (e.g. by sending the animal hunting or swimming). The replacement of the saddle often alleviates low grade back troubles. Many owners spend a good deal of money on a heavy saddle which is really designed for more advanced dressage when all they need is a lighter general purpose one for hacking and hunting.

Once it has been decided to put the horse back into work a graduated programme of exercise is always advisable starting with ground work and lunging to build up the back muscles and improve the animal’s suppleness. In this regard the use of a chambon to lower the head and neck carriage during lunging can be very helpful. Also massage or gentle strapping of the back
muscles after exercising is a useful procedure in horses convalescing from a TL disorder.

MEDICAL TREATMENT
In horses with acute or severe back pain (e.g. fractured spinous processes of the withers) parenteral analgesic medication is indicated for the first few days or so. After this oral nonsteroidal anti-inflammatory (NSAI) drugs, such as phenylbutazone, naproxin, meclofenamic acid and orgotein, can be given for as long as the horse is really uncomfortable. After this the animal should be rested and further oral NSAI drugs only given in association with a return to work. Longterm therapy with these drugs is contraindicated. Local injection of longacting cortico-steroids into the interspinous spaces in cases of overriding spinous processes has been used quite successfully by some practitioners (Hartley, 1973).

The practice of using sclerosing agents locally between the spinous processes and into the ventral sacroiliac ligaments has been used with mixed results.

PHYSIOTHERAPY
The application of heat by various means has been used for acute back injuries for many years (Table 1), although whether they have any real advantage over rest and medication is equivocal. Good results have been reported for various methods of physiotherapy, such as faradic stimulation of muscles (Strong, 1956; Fraser, 1961), shortwave diathermy and ultrasonic therapy. Deep massage by cyclotherapy has also been used particularly in the United States (Burns, 1967) and more recently therapy by swimming horses has been advocated (Hartley, 1973; Swanstrom and Lindy, 1973). However, no controlled trials on the benefits of these lines of physiotherapy compared with rest or not treatment at all have yet been made. I have the impression that faradism, cyclotherapy and swimming are valuable aids to recovery from basic problems once the acute signs and pain have subsided. Recently other techniques such as pulsed-high frequency electromagnetic energy and magnetic field therapy are being used for soft tissue injuries, although it is difficult to judge their efficacy at this stage.

A gradually increasing programme of exercise following a back injury is always advised. Initially lunging exercise in a sand ring is recommended to assist in building up the back and quarters muscles and improving spinal flexibility. This can be coupled with a course of physiotherapy and, if there has been some overriding of the spinous processes or sacroiliac arthroses, then a month's course of an oral anti-inflammatory drug is often beneficial.

MANIPULATIVE THERAPY
A method of treatment for equine back problems which is becoming increasingly popular is that of chiropractic or osteopathy. It is said that many animals showing poor performance and/or back pain have one or more vertebrae subluxated or "put out" of alignment particularly in the caudal lumbar region. (L₄-L₆) (Herrod-Taylor 1967; Watson 1975, personal communication; Paterson 1979, personal communication). It is claimed that these vertebrae can be "put back" into their correct position by means of a manipulative technique which involves sharp pressure being applied to the dorsal tip of each affected summit. From an anatomical point of view this claim is unacceptable because, either naturally or by manual manipulation, movement of individual vertebrae or their spinous processes is contrary to all that has been considered here. It seems more realistic to explain this malalignment of the dorsal midline of the back as some alterations in postural tone between the right and left epaxial musculature. The increased tone or spasm caused by local muscle injury of the longissimus dorsi could produce a slight curvature of the horse's spine (i.e. spastic scoliosis). This situation would lead to abnormal biomechanical stress on the TL spine (i.e. the bow) and so effect normal locomotor pattern and performance.

The results of chiropractic manipulation of horses with back problems are reported to be dramatic and instantaneous although the incidence of recurrence of symptoms is, apparently, high (Herrod-Taylor 1967; Watson 1975, personal communication). The technique is now
routinely performed in most European countries, the United States, Australia and South Africa but no critical or controlled trails of the efficacy or mode of action of the technique have yet been published. It is possible that the sharp pressure applied to one or more of the spinous summits and muscles in the affected area creates a reflex contraction in the back muscle of the contralateral side. This would produce a state of transient muscle tension thereby eliminating the previous postural imbalance. Both sides would have equal muscle tone again and so be able to relax, the spastic scoliosis disappearing and the horse's performance instantly improved. However, this is only a tentative theory and the whole matter needs further investigation before it can be satisfactorily resolved.

**“NATURAL” MEDICINE**

Natural or "fringe" medicine is also becoming increasingly used to treat horses with back problems. In Japan the technique of acupuncture in horses has been used with apparent success for muscular problems of the back. Long Japanese needles (5-15 cm) are used; 10 to 20 needles are used for one to two minutes each and the needles must be continuously stimulated. The treatment which takes about half an hour is repeated two to three times in a week, and faradic therapy may also be given at this time. The pain usually takes about 48 hours to disappear (Nagata, 1975). Some preliminary work on acupuncture has also been carried out in the United States, and a good response to treatment was reported in cases of dorsolumbar myositis (de Groot and Bresler, 1973; Gideon, 1977). These workers concluded that the technique did work, but that correct diagnosis and proper judgement of treatment application were essential for effective acupuncture therapy. More recently the use of lasers are being introduced to produce the same sort of analgesic effect.

One other line of treatment, which appears to have no veterinary basis at all, is the so-called "black box". This technique involves sending a hair from the mane of the patient to the operator of the black box. The hair is placed in the box and then it is claimed that an exact diagnosis of the animal's condition can be made and the horse can be put on to treatment at the same time. It is hard to envisage how this technique can have any medical or scientific foundation although there are a number of proponents in the U.K. and U.S.A. who claim beneficial results.

**SURGERY**

For crowding and overriding of the dorsal spinous processes in the thoracolumbar spine, surgical resection of part of the summits was first described by Roberts (1968) to relieve pain and thereby eliminate the associated lameness. He performed the technique on 29 cases with apparently encouraging results. A slight modification of this method has recently been described by Jeffcott and Hickman (1975).

**Technique of a resection of the summits of overriding dorsal spinous processes:**

With the animal in left lateral recumbency the technique involves a midline skin incision directly over the spinous summits to be resected. The skin edges are retracted and haemorrhage controlled with artery forceps or by diathermy. The supraspinous ligament is identified, divided longitudinally and dissected from the summits of the dorsal spines. The interspinous ligaments and any false joint capsules are then severed. The insertions of longissimus dorsi muscles are dissected from the lateral edges of the dorsal spines with a Jones periosteal elevator. The left longissimus dorsi muscle is retracted upwards (i.e. laterally) with a Patons retractor. This effectively exposes the dorsal spines and enables 3 to 4cm of each spine to be resected using an oscillating Stryker bone saw fitted with iliac bone graft cutting blade. The resected portion is then removed by grasping it in Farabeuf's sequestrum forceps and separating any remaining attach-
ments of the interspinous ligaments and adhesions between the adjacent spines with Mayo's angles scissors. Finally the cranial and caudal edges of each resected spine are smoothed and bevelled off using the oscillating saw or Wilm's gouge forceps.

Prior to closure some antibiotic powder is sprayed into the wound. The supraspinous ligament is coapted using double thickness single interrupted chromic cat gut or linen sutures (4 metric) and the skin with single interrupted horizontal mattress sutures of braided nylon (6 metric). The incision is then covered with an Elastoplast waterproof porous wound dressing. The whole area is protected with a large pad of gamgee which is stuck to the skin using Vi-Drape adhesive.

The gamgee pad is usually removed on the evening or the day after surgery and the airstrip dressing on the third or fourth post-operative day. If any excessive exudation or suppuration from the wound occurs a swab is taken for bacteriological examination. The skin wounds heal satisfactorily in most cases. In a few a small pocket of infection may develop and wound breakdown results, but it quickly responds to topical applications of an antibiotic selected according to the organisms present. Occasionally a number of small stitch abscesses may develop in the supraspinous ligament. After the sutures are removed the wound heals rapidly.

The skin sutures are removed at 10 to 14 days. At this time a slight subcutaneous swelling still persists, but within two months it is difficult to detect the operation scar and there is good union of the supraspinous ligament. After the second or third post-operative day the horses are exercised at the walk for 15 to 20 minutes. This is gradually increased over the next month to 45 to 60 minutes. They are gradually returned to ridden exercise four months post-operatively and should be in full work and jumping again within another two months.

**OUTCOME AND PROGNOSIS**

Although there are still great difficulties in evaluating the diagnosis, an assessment for prognosis of the various TL conditions of horses should be made. In a series of 190 horses (Jeffcott, 1977) with a chronic back complaint from which clinical follow-up information was obtained, some 57% recovered completely irrespective of the diagnosis and treatment given and in only 17% was there no improvement shown at all.

The most common regimen of treatment for all 190 cases was rest or no specific therapy at all, and in only 11% was some form of physiotherapy given. This was chiefly in the form of faradic treatment, although swimming was successfully used in a few horses.

The highest recovery rate was in those cases where no specific diagnosis could be established (78%), whilst the lowest was in those with spondylosis (9%). As might have been expected there was a good recovery (73%) with a comparatively low recurrence rate (25%) in the group of soft tissue injuries (i.e. the muscular and ligamentous damage to the back). The highest incidence of recurrence was in the horses with spondylosis (91%) despite their receiving anti-inflammatory medication and few (only 9%) returned to full work.

The full recovery rate for horses with sacroiliac strain (45%) was considerably less than that for other soft tissue injuries (73%), but was also lower than that reported for the overriding dorsal spinous process cases (57%). The likelihood of continuence or recurrence of clinical signs was higher for sacroiliac strain (45%) than for overriding (37%) but a greater percentage of anti-inflammatory medication was used in this latter group.

For the condition of overriding of the dorsal spinous processes a comparison of the outcome of surgical and conservative treatment was carried out. The overall recovery rates of these two groups of cases was very similar. The surgical cases, which generally comprised the more severely affected horses tended to make better progress and a greater percentage returned to full work in this group. Nevertheless, it should not be forgotten that the surgical cases all received 4 to 6 months rest by way of convalescence, and this was the principal mode of treatment used in the medical group. It would therefore appear from these results that surgical treatment for overriding dorsal spinous processes frequently does not provide any major advantage over the
conservative approach to therapy. The cases which showed the best response to surgery were those in which only one or at the most two spinous processes were resected. In these horses the overriding was confined to just two or three summits and did not extend from the midback to the lumbar region.

CONCLUSION

There is undoubtedly a tendency to spontaneous recovery of back problems in horses similar to the situation in man. The simple recourse to a period of rest followed by a graduated programme of exercise is all that is required in many cases. The technique of physiotherapy, including chiropractic manipulation, appears subjectively to be of therapeutic benefit in some cases, but controlled trials are necessary to gain a more objective assessment. Surgical resection of overriding spinous processes should only be carried out on selected cases and where the diagnosis has been confirmed by radiological examination and local anaesthesia of interspinous spaces. Further studies on the biomechanics of the vertebral column and pathology of TL injuries are essential to better understand pathogenesis and from this sounder principles for therapy can be established.

REFERENCES
Seckington, I.M. (1975) personal communication.
SECTION 3

CONDITIONS AFFECTING THE PELVIC GIRDLE.


SECTION 3 CONDITIONS AFFECTING THE PELVIC GIRDLE

In this section the material largely involves radiological investigation of chronic pelvic lameness and its relation to diagnosis and prognosis. One of the important and difficult to diagnose forms of hindlimb lameness with poor performance and low back pain is due to sacroiliac damage. The method used for radiographic evaluation was found to be inadequate and a technique of linear tomography for the lumbosacral spine was developed which provided considerable improvement.

The general lack of information on the sacroiliac joint of the horse prompted the first detailed investigation into the normal morphology and histology of this joint. This study was followed up by comparing the normal findings with horses showing clinical signs of sacroiliac damage. It is interesting that the underlying lesion in clinically affected horses is not usually an arthrosis, but a mild instability at the sacroiliac joint. This results in a lack of hindlimb impulsion and low grade, intermittent lameness or poor performance.

Statement on Share of Work:

Paper 18 - The paper on pelvic lameness (Jeffcott, 1982) was written on my own clinical material without assistance from other authors.

Papers 19-21 - The papers on sacroiliac anatomy by Dalin and Jeffcott (1986) and Ekman et al (1986) were part of a collaborative project carried out during the year I spent in Sweden. The project was planned and supervised by myself, but much of the work was carried out by Göran Dalin and Stina Ekman. I played a major role in the publication of the three papers.

Papers 22-23 - The papers on sacroiliac tomography were planned, executed and published by myself.

Paper 24 - The paper on sacroiliac pathology (Jeffcott et al., 1985) involved a collaborative study on cases presented to me in the UK and Sweden. I coordinated the project and prepared the paper for publication.
A series of 110 horses mostly with chronic lameness due to a pelvic injury were referred for radiological examination. The technique of radiography of the lumbosacral and pelvic region with the animal anesthetized in dorsal recumbency is described. It was found that good quality pelvic radiographs not only were valuable for diagnosis but also proved of assistance in assessing prognosis.

Traumatic damage to the pelvis was the most common reason for referral and in 37% of horses evidence of fracture was found. The prognosis in these cases depended on the age of the animal and site of the fracture but was generally quite good with an overall complete recovery rate of 51%. The other important condition seen was that of chronic sacroiliac strain (41%) which caused mild, intermittent hindlimb lameness and a loss of performance. Clinical diagnosis was frequently difficult to achieve and the radiological changes were minimal. Musculoligamentous damage to the pelvis was diagnosed in 15.5% of cases. Congenital or developmental defects of the hip were rarely recorded and only one case of primary osteoarthritis was seen.

Pelvic Lameness in the Horse

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England

Introduction

There are few detailed accounts concerning the cause and outcome of pelvic lameness in the horse. Lewis and Heinze described a method of radiography of the pelvic region and these authors also reported on 116 cases in which the principal diagnosis was pelvic fracture. The incidence of pelvic problems in horses is not well documented, although Vaughan recorded 4.4% of pelvic damage in 835 horses referred for hindlimb lameness. A survey carried out by the British Equine Veterinary Association showed an incidence of 0.9% hip and quarter lameness in a series of 6588 lameness cases.

Specific diagnosis of pelvic damage is often complex particularly in the more chronic cases and the value of radiography can be of considerable assistance in both diagnosis and prognosis. The purpose of this paper is to report on some of the important clinical and radiological features of a series of mainly chronic cases and to describe a practical system of radiography.

Clinical Material

During the last 8 years a total of 1857 horses have been referred to the Clinical Department of the Equine Research Station for radiological examination and a second opinion. Of these there were 404 horses with hindlimb lameness of which 110 had some damage to the pelvic region. A clinical examination was performed and radiography of
the pelvic, sacral and caudal lumbar regions carried out with the animal under general anesthesia. Routine hematological and biochemical examinations were undertaken as well as serological tests for *Brucella abortus* antibodies in serum. Follow-up examinations were carried out in only a few cases, but information on the outcome was obtained from the referring veterinarians and owners in 92% of cases.

**Radiological Examination**

The equipment used was a Siemens Triplex Optimatic 1023 generator with the x-ray tube mounted on a 3D overhead suspension. The tube was capable of 150 kV and 1250 mA and had a high speed rotating anode (8000 rpm) with fine and broad focal spots (0.6 and 1.2 mm respectively). Rare earth intensifying screens (Kodak orthochromatic film). The range of exposures varied from 100 to 150 kV and 250 to 400 mA for adult horses. In order to assist in reducing secondary radiation crossed high ratio (12:1) grids were used. A sheet of lead was placed behind to prevent back scatter and a lead cone was placed in front of the light beam diaphragm. A focus-to-film distance of 130 cm (51 in) was employed and a lead intensifying screen [0.005 cm (0.001 in)] was placed in front of the grids to help eliminate lower intensity scatter and so improve radiographic quality.

Lateral projections of the pelvic region with the horse standing proved to be of little or no diagnostic value, except in cases of sacral fracture. It was necessary to use a ventrodorsal view and place the horse under general anesthesia in dorsal recumbency. This routine involved premedication with 0.05 ml/kg acetylpromazine maleate followed by induction with 1 g/100 kg thiopentone. Anesthesia was maintained with halothane and oxygen using a circle-absorber. The legs were hobbled and the horse placed on the pallet [213 x 131 cm (83.8 x 51.5 in)] of a forklift so that it could be transported from the anesthetic box to the radiographic examination room (Figs. 1 & 2). Careful positioning of the horse in dorsal recumbency (i.e., "frog leg")
Fig. 2A & B — Photographs of horse in dorsal recumbency on the pallet of forklift truck, which is supported on wooden trestles during the radiographic examination.

Figs. 2A & B — Photographs of horse in dorsal recumbency on the pallet of forklift truck, which is supported on wooden trestles during the radiographic examination.

### Table 1

<table>
<thead>
<tr>
<th>Category of Diagnosis</th>
<th>No. of Cases</th>
<th>Percent Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvic Fracture</td>
<td>41</td>
<td>37.3%</td>
</tr>
<tr>
<td>Osteoarthritis (coxitis)</td>
<td>1</td>
<td>0.9%</td>
</tr>
<tr>
<td>Epiphysiolysis</td>
<td>1</td>
<td>0.9%</td>
</tr>
<tr>
<td>Muscle/ligamentous Damage</td>
<td>17</td>
<td>15.5%</td>
</tr>
<tr>
<td>Chronic Sacroiliac Strain</td>
<td>45</td>
<td>40.9%</td>
</tr>
<tr>
<td>Pelvic Abscess</td>
<td>2</td>
<td>1.8%</td>
</tr>
<tr>
<td>Miscellaneous Conditions</td>
<td>3</td>
<td>2.7%</td>
</tr>
</tbody>
</table>

position) was essential to avoid any lateral curvature or deviation of the caudal lumbar spine and sacrum (Fig. 3A). Because of the size and variable density of the different anatomical regions it was usually necessary to take at least six radiographs to give an adequate survey of the pelvic and lumbosacral region. After radiographing the pelvic canal each hip joint was taken separately and the limb involved tipped down toward the cassette (Fig. 3B) to give a better view of the rim of the acetabulum, the hip joint and proximal femur (Fig. 4). The horse has a deep, semicircular hip joint with a prominent acetabular fossa. A small area of mild radiolucency could usually be detected in the femoral head near the insertion of the teres ligament.

The lumbosacral articulation was generally outlined satisfactorily, but it was difficult to clearly delineate the sacroiliac joint space. The spinous processes of the sacral vertebrae were easily defined, although the outline of the body of the sacrum itself was often difficult to visualize (Fig. 5). The centers of ossification at the tubera coxae, tubera ischii and femoral epiphyses were usually closed by 2 years of age. The pelvic symphysis did not begin to close until after 2 years.
and was not completely fused until the end of the sixth year.

Results

A breakdown of the main categories of diagnosis is shown in Table 1 and the details of sex, age, type, use and mean body weight of the four major categories of diagnosis in Table 2. These cases had all been referred for radiological evaluation of a suspected bone lesion and so the incidence of soft tissue injuries (58%) was unexpectedly high. The results of the hematological and biochemical examinations were not usually of positive diagnostic assistance. However, changes in the muscle enzymes were recorded in some cases of muscular damage and a leukocytosis was noted in the presence of a focus of infection. All the horses were checked serologically for brucellosis and, although there was sometimes evidence of previous infection experience, no cases of active infection were recorded.

Bone Lesions

PELVIC FRACTURES

The suspicion of a fracture was the most important reason for referral. The clinical picture in many cases was variable because of the wide range of sites involved (Table 3). However, most horses had a history of trauma or a fall; persistent unilateral lameness with muscle wastage from the affected quarter and pain on flexion of the limb were common features. Most of the cases were long-standing ( > 3 months) and so crepitus was not usually demonstrable at the time of referral, although it was often reported in the history. Rectal palpation was only of positive diagnostic assistance in pubic and acetabular fractures when some deformity to the pelvic canal was discernible. The fracture sites involved have been depicted diagrammatically in Fig. 6.

The majority of horses in this group were 3 years old or less and principally Thoroughbred in type (Table 2). There was a sex ratio 27:14 male/female which may indicate a

Continued
TABLE 2
Distribution of Age, Sex, Breed, Use and Mean Body Weight
According to the Four Main Categories of Diagnosis

<table>
<thead>
<tr>
<th>Category of Diagnosis</th>
<th>Pelvic Fracture (41)</th>
<th>Musc/lig Damage (17)</th>
<th>Chronic Sacroiliac Strain (45)</th>
<th>Other Pelvic Injuries (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SEX:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male — entire</td>
<td>9</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>gelding</td>
<td>18</td>
<td>4</td>
<td>34</td>
<td>2</td>
</tr>
<tr>
<td>Female</td>
<td>14</td>
<td>8</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td><strong>AGE:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-3 years</td>
<td>22</td>
<td>10</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4-6 years</td>
<td>8</td>
<td>3</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 6 years</td>
<td>11</td>
<td>4</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td><strong>TYPE:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thoroughbred</td>
<td>31</td>
<td>8</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>Partbred</td>
<td>3</td>
<td>3</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Pony</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td><strong>USE:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flatracing</td>
<td>11</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>NH racing*</td>
<td>8</td>
<td>0</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Showjumping</td>
<td>3</td>
<td>2</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Eventing</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>At stud</td>
<td>9</td>
<td>4</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>9</td>
<td>4</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td><strong>BODY WEIGHT:</strong> (mean, kg)</td>
<td>442</td>
<td>455</td>
<td>528</td>
<td>465</td>
</tr>
</tbody>
</table>

* NH racing = National Hunt racing (i.e., Steeplechase, Hurdling and Point-to-point racing).

TABLE 3
The Location of 50 Sites of Pelvic Fracture in 41 Horses According to Their Sex, Age and Type

<table>
<thead>
<tr>
<th>Fracture Site</th>
<th>No.</th>
<th>Sex</th>
<th>Age (yrs)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>F</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>Ischium Body</td>
<td>7</td>
<td>7</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Tuber ischii</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Ilium Wing</td>
<td>11</td>
<td>8</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Shaft</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Tuber coxae</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Tuber sacrale</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pubis</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Acetabulum</td>
<td>7</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Sacrum Body</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Wing</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Femoral Head</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
TABLE 4
Follow-up Information on the Recovery and Outcome of 110 Cases of Pelvic Lameness

<table>
<thead>
<tr>
<th>Pelvic Fracture (41)</th>
<th>Musc/lig Damage (17)</th>
<th>Chronic Sacroiliac Strain (45)</th>
<th>Other Pelvic Injuries (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. (%)</td>
<td>No. (%)</td>
<td>No. (%)</td>
<td>No. (%)</td>
</tr>
<tr>
<td>Complete Recovery</td>
<td>21 (51%)</td>
<td>8 (47%)</td>
<td>21 (47%)</td>
</tr>
<tr>
<td>Partial Recovery</td>
<td>10 (24%)</td>
<td>3 (18%)</td>
<td>6 (13%)</td>
</tr>
<tr>
<td>No Improvement</td>
<td>10 (24%)</td>
<td>4 (23%)</td>
<td>11 (24%)</td>
</tr>
<tr>
<td>No Follow-up Information</td>
<td>0 (0%)</td>
<td>2 (12%)</td>
<td>7 (16%)</td>
</tr>
</tbody>
</table>

TABLE 5
The Recovery Rates of 50 Pelvic Fracture Sites in 41 Horses

<table>
<thead>
<tr>
<th>Fracture Site</th>
<th>No.</th>
<th>Complete</th>
<th>Partial</th>
<th>No Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ischium Body</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Tuber ischii</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Ilium Wing</td>
<td>11</td>
<td>8</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Shaft</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Tuber coxae</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tuber sacrale</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pubis</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Acetabulum</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Sacrum Body</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Wing</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Femoral head</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>23</td>
<td>12</td>
<td>15</td>
</tr>
</tbody>
</table>
PELVIC LAMENESS (Continued)

Fig. 4 — Ventrodorsal radiograph and accompanying diagram of the left hip of 9-year-old Thoroughbred gelding.
Fig. 5 — Ventrodorsal radiograph and accompanying diagram of the lumbosacral and pelvic area of 4-year-old pony to demonstrate the normal radiographic features.
higher than expected frequency of fractures occurring in mares and fillies. The wing of ilium was the most common site of fracture, although the ilial shaft, tuber coxae and tuber sacrale were also involved occasionally. Wing of ilium fractures were more often seen in older horses (>6 years) and this was a common sequel to an accident jumping at speed (i.e., hunting, steeplechasing, etc.) (Fig. 7). The pubic and acetabular fractures were almost exclusively seen in youngsters and there was a particularly high incidence of acetabular fractures in fillies (Figs. 8A & B). These latter cases often had a history of slipping over or “doing the splits.” The body of the ischium was another site of fracture seen principally in young animals and these were found only in males. In older horses this type of fracture tended to heal by fibrous union, often with considerable displacement of the bony fragment (Fig. 9). This was not a good site for bony union although the horses usually became reasonably sound for general riding work but proved unsatisfactory for dressage. However, fractures of the tuber ischilii invariably carried a very good prognosis (Fig. 10).

A conservative line of treatment was employed on all cases. This involved a prolonged period of rest followed by a gradually increasing program of exercise. The animals were box rested for about 3 months and then turned out into a small paddock or yard for another 3 months or so. In addition to the
Flg. 7 - Radiograph of a malunion fracture of shaft of the left ilium in a 6-year-old Thoroughbred mare which sustained a bad fall during a race 9 months previously. Note also the increased joint space of the sacroiliac joint. The animal became sound enough for breeding but not for a return to racing.

osteoarthritic exercise program some horses were given various forms of physiotherapy (i.e., swimming, faradism, cyclotherapy). The overall recovery rate was encouraging and satisfactory healing occurred in over 50% of cases. An example of fracture repair and remodeling in the ischium of a yearling Thoroughbred colt is shown in Figs. 11A & B).

OSTEOARTHRITIS

Only one case of lameness due to early osteoarthritis (coxitis) of the hip was encountered in a 6-year-old Thoroughbred brood mare. There were changes of mild periosteal reaction around the acetabular brim but no serious damage to the articular surfaces of the hip. The animal was treated with a 2-month course of an analgesic, antiarthritic medication (i.e., oral phenylbutazone) and
Fig. 9 – Radiograph of malunion fracture of the distal shaft of the ilium in an 8-year-old partbred eventer gelding. Radiographic examination at 12 months showed no change.

Fig. 10 – Radiograph of fracture of the tuber ischil in a 6-year-old Thoroughbred steeplechase gelding. After 3 months rest the animal became sound and returned to racing.

Fig. 11A – Radiograph of comminuted fracture of the body of the ischium in a 9-month-old Thoroughbred colt. There also appears to be some involvement of the caudal part of the acetabulum.

Fig. 11B – Follow-up radiograph of the same colt illustrated in Figure 11A taken 6 months later. The radiograph shows excellent healing and remodelling of the fracture site.
Fig. 12A — Radiograph of severe secondary osteoarthritis in a 2-year-old Thoroughbred filly following fracture through the acetabulum and ischium.

Fig. 13 — Chronic osteoarthritis of the hip (coxitis) in an aged pony gelding. Note the marked chronic reaction around the acetabular rim as well as the erosion of the articular surface.

she improved satisfactorily to continue as a brood mare. A few cases of secondary osteoarthritis resulting from poor fracture-healing were seen (Figs. 12A & B) and one aged pony with prolonged history of stiffness, lameness and laminitis had severe changes of osteoarthritis in one hip (Fig. 13) at postmortem.

OTHER BONE DAMAGE

One case of epiphysiolysis capitis femoris was recorded in a 6-month-old Thoroughbred colt foal. The clinical signs were principally of stiffness of the hindlimb action with poor muscle and skeletal development of the quarters in relation to the rest of the body. Radiologically there was severe change of radiolucency suggesting a wide area of lysis.
in both proximal femoral epiphyses (Fig. 14). No damage to the acetabulum or other bones of the pelvis was seen and no similar lesions in other growth plates of the body. The colt was eventually destroyed at about 10 months of age as it failed to show any clinical improvement. Three other cases showing miscellaneous damage to the pelvis were encountered. The first involved some low grade presumably traumatic damage to right tuber coxae in a 6-year-old riding horse. This was not associated with demonstrable fracture and the animal made an uneventful recovery. There was a yearling Thoroughbred colt with hindlimb lameness and pain in the pubic region which showed some separation of the pelvic symphysis radiographically. This responded to a conservative line of treatment.

The final case was a 5-year-old horse showing signs of poor performance and hindlimb action which showed an unusually wide sacrolumbar joint space. No other radiological abnormalities were noted and the exact significance of the sacrolumbar laxity was equivocal.

Soft Tissue Injuries

This group of injuries was associated with mild to moderate hindlimb lameness of 2 to 3 months standing in which no clinical or radiological damage could be found in the caudal lumbar, stifle or distal limbs, and no radiographic abnormalities were present in the pelvis or sacrum. Furthermore no areas of severe pain or swelling were detectable by external palpation or on rectal examination. Atrophy of the gluteal and thigh muscles was not usually a feature and no asymmetry of the pelvis was noted. In most instances there was no appreciable increase in lameness following flexion of the hindlimbs. Following an exercise test of 10 to 15 minutes lunging on a soft sand ring, a 2- to 3-fold increase in muscle enzymes (creatine kinase, CK, and aminoaspartate transferase, AST) was demonstrable within 18 hours in some but not all horses. The diagnosis made was of some soft tissue damage (i.e., musculoligamentous in origin) to the pelvic region and the outcome after a further convalescent period of 2 to 3 months was favorable.

The horses with more severe signs of lameness usually involved ligamentous injury to the pelvic region and carried a much less hopeful prognosis. One example was a large partbred eventer mare [170 cm (66.9 in) in height] which exhibited marked and persistent lameness for several weeks after a fall with pain and swelling over the hip joint and muscle atrophy from the quarter. Under general anesthesia some instability of the affected hip was demonstrable, but no significant radiological damage was seen. The synovial fluid was increased in volume, had reduced viscosity and contained many red blood cells. A clinical diagnosis of rupture of the teres ligament was made. The animal
Fig. 15 - Caudal view of the quarters of a 5-year-old Thoroughbred cross gelding with chronic sacroiliac strain showing asymmetry with apparent tilting of the tuber down to the left and muscle atrophy of the left gluteal mass.

was destroyed, but a postmortem was not carried out to confirm the clinical findings.

There were two cases of a local focus of infection in the quarters which showed lameness, some pain and no radiological findings. However, there was raised white count and neutrophilia and both animals responded to administration of broad spectrum antibiotics.

CHRONIC SACROILIAC STRAIN

Horses with chronic sacroiliac strain usually presented with signs of poor performance, intermittent lameness or a back problem. They sometimes had a history of severe pain in the pelvic or sacroiliac region associated with marked hindlimb lameness. A fall or similar incident was often reported although signs were not always recognized for some time afterwards. The animal's performance was affected, particularly at slower paces or during dressage. An intermittent, sometimes shifting hindlimb lameness associated with stiffness and rigidity of the spine in one direction was seen in large animals [162 to 172 cm (63.7 to 67.7 in) in height] with long backs and poor muscling of the quarters. The tail was sometimes held across the midline usually to the affected side. In the acute stages pain could be evinced by applying pressure to the midline just in front of the tuber sacrale, by pressing down over the tuber coxae or by flexing the affected leg. Once the condition was chronic, no pain could be elicited in the lumbosacral region and hyperflexion of the hindlimbs was rarely resented. However, there was often a reduction in the normal range of flexibility of the thoracolumbar spine due to a resentment of reluctance to extend or dip the back (i.e., dorsiflex). Most cases showed some degree of asymmetry of the hindquarters due to a malalignment or apparent tilting of the pelvis. This could be seen as a lowered tuber coxae (ca 1-2 cm) on the affected side with some muscle atrophy of the gluteal muscles (Fig. 15).

At exercise there was often some stiffness in the back with dragging of one or both toes and a tendency to "plait" (i.e., the foot of the affected limb swings inwards in the anterior phase of the stride and is placed almost in front of the opposite hindfoot). Few cases showed consistent signs of hindlimb lameness, but slight dropping of the affected quarter was sometimes noted. A flexion (i.e., "spavin") test rarely produced any affect on hindlimb action. When ridden, horses showed evidence of stiffness of the hindlimb action with an apparent lack of impulsion from the quarters. In many longstanding cases, jumping was not seriously impaired and continued exercise did not seem to exacerbate the clinical signs. Many of these animals responded temporarily to administration of therapeutic doses of an anti-inflammatory drug such as phenylbutazone.

The radiographic features were usually minimal and involved increased joint space of the sacroiliac articulation sometimes with slight rotation of the pelvis or sacrum. In some instances signs of some early osteoarthritic change at the caudal edge of the joint were seen (Fig. 16A). Only two cases...
Fig. 16 A — Radiological changes of chronic sacroiliac strain in an 8-year-old Thoroughbred gelding. These two radiographs were taken during life (top) and at postmortem (bottom) and show a chronic arthrosis of the caudal aspect of the sacroiliac joints.

Continued
PELVIC LAMENESS (Continued)

Fig. 16B — The postmortem changes found in the caudal wing of the sacrum of the same case and for comparison, the articular surface of the sacral wing of a 7-year-old partbred eventer which did not show any clinical signs of sacrolilac strain.

became available for postmortem examination, but both showed similar findings; there was no obvious stretching of the sacroiliac ligaments, but noticeable new bone prolif-
eration was present at the caudal aspect of the sacral wing (Fig. 16B). This large spur of new bone was covered in cartilage and articulated with a similar, but smaller, spur on the opposite auricular surface of the ilium. The sacrolumbar articulation, hip joints and remainder of the caudal vertebral column showed no remarkable pathological abnormality.

Discussion

The range of conditions causing pelvic lameness in the horse is quite extensive and there seem to be some important differences between the various breeds. Another feature is that less developmental disorders of the pelvis are seen than in many other domestic species. For example, no cases of hip dysplasia were encountered here and only one report has been found in the literature in an Andalusian/Arab cross filly. The clinical and radiological features were very similar to those seen in the dog. The hip is rarely involved in the syndrome of osteochondrosis in spite of the fact that the condition is common elsewhere in the skeleton. Deformities of the hip have been reported in the Norwegian Dole breed. Lesions are usually bilateral with thickening of the capsule and shredding or absence of the teres ligament resulting in joint laxity, cartilage erosion and secondary joint changes, sometimes with dislocation of the femoral head. This condition may well have a genetic background. The only developmental condition seen here was a case of epiphysiolysis capitis femoris.

Primary dislocation of the hip is rare, presumably because of the strength of this joint and its associated ligamentous structures. When it does occur, it is usually seen in ponies and is often complicated by patellar fixation. Damage to the teres ligament without luxation is diagnosed in the United States, and the clinical signs are similar to luxation, but the hindlimbs are of the same length. The prognosis is always grave because of the loss of joint stability resulting in severe secondary joint damage. Jögi and Norberg reported on a Standardbred...
PELVIC LAMENESS (Continued)

colt with severe unilateral lameness of sudden onset that was attributed to a hip malformation. It seems possible in hindsight that this was misdiagnosed and was actually a case of traumatic teres ligament rupture, the pathological changes being consistent with laxity of the hip joint and producing the marked deformity of the acetabulum.

The very low incidence of primary osteoarthritis of the equine hip is perhaps surprising in an animal that lives and works into old age. Only one case report was found in a search of the recent literature which referred to a 14-year-old Quarter horse. Secondary hip arthritis is more common as a sequel to fracture or teres ligament rupture.

The value of pelvic radiography was not purely diagnostic as it proved here to be of considerable use in prognosis, particularly as regards fractures. Those fractures involving the tuber coxae and wing of ilium and the tuber ischii generally carried an excellent prognosis. There was a surprisingly good outcome in some of the acetabular and body of ischium fractures, notably in young animals (Fig. 11). However, the condition referred to as chronic sacroiliac strain was associated with a complex and often frustrating clinical picture. These animals were not apparently in any obvious pain, showed a distinct loss of performance potential with lack of hindlimb impulsion and intermittent or mild lameness. Clinical and pathological reports of sacroiliac strain have been made. The condition in its chronic state appears to be more associated with an instability and arthrosis of one or more articulations. Rooney feels it is probably an important and underrated clinical entity in harness racing horses. A good deal more research is required to assist in better means of establishing the diagnosis and the underlying pathogenesis so that a rational system of treatment and prevention can be established.

In conclusion there seem to be definite indications for equine pelvic radiography in the routine diagnosis of obscure hindlimb lameness providing there are good facilities and anesthesia. For the future an improvement in radiographic quality of certain areas
of the pelvis (e.g., sacroiliac and hip joints) should be attempted by such means as tomography or arthrography.

ACKNOWLEDGEMENTS

I wish to thank Lady Beaverbrook for her generosity and foresight in endowing the radiographic facility at the Equine Research Station, without her help none of this work would have been possible. I am also grateful to the Horserace Betting Levy Board and the International League for the Protection of Horses for contributing to costs of this investigation. It is a pleasure to acknowledge the skilled technical assistance throughout this study of Janet Butler and Mavis Whitehead. I am also particularly grateful to Billy Foster for his help with expert handling of the horses and to my other colleagues in the Clinical Department of the Equine Research Station. Finally, my thanks are due to the many practicing veterinarians who referred horses for radiological examination.

REFERENCES

Sacroiliac Joint of the Horse

1. Gross morphology

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With 9 figures and 5 tables

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Abstract

A total of 22 morphological features were described in the sacroiliac joints of 41 horses which had no history of any low back condition. Some dramatic differences in both sacral and iliac aspects of joint shape and articular surfaces were seen according to age. These findings were thought to be due to progressive cartilaginous degeneration. Only minor significant differences were seen between left and right sacroiliac joints or between breeds and sex. The iliac surface was more prone to degenerative change. Ankylosis of the joints was not recorded and the incidence of articular or para-articular spur formation was low.

Introduction

The importance of thoracolumbar injuries in horses is well recognised (Jeffcott, 1980) although the difficulties in establishing specific diagnoses vary with the type and sites of the lesions present. The involvement of the deep structures of the vertebral column are particularly problematic in this regard. Recently, special interest has been paid to the sacroiliac joint and to the degenerative changes attributed to causing chronic lameness or poor performance (Rooney, 1981; Jeffcott, 1982, 1983b; Jeffcott et al., 1985). The introduction of a method of linear tomography of the lumbosacral region (Strömberg et al., 1982; Jeffcott, 1983a) has assisted the radiological investigation of these cases although a definitive interpretation of findings involving the sacroiliac joint has been hampered by the lack of basic information on the morphology, functional anatomy and pathology of the joint. As yet, there has been no detailed anatomical description of the sacroiliac joint in the horse.

This report concerns the gross morphology of the sacroiliac joint in horses of differing breeds, age and sex. The details of morphometry and the histological appearance of the joints are the subjects of separate publications (Dalin/Jeffcott, 1986; Ekman et al., 1986).

Material and Methods

A total of 43 horses, which had no previous history of back problems, were examined. Two cadavers were used to show the local anatomic relationships of the sacroiliac joint. The lumbosacral
spines of these animals were frozen (−20°C) so that sagittal and transverse sections could be made of the sacroiliac region using a bone cutting band saw.

The lumbosacral region was collected from 41 horses after routine post mortem examination. The distribution of age and sex of the animals is shown in Table 1 and the causes of death are summarised in Table 2.

### Table 1
The age and sex distribution of 41 horses examined

<table>
<thead>
<tr>
<th>Age</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>Group 5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2 month</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>2 month to</td>
<td>10</td>
<td>8</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>29</td>
</tr>
<tr>
<td>2 year to &lt;4 year</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>4 year to &lt;6 year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>41</td>
</tr>
<tr>
<td>6 year to &lt;15 year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Mean age</td>
<td>0.05</td>
<td>1.3</td>
<td>2.4</td>
<td>4.7</td>
<td>11.8</td>
<td>41</td>
</tr>
<tr>
<td>SD</td>
<td>0.05</td>
<td>0.39</td>
<td>0.42</td>
<td>0.57</td>
<td>2.04</td>
<td></td>
</tr>
</tbody>
</table>

* 3 fetuses are excluded from the mean age calculation (9, 10 and 11 months of gestation).

### Table 2
The causes of death of the 41 horses in the study

<table>
<thead>
<tr>
<th>Category</th>
<th>Died</th>
<th>Euthanatized</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiopulmonary disorder</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Abdominal crisis</td>
<td>4</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>Neurological disorder</td>
<td>0</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Severe fracture</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sudden death and/or</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>negative PM findings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fetus</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>13</td>
<td>28</td>
<td>41</td>
</tr>
</tbody>
</table>

The sacroiliac joints were dissected out by disarticulating the hindlimbs at the hip joints and cutting through the caudal lumbar spine at approximately L5—L5 with a heavy duty bone cutting band saw. The muscle mass was roughly removed from the dorsal and ventral surfaces of the pelvis and sacrum before cutting the sacrosciatic ligaments. This loosened the wing of the ilium to some extent and facilitated the introduction of a knife to cut the ventral sacroiliac ligament which enabled the sacroiliac joint to be disarticulated. The wings of the ilium and sacrum were then trimmed down on the band saw so that only the area involving the sacroiliac joint was retained (Fig. 1). The specimens were examined and then stored in 10 per cent formalin in phosphate buffer. They were later photographed by mounting them in a copy stand (Leitz Reprovit IIa, Ernst Leitz GmbH, D-6330 Wetzlar, Germany) with their articular surfaces perpendicular to the optical axis of the camera and photographed using professional colour slide film (Kodak Ektachrome 50 EPY, Eastman Kodak Co., Rochester, NY 14650, USA). A millimetre scale was placed adjacent to the articular surface.

Preliminary macroscopic examination was made of the fresh specimens at the time of collection. The final examination was performed on the fixed specimens and from the photographs. Altogether 82 joints or 164 joint surfaces were analysed. The horses were divided into the following age groups:

- **Group 1** — Perinatal group (3 fetuses and 10 foals less than 2 months old) (n = 13);
- **Group 2** — Foals and yearlings (2 months to < 2 years) (n = 10);
- **Group 3** — Young horses (2 years to < 4 years) (n = 5);
- **Group 4** — Mature horses (4 years to < 6 years) (n = 7);
- **Group 5** — Older horses (6 years to < 15 years) (n = 6).
The morphological examination included visual appraisal of the joint shape, and assessment of the character of the articular surfaces and the identification of any spur formation at the joint edges. The features recorded are summarised in Table 3. The relative frequency of each characteristic was calculated for the whole material and within each age group. The intraindividual contralateral differences were noted (i.e. laterality) and a correlation between the findings in opposing sacral and iliac surfaces recorded. Finally, the incidence of the findings was studied according to sex and breed (i.e. Standardbreds and other breeds).

The statistical analyses were carried out by standard methods and included the calculation of standard deviation (SD), significance by Student’s t test, the Chi-square test and Kendall’s test for rank correlation to give the degree of probability (i.e. P value) (Armitage, 1971).
Fig. 2. a) Transverse section through the right sacroiliac joint in a 5 year old Arab/Welsh mare and b) sagittal section of the right sacroiliac joint in a 3 year old Standardbred mare. The plane of cut for the sagittal section which was midway through the joint is shown in a) as the dotted line (y-y'). The transverse section was cut along the line (z-z') as depicted in b). S — Os sacrum. I — Os ilium. L — Transverse processes of lumbar vertebrae. Mgm — M. gluteus medius. Mpm — M. psoas major.
Results

The sacroiliac joints were situated on either side of the midline between the auricular surfaces of the wings of the sacrum and ilium (Fig. 2). The joint surfaces were flattened and angled at approximately $30^\circ$ with the horizontal plane. The joints were essentially immobile even after cutting through the dorsal and lateral sacrosciatic ligaments and dissecting away the surrounding muscle groups. The joint capsule was well-developed and close-fitting. It was surrounded by the ventral sacroiliac ligaments, which were extensive on the dorsal aspect of the sacrum and located at the angle between the wing of the sacrum and ilium immediately cranial to the sacroiliac joint (Fig. 2). The fibres ran obliquely and craniodorsally from the sacrum onto the ilium and were firmly attached to bone. There were no major variations noted in the joint capsule, ligamental size or structure.

The overall incidence of the different morphological findings are summarised in Table 3 and their frequencies according to age are given in Fig. 3.

None of the 82 joints showed any sign of ankylosis. The joint surfaces were examined after disarticulation and a minute amount of fluid resembling synovial fluid was noted. The size and contour of the joints varied greatly. In the majority of horses, the sacroiliac joint outline was sock-shaped with the convex border facing caudally and ventrally (Fig. 7). In some instances the joints were more C-shaped (i.e. auricular) or without much curvature in them at all (i.e. spatulate) and a few had quite bizarre outlines (Fig. 8e). The joint

| Table 3 |
| A list of the morphological features recorded in the 82 joints examined with the incidence of their occurrence and key to the Figures used to illustrate specific features |

<table>
<thead>
<tr>
<th>Morphological feature</th>
<th>Incidence per cent</th>
<th>Sacrum</th>
<th>Ilium</th>
<th>Figure No.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Joint shape:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Atypical shape of joint outline</td>
<td>36.6</td>
<td>32.9</td>
<td>8e</td>
<td></td>
</tr>
<tr>
<td>2. Irregular and ragged outline</td>
<td>9.8</td>
<td>43.9</td>
<td>9a, 6d</td>
<td></td>
</tr>
<tr>
<td>3. No abrupt line of demarcation of joint outline</td>
<td>0.0</td>
<td>28.0</td>
<td>7b</td>
<td></td>
</tr>
<tr>
<td>4. Small clefts around joint margin</td>
<td>46.3</td>
<td>64.6</td>
<td>6a, 6d</td>
<td></td>
</tr>
<tr>
<td>5. Incomplete division of articular surface</td>
<td>8.5</td>
<td>9.8</td>
<td>9a, 9b</td>
<td></td>
</tr>
<tr>
<td>6. Complete division of articular surface</td>
<td>7.3</td>
<td>6.1</td>
<td>8a</td>
<td></td>
</tr>
<tr>
<td>7. Encroachment of ventral sacroiliac ligament insertion onto edge of articular surface</td>
<td>81.7</td>
<td>0.0</td>
<td>6a</td>
<td></td>
</tr>
<tr>
<td><strong>Articular surface:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Smooth and glistening articular cartilage</td>
<td>85.4</td>
<td>0.0</td>
<td>5a</td>
<td></td>
</tr>
<tr>
<td>9. Uneven articular cartilage</td>
<td>54.9</td>
<td>100.0</td>
<td>8f</td>
<td></td>
</tr>
<tr>
<td>10. Areas of thinning of articular cartilage</td>
<td>37.8</td>
<td>81.7</td>
<td>8f, 6d</td>
<td></td>
</tr>
<tr>
<td>11. Wrinkling of articular cartilage</td>
<td>29.3</td>
<td>47.6</td>
<td>8c, 9b</td>
<td></td>
</tr>
<tr>
<td>12. Obvious crevices or creases in articular cartilage</td>
<td>30.5</td>
<td>17.1</td>
<td>8c, 9b</td>
<td></td>
</tr>
<tr>
<td>13. Focal indentations in articular cartilage</td>
<td>50.0</td>
<td>2.4</td>
<td>5a</td>
<td></td>
</tr>
<tr>
<td>14. Areas visually devoid of articular cartilage (&quot;erosion&quot;)</td>
<td>19.5</td>
<td>37.8</td>
<td>8f, 6d</td>
<td></td>
</tr>
<tr>
<td>15. Fibrous strands on articular surface</td>
<td>31.7</td>
<td>30.5</td>
<td>6a, 6b</td>
<td></td>
</tr>
<tr>
<td>16. Small amorphous surface deposits</td>
<td>18.3</td>
<td>40.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. &quot;Wear&quot; lines in articular cartilage</td>
<td>6.1</td>
<td>2.4</td>
<td>9a</td>
<td></td>
</tr>
<tr>
<td><strong>Signs of spur formation:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Absent</td>
<td>85.4</td>
<td>98.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Small spur formation at caudal edge of joint margin</td>
<td>7.3</td>
<td>1.2</td>
<td>9a</td>
<td></td>
</tr>
<tr>
<td>20. Medium spur formation at caudal edge of joint margin</td>
<td>4.9</td>
<td>0.0</td>
<td>8b</td>
<td></td>
</tr>
<tr>
<td>21. Large spur formation at caudal edge of joint margin</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22. Spur at other sites</td>
<td>2.4</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23. Partial ankylosis</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 3. Incidence of the morphological features on the sacral and iliac joint surfaces listed in Table 3 according to age (each bar of the histograms represents one of the five age groups). The dotted lines show the mean incidence (%) for all joints examined. The features which had significant age dependency are marked with asterisks.

* P < 0.05, ** P < 0.01.
surfaces were almost flat (Fig. 4). In the youngest animals (Group 1) there was a tendency for the sacral surface to be slightly convex and the iliac mildly concave.

In only a small number of joints (14.6 per cent on the sacrum and 1.2 per cent on the ilium) was there evidence of spur formation at the joint margins.

Fig. 4. Sagittal sections of the sacral and iliac joint components to show the relative flatness of the surfaces. Upper row from left to right: 6 weeks old Standardbred colt; 1.5 year old Standardbred stallion; 2.5 year old Swedish Warmblood gelding. Lower row: 5 year old Swedish Warmblood mare; 14 year old Thoroughbred gelding.

Sacral joint surface

The sacral joint surfaces were smooth and glistening with a bluish-white colour, resembling hyaline cartilage in most horses in Groups 1–4 (Fig. 5 a). In the older animals, Group 5, there was roughening and a brownish yellow discolouration of the joint surfaces.

The incidence of atypical shape of joint outline increased with age and an irregular and ragged outline was only found in the older horses, Group 5 (Fig. 9 a). In nearly 50 per cent of the joints there were small clefts devoid of articular cartilage present around the joint margins (Fig. 6 a). The incidence increased with age and all the older horses showed some degree of cleft formation. The presence of deep fissures in the articular surfaces, resulting in a complete or incomplete division of the joint outline (Figs. 8 a and 9 a), was seen principally in animals older than one year, Groups 3–5.

Most of the features affecting the articular surfaces appeared to have an age dependency. Unevenness of the articular cartilage (Fig. 8 f) was found regularly from the age of 2 years onwards. In some areas, the subchondral bone could be clearly seen indicating an area of thinning of the articular cartilage (Fig. 8 f). There were no cases of cartilage thinning in the perinatal group, but the incidence of this feature also increased with age. Wrinkling of the articular cartilage referred to the presence of small grooves and undulations across the joint surface (Fig. 8 c) and this was also closely associated with age. The more dramatic finding of obvious crevices or creases in the cartilage (Fig. 8 c) was also commonly encountered in the mature and older horses, Groups 4–5.

In Groups 1 and 2 there was a high incidence of what appeared to be focal indentations or small holes in the articular cartilage (Fig. 5 a). This was the only feature recorded that showed a marked reduction in incidence with age. In some joints, especially in older
Sacroiliac Joint of the Horse/1.

Fig. 5. Group 1. a) Left sacral joint surface from a month old Standardbred colt showing focal indentations in the articular cartilage. b) Left iliac joint surface from the same horse.

Fig. 6. Group 2. a) Left sacral joint surface from a 1.5 year old male Standardbred showing small clefts around the joint margin and fibrous strands on the articular surface. b) Left iliac joint surface from the same horse showing obvious crevices or creases and fibrous strands. c) Left sacral joint surface from a 1.5 year old male Standardbred showing fibrous strands and thinning of the cartilage. d) Left iliac joint surface of the same horse showing an irregular and ragged joint outline with small clefts around the joint margin, areas of thinning and areas visually devoid of articular cartilage.

Horses, apparent erosion of the articular cartilage was observed macroscopically (Fig. 8f). Large fibrous or ligamentous strands were found on almost 50 per cent of the articular surfaces from horses older than two months (Fig. 6a). On a number of joint surfaces, mainly in older horses, there were areas with deposits of a granular amorphous or fibrin-like material. In a small number of joints parallel lines traversing the joint surface were found and are referred to here as "wear" lines (Fig. 9a).

At the caudal edge of the sacral joint margins spur formation was seen in 12.2 per cent of the joints (Figs. 8b and 9a). In addition in one joint in Group 2 and one joint in Group 3 spur formation was found at the medial joint margin.
Fig. 7. Group 3. a) Left sacral joint surface from a 2.5 year old Swedish Warmblood gelding showing small clefts around joint margin and areas of thinning of the articular cartilage. b) Left iliac joint surface from the same horse with no abrupt line of demarcation and showing areas of thinning of the articular cartilage.

Fig. 8. Group 4. a) Left sacral joint surface from a 5 year old Norwegian Fjord gelding showing a complete division of the articular surface. b) Right sacral joint surface from the same horse showing a medium sized spur formation at the caudal edge of the joint margin. c) Left sacral joint surface from a 5 year old Swedish Warmblood gelding. To the left in the figure there is wrinkling of the articular surface and to the right obvious crevices or creases are seen. d) Left iliac joint surface from the same horse showing uneven articular cartilage. e) Right sacral joint surface from the same horse showing atypical shape of joint outline. f) Left sacral joint surface from a 5.5 year old Swedish Warmblood stallion showing an uneven articular cartilage with areas of thinning and areas visually devoid of articular cartilage.
Iliac joint surface

There were some notable differences between the iliac and sacral joint surfaces. Generally the articular cartilage appeared thinner than on the sacral surface and was of a more fibrocartilaginous character. The iliac joint cartilage had a much more uneven surface, frequently showing areas of wrinkling and localised thinning of the cartilage. In the perinatal group, the iliac cartilage had a bluish-brown colour while in the older animals it was dull brown. In all cases the surface was considered to be uneven and in most specimens there were marked cranio-caudal striations on the surface (Fig. 6 d).

The joint outlines were frequently irregular and ragged (Fig. 6 d), often with no abrupt indication of the extent of the joint margin (Fig. 7 b). There were small clefts often present at the joint margins (Fig. 6 d). A low, but age-related, incidence of incomplete division of the joint surfaces was also found (Fig. 9 b), while complete division was only present in a few joints in Groups 3—5. In contrast to the sacral side, the ventral sacroiliac ligament never encroached on the edge of the articular cartilage.

The majority of the iliac joint surfaces had areas of apparent thinning of the cartilage (Fig. 6 d). Wrinkling of the surface occurred in about 50 per cent of the joints and more often in older horses (Fig. 9 b). Compared to the sacral side, the incidence of crevices and creases was low (Fig. 6 b). Focal indentations were seen in only two joints in Group 2. Areas visually devoid of articular cartilage were common in all age groups (Fig. 6 d). Fibrous strands were found in approximately the same frequency as on the sacral side (Fig. 6 b). Small amorphous surface deposits on the cartilage were found in more than double the sacral frequency and had an age-related occurrence. "Wear" lines were only found in two joints from Group 5.

A small spur was found at the caudal edge of the joint margin in one joint from a 14 year old horse.

Contralateral and opposing joint surfaces

The majority of morphological features were found bilaterally. Some features were, however, principally present unilaterally. The frequencies of these more common unilateral findings are shown in Table 4 compared with the same features occurring bilaterally but no consistent sidedness (i.e. laterality) could be statistically demonstrated.

In most joints the morphological changes were either detected on the sacral side or on the iliac side. However, a few were commonly found affecting both opposing joint surfaces.
### Table 4
Results of the number of horses showing the different morphological features unilaterally (U) compared with the number of horses exhibiting the same changes bilaterally (B)

<table>
<thead>
<tr>
<th>Morphological feature</th>
<th>No. of horses displaying feature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sacrum U</td>
</tr>
<tr>
<td><strong>Joint shape:</strong></td>
<td></td>
</tr>
<tr>
<td>1. Atypical shape of joint outline</td>
<td>–</td>
</tr>
<tr>
<td>3. No abrupt line of demarcation of joint outline</td>
<td>–</td>
</tr>
<tr>
<td>4. Small clefts around joint margin</td>
<td>12</td>
</tr>
<tr>
<td>5. Incomplete division of articular surface</td>
<td>5</td>
</tr>
<tr>
<td>6. Complete division of articular surface</td>
<td>2</td>
</tr>
<tr>
<td><strong>Articular surface:</strong></td>
<td></td>
</tr>
<tr>
<td>11. Wrinkling of articular cartilage</td>
<td>–</td>
</tr>
<tr>
<td>12. Obvious crevices or creases in articular cartilage</td>
<td>9</td>
</tr>
<tr>
<td>13. Focal indentations in articular cartilage</td>
<td>–</td>
</tr>
<tr>
<td>14. Areas visually devoid of articular cartilage (“erosion”)</td>
<td>–</td>
</tr>
<tr>
<td>16. Small amorphous surface deposits</td>
<td>9</td>
</tr>
<tr>
<td><strong>Signs of spur formation:</strong></td>
<td></td>
</tr>
<tr>
<td>19. Small spur formation at caudal edge of joint margin</td>
<td>2</td>
</tr>
<tr>
<td>22. Spur at other sites</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 5
Results of statistical analysis of the sacroiliac joint morphology according to sex and breed

<table>
<thead>
<tr>
<th>Feature</th>
<th>Incidence per cent</th>
<th>Sex</th>
<th>Breed</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>male</td>
<td>female</td>
<td>STB</td>
</tr>
<tr>
<td>Mean age, years</td>
<td></td>
<td>3.3</td>
<td>3.8</td>
<td>2.0</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>4.30</td>
<td>3.79</td>
<td>2.73</td>
</tr>
<tr>
<td>Student’s t test for age distribution</td>
<td>ns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No of joints examined</td>
<td>58</td>
<td>24</td>
<td>44</td>
<td>38</td>
</tr>
<tr>
<td><strong>Sacrum</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Atypical shape of joint outline</td>
<td>46.6</td>
<td>12.5</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2. Irregular and ragged outline</td>
<td>–</td>
<td>–</td>
<td>0</td>
<td>21.1</td>
</tr>
<tr>
<td>8. Smooth and glistening articular cartilage</td>
<td>–</td>
<td>–</td>
<td>93.2</td>
<td>76.3</td>
</tr>
<tr>
<td>11. Wrinkling of articular cartilage</td>
<td>–</td>
<td>–</td>
<td>13.6</td>
<td>47.4</td>
</tr>
<tr>
<td>13. Focal indentations in articular cartilage</td>
<td>–</td>
<td>–</td>
<td>65.9</td>
<td>31.6</td>
</tr>
<tr>
<td>14. Areas visually devoid of articular cartilage</td>
<td>–</td>
<td>–</td>
<td>6.8</td>
<td>34.2</td>
</tr>
<tr>
<td>17. &quot;Wear&quot; lines in articular cartilage</td>
<td>–</td>
<td>–</td>
<td>0</td>
<td>13.2</td>
</tr>
<tr>
<td><strong>Ilium</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Complete division of articular surface</td>
<td>–</td>
<td>–</td>
<td>0</td>
<td>13.2</td>
</tr>
<tr>
<td>11. Wrinkling of articular cartilage</td>
<td>39.7</td>
<td>66.7</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>14. Areas visually devoid of articular cartilage</td>
<td>44.8</td>
<td>20.8</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>14. Areas visually devoid of articular cartilage</td>
<td>–</td>
<td>–</td>
<td>47.7</td>
<td>26.3</td>
</tr>
</tbody>
</table>

a Two fetuses excluded from the mean age calculation. b One fetus excluded from the mean age calculation.
and those most frequently noted were: atypical shape of joint outline, small clefts around joint margin, uneven articular cartilage, fibrous strands on articular cartilage and the absence of spur formation.

**Sex and breed**

The incidence of the different features was analysed statistically according to sex and breed. The significant differences between sexes and between Standardbreds and other breeds are summarised in Table 5.

On the sacrum, atypical shape of the joint outline and, on the ilium, areas visually devoid of articular cartilage ("erosion") were found to be more frequent in males. Mares showed a higher incidence of wrinkling of the iliac cartilage.

A number of significant differences were recorded between Standardbreds and other breeds. With the exception of areas on the ilium visually devoid of articular cartilage, these findings are likely to be effects of the significant age difference between the younger Standardbreds and the older horses in the group of "other breeds".

**Discussion**

There seems to be a general lack of precise anatomical information on the sacroiliac joint of all domestic species. In the horse more recent texts (KADLETZ, 1932; SMYTHE/GOODY, 1972; GETTY, 1975) add little to the original description given by ELLENERGER and BAUM (1943). The situation in man is somewhat better presumably because of the socioeconomic importance of low back pain. Although, since the first reports of William Hunter in the eighteenth century much of the literature has been fragmentary and confusing. Recently the situation has been greatly clarified by the comprehensive gross and microscopic investigations of BOWEN and CASSIDY (1981).

The sacroiliac is a difficult joint to classify. It has been designated as being syndesmotic in young and synostotic in older animals in the same chapter and as a synovial joint in another chapter of a modern book (GETTY, 1975). From the presence of a joint cavity containing synovial fluid, articular cartilage on opposing surfaces, an articular capsule and surrounding ligaments connecting the bones, the sacroiliac joint in the horse should be classified as a synovial/diarthrodial joint. The reason that the joint has been called a synostosis may be that the observations were made on ankylosic specimens. No signs of ankylosis of the sacroiliac joints were noted although none of the animals examined here was older than 14 years. Other workers have noted the absence of ankylosis in the horse (STECHE/Goss, 1971; ROONEY, 1977). We have also examined a 22 year old brood Thoroughbred mare, a 23 year old Swedish Warmblood mare and a 30 year old hunter type gelding which showed no signs of joint fusion (JEFFCOTT and DALIN, unpublished data). In view of the relative immobility of this joint this is perhaps surprising. In bulls, periarticular ossification and synostosis in the sacroiliac joints have been interpreted as a physiological compensatory adjustment to strain at service (BANE, 1954). In man true ankylosis in later life is rare, but para-articular osteophyte formation is much more common (BOWEN/CASSIDY, 1981).

Fibrous interconnections linking the joint surfaces are seen in man from the age of fifty onwards (BOWEN/CASSIDY, 1981). The present finding of fibrous strands, usually occurring on both opposing joint surfaces, may be similar to that seen in human sacroiliac joints. However, in horses they occur much earlier in life. The fibrous strands could not definitely be shown to connect the joint surfaces because of the dissection method used. Further studies should therefore include serial sections of intact joints.

The rate and extent of morphological changes demonstrated here was unexpected as none of the animals had any known history of a back problem. Other diarthrodial joints (eg. carpal, tarsal and interneural) do not show the same frequency or type of changes unless there is some clinical reason for them. The findings in the sacroiliac joints appeared to follow a pattern of progressive degeneration with advancing age. The iliac articular
cartilage seemed to be affected to a greater extent than that of the sacrum. However, there was a relatively low incidence of spur formations, which may indicate the presence of a chronic arthrosis. The extent of these findings was also minor when compared to those found in clinical cases of sacroiliac instability and arthrosis (Jeffcott, 1980, 1982, 1983b; Jeffcott et al., 1985). Rooney (1977) suggests that sacroiliac arthrosis is probably prevalent in both harness and racehorses. He examined the sacroiliac joints of 55 animals and, although not specific in his definition, based an opinion of arthrosis on cartilaginous discolouration. It seems likely to us that his observations fit into the pattern of age-related changes recorded in the present study and therefore would have doubtful clinical significance. The mean age of the horses displaying “abnormal” sacroiliac joints in Rooney’s series was obviously higher than that of the “normal” horses. Furthermore, he suggested that Standardbreds were more prone to develop sacroiliac arthrosis than Thoroughbreds because of differences in the biomechanics of the pacing/trotting and galloping gaits. The theory was supported by a higher incidence of cartilage discolouration in Standardbreds and that the changes occurred in younger horses. The findings in this study neither support nor contradict that opinion. The only difference between Standardbreds and the other breeds that could not be explained by the difference in age distribution was the higher incidence of areas visually devoid of articular cartilage on the ilium of the Standardbreds.

The sacral articular cartilage appeared to be hyaline, while the iliac one was judged to be of a more fibrocartilaginous character. Most of the features indicating a progressive degenerative process, such as irregular and ragged outline, areas of cartilage thinning and areas visually devoid of articular cartilage, were more frequent and occurred at lower age on the iliac side of the joint. This is in accord with the findings reported for the human sacroiliac joint, where it was suggested that the sacral hyaline cartilage has a better capacity to resist degenerative changes than the iliac fibrocartilage (Bowen/Cassidy, 1981).

In individual animals some features were commonly found in only one joint. This means that the morphological changes in contralateral joints need not follow the same pattern. There was, however, no consistent sidedness found indicating that the left or right side joints had been subjected to more wear and tear.

The mechanisms underlying the quite dramatic anatomical features in the equine sacroiliac joint are equivocal. Changes of a degenerative character occur in joints from young animals with no known back disorder. From a functional anatomy point of view it might be suggested that the sacroiliac joints of the horse are subjected more to shearing than to compressive forces. The effect could be that the fluid turnover of the cartilage is impaired leading to nutritional disturbances. The histopathology of the different macroscopic features and the biomechanics of the sacroiliac joint have, however, to be analysed in detail before any more precise theories on the mechanisms leading to the changes can be put forward.

Summary

This study describes the macroscopic examination of the sacroiliac joints of 41 horses of different age (late fetal life to 14 y.), sex and breed. A total of 22 different morphological features involving the joint shape, the articular surfaces and the presence of articular spur formation was described. The most significant changes occurred with age and only minor differences were noted between sex and breed. Even though none of the horses had any clinical history of a low back condition there were obvious changes indicating articular cartilage degeneration. The iliac surface was more prone to these degenerative changes. These were noted even in very young animals and increased in incidence with advancing years. The findings included irregular or ragged joint outline, uneven surfaces, thinning of articular cartilage, focal indentations, creases or wrinkling of cartilage, areas of apparent cartilage erosions and fibrous strands on joint surfaces. There were only minor significant differences seen between left and right sacroiliac joints. Ankylosis of the joints was not recorded in any instance and the incidence of articular or para-articular spur formation was low.
Acknowledgements

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Zusammenfassung
Zur Articulatio sacroiliaca des Pferdes

1. Makromorphologie


Obwohl keines der Pferde in der klinischen Vorgeschichte Merkmale einer Rückenschwäche aufweist, deuten offensichtliche Veränderungen auf eine Degeneration des Gelenkknorpels hin. Diese wird sogar schon bei sehr jungen Tieren und mit zunehmender Häufigkeit dann bei älteren Tieren gefunden.


Außerordentlich geringfügig sind die Unterschiede zwischen rechten und linken Kreuzdarmbeingelenken.

Versteifungen (Ankylosen) der Gelenke werden in keinem Fall beobachtet. Artikuläre oder paraartikuläre knöcherne Zubildungen kommen selten vor.

Résumé
L’articulation sacro-iliaque du Cheval

1. Morphologie macroscopique

Cette étude décrit l’examen macroscopique des articulations sacroiliaques de 41 chevaux de différents âges (des derniers stades foetaux jusqu’à 14 ans), sexes et races. Un total de 22 caractères morphologiques différents a été défini au sujet de la forme de l’articulation, de celle des surfaces articulaires et de la présence de néoformations articulaires. Les modifications les plus significatives sont liées à l’âge, alors que les différences sexuelles et raciales ne sont que mineures.

Bien qu’aucun des chevaux n’ait eu d’antécédents cliniques de faiblesse du dos, on a constaté des altérations évidentes révélant de dégénérescence des cartilages articulaires, surtout au niveau des surfaces articulaires de l’ilium; et cela, même chez les très jeunes animaux, mais selon une incidence plus grande avec l’âge. Les faits relevés consistaient en déformations et altérations du profil articulaire, irrégularités des surfaces, amincissement du cartilage articulaire, fissurations localisées, épaississements ou plissements de cartilage, ainsi qu’en la présence d’aires d’érosion nette des cartilages et de brides fibreuses sur les surfaces articulaires.

Entre les articulations sacro-iliaques gauches et droites, les différences significatives étaient mineures. On n’a constaté aucun cas d’ankylose articulaire et l’incidence de néoformations articulaires ou para-articulaires a été faible.
Resumen
La articulación sacroiliaca del caballo.
1. Morfología macroscópica

El presente estudio describe el examen macroscópico de la articulación sacroiliaca de 41 caballos de diferente edad (del período fetal tardío hasta 14 años) y de sexo y raza diferentes. Se encontraron 22 diferencias morfológicas con respecto a la forma de la articulación, las superficies articulares y la formación de espolones articulares. Los cambios más significativos se presentaron en relación con la edad, mientras que las diferencias observadas entre los sexos y las razas eran de menor importancia. A pesar de que ninguno de los caballos presentó una historia clínica de la condición de un dorsa bajo, se encontraron cambios obvios indicando una degeneración del cartílago, especialmente en la superficie articular ilíaca, aún en animales muy jóvenes y aumentando con la edad. Los hallazgos incluyeron líneas articulares irregulares o dilaceradas, superficies desiguales, enrarecimiento del cartílago, indentaciones focales, fisuras y arrugas del cartílago, áreas de aparente erosión del cartílago y cintas fibrosas en las superficies articulares. Entre las articulaciones sacroilíacas izquierda y derecha se observaron sólo diferencias de menor significado. Anquilosis de las articulaciones no se anotó en ningún caso y la incidencia de espolones articulares o paraarticulares fue baja.

References
Sacroiliac Joint of the Horse

2. Morphometric features

G. Dalin and L. B. Jeffcott

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With 5 figures and 3 tables

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Abstract

The sacroiliac joints were collected from 41 horses from late fetal life to 14 years of age. The sacral and iliac articular surfaces were analysed by morphometry with regard to area, length, width and form factor. The body weights of the animals varied from 10 to 550 kg and the sacral articular surface area from 1.0 to 17.8 cm². Highly significant correlations were found between articular surface dimensions and body weights. Accordingly, the relative size of the joints decreased with increasing body weight/age. The sacral and iliac measurements were essentially comparable. No consistent left-right sidedness was found and no significant sex or breed differences were present.

Introduction

During the study of the gross morphology of the equine sacroiliac joint considerable age-related variations in joint shape and contour were observed (Dalin/Jeffercott, 1986). In cases of chronic sacroiliac strain in horses the joint outline is often distorted (Jeffercott, 1982, 1983; Jeffercott et al., 1985). However, the interpretation of suspected pathological changes in joint shape is difficult as there are no reports available on the normal variation in size and contour of the sacroiliac joint in the horse. In man, age-related changes in size and form of the sacroiliac joints have been described (Brooke, 1924; Weisl, 1954).

The purpose of the present study was to examine a series of horses to establish the variation in size and contour of the sacroiliac joints. The report forms part of a morphologic and morphometric study of the age-related changes in the sacroiliac joints of a series of horses which had no clinical history of a thoracolumbar or lumbosacral disorder (Dalin/Jeffercott, 1986; Ekman et al., 1986).

Material and Methods

The sacroiliac joints from 41 horses with no known history of back problems were examined. The details of sex and breed distribution and the causes of death of the animals and the method of dissection have been described previously (Dalin/Jeffercott, 1986). The cadavers were weighed before the post mortem examination and the distribution of age and body weight (BW) is shown in Fig. 1.
Fig. 1. The distribution of age and body weights of the 41 horses used in the study.

The horses were divided into the following age groups:

- **Group 1** — Perinatal group (3 fetuses and 10 foals less than two months old) \( n = 13 \);
- **Group 2** — Foals and yearlings (2 months to < 2 years) \( n = 10 \);
- **Group 3** — Young horses (2 years to < 4 years) \( n = 5 \);
- **Group 4** — Mature horses (4 years to < 6 years) \( n = 7 \);
- **Group 5** — Older horses (6 years to < 15 years) \( n = 6 \).

The sacral and iliac articular specimens from each horse were mounted together in a copy stand (Leitz Reprovit II a, Ernst Leitz GmbH, D-6330 Wetzlar, Germany) with their articular surfaces at the same level and perpendicular to the optical axis of the camera (Fig. 2). A millimetre scale was placed at the same level as the joint surfaces. Each set of four specimens was photographed using professional black and white film (Kodak Panatomic-X, Eastman Kodak Co., Rochester, NY 14650, USA). One 18 × 24 cm print (Brovira-Speed BW 310 pe, Agfa-Gevaert, D-5090 Leverkusen, Germany) was made of each set of specimens.

The prepared photographs were used for morphometric analysis using a semi-automatic image analysis system equipped with a programmable calculator (MOP-2, Kontron GmbH, Munich, Germany). The prints were placed on the measuring tablet and the conversion factor (i.e. magnification) was determined.
Sacroiliac Joint of the Horse.

The joint surface areas and perimeter lengths were measured by tracing the perimeter of each articular surface with a stylus. The widths and lengths of the joint surfaces were also measured (Fig. 3).

For each articular surface, the following variables were calculated as the means of five successive readings (Fig. 3):
- Area (A), cm²;
- Perimeter length (P), cm;
- Length (L), cm;
- Width (W), cm.

From the basic variables, the following data were obtained:
- Sacral area, cm²/100 kg body weight;
- W/L ratio;
- Form factor (Ff) = \( \frac{4\pi A}{P^2} \).

The form factor is a ratio between the area and the perimeter length, Ff = 1 in a perfect circle. Deviations from the circle result in lower values, whereby a substantial perimeter with little area would yield a form factor close to 0.

The possibility of consistent sidedness (i.e., laterality) was studied by Student’s t test for paired observations. The coefficient of variation between the left and right sides is expressed as:

\[
CV = \sqrt{\frac{\sum d^2}{2n}} \times 100/\hat{x};
\]

where \( \hat{x} \) is the overall mean, d the difference between left and right sides in each horse and n the number of pairs of data. Opposing joint surfaces were compared in the same way.

The further analyses included tests for the possible mutual relationship between the sacral and iliac variables and tests for significant differences between them. The effects of sex and breed was studied. The significance of age was studied by comparing the data from the five age groups.

The relationship between body weight and articular size was studied by allometric analysis (Günther, 1975). The data were fitted to the equation:

\[
\log y = \log a + b \log BW;
\]

where BW is body weight in kilograms. This gives the allometric equation:

\[
y = a \times BW^b.
\]
The statistical analyses were carried out by standard methods and included the calculation of standard deviation (SD), correlation coefficient (r), and significance by Student's t test for paired and unpaired observations to give the degree of probability (ie. P value) (Armitage, 1971). Regression analyses were carried out by the method of least squares (Armitage, 1971).

With the exception of the comparisons between the left and right sides, all calculations were based on the means of the left and right measurements in each horse.

**Methodological aspects**

To determine the accuracy of the morphometry method, including photography and planimeter analysis, a series of twenty known areas (1.0 - 20.0 cm²) were photographed and analysed. The least square regression of estimated areas on the original ones was $y = 1.003x - 0.019$ and the correlation coefficient $r = 1.000$. The residual standard deviation of the regression was $SD = 0.058$ cm² and the coefficient of variation $CV = 0.55$ per cent. Ten distances (1.0 - 10.0 cm) were analysed in a similar manner and the regression of estimated distances on the original ones was $y = 1.002x - 0.035$ with a correlation coefficient of $r = 1.000$. The residual standard deviation was $SD = 0.022$ cm and the coefficient of variation $CV = 0.41$ per cent.

The repeatability of the planimeter measurements was estimated by duplicate determinations of areas, lengths, widths and form factors of ten articular surfaces. The repeatabilities as expressed by standard deviations of duplicate determinations (SD) and coefficients of variation (CV) were, for area measurements $SD = 0.09$ cm² and $CV = 0.96$ per cent; for lengths $SD = 0.07$ cm and $CV = 1.23$ per cent; for widths $SD = 0.04$ cm and $CV = 1.74$ per cent; and for form factors $SD = 0.008$ and $CV = 1.61$ per cent.

Most surfaces were flattened. In a few perinatal animals there were slightly convex sacral and concave iliac joint surfaces. The maximum underestimation of areas caused by this curvature was estimated to less than 5 per cent of the true area.

When the specimens were mounted in the copy stand for photography there was a risk that the articular surfaces were not at exactly the same level; also the level between the joint surfaces and the millimeter scale may have varied slightly. This "mounting error" was estimated to less than ± 3 mm, which gives a maximum error for the area determinations of ± 2 per cent and for the distance measurements of ± 1 per cent.

The accuracy of the analytical system and the repeatability of measurements must be considered very good. The error in determination of the articular surface areas in a few young animals because of slightly curved articular surfaces and the error introduced by difficulties to mount the specimens at exactly the same level were small and, from a practical point of view, considered negligible.

**Results**

The area of the sacral surface of the sacroiliac joint varied from 1.0 cm² in a 10 kg Shetland pony foal to 17.8 cm² in a 5.5 year old Swedish Warmblood gelding (BW 480 kg). The length and width of the sacral joint surface were 1.8 and 0.9 cm, respectively, in the Shetland pony foal while a maximum length of 9.0 cm was found in a 14 year old Thoroughbred gelding (BW 440 kg) and a width of 4.6 cm in a 2 year old Standardbred mare (BW 380 kg). The iliac parameters corresponded in a similar fashion (Table 1).

**Contralateral articular measurements**

No consistent sidedness (ie. laterality) could be demonstrated for any of the variables studied. The differences found between the left and right side in individual horses were usually small. The coefficient of variation (CV) between the two sides varied from 5.2 per cent for the sacral articular length to 10.0 per cent for the iliac articular area and the iliac width.

**Sacral and iliac articular measurements**

Very strong correlations ($r \geq 0.923$) existed between the sacral and iliac articular areas, lengths and widths (Table 2, Fig. 4). The coefficients of variation between the measurements from opposing joint surfaces in the 82 joints examined varied from 5.7 per cent for articular lengths to 11.3 per cent for the widths. The width/length ratios had moderate ($r = 0.681$) and the form factors strong ($r = 0.756$) correlations. The only significant differences found were that the sacral joint surface tended to be somewhat...
Table 1
Results from the morphometric analysis of the sacroiliac joints from 41 horses presented as the means of the age groups and for all horses

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group 1 &lt;2m n = 13</th>
<th>Group 2 2m to &lt;2 y n = 10</th>
<th>Group 3 2y to &lt;4 y n = 5</th>
<th>Group 4 4y to &lt;6 y n = 7</th>
<th>Group 5 6y to &lt;15 y n = 6</th>
<th>All horses n = 41</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) (SD)</td>
<td>0.05± (0.05)</td>
<td>1.3± (0.39)</td>
<td>2.4± (0.42)</td>
<td>4.7± (0.57)</td>
<td>11.8± (2.04)</td>
<td>3.4± (4.12)</td>
</tr>
<tr>
<td>Body weight (kg) (SD)</td>
<td>53.3± (30.98)</td>
<td>299.5± (72.05)</td>
<td>382.0± (48.17)</td>
<td>429.3± (74.97)</td>
<td>458.3± (97.23)</td>
<td>276.9± (174.56)</td>
</tr>
</tbody>
</table>

**Articular area, cm²**

<table>
<thead>
<tr>
<th></th>
<th>Sacrum</th>
<th>Ilium</th>
</tr>
</thead>
<tbody>
<tr>
<td>(SD)</td>
<td>(1.16)</td>
<td>(2.49)</td>
</tr>
<tr>
<td></td>
<td>(2.76)</td>
<td>(2.84)</td>
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<td></td>
<td>(2.11)</td>
<td>(1.69)</td>
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<tr>
<td></td>
<td>(2.18)</td>
<td>(3.35)</td>
</tr>
<tr>
<td></td>
<td>(2.75)</td>
<td>(5.01)</td>
</tr>
<tr>
<td></td>
<td>(5.02)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Sacrum</th>
<th>Ilium</th>
</tr>
</thead>
<tbody>
<tr>
<td>(SD)</td>
<td>(0.66)</td>
<td>(0.55)</td>
</tr>
<tr>
<td></td>
<td>(0.99)</td>
<td>(0.85)</td>
</tr>
<tr>
<td></td>
<td>(0.63)</td>
<td>(0.58)</td>
</tr>
<tr>
<td></td>
<td>(0.53)</td>
<td>(0.48)</td>
</tr>
<tr>
<td></td>
<td>(1.33)</td>
<td>(1.19)</td>
</tr>
<tr>
<td></td>
<td>(2.06)</td>
<td>(1.97)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Sacrum</th>
<th>Ilium</th>
</tr>
</thead>
<tbody>
<tr>
<td>(SD)</td>
<td>(0.35)</td>
<td>(0.37)</td>
</tr>
<tr>
<td></td>
<td>(0.32)</td>
<td>(0.45)</td>
</tr>
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**Articular length, cm**

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**Form factor**

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<td>(0.095)</td>
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* 3 fetuses are excluded from the mean age calculations (9, 10 and 11 months of gestation)

longer than the iliac one (P < 0.05) (Table 1, Fig. 4) and that the sacral form factor was lower (P < 0.001) than that of the ilium (Table 1).

**Sex and breed comparisons**

There were no statistically significant differences found when comparing the variables between sexes (29 male and 12 female animals) and between breeds (22 Standardbreds compared to 19 horses of other breeds, mainly Swedish Warmblood horses).
Table 2
Linear regressions of iliac variables on sacral variables in 41 horses

<table>
<thead>
<tr>
<th>Variable</th>
<th>$r$</th>
<th>$b_0$</th>
<th>$b_1$</th>
<th>SD</th>
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<tbody>
<tr>
<td>Area (cm$^2$)</td>
<td>0.978</td>
<td>0.596</td>
<td>0.981</td>
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<tr>
<td>Length (cm)</td>
<td>0.990</td>
<td>0.207</td>
<td>0.943</td>
<td>0.276</td>
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<tr>
<td>Width (cm)</td>
<td>0.923</td>
<td>0.445</td>
<td>0.817</td>
<td>0.306</td>
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</tbody>
</table>

$r$ Correlation coefficient; $b_0$ Intercept; $b_1$ Regression coefficient; SD Standard deviation

Table 3
Allometric analysis of sacral articular surface measurements. Based on $y = aBW^b$; BW is body weight in kilograms; $n = 41$ horses

<table>
<thead>
<tr>
<th>Variable</th>
<th>$r$</th>
<th>$a$</th>
<th>$b$</th>
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<tbody>
<tr>
<td>Area (cm$^2$)</td>
<td>0.978</td>
<td>0.151</td>
<td>0.732</td>
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<tr>
<td>Length (cm)</td>
<td>0.976</td>
<td>0.706</td>
<td>0.387</td>
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<tr>
<td>Width (cm)</td>
<td>0.931</td>
<td>0.366</td>
<td>0.351</td>
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</table>

$r$ Correlation coefficient

Fig. 4. Iliac vs. sacral articular surface areas and iliac vs. sacral articular surface lengths with regression lines for the 41 horses studied. For numerical data on the regressions, see Table 2

Allometric analyses

As there were strong correlations between the sacral and iliac variables, the allometric analyses were confined to the sacral measurements. Very strong correlations were found between the different sacral variables and the body weight of the animals ($r \geq 0.931$). The results from the allometric analyses are summarised in Table 3. In Fig. 5 the distribution of the sacral measurements as functions of body weights is shown.

Age variations

The statistical analyses for differences between the five age groups were done for the relative variables, (ie. sacral joint area per 100 kg BW, the width/length ratios and the form factors). The means of these variables in the different age groups are given in Table 1.

The body weights of the animals of Group 1 ranged from 10 kg to 105 kg. This group of perinatal animals (fetuses and foals < 2 months old) had a larger sacral articular area per
Sacroiliac Joint of the Horse/2.

100 kg body weight than the horses in the other groups (P < 0.05). The sacral and iliac width/length ratios of the Group 1 horses were significantly higher than those found in Group 5 (P < 0.05). The sacral form factor was higher than in Groups 2, 4 and 5 (P < 0.05), while the iliac form factor differed from those of Groups 4 and 5 (P < 0.05).

The horses of Group 2 (2 months to < 2 years) were also lighter than the horses aged more than two years (P < 0.05). The sacral area/body weight ratio, the width/length ratios and the form factors differed from the measurements of Group 5 (P < 0.05).

In Group 3 (2 years to < 4 years) there was still a higher sacral area/body weight ratio than in the horses of Groups 4 and 5 (P < 0.05) and the sacral form factor exceeded that of Group 5 (P < 0.05).

The Group 4 horses (4 years to < 6 years) also had a larger sacral articular area per 100 kg body weight than the horses of Group 5 (P < 0.05).

The horses of Group 5 (6 years to < 15 years) had the smallest articular areas in relation to body weight. The mean sacral area per 100 kg body weight was 2.5 cm². They also showed the lowest width/length ratios and form factors.

Discussion
In spite of the pronounced variations in shape and outline of the sacroiliac joint in the horse (Dalin/Jeffcott, 1986), the dimensions of the articular surfaces vary regularly with the body weights of the animals (Fig. 5). In this study, a 55-fold increase of body weight was accompanied by an only 18-fold increase in articular surface area. It was notable that the joint surface area of a 10 kg pony foal was only 1.0 cm² compared to about 1.5 cm² seen in newly born babies (Brooke, 1924). Perhaps more remarkable were the corresponding figures of about 18 cm² in horses weighing 500–600 kg, and 17.5 cm² in adult humans (Brooke, 1924). The reason for the comparatively large articular surfaces in man is probably related to the biomechanics of upright posture.

Sidedness with regard to motor function is recognized in horses (Grzimek, 1949; Meij/Meij, 1980). However, a corresponding bilateral asymmetry could not be found in the sacroiliac joint measurements. Although bilateral differences between pairs of organs is a well-known biological entity, most textbooks give little or no information on the left-right variations of osteological and articular structures (Ellenberger/Baum, 1943; Getty, 1975). Heuss (cit. by Grzimek, 1949) described small length and width differences between contralateral extremity bones to be present in most horses. However, in a recent study on the geometric properties of equine metacarpi, the authors state that "the most obvious feature is the lack of left-right bias..." (Piotrowski et al., 1983). In the present material the coefficients of variation (CV) between the two sides varied from 5.2 to 10.0
per cent for the different measurements. These CV values are rather low when, for instance, compared to the left-right variations of cross-sectional muscle fibre areas in horses (Essén-Gustavsson et al. 1983). In ten horses the CV for the mean area was 12.6 per cent for the middle gluteal and 18.2 per cent for the semitendinosus muscle (Essén-Gustavsson et al., 1983). The variations found between contralateral measurements of the sacroiliac joints probably reflect the unilateral changes in articular structure seen in many horses (Dalin/Jeffcott, 1986).

The very strong correlations between the sacral and iliac joint surface measurements were accompanied by small differences between opposing joint surfaces. The coefficients of variation were between 5.7 and 11.3 per cent for the different dimensions. This is interesting with regard to the quite notable differences in the gross morphology of the sacral and iliac articular surfaces facing each other (Dalin/Jeffcott, 1986). The lower form factor on the sacral side indicates a longer perimeter in relation to surface area than on the iliac side. This might be explained by the higher incidence of crevices and creases in the sacral cartilage. When these crevices and creases reach the articular edge they add to the perimeter length (Dalin/Jeffcott, 1986).

The absence of sex differences was surprising as pronounced sex differences in pelvic shape are present in the horse (Getty, 1975). However, it is known that the pelvis of geldings tends to develop more like that of the mare if they are castrated before sexual maturity (Getty, 1975), and here there were 18 stallions and 9 geldings. No data on the age at castration were available. The results on sex differences are thus inconclusive until further studies have been made. In man, Weisl (1954) found that "the articular surfaces of males and females did not differ significantly either in dimensions or relative proportions".

Standardbreds have been reported to show a higher incidence of sacroiliac arthrosis than other breeds (Rooney, 1977). Thus, the group of Standardbreds was compared to the remaining horses to see if there were any dimensional differences of possible importance for the development of arthrosis. The data on the Standardbreds did not differ significantly from those of the other horses, most of which were of lighter breeds (only two draughthorses).

The very strong correlations between the sacroiliac joint measurements and the body weight of the animals facilitates the assessment of the dimensional changes seen in cases of sacroiliac strain or arthrosis (Jeffcott, 1982, 1983; Jeffcott et al., 1985). From a theoretical point of view it is interesting to note that the somatic exponent b in the allometric equation \( y = aBW^n \) showed reasonable agreement with the predictions of the model of elastic similarity (McMahon, 1973, 1975). From that model the diameter exponent was expected to be 0.375 and the cross-sectional area exponent, which corresponds to a flat surface area, was expected to be 0.75. The exponents found were 0.387 and 0.351 for length and width, respectively, and 0.732 for the articular surface area.

The differences between age groups were studied with regard to the relative proportions of the joints (ie. sacral surface area/100 kg body weight, width/length ratios and form factors). This was done to overcome the effects of the differences in body weights between the age groups and the effects of a few animals with rather low body weights (ie. a Shetland pony foal of 10 kg in Group 1 and a pony gelding of 280 kg in Group 5). The age groups were the same as in the studies on the gross morphology and histology of the same specimens (Dalin/Jeffcott, 1986; Ekman et al., 1986). The most prominent difference between age groups was the dramatic decrease in articular surface area in relation to body weight. This decrease is explained by the increase in weight from the perinatal period to the older animals. As has been shown by allometric analysis, the area of the joint surface would increase about 4.4 times when the body weight of an animal increased 10-fold from 50 to 500 kg.

The older horses, Group 5, had a lower width/length ratio than the younger horses. This seems to be the effect of a relative narrowing of the joint width rather than an elongation of the joint surface. The relative narrowing might be an effect of the age-related changes of the gross morphology of the sacroiliac joint (Dalin/Jeffcott, 1986). The lower
form factors found in older animals correlate well with the gross morphology finding of age-related joint outline distortions (DALIN/JEFFCOTT, 1986), leading to an elongation of the joint surface perimeter.

In the earlier study on the gross morphology of the equine sacroiliac joint (DALIN/JEFFCOTT, 1986), dramatic variations in joint shape and contour were recorded. It was therefore unexpected to find highly significant correlations between articular measurements and body weights accompanied by relatively small variations. However, the conformity of the measurements to body weight means that the method of morphometrical analysis might be a useful tool in the study of pathological changes in the sacroiliac joints where articular surface enlargement occurs due to prominent articular extension (JEFFCOTT, 1982, 1983; JEFFCOTT et al., 1985).

Summary

The sacroiliac joints were collected from 41 horses which had no history of any back disorder. The specimens were taken from late fetal life to 14 years of age and the body weights of the animals ranged from 10 to 550 kg. The sacral and iliac joint surfaces were analysed by morphometry with regard to area, length, width and form factor. The articular surface areas ranged from 1.0 to 17.8 cm² and the lengths and widths varied from 1.8 to 9.0 cm and from 0.9 to 4.6 cm, respectively. Very strong correlations were found between the sacral and iliac measurements and the only difference found between them was a tendency for the sacral articular surface to be somewhat longer. Although some differences were found between the left and right side measurements in individual animals, no consistent sidedness could be demonstrated. No significant sex or breed differences were found.

Very strong correlations existed between articular surface measurements and body weights and there were relatively low coefficients of variation found in the regression analyses of the material. The variations in joint size with age are thus mainly attributable to body weight differences.

Acknowledgements

This work was supported by grants from Jordbrukets Försäkringsbolag (the Agricultural Insurance Co.), and the Swedish Council for Forestry and Agricultural Research (550/82 D 20 : 1). Travel grants awarded to G. DALIN by Fortia-Pharmacia Co., Knut and Alice Wallenberg’s Anniversary Fund, Lennart Hjelm’s Scholarship Fund, and Gunnar Philipsson’s Scholarship Fund, are acknowledged. Our thanks are also due to Messrs. LARS-ERIK ERIKSSON, and BJÖRN HELLMÉN for excellent technical assistance.

Zusammenfassung

Zur Articulatio sacroiliaca des Pferdes
2. Morphometrische Merkmale

Von 41 Pferden ohne klinische Hinweise auf eine Schwäche im Bereich des Rückens werden die Kreuzdarmbeingelenke gesammelt. Das Alter der untersuchten Tiere, deren Körpergewicht zwischen 10 und 550 kg liegt, reicht vom späten Fetalen bis zum 14. Lebensjahr.

Analysiert werden morphometrisch Flächeninhalt, Länge, Breite und Formfaktor der Gelenkflächen an Kreuz- und Darmbein. Die Flächeninhalte schwanken hierbei zwischen 1,0 und 17,8 cm², die Werte für die Länge variieren zwischen 1,8 und 9,0 cm, diejenigen für die Breite zwischen 0,9 und 4,6 cm. Mit Ausnahme der Tendenz, daß die jeweils am Kreuzbein gelegene Gelenkfläche etwas länger ist, stimmen die Meßergebnisse an Kreuz- und Darmbein deutlich überein. Obwohl rechte und linke Seite bei einzelnen Individuen Meßdifferenzen erkennen lassen, können Gesetzmäßigkeiten für die jeweilige Seite nicht aufgestellt werden. Für geschlechts- oder rassespezifische Besonderheiten gibt es keine Hinweise.
Schr enge Zusammenhänge bestehen zwischen den Maßen der Gelenkflächen und dem Körergewicht; die bei der Regressionsanalyse des Materials errechneten Werte der Variationskoefizienten sind niedrig. Die altersbedingten Variationen der Gelenkmaße sind daher hauptsächlich auf die Unterschiede im Körergewicht zurückzuführen.

Résumé
L’articulation sacro-iliaque du Cheval.
2. Observations morphométriques

Une série d’articulations sacro-iliaques a été rassemblée, à partir de 41 chevaux, sans antécédent pathologique rachidien; l’âge des sujets s’étalait depuis la fin de la vie foetale jusqu’à 14 ans et les poids corporels allaient de 10 à 550 kg.

Les surfaces articulaires sacrales et iliaques ont été analysées par morphométrie dans leur étendue, leur longueur, leur largeur et leur forme. L’étendue des surfaces articulaires variait de 1,0 à 17,8 cm², leurs longueurs et largeurs de 1,8 à 9,0 cm et de 0,9 à 4,6 cm, respectivement. De très fortes corrélations ont été trouvées entre les mesures sacrales et iliaques, la seule différence entre elles étant une tendance à une plus grande longueur pour les surfaces articulaires du sacrum. Bien que quelques différences fussent trouvées, à titre individuel, entre les côtés droit et gauche, aucune dissymétrie significative n’a pu être démontrée. De même, aucune divergence sexuelle ou raciale n’a pu être mise en évidence.

Il existe de très fortes corrélations entre l’étendue des surfaces articulaires et le poids du corps et les coefficients de variation trouvés dans l’analyse de la régression sont relativement bas. Les variations de la taille articulaire selon l’âge sont donc imputables aux différences du poids du corps.

Resumen
La articulación sacro-ilíaca del caballo.
2. Aspectos morfométricos

Se coleccionaron las articulaciones sacroilíacas de 41 caballos que no presentaron historias clínicas de cualquier enfermedad del dorso. Las preparaciones correspondieron a animales de una edad entre el final de la vida fetal y 14 años y de un peso entre 10 y 550 kg. Las superficies articulares sacra e ilíaca fueron analizadas con respecto a su área, longitud, anchura y forma. Las dimensiones de las superficies articulares varían entre 1,0 y 17,8 cm², y las medidas de longitud y anchura correspondieron a 1,8 hasta 9,0 y 0,9 a 4,6 cm respectivamente. Se encontraron muy fuertes correlaciones entre las medidas sacra e ilíaca, y la única diferencia entre ellas fue una tendencia de la superficie articular sacra de ser algo más larga. A pesar de que se encontraron algunas diferencias entre las medidas izquierda y derecha en animales individuales, no se logró demostrar ningún predominio unilateral. Tampoco se encontraron diferencias significativas entre los sexos o las razas.

Entre las extensiones de las superficies articulares y los pesos corporales existieron correlaciones muy significativas y en los análisis de regresión del material se encontraron coeficientes relativamente bajos de la variación, atribuyéndose por consiguiente estas variaciones del tamaño de las articulaciones principalmente a las diferencias del peso corporal en relación con la edad del animal.

References
Sacroiliac Joint of the Horse.

Sacroiliac Joint of the Horse

3. Histological appearance

S. Ekman1, G. Dalin1, S.-E. Olsson3 and L. B. Jeffcott1

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With 15 figures

(Received for publication April 10, 1984)

Abstract

To establish a baseline for the histological appearance of the sacroiliac joint of the horse, joint specimens were collected from 41 horses from late fetal life to the age of 14 years. Sagittal sections from the joints were radiographed and sectioned for histological examination.

There was a striking difference in structure between the sacral and iliac articular cartilages, the former being hyaline and the latter predominantly fibrous. Degenerative changes were seen even in young horses and were more marked on the iliac side. The degeneration of the articular cartilage showed a progressive, age-related pattern.

Introduction

The gross morphology of the sacroiliac joint of the horse from late fetal stage to 14 years of age has been described in two previous papers (Dalin/Jeffcott, 1986a, 1986b). These macroscopic studies showed that the appearance of the joint varies considerably between individuals and according to age. The microscopic anatomy of the articular cartilage and the subchondral bone of the sacroiliac joint in the horse has not been described. Without a knowledge of the normal morphology of the joint and the age-related changes, particularly within the articular cartilage, the interpretation of suspected pathological alterations in the joint is difficult.

The purpose of the present study was to examine a series of horses, all included in the previous gross anatomy studies (Dalin/Jeffcott, 1986a, 1986b), to establish a baseline for the histological appearance of the sacroiliac joint. Furthermore, the morphology of certain macroscopic features was investigated.

Material and Methods

The sacroiliac joints from 41 horses with no known history of back problems were examined. The details of age, sex and breed distribution and the causes of death of the animals used and the method of dissection have been described previously (Dalin/Jeffcott, 1986a).
Fig. 1. The sacroiliac joint surfaces of a horse. In the upper row are the left and right sacral joint surfaces and in the lower row the left and right iliac ones. The sites are indicated where sections for radiographical and histological examinations usually were taken.

Fig. 2. Group 2. Radiograph (a) and schematic drawing (b) of a slab from the sacrum of a 1.5 year old Standardbred colt. There is retention of cartilage in the subchondral bone. C = articular cartilage; B = bone; L = cut ligament.

Fig. 3. Group 4. Radiograph of a slab from the sacrum of a 5 year old Swedish Warmblood gelding. The slab was cut at right angles to the crevice/crease present on the articular surface. There is a deep cleft in the bone. The walls of the cleft are covered by joint cartilage. Under the cleft the bone is dense.
The horses were divided into the following age groups:

- **Group 1** — Perinatal group (3 fetuses and 10 foals less than 2 months old) (*n* = 13);
- **Group 2** — Foals and yearlings (2 months to < 2 years) (*n* = 10);
- **Group 3** — Young horses (2 years to < 4 years) (*n* = 5);
- **Group 4** — Mature horses (4 years to < 6 years) (*n* = 7);
- **Group 5** — Older horses (6 years to < 15 years) (*n* = 6).

The left sacroiliac joint specimens from the 41 horses were cut sagittally into 5 mm thick slabs with a band saw. Usually, two slabs were taken from each articular cartilage. In some cases, additional slabs were made from areas with identified macroscopic features of interest (Dalin/Jeffercott, 1986a). The slabs from 20 horses were radiographed using envelope wrapped film (Kodalith Ortho type 3 film, Kodak Ltd., London, Great Britain) and a custom-built x-ray machine with a tube having a 1.5 x 1.5 mm tungsten target and a 1 mm thick beryllium window. Exposure data were 23 kV, 18 mA and 11 min and a focus-to-film distance of 40 cm.

For histological examination, the specimens were decalcified under vacuum in phosphate buffered saturated EDTA solution, embedded in paraffin and sections cut at about 6 μm. The sections were stained with Delafield's hematoxylin and eosin (H & E). Some additional sections were also stained with alcian-blue PAS, Van Gieson and Verhoff's elastin.

**Results**

**Radiography**

In the radiographs of the slabs, it was possible to identify the articular cartilage as a thin shadow covering the bone. As a rule, the cartilage was thinner on the iliac than on the sacral side. There were some other noticeable findings. In the horses of **Groups 2 and 3**, irregularities of the border line between the cartilage and subchondral bone were seen (Fig. 2). In one case the feature macroscopically described as "crevices or creases in the articular cartilage" (Dalín/Jeffercott, 1986a) was radiographed and found to be a deep cleft in the bone with an infolding of the cartilage. An area of sclerotic bone was seen immediately under the deepest part of the cleft (Fig. 3).

**Histology of the sacral articular cartilage**

In the perinatal animals, **Group 1**, most of the sacrum consisted of hyaline cartilage with vascular channels (Fig. 4). In the cartilage facing the joint cavity there were cells with a shape and arrangement resembling the surface layer of articular cartilage as seen in other diarthrodial joints.

By one year of age, **Group 2**, most of the sacrum was ossified. The columnar arrangement of the chondrocytes in the basal layer of the cartilage and the large cartilaginous cores in the primary bone trabeculae were evidence of growth and endochondral ossification. Large numbers of chondrocytes with pyknotic nuclei were noted in the superficial layers of the articular cartilage. These cells were not flattened in the manner normally seen in the superficial layers of joint cartilage. In a number of joints, parts of the surface was covered by a tissue with fibrillar structure and only a few flattened cells. This tissue stained light blue with alcian-blue PAS, red with Van Gieson and red with elastin. In some specimens, vascular channels could still be seen and some of them almost reached to the articular surface. Some of the vascular channels were surrounded by areas of endochondral bone formation.

The joint surfaces of the horses of **Group 3** had a rather regular appearance with little variation between animals. In a few joints, depressions were found in the articular surfaces. The depressions were usually filled with large amounts of a tissue less fibrillar in structure and with more cells than the one covering parts of the cartilage in the younger horses (Fig. 5). Occasionally, cartilage was retained in the subchondral bone.

The subchondral bone in the **Group 3** specimens usually had rather slender trabeculae, most of them oriented parallel with the joint surface (Fig. 5).

In the mature horses, **Group 4**, growth and endochondral ossification had ceased. As a rule, marked cluster formation of the chondrocytes was present (Fig. 6). The thickness of
Fig. 4. Group 1. Section of the cartilaginous sacrum from a Standardbred fetus (11 months of gestation). Two vascular channels are seen. H & E × 40

Fig. 5. Group 3. Section of the joint cartilage and the subchondral bone of the sacrum from a 2.5 year old Swedish Warmblood gelding with a depression filled by fibrillar tissue. There is some cluster formation of the chondrocytes in the basal layer and no evidence of endochondral ossification. The subchondral bone trabeculae run parallel with the joint surface. H & E × 40
Fig. 6. **Group 4.** Sections of the joint cartilage and the subchondral bone of the sacrum at two sites close to one another from a 4 year old Standardbred gelding. a) Marked basophilia and some cluster formation of the chondrocytes in the basal layer. b) Absence of basophilia and cluster formation. The matrix of the deeper layer of the cartilage has a slightly fibrillar structure. H & E × 40

the cartilage varied greatly within the same joint and between different joints. In a few cases, focal areas of retained cartilage were seen deep in the subchondral bone. In some joints from **Groups 3 and 4** there were, as in Group 2, a fibrillar tissue covering parts of the joint surface (Fig. 7).

In the older horses, **Group 5**, the cartilage was usually thinner than in the younger horses and the basophilia in HE staining was generally less marked. Very slight fraying of the surface was seen in a few cases. The cartilage thickness varied more and the size and number of cells in cluster formations was even greater than in Group 4 (Fig. 8). The development of a subchondral bone plate was seen in the older horses (Fig. 8).
In an effort to clarify the nature of some of the macroscopical features described by Dalin/Jeffcott (1986 a) a number of additional observations were made:

a) The so-called focal indentations mainly seen in the horses of Groups 1—3 were identified as being vascular channels close to the surface of the articular cartilage. Hence, they were not true indentations.

b) The “fibrous or ligamentous strands on articular surface” were examined in two joints and could best be characterized as composed of cartilage with a prominent fibrillar structure. The staining properties indicated that the cartilage had lost most of its glycosaminoglycan contents. Focal areas of chondrocytes in clusters were present in the fibrillar tissue and sloughing was also seen. Occasional necrotic areas were found in the basal layers of the articular cartilage.

c) The “erosions” of the sacral joint surface reported to be more frequent in older horses were apparently areas where the cartilage was invaded by a fibrous tissue rich in collagen and rather poor in cells but with many cavernous blood vessels (Fig. 9).
d) The "obvious crevices or creases in articular cartilage" were found to be narrow recesses or clefts of varying depths in the sacrum (Fig. 3). The walls and the bottom of these recesses were covered by a hyaline cartilage of relatively normal thickness. The cell columns of the basal layers of the cartilage of the walls were in some areas oriented
obliquely towards the surface of the sacrum. Necrosis in the superficial layer of the cartilage and sloughing were sometimes present. Beneath the deepest recess there was a rather thick bone plate.

**Histology of the iliac articular cartilage**

The iliac joint cartilage differed markedly from that of the sacrum. It was usually thinner and had more cells and less matrix. The cartilage could not be easily characterized as either hyaline or fibrous. In some areas one type of cartilage predominated, while in other areas they intermingled. Usually, the surface layers of the cartilage were more fibrous than the deeper layers. When specimens from the different age groups were compared it was evident that the cartilage became more fibrous in character with increasing age.

In the fetuses and very young foals, Group 1, the fibres in the surface layers were arranged tangentially in a wavy pattern with the underlying cartilage being more of the hyaline type. There were occasional areas where fibrocartilage was predominant (Fig. 10). In certain places, the cartilage was invaded by fibrous tissue with large dilated blood vessels (Fig. 11).

In the horses of Group 2 the fibrous component of the cartilage was more apparent. The variations of cartilage structure and thickness were more obvious than on the sacral side. Signs of degeneration were found even in horses as young as one year old. These signs included clustering of chondrocytes, sometimes necrosis (Fig. 12) and loss of cartilage. As in the horses of Group 1, invasion of the cartilage by a highly vascularized tissue was seen.

In the oldest horses of Group 3 and in all horses of Groups 4 and 5, all the above mentioned changes were present and were more marked. In addition, longitudinal splitting and clefts in the surface layer of the joint cartilage and sloughing were found (Fig. 13). Endochondral ossification had ceased in the horses of Groups 4 and 5.

It was apparent that endochondral bone formation was less marked on the iliac side in all horses. The subchondral bone plate developed earlier than on the sacral side. The arrangement of the bone trabeculae parallel with the joint surface was even more obvious on the iliac side (Figs. 10 and 11 a).
Fig. 11. Group 1. Sections of the joint cartilage and subchondral bone of the ilium from a 5-day-old Standardbred colt. a) The joint cartilage with a very irregular border to the underlying bone has an irregular and immature appearance. The deepest layer of the cartilage is calcified, the cells are vesiculated and to the right in the figure a fibrous tissue with large vessels has invaded the cartilage. Considering the age of the animal the subchondral bone trabeculae are rather plump. They are oriented parallel with the joint surface. H & E × 40. b) A close up of the right part of a) demonstrates the tangential arrangement of the surface layer. To the right, the deep layer of the cartilage is of the hyaline type with some parts being calcified. To the left, the cartilage has been replaced by a fibrous tissue with large, dilated blood vessels. The overlying tissue has thin, slightly wavy fibres and spindle shaped cells. H & E × 125
Fig. 12. Group 2. Section of the joint cartilage and subchondral bone of the ilium from a 1.5 year old Standardbred filly. There are only remnants of hyaline cartilage and in the fibrocartilage several necrotic areas are seen (arrows). The subchondral bone is compact and there are no signs of endochondral ossification. H & E × 40

Fig. 13. Group 5. Section of the joint cartilage and subchondral bone of the ilium from a 9 year old crossbred mare. Sloughing of the surface layer of the fibrous articular cartilage and clefts are present. The subchondral bone is compact. H & E × 40
Fig. 14. Group 5. Section of the joint cartilage and subchondral bone of the ilium from a 12 year old Standardbred mare. There is sloughing of the surface layer which is degenerated as revealed by the homogenous matrix and the pycnotic nuclei of the chondrocytes. The subchondral bone is compact. H & E x 40

Fig. 15. Group 5. Section of the joint cartilage and subchondral bone from a 12 year old pony gelding. In a large area the fibrocartilage has been replaced by granulation tissue. Some of this tissue is necrotic as are some remnants of the cartilage. A few spicules of bone are also seen in the granulation tissue. H & E x 40
Additional observations were made to clarify the nature of some of the gross morphology features described by Dalin and Jeffcott (1986a):

a) The macroscopic feature described as "small amorphous surface deposits" (Dalin/Jeffcott, 1986a) seemed to be sloughing of the cartilage in areas with degenerative changes (Fig. 14).

b) It was not possible to identify one common histological feature that corresponded to the macroscopical finding of "erosion". In one case, there would be an area of very thin cartilage with some sloughing, in another an invasion of the subchondral bone and the cartilage by a highly vascular fibrous tissue. A third alternative seemed to be necrosis of all layers of the cartilage with the invasion by granulation tissue, some of which was necrotic (Fig. 15).

c) The "fibrous or ligamentous strands" had the same appearance on the ilium as on the sacrum.

Discussion

This study confirms the macroscopic observation (Dalin/Jeffcott, 1986a) that the sacroiliac joint of the horse is a diarthrodial joint with a considerable variation in its appearance. This is true both within the same joint and between joints of the same animal as well as between horses.

The most striking histological feature was the difference in structure between the sacral and iliac articular cartilages. While the sacrum was covered by a hyaline cartilage, the one on the ilium had a predominantly fibrous structure and was thinner. These features have also been described for the human sacroiliac joint (Schunke, 1938; Bowen/Cassidy, 1981).

Another prominent histological finding was the presence of cartilage degeneration in horses as young as one year old. This was particularly evident on the iliac side. The degenerative changes were characterized by sloughing of the cartilage, loss of basophilia, and focal necrosis. It is tempting to assume that the absence of a smooth cartilage surface was the result of loss of contact with an opposing joint surface. This loss of contact may cause nutritional disturbances in the articular cartilage leading to further changes in the morphology.

Even in the young horses it was common to find the cartilage of both the sacrum and the ilium to be invaded from below by a highly vascularized tissue. It was noteworthy that this could happen without the invaded cartilage being degenerated or necrotic. This feature is rarely, if ever, seen in other diarthrodial joints and it bears little resemblance to the pannus ingrowth seen in arthritis.

It should be mentioned that even in horses with rather marked changes in the articular cartilage, no or little reaction was seen in the subchondral bone. The bone trabeculae of the subchondral bone were sometimes thicker and in some horses they formed a true bone plate, particularly on the iliac side. This was, however, more age-related than directly correlated with changes in the cartilage.

The orientation of the subchondral bone trabeculae parallel with the joint surface and the appearance of the superficial layers of the articular cartilage, ie. sloughing and tangential splitting, implies that the sacroiliac articular cartilage of the horse is subjected more to shearing than to compressive forces. Considering the very irregular appearance and thickness of the cartilage and the presence of degenerative changes even in young horses it is tempting to assume that this joint in the horse is in its final stage of being a true functional diarthrodial joint.

It was unexpected to find marked degenerative changes in the articular cartilage of horses with no known history of back problems. From the presence of discoloration of the articular surfaces, Rooney (1977) diagnosed sacroiliac arthrosis in a number of horses. As there were no clinical data supporting his statement that the horses were affected by an arthrosis of the joint, he may well have misinterpreted changes occurring in an age-related fashion in the joints of "normal" horses.
A thorough knowledge of the morphology of the sacroiliac joint is a prerequisite for the interpretation of pathological findings in the joint and their clinical importance. The macroscopic observations (DALIN/JEFFCOTT, 1986a) and the present histological study show that many pathological changes were present in the sacroiliac joints of "normal" horses. Most of these changes had an age-related occurrence, the frequency and severity increasing with age. This is in accordance with findings in man (SASHIN, 1930; BOWEN/CASSIDY, 1981).

The present histological study was planned as being complementary to the macroscopic investigation of the same joint specimens. Because of this, the joints had to be opened and could not be treated as a unity when the slabs for histology were cut. A study of the opposing joint surfaces in one and the same histological section could thus not be done. Small intra-articular bands as seen in man (SCHUNKE, 1938) might therefore have been overlooked.

Summary

Age-related progressive degenerative changes and an obvious difference between the sacral and iliac articular cartilages were the most striking findings in the present histological investigation. It should be noted that these findings were made on horses with no history of back problems.

The sacral articular cartilage was hyaline while the one on the iliac side was thinner and more fibrous in character. Degenerative changes were seen even in young horses and were more marked on the iliac side. They included areas with loss of basophilia, focal necrosis and, in the superficial layers, sloughing and tangential splitting of the cartilage. The subchondral bone trabeculae were often oriented parallel to the joint surface. This feature in combination with the findings of superficial sloughing and tangential splitting indicates that the sacroiliac joint of the horse is subjected more to shearing than to compressive forces.

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Zusammenfassung

Zur Articulatio sacroiliaca des Pferdes
3. Histologisches Erscheinungsbild

Die auffälligsten histologischen Befunde betreffen einerseits altersbedingte progressiv-degenerative Veränderungen, andererseits klare Unterschiede der Gelenkknorpel an Kreuz- und Darmbein. Es soll hervorgehoben werden, daß die Befunde an Pferden ohne klinischen Hinweis auf Probleme im Bereich des Rückens erhoben werden.


Die Summe dieser Befunde zeigt an, daß das Kreuzdarmbeingelenk mehr Scherkräften als Druckkräften unterworfen ist.
Résumé
L’articulation sacro-iliaque du Cheval
3. Images histologiques

La présente recherche histologique a révélé, comme faits les plus marquants, une évolution dégénérative progressive et une différence nette entre les cartilages articulaires sacral et iliaque. Il est à noter que ces faits ont été relevés sur des chevaux sans antécédents de problèmes de dos.

Le cartilage articulaire sacral était hyalin, alors que celui de l’iliaum, plus mince, était de nature plus fibreuse. Des modifications dégénératives furent observées, même chez le jeunes sujets, plus marquées du côté iliaque. Elles consistaient en la présence de plages ayant perdu leur basophilie, de foyers de nécrose, et, dans les couches cartilagineuses superficielles, de pertes de substance et de fissurations tangentielles. Les trabéculles osseuses sous-chondrales étaient souvent orientées parallèlement à la surface articulaire. Ce fait, joint à la mise en évidence des pertes superficielles et des fissures tangentielles, indique que l’articulation sacro-iliaque du cheval est davantage soumise à la traction qu’aux forces de compression.

Resumen
La articulación sacro-ilíaca del caballo
3. Aspectos histológicos

En esta investigación histológica, los cambios degenerativos progresivos en relación con la edad y una diferencia obvia entre los cartilágeos articulares sacro e ilíaco eran los hallazgos más importantes, encontrados en caballos sin historia clínica de problemas del dorso.

El cartílago de la articulación sacra era hialino, mientras que el del lado ilíaco era más delgado y tenía un caracter más fibroso. Los cambios degenerativos se observaron aún en caballos jóvenes, ubicándolo más intensamente en el lado ilíaco, e incluyendo áreas con pérdida de la basófilica, necrosis focales y en las capas superficiales del cartílago descamación y fisura. Las trabéculas óseas subcondrales se orientaron frecuentemente en sentido paralelo a la superficie articular. Estos detalles junto a los hallazgos de la descamación superficial y la fragmentación tangencial indican que la articulación sacro-ilíaca del caballo está expuesta más bien a fuerzas de roce que de compresión.

References

TECHNIQUE OF LINEAR TOMOGRAPHY FOR THE PELVIC REGION OF THE HORSE

L. B. JEFFCOTT, BVETMED, PHD, FRCVS*

A method of linear tomography for the pelvic region of the horse is described. A custom-built unit was employed, and exposures of 140 kV and 400 mAs for three to four seconds were required in horses weighing approximately 450 kg. Animals were anesthetized and placed in lateral or dorsal recumbency. Radiographic quality of the lateral projection was considered unsatisfactory, but on ventrodorsal tomograms taken at an angle of swing of 10° or 20° most of the anatomic structures in the lumbar spine and pelvic girdle could be identified. The height of the plane of cut varied from 30 to 300 mm, according to anatomic location, but between animals the height of each structure was reasonably consistent. *Veterinary Radiology, Vol. 24, No. 5, 1983; pp 194–200.

Key words: radiography, tomography, x ray, sacroiliac joint, lumbosacral region, pelvic bones, horses.

THE IMPORTANCE of caudal lumbar and pelvic conditions in horses and the role of radiologic examination in the diagnosis of these conditions have been reported. However, in spite of the availability of powerful and sophisticated equipment as well as improved intensifying screens and film, the quality of radiographs of the lumbar and sacral regions remains unsatisfactory. This is due mainly to the thickness of the pelvic region, the composite structure of the pelvic girdle, and the limited range of radiographic projections possible with the animal under general anesthesia. The present paper reports the use of linear tomography of the equine pelvic area in an attempt to obtain radiographs of diagnostic value.

Materials and Methods

Five mature Standardbred horses maintained as experimental animals for an exercise physiology project were used. They were in good condition, had no clinical signs of thoracolumbar or hindlimb disease, and were regularly exercised on a treadmill. Their ages ranged from five to ten years and their body weights from 300 to 500 kg. There were two geldings and three mares. In addition, a yearling Standardbred colt that had been submitted to the Department of Clinical Radiology for euthanasia because of cervical vertebral stenosis was included.

The radiographic facility was custom-built by Siemens–Elema (Solna, Sweden) and Sikob AB (Sollentuna, Sweden) for the Department of Clinical Radiology and was described previously. For this investigation the main x-ray tube (150 kV, 2000 mA) above the radiolucent table top was used with a cassette holder beneath in a separate film carriage, which also housed a Potter-Bucky grid. The x-ray tube and film carriage were automatically linked for linear tomography (Fig. 1). Settings for the required tomographic cycle and selection of the plane of cut were made on a separate console that controlled all functions of the table and overhead equipment. The plane of cut could be adjusted from 0 to 310 mm by altering the height of the table; the tube and film carriage remained fixed at a focus-to-film distance (FFD) of 1350 mm.

The movement of the x-ray tube followed a longitudinal path over the long side of the table, and the overall area for tomographic examination was 1500 x 2700 mm. During the tomographic cycle (Fig. 2) the x-ray tube, which moved 800 mm, was turned by a separate motor to direct the primary beam at the cassette while the film carriage moved 400 mm in the opposite direction. The x-ray tube moved twice as far and at twice the speed, which gave a fixed enlargement factor of 1.5.

The maximum angle of swing of the tube was 40°, and the minimum was 5°. In this study an angle of swing of either 10 or 20° was used, giving layers approximately 6.6 and 3.3 mm thick, respectively. Ten different speed settings could be selected, depending on the choice of exposure. Once the tomographic...
cycle had been set, the tube and film carriages were moved to their starting positions. When the exposure button was pressed both carriages accelerated, and the exposure commenced automatically once they had reached a steady speed. At the end of the exposure they returned to their original resting position. The entire tomographic cycle required ten seconds. Rare earth intensifying screens were used. Films were processed by an automatic processor. Animals were sedated with 25-35 mg of acetylpromazine before induction of anesthesia with glyceryl guiacolate and thiopentone sodium. A state of light anesthesia was maintained with a mixture of halothane and oxygen. After transportation to the x-ray examination room, the horse was placed in lateral or dorsal recumbency (Fig. 3). The latter position was maintained by two pairs of adjustable sloping metal supports at the withers and at the caudal lumbar region. The hindlimbs were kept flexed in the frog-leg position.

Linear tomograms in the lateral plane were attempted in only one horse, a five-year-old mare weighing 390 kg. In this case a plane of cut from 100 to 300 mm was used.

In the ventrodorsal projection survey radiographs of the lumbar and sacroiliac regions were taken to assess the exact position and optimum exposure. A series of tomograms were then taken at heights of 30-200 mm. In one animal tomograms of the right acetabulum were also taken at heights of 200-280 mm.

Results

The exposure values required for satisfactory radiographic quality ranged from 109 kV and 250 mAs to 140 kV and 400 mAs, depending on the area of ex-
amination. Various angles of swing were tried, but 10° provided adequate sharpness of the tomographic layer. Speed selection numbers 3 and 4, which gave exposure times of 3.2 and 4.0 seconds, respectively, were most commonly used. The plane of cut (i.e., height of the tomographic layer) above the table top varied according to anatomic location but did not vary significantly between horses (Table 1).
Table I. Approximate Values of the Plane of Cut (i.e., height of tomographic layer above the table) for Different Locations in the Pelvic Region with the Animal under General Anesthesia

<table>
<thead>
<tr>
<th>Position of Animal</th>
<th>Anatomic Location</th>
<th>Plane of Cut (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsal recumbency</td>
<td>Lumbar dorsal spinous processes</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Lumbar articular processes</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Lumbar vertebral bodies, transverse processes, and lumbosacral articulation</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Sacroiliac articulation</td>
<td>140–160</td>
</tr>
<tr>
<td></td>
<td>Acetabulum</td>
<td>250–280</td>
</tr>
<tr>
<td>Right lateral recumbency</td>
<td>Lumbar vertebral bodies and lumbosacral articulation</td>
<td>290</td>
</tr>
<tr>
<td></td>
<td>Sacroiliac articulation (right side)</td>
<td>180</td>
</tr>
</tbody>
</table>

Lumbar Spine (L2–L6)

In the ventrodorsal projection it was possible to identify many anatomic structures normally hidden by bowel or obscured by superimposition (Fig. 4). At a plane of cut of 30–50 mm the top of the dorsal spinous processes was visible, and on either side of the spinous of L6, the tips of the tuber sacrale of the ilium were visualized. It was also possible to see the intervertebral articulations, although they became much clearer at a height of 80 mm. At this level the vague outline of the transverse processes and intervertebral disc spaces could be seen. At about 120 mm these structures could be distinguished, together with articulations between the transverse processes and vertebral notches.

Lumbosacral Region (L7–S3)

In the majority of horses the optimal height of the tomographic layer was approximately 150 mm with the animal in dorsal recumbency. The structures visible at this level (Fig. 5) were compared with those in a postmortem specimen sectioned horizontally through the sacroiliac joint (Fig. 6). At this level it was possible to identify the lumbar vertebral bodies and the lumbosacral articulation, as well as the articulation between...
the transverse process of L6 and the cranial wing of the sacrum. On the lateral aspects of the lumbosacral joint were the prominent notches on the L6 transverse processes and sacral wings. Immediately caudal and medial to the notches were the articular processes of the first sacral vertebra. The sacroiliac joint space was viewed as a rather irregular line extending from the junction of the cranial extremity of the lateral sacral border across the auricular surface of the wing of the ilium toward the lateral tip of the transverse process of L6. Other structures included the body of the sacrum, sacral spinous processes, and the medial border of the wing of the ilium.

A series of tomograms taken at different heights (Fig. 7) through the sacroiliac region of a five-year-old mare illustrated the necessity of multiple exposures for a fully comprehensive radiographic survey. At 100 mm the lumbosacral intervertebral space or foramen formed between the bases of the spinous processes of L6 and S1 was visible, as well as the lumbar and sacral spinous processes. At 120 mm the articulation between the transverse process of L6, the lumbosacral joint, and the cranial wing of the sacrum could also be seen, while at 140 mm the sacroiliac joint and vertebral notches were in the tomographic layer. At 160 mm the articular processes of S1 were visible. At higher tomographic layers (180 and 200 mm) the shadow of the ventral colon and, presumably, the pelvic flexure could be seen on the left side.

With the horse in lateral recumbency it proved to be very difficult to obtain radiographs of satisfactory quality. At a layer height of 290 mm it was possible to distinguish only the border of the caudal lumbar vertebra and sacrum and the lumbosacral transverse processes. At a height of 180 mm the auricular surface of the wing of the ilium, the sacral wing, and L6 trans-
verse process could be roughly identified, but the definition was not good enough to identify any minor changes.

Acetabulum

In the ventrodorsal projection tomograms through the hip could be obtained at heights of 200–280 mm. The plane of cut varied much more than in the lumbarosacral region due to the variability of the position of the quarters on the table and the tension required to keep the limb in flexion. The best results were usually obtained at about 225 mm, when the joint space and acetabular fossa were clearly visible.

Discussion

Linear tomography of the pelvic region of large animals has not been reported previously. The method employed in the present study was simple and practical but required a specially designed, expensive custom-built unit. This will inevitably limit its usefulness as a standard technique, which is unfortunate as it could well prove helpful in the diagnosis of some conditions that cause pelvic lameness and loss of performance. The sacroiliac area was considered the most important region, partly because of its anatomic inaccessibility and partly because of the clinical importance of sacroiliac lesions.\textsuperscript{2,7} A plane of cut of 150 mm usually sectioned the midportion of the joint, giving good visibility of the caudal portion of the sacral wing. However, for a complete survey of both articulations three or four tomograms at 10-mm intervals were necessary (e.g., 130–160 mm), which was time-consuming, with the entire procedure requiring an anesthetic time in excess of 90 minutes. The system could have been improved and the patient doses of radiation greatly reduced if a multicassette box had been used.\textsuperscript{6} This type of equipment is available commercially. In this way a series, typically five or six, of simultaneous multiple cuts through the structure being radiographed could be included in a single exposure. For an FFD of 1350 mm, the height of the plane of cut at 200 mm, and spacing the film in the multicassette box 12 mm apart, a number of 10-mm cuts through the sacroiliac region could be obtained. To ensure that all films are of comparable density, it is necessary to use intensifying screens of graded speeds (i.e., fastest for the lower films).

The quality of survey ventrodorsal radiographs of the hip joint\textsuperscript{2,8} is such that tomography is usually unnecessary. However, if minor articular damage is suspected, some benefit might be gained by using tomography at a plane of cut through the center of the hip joint. The use of tomography in a sagittal plane was
disappointing, although improvement in the quality of the lateral tomograms might have been gained by using a faster screen/film combination, reducing secondary radiation and improving contrast.

The length of the tomographic procedure was usually 1½ hours but varied from 1 to 2½ hours. No difficulties were encountered with general anesthesia or the maintenance of the animal in dorsal recumbency for this period. The respiratory rate was usually about 5–10/minute, which gave ample time for tomographic exposures up to 4.0 seconds. If breathing occurred during the midpoint of an exposure, some motion blurring was seen.

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REFERENCES

RADIOGRAPHIC APPEARANCE OF EQUINE LUMBOSACRAL AND PELVIC ABNORMALITIES BY LINEAR TOMOGRAPHY

L. B. JEFFCOTT, BVetMED, PhD, FRCVS*

Radiologic findings are described in 20 horses with clinical signs of a caudal lumbar or hindlimb problem; the horses were subjected to linear tomography of the lumbosacral and pelvic regions. The cases could be divided into four groups: sacroiliac arthrosis (6 horses), lumbosacral abnormalities (3 horses), pelvic or lumbar fracture (6 horses), and no radiographic abnormalities (5 horses). Five of the six horses with sacroiliac arthrosis had spur formation, with localized arthrosis at the caudal aspect of the sacral wing and its articulation with the auricular surface of the ilium. In one horse these lesions were confirmed at postmortem examination. The sixth horse, a Standardbred trotter, had more even and widespread arthrosis of the sacroiliac joint. The three lumbosacral abnormalities were present in two horses with fusion of the L7-L8 articulation and one horse with a wider than normal sacrolumbar articulation. Linear tomography also proved to be of diagnostic and prognostic value in the evaluation of lumbar and pelvic fractures. Finally, tomography could be used to eliminate the presence of sacroiliac or lumbosacral damage in some horses that presented with clinical signs suggestive of disease of the lumbosacral or sacroiliac region.

Key words: radiography, tomography, x-ray, linear tomography, sacroiliac joint, lumbosacral region, pelvic bones, horses.

THE RANGE OF CLINICAL CONDITIONS affecting the lumbosacral and pelvic regions of the horse is extensive. From a radiologic point of view, pelvic fracture is the most important entity, and osteoarthritis of the hip (i.e., coxitis) is rare. However, definitive diagnosis in many horses is not possible, and only a clinical opinion based on subjective experience can be given for the cause of lameness. The inherent difficulties of survey radiography of the lumbosacral region have been considered previously, but principally they involve the considerable thickness of the quarters of the horse, the limited projections possible in this region, and the superimposition on skeletal structures by large bowel. The present paper reports the potential value of linear tomography as an additional diagnostic aid in a series of horses with lameness, back pain, or loss of performance.

Materials and Methods

A total of 20 horses of varying ages and types was referred to the Department of Clinical Radiology (Table 1). The case histories were assessed, and the appropriate clinical and radiographic investigations leading to a tentative or presumptive diagnosis of lumbosacral or pelvic injury were performed. Radiographic evaluation in the ventrodorsal projection, including linear tomography of the lumbar, lumbosacral, or pelvic regions, was then performed. The technique of tomography, including the method of general anesthesia, was previously described. A series of three or more tomograms was taken at approximately 10-mm intervals through the area of the suspected abnormality.

Results

The cases were grouped according to the anatomic region concerned and the type of radiographic changes demonstrated. Radiographic findings with potential clinical significance were recorded in 15 of the horses (75%) investigated.

Sacroiliac Arthritis

The most frequent single entity diagnosed was sacroiliac arthrosis, which was found in six horses (30%). The clinical history in these horses was poor
performance associated with lack of impulse from the quarters and intermittent or low-grade hindlimb lameness. The problem was primarily unilateral, but some contralateral involvement was often encountered. Another important clinical sign was noticeable asymmetry of the hindquarters, usually due to muscle atrophy of the gluteal mass with slight lowering of the quarters and intermittent or low-grade hindlimb lameness, the cause of which was suspected to be a sacroiliac abnormality. Pelvic asymmetry was present in two of the three horses. Tomographic evaluation of the back and hindlimbs proved inconclusive.

Survey radiography of the pelvic, sacral, and lumbar regions revealed no diagnostic findings. On linear tomograms some irregularity of the outline of the sacral wing, with apparent widening of the sacroiliac joint space, was seen. In five riding/dressage horses (Horses 1–4, 6) there was also evidence of spur formation at the caudal wing of the sacrum and arthrosis involving the auricular surface of the wing of the ilium (Fig. 1). These changes were usually bilateral but more pronounced on the clinically affected side. The remaining horse (Horse 5) was a Standardbred trotter in which the arthrosis was not confined to the caudal sacral wing but seemed rather to involve the entire lateral aspect of the sacroiliac articulation (Fig. 2). In addition, the vertebral body of L5 was slightly mal-aligned to the left, and the lumbosacral intervertebral space was less distinct than normal.

Only one of these horses became available for post-mortem examination (Horse 6). Considerable spur formation at the caudal wing of the sacrum was found (Fig. 3). A large notch of new bone had formed on the auricular surface of the ilium, but no demonstrable damage in the ventral sacroiliac ligaments was present. The spur on the caudal sacral wing was covered with articular cartilage.

**Lumbosacral Abnormalities**

Clinical signs in these horses were obscure hindlimb lameness, the cause of which was suspected to be a sacroiliac abnormality. Pelvic asymmetry was present in two of the three horses. Tomographic evaluation of two of the horses (Horses 7 and 8) demonstrated evidence of fusion of the last lumbar intervertebral disc spaces (L5–L6) (Fig. 4). The principal radiographic change was loss of the lumbosacral intervertebral space due to partial ankylosis, accompanied by a wider than normal L5–L6 intervertebral space. The sa-
Fig. 1. (A) Linear tomogram and (B) line diagram of the lumbosacral region at a plane of cut of 165 mm in a 6-year-old Thoroughbred gelding with sacroiliac arthrosis (Horse 1).

Fig. 2. (A) Linear tomogram and (B) line drawing taken at a plane of cut of 150 mm in a 4-year-old Standardbred in which irregularity and arthrosis affecting the lateral aspect of the right sacroiliac joint can be seen (Horse 5).
eral wings were unusually narrow, and on one side partial or complete fusion with the transverse process of $L_6$ had occurred. In Horse 8 the sacroiliac articulation (on the side not fused to the $L_6$ transverse process) was indistinct and apparently undergoing ankylosis (Fig. 5).

Horse 9 exhibited consistent loss of performance as a trotter, with low-grade left hindlimb lameness, but showed radiographic changes very different from those of the two previously discussed horses. The lumbosacral intervertebral space and the articulations between the wings of the sacrum and the $L_6$ transverse processes appeared much wider than normal (Fig. 6); this condition was accompanied by evidence of low-grade sacroiliac arthrosis. At postmortem examination no detectable abnormalities were noted in the lumbosacral intervertebral space or the articulation between the sacral wings and transverse processes of $L_6$. However, signs of bilateral low-grade sacroiliac arthrosis with spur formation at the caudal aspect of the joints were present.

**Fractures of Lumbosacral and Pelvic Regions**

Linear tomography proved beneficial in confirming the site and providing a more accurate prognosis in six horses with a lumbosacral or pelvic fracture (Table 2). Lesions were confirmed at postmortem examination in four of the six cases.

In Horse 10, a foal presented with a sudden onset of partial paraplegia, a crushed first lumbar vertebra was detected by lateral survey radiography. The extent of the fracture site and crushing of the vertebral body of $L_1$ could be clearly seen on the ventrodorsal tomogram taken at a plane of cut of 80 mm above the surface of the table (Fig. 7). Upon myelography, made by injection of 20 ml of metrizamide$^\dagger$ into the atlanto-

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$^\dagger$ Amipaque, Nyegard, AB, Norway.
occipital space, stenosis of the vertebral canal just proximal to L₁ was identified.

Horse 11 had a long history of poor racing performance. Trotting at speeds of greater than 7 m/second evoked a hiking-type lameness in the left hindlimb. Clinical examination, including selective nerve blocks up to and including the hip joint, did not reveal the site of lameness. Survey radiographs of the thoracolumbar spine (T₂-L₆) and pelvic region were normal. In a tomogram at a plane of cut of 155 mm, a suspected partial nonunion in a fracture of the sacral wing was seen (Fig. 8). In Horse 12 a comminuted fracture of the shaft of the ilium was complicated by a complete longitudinal fracture line through the left sacral wing. This second fracture site was not visible on survey ventrodorsal radiographs (Fig. 9) but was clearly seen at postmortem examination (Fig. 10).

Horse 13 became acutely lame in the hindlegs with marked asymmetry of the hindquarters after an accident. An overriding fracture of the body of the ischium was seen on survey radiographs, but in a tomogram at a height of 150 mm a much more distinct and wider sacroiliac joint space was seen on the affected side (Fig. 11). This change was suggestive of sacroiliac strain or subluxation which could have accounted for the pronounced asymmetry of the quarters seen clinically. Horse 14 had a previous history of ischial fracture and possible acetabular involvement. Tomography confirmed the presence of a low-grade, chronic osteoarthritis at the caudal aspect of the hip joint (Fig. 12), which was confirmed at necropsy.

In survey radiographs of Horse 15 a chronic overriding fracture of the ilial shaft with possible extension into the acetabulum was seen. In linear tomograms, it could be seen that a narrow fragment of ilial shaft had passed behind the acetabulum but did not involve the hip joint itself (Fig. 13).

No Radiographic Findings

In five of the horses examined (Table 1) no significant radiologic abnormalities were detected on survey
radiographs or tomograms of the lumbosacral and pelvic regions. Although the clinical histories in these horses suggested a possible sacroiliac or lumbosacral abnormality, the clinical history was not typical, and tomography was performed as an eliminative procedure. None of these horses was available for follow-up or postmortem examination.

Discussion

Previous accounts of radiography of the equine pelvis have concentrated mainly on sites of fracture.\textsuperscript{2,3} This is the first report of an attempt to use linear tomography of the equine pelvic region as an aid to diagnosis of obscure hindlimb lameness. Tomography has been helpful in permitting visualization of the lumbosacral spine, pelvis, sacroiliac joints, and associated structures.\textsuperscript{9} However, interpretation is hampered due to lack of knowledge of normal morphology and functional anatomy of the lumbosacral and sacroiliac articulations. In humans some elegant radiographic and morphologic studies, including an assessment of the normal range of movement,\textsuperscript{9,10,11} have greatly assisted in the clinical evaluation of back pain. Pathologic analysis of traumatic sacroiliac strain or subluxation has received some attention\textsuperscript{4,12} in horses with gross ligamentous damage. However, a more prevalent clinical entity may be that due to long-standing sacroiliac instability, which results in low-grade arthrosis.\textsuperscript{5}

The prevalence of chronic sacroiliac damage in Standardbreds as compared with Thoroughbreds has been noted, but a detailed description of the changes involved has not been provided. The radiologic findings of arthrosis in six horses in the present series seem to confirm the possibility that this is an important clinical entity. The biomechanical theory behind the production of these lesions was described recently\textsuperscript{13} with some suggestions for their prevention.
Fig. 6. (A) Linear tomogram and (B) line drawing taken at a plane of cut of 150 mm in a 9-year-old Standardbred gelding (Horse 9). There is apparent widening of the lumbosacral, sacroiliac, and joint space between the transverse process of L5 and the sacral wing.

Table 2. Radiographic Findings in 6 Horses with Lumbar, Sacral, or Pelvic Fracture Examined by Linear Tomography

<table>
<thead>
<tr>
<th>Horse No.</th>
<th>Radiographic Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Crush fracture of L1 and L2 with vertebral stenosis</td>
</tr>
<tr>
<td>11</td>
<td>Partial nonunion fracture of sacral wing</td>
</tr>
<tr>
<td>12</td>
<td>Complete fracture of sacral wing and comminuted fracture of shaft of ilium</td>
</tr>
<tr>
<td>13</td>
<td>Overriding fracture of ischium and possible sacroiliac subluxation</td>
</tr>
<tr>
<td>14</td>
<td>Fracture of body of ischium with secondary osteoarthritis of hip</td>
</tr>
<tr>
<td>15</td>
<td>Overriding fracture of shaft of ilium without acetabular involvement</td>
</tr>
</tbody>
</table>
Fig. 7. (A) Linear tomogram and (B) line drawing taken at a plane of cut of 80 mm in a 6-week-old Standardbred colt (Horse 10). There is a fracture through the vertebral body of L₁ and L₂.
FIG. 8. (A) Linear tomogram and (B) line drawing taken at a plane of cut of 155 mm in a 6-year-old Standardbred mare exhibiting obscure right hindlimb lameness (Horse II). A fissure line in the right sacral wing was detected.
FIG. 9. (A) Linear tomogram and (B) line drawing taken at a plane of cut of 120 mm in a 2-year-old Standardbred (Horse 12). There is a fracture of the left sacral wing.
Fig. 10. Postmortem appearance of fracture in the left sacral wing of a 2-year-old Standardbred (Horse 12).
FIG. 11. (A) Linear tomogram and (B) line drawing taken at a plane of cut of 150 mm in an 11-year-old Standardbred (Horse 13) with a pelvic fracture. Considerable widening of the left sacroiliac articulation is present.

FIG. 12. (A) Linear tomogram and (B) line drawing of the hip of a 2-year-old Standardbred taken at a height of 220 mm (Horse 14). A previous fracture of the ischium has healed, but secondary arthrosis of the acetabulum is detectable.
In anatomic accounts of the lumbosacral region of the horse there is no mention of sacralization or the presence of transitional vertebrae as a common finding. In humans sacralization of the fifth lumbar vertebra has been incriminated as a cause of severe low back pain. This type of abnormality is noted in approximately 2% of dogs as an apparently incidental radiologic finding. The clinical significance of the fusion of the lumbosacral space with apparent sacralization of L5 and associated changes observed in two horses in the present series is uncertain, but it may well have predisposed these horses to the low-grade hindlimb lameness and loss of performance encountered. A similar clinical history was reported in a single case of so-called subluxation of L5 in a series of 443 horses referred for back problems. If tomography had been available in this case, a more accurate description of the abnormality might have been possible. In retrospect, it seems likely that a partial fusion at the L5-L6 articulation, associated with a mild compensatory spinal curvature, was present. In another horse in the same series congenital vertebral fusion at L1-L2 (synostosis) was accompanied by local scoliosis and kyphosis of the vertebral column. Tomography could also be utilized for better visualization of lumbar and pelvic fractures, particularly those in which overriding of bone fragments is present. Use of tomography gives valuable prognostic information and improves radiologic diagnosis as well. Lesions within the hip joint are less common, but the changes of osteoarthritis, osteochondrosis, and hip dysplasia would be more accurately defined by tomography than by survey radiography.

It is concluded that linear tomography of the equine lumbosacral and pelvic regions can be beneficial in selected horses with hindlimb or back problems. At this stage it does not always provide a definitive diagnosis but can materially assist the radiologist in defining structural changes in this area and in eliminating certain important conditions (e.g., sacroiliac arthrosis).

REFERENCES

Sacroiliac lesions as a cause of chronic poor performance in competitive horses

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Summary
The histories and clinical signs in 11 horses with longstanding poor performance attributed to chronic sacroiliac damage are described. The main clinical feature was a lack of impulsion from one or both hindlimbs causing a restriction in the hind gait or lowgrade lameness. A temporary improvement was often achieved using anti-inflammatory medication, but eventually all the horses were killed because of unsatisfactory progress at exercise. Post mortem examination revealed that changes were confined to the sacroiliac joints. The macroscopic and histological findings varied considerably and in only two cases could the changes be classified histologically as arthrosis. In the other nine horses there was increased joint surface area or irregular outline associated with extensions of the joint on the caudomedial aspect. These changes were interpreted as indicating a chronic instability of the joint leading to restriction of hindlimb impulsion. The underlying cause of the problem was not ascertained but the significance and possible pathogenesis of the lesions are discussed.

Introduction
In recent years considerable importance has been attributed to injury of the sacroiliac joint as a cause of lowered performance in horses (Adams 1969; Rooney, Delaney and Mayo 1969; Rooney 1977, 1981; Koch 1980; Jeffcott 1982). However, the exact nature of the changes involved are not yet clear. There have been a few reports of post mortem changes (Rooney et al. 1969; Jeffcott 1982) but these can by no means be described as definitive. There are several reasons for the lack of basic knowledge on the sacroiliac joint of the horse: (a) Clinical diagnosis of sacroiliac damage is imprecise because of its inaccessible anatomical location; (b) the biomechanics of the joint are not fully understood; (c) the clinical signs are rarely severe enough to warrant euthanasia, even though the incidence of the condition may be quite high, and post mortem examination is therefore seldom possible; (d) the joint is difficult to examine effectively at autopsy; (e) until recently, little has been known about the normal macroscopic and histological appearance of the joint (Dalin and Jeffcott 1985a, b; Ekman, Dalin, Olsson and Jeffcott 1985).

The purpose of this study is to report on the clinical findings of 11 competitive horses with suspected chronic sacroiliac damage and to correlate the clinical signs with the post mortem changes in the joint.

Materials and methods
A total of 11 horses of varying breed, age and size with a history of poor performance at exercise, usually with low grade hindlimb lameness, were investigated (Table 1). A full history was obtained for each case and clinical examination carried out with particular reference to examination of the back (Jeffcott 1981). Elimination of thoracolumbar, stifle, hock and distal limb problems was performed by appropriate flexion tests, local anaesthetic nerve blocks and radiography. Radiographic examination of the thoracolumbar, lumbosacral and pelvic areas was performed on six cases (Jeffcott 1982) and linear tomography of the lumbosacral region on four cases (Jeffcott 1983a, b).

Post mortem examination was carried out as described by Dalin and Jeffcott (1985a) including morphometric measurements of the sacral and iliac joint surfaces (Dalin and Jeffcott 1983b). Histological examination was done in seven horses and in six of these radiographic examination of slabs from the sacroiliac joints was performed.

Statistical analyses were carried out by standard methods and included the calculation of significance by Student's t test for paired observations.

Results
Clinical findings

The horses were predominantly geldings of middle age (five to 12 years old) and large body size (Table 1). They were all competitive animals; four horses were mainly used for general riding purposes but did compete in some showing and amateur equestrian competitions. Only two of the horses were less than 155 cm in height and these were both Standardbred harness racing horses; the others were Thoroughbreds or Warmblood types. No consistent history of trauma could be incriminated as being the inciting cause of lameness in any of the cases in this series.

There was always a prolonged history of poor performance at exercise. The estimated mean time for the duration of
clinical signs was about 14 months (Table 2). Mild hindlimb lameness (ie, swinging type) was usually present and was frequently most noticeable at a slow trot. This was often associated with some stiffness of the hind action at the commencement of exercise. The lameness was often difficult to define precisely. It tended to be unilateral but from time to time the opposite hindlimb was also affected. The lameness was seen from behind as an unlevel action with restriction in hindlimb stride and poor impulsion from the quarter. There was commonly mild abduction of the affected limb during mid stride followed by bringing the leg underneath the body before landing (ie, plaiting). Some restriction in hock flexion was frequently suspected, often with dragging of the toe during the cranial phase of the stride.

The response to hock flexion was variable but in no case was there a dramatic and positive response. Radiographic examination of the hocks was carried out in nine cases and no signs of any changes resulting from bone spavin were demonstrated, when viewed from behind the majority of horses showed some asymmetry of the hindquarters with the tuber coxae and tuber sacrale lower on the side the animal was lame on. However, this was not consistent in all cases. Atrophy of the gluteal muscles was another frequent finding and this was usually more pronounced on the lame quarter. Often associated with this was a greater prominence of the tips of the caudal lumbar spinous processes and tuber sacrale, referred to colloquially as a ‘jumper’s bump’. Palpation of the distal lumbar spine and lumbosacral region was frequently resented, although none of the horses showed a marked pain response. There was usually some reduction in the normal range of spinal flexibility to dorsiflexion (ie, dipping), ventroflexion (ie, arching) or lateral flexion of the back. In most cases, no obvious difficulties turning in a tight circle or moving backwards were seen.

Rectal palpation of the skeletal structures in the pelvic canal was normal and no pain could be elicited from the ilioosposas muscles. Clinical pathological examination, including analysis of the haematological profile and the enzymes aspartate amino transferase and creatine kinase, did not indicate the presence of any active skeletal muscle damage.

The Standardbreds encountered problems when performing at speed, particularly on the turns where they tended to lose their action and go out of trot into transitional gait or gallop. Case 2 was exercised on a treadmill (Fredricson et al 1983) and showed poor hindlimb impulsion and difficulty maintaining the trotting gait at speeds greater than 7 m/sec. A marked improvement was obtained up to speeds of 9.5 m/sec when the animal was maintained on therapeutic levels of phenylbutazone. There was a rapid deterioration in performance once medication was withdrawn. The riding and jumping horses invariably performed at their worst at slower speeds, particularly during ground work and dressage movements. They showed stiffness of the back and

### TABLE 1: Breed, use, sex, body weight and height of 11 horses examined with sacroiliac damage

<table>
<thead>
<tr>
<th>Case number</th>
<th>Breed</th>
<th>Use</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Body weight (kg)</th>
<th>Height at withers (cm)</th>
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<tr>
<td>1</td>
<td>SWB</td>
<td>Hack</td>
<td>9</td>
<td>G</td>
<td>590</td>
<td>167</td>
</tr>
<tr>
<td>2</td>
<td>STB</td>
<td>Trotter</td>
<td>6</td>
<td>G</td>
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<td>155</td>
</tr>
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<td>3</td>
<td>TB</td>
<td>Dressage</td>
<td>7</td>
<td>M</td>
<td>600</td>
<td>160</td>
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<td>SWB</td>
<td>Hack/Dressage</td>
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<td>G</td>
<td>550</td>
<td>164</td>
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<td>Hack</td>
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<td>M</td>
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<td>Trotter</td>
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<td>M</td>
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<td>152</td>
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<td>Hack/Dressage</td>
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<td>SWB</td>
<td>Hack</td>
<td>6</td>
<td>M</td>
<td>590</td>
<td>168</td>
</tr>
</tbody>
</table>

**SWB** Swedish Warmblood  **TB** Thoroughbred  **G** Gelding

**STB** Standardbred  **Holst** Holsteiner  **M** Mare

### TABLE 2: Presence of certain clinical features and radiological findings in 11 horses with sacroiliac damage

<table>
<thead>
<tr>
<th>Case number</th>
<th>Duration of signs (months)</th>
<th>Poor performance at exercise</th>
<th>Stiff back at exercise</th>
<th>Plaiting with hind feet</th>
<th>Scuffing or dragging hind toes</th>
<th>Rectal palpation of the skeletal structures in the pelvic canal</th>
<th>Changes noted on plain X-rays of sacroiliac region</th>
<th>Changes noted at linear tomography</th>
<th>Temporary response to phenylbutazone medication</th>
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<td>ND</td>
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</tr>
</tbody>
</table>

+ Present  - Absent  ND Not done  RH Right hindlimb  LH Left hindlimb  BH Both hindlimbs  ± Equivocal
Macroscopic findings

Changes were confined to the sacroiliac region (Table 3). On dissection no laxity of the joints could be demonstrated. The ventral sacroiliac ligaments showed no detectable gross changes, but asymmetry of the ilium or wings of sacrum was found in six cases (Figs 1 and 2). The sacroiliac joint surfaces showed evidence of articular cartilage degeneration but the extent was essentially similar to that seen in normal horses (Dalin and Jeffcott 1985a). In two animals (Cases 3 and 11) there were erosive lesions of the articular cartilage which affected both the sacral and iliac surfaces (Fig 3). There was a high incidence of abnormal joint outline with extension of the joint surfaces and peri-articular spur formation was seen in three cases (Figs 4 and 5). The extensions of the joints could best be described as follows.

Type 1 was seen as a prominent articular extension at the caudal edge of the wing of sacrum apparently covered by articular hyaline cartilage and surrounded by joint capsule. This triangular-shaped sacral structure fitted into a depression (ie, notch) in the opposing iliac surface which was covered by fibrocartilage (Figs 4 and 6).

Type 2 had a much more diffuse appearance involving extension of the sacral joint surface over a large area of the caudal edge of the wing of sacrum. This, too, was covered by hyaline cartilage and fitted into a large notch on the iliac surface (Figs 4 and 7).

Type 3 showed a large eminence on the medial aspect of the sacrum covered by articular cartilage, projecting dorsally into a notch in the iliac surface (Figs 4, 5 and 6). This gave the appearance of an unusual and pronounced concavity of the sacral surface of the joint.

Type 4 were small periarticular spurs close to the joint capsule and involving the insertion of the sacroiliac ligament (Figs 4 and 11).

Morphometric analyses

The results of the measurements of the surface area, length, width and width/length ratio of the sacroiliac joint surfaces are shown in Table 4. From comparisons with results obtained from a series of 41 normal horses (Dalin and Jeffcott 1985b) it was found that the sacral articular areas in the Type 1 and 2 cases (ie, Cases 1, 2, 9 and 10) were significantly larger than expected (Table 5). In one case, the area was more than double the normal size. From the measurements of length and width
of the joint surfaces it was seen that enlargement of the joint surface was caused primarily by a widening of the joint surfaces. The horses with erosions and Types 3 and 4 changes were all within the normal range of joint surface measurements.

Radiography of slabs

In two horses (Cases 3 and 11) the subchondral bone of ilium and sacrum had a very irregular surface and cyst-like formations of varying sizes were present. The Types 1, 2 and 3 articular extensions (Cases 1, 2, 4 and 5) consisted of apparently normal spongy bone (Fig 5b).

Histological findings

The histological appearance of sacral and iliac articular cartilage and the subchondral bone was much the same as seen in normal horses of the same age (Ekman et al 1985). There were marked changes in the subchondral bone in only two of the horses (Cases 3 and 11). These changes consisted of large cavities (so-called pseudocysts; Olsson, Relland, Petterson and Strömberg 1983) filled by granulation tissue (Fig 9) with areas of chondroid metaplasia. Multiple areas of bone marrow fibrosis were also present. In addition there was severe degeneration of the articular cartilage as demonstrated by fraying, clefts and clusters of cells. In large areas the entire cartilage was lost (Fig 9).

The Types 1, 2 and 3 articular extensions consisted of apparently normal bone covered with cartilage. When there were changes in this cartilage they did not differ from those seen in the preformed articular cartilage (Fig 10).

Mature osteophytes (Type 4) were found at the caudal or cranial edges of the sacral articular cartilage in three cases (Cases 3, 4 and 8) (Fig 11).

Discussion

The terminology concerning chronic sacroiliac disease in the horse has been confused because of the lack of thorough pathological studies. Terms used to describe the same clinical syndrome have included sacroiliac subluxation or dislocation (Adams 1969), sacroiliac strain or instability (Jeffcott 1980, 1982) and sacroiliac arthrosis (Rooney 1977; Jeffcott 1983b). The chronic sacroiliac lesions reported in the present study could possibly have arisen from a trauma producing asymmetry of the ilium and sacrum over a prolonged period. No macroscopic damage to the ventral sacroiliac ligaments was found as has been recorded in acute trauma to this joint (Rooney et al 1969). The present findings cannot be classified as subluxation or dislocation and the indication for manipulative treatment (Herrod-Ta ylor 1967) must therefore be seriously questioned. The condition can be partially or temporarily alleviated by anti-inflammatory medication but not with any lasting success.

The history and findings associated with chronic sacroiliac damage are characteristic, although diagnosis must still largely be made by elimination of all other causes of hindlimb lameness and back injury. Because effective local anaesthesia of this joint is impractical, linear tomography is the only available objective diagnostic aid (Jeffcott 1983a, b), and this is only useful for demonstrating the joint extensions (Types 1 and 2). Nevertheless, the present data should provide a sound basis for tentative diagnosis and prognosis. The incidence of chronic sacroiliac damage in competitive horses and racehorses is probably quite high (Rooney 1977; Dalin, Magnusson and
The condition probably always causes some abnormality of gait of both hindlimbs. It is interesting that the clinical picture once recognised is not usually progressive. Treatment appears to be very difficult and is usually aimed at overcoming the sacroiliac damage by progressively building up the muscles of the quarters and back. Improvement in muscular tone and fitness tends to counteract the clinical signs of poor hindlimb impulsion (Jeffcott 1982). In mild cases this type of management has been successful, although once fit the horse must be kept fit all the time and not allowed to rest or it would lose muscle tone and return to the original state.

The histopathological findings were surprising. There was evidence of carilaginous degeneration in all cases, but only to a minor extent that as seen in normal horses (Dalin and Jeffcott 1985a; Ekman et al 1985). In only two horses was there substantive histological evidence of an antrum (Cases 3 and 11). The most significant gross finding was alteration or enlargement of the articular surfaces to produce a widening of the joint resulting in a gradual loss of muscle tone and return to the original state.

The most consistent clinical feature was a longstanding history of reduced performance at exercise. This was more readily noticed in riding horses at slow speeds, whereas in the harness racing horses it was only evident at racing pace. The condition is not confined to these two types of horses and is an important clinical entity in galloping and National Hunt horses (Jeffcott 1980). The correlation of the side of lameness with the sacroiliac lesion was usually, but not always, made correctly. This was probably due to the difficulty of precisely defining the lameness and the leg primarily involved. In addition, the condition probably always causes some abnormality of gait of both hindlimbs.
The pathological picture of chronic sacroiliac disease has not been completely elucidated, but it is clear that arthrosis is not nearly as prevalent as has been suggested by Rooney (1977). The mechanics of sacroiliac movement are largely unknown and the limits of stress to which the joint is subjected during exercise have not been measured. Rooney (1981) has put forward a theoretical basis for the forces acting on the sacroiliac region that lead to articular cartilage degeneration (i.e., arthrosis). However, it seems as if his pathological...
Fig 7. Sacroiliac articular extension, Type 2, in a six-year-old Standardbred gelding (Case 2) showing widespread extension of the caudal aspect of the left articular surface (a) resulting in increased surface area of both sacral and iliac (b) surfaces.

Fig 8. (a) Large dorsal eminence covered by articular cartilage, Type 3, on the most medial aspect (arrows) of the left sacral joint surface of a five-year-old Holstein gelding (Case 5). (b) A depression on the iliac surface (arrows) corresponding to the dorsal eminence in Fig 8a. (c) Caudocranial view of the same area as in Fig 8a showing the concavity of the sacral surface caused by the dorsal eminence on the medial aspect of the sacral wing (arrow). A radiograph of a slab from this area is shown in Fig 8h. (d) Caudocranial view of a section through the same area as in Fig 8b showing the convex iliac surface.

Fig 9. Sagittal section of the caudal part of the left sacral wing from a seven-year-old Thoroughbred mare (Case 3) showing obvious pathological changes. In the centre, the joint cartilage is completely lost and large so-called pseudocysts (arrows) filled by granulation tissue are seen in the subchondral bone. To the right, the surface of the joint cartilage is slightly frayed and to the left, the cartilage is disintegrating. The bone trabeculae of the subchondral bone are thick and plump. Haematoxylin and eosin × 4

interpretation of the lameness involved is incorrect and Crawford (1982) has questioned his theoretical analysis. It is important to remember that this joint is probably never fully loadbearing and the forces to which it is subjected are more shearing in type than compressive (Dalin and Jeffcott 1985a; Ekman et al 1985). This would account for the articular degeneration that occurs with normal ageing (Dalin and Jeffcott 1985a; Ekman et al 1985) and if unduly stressed by exercise could lead to mild articular instability which could result in a gradual remodelling with enlargement of the joint. The movements of the sacroiliac joint in man have been investigated in vivo (Beal 1982; Bellamy, Park and Rooney 1983), although the results are somewhat contradictory. In any case data are not meaningful because it is wrong to draw analogies between two species that have such a different posture and means of locomotion. Sacroiliac movement in the normal horse seems to be extremely limited (Getty 1975; Dalin and Jeffcott 1985a).

The underlying cause of acute damage to the sacroiliac joint and the ventral sacroiliac ligaments is undoubtedly traumatic (Rooney et al 1969). It is also clear that some of these cases may progress to the chronic state (Jeffcott 1980). The pathogenesis of the apparently spontaneous or insidious cases
of sacroiliac damage needs further investigation. This would require a means of precise measurement of sacroiliac movement according to gait and speed. Another important factor is to determine the extent and origin of the pain involved. It may be that the joint extensions at the caudal aspect of the sacrum can create pressure on the adjacent obturator nerves. If this were true, it might create the equivalent situation of sciatica or lumbar disc herniation seen in man which could perhaps explain why anti-inflammatory medication produces a temporary response.

Acknowledgements

We are indebted to the veterinary surgeons who referred the cases and in particular to Dr Gunnar Bergsten of the Agricultural Insurance Co (JFB) and Dr Lars-Erik Magnusson of the Animal Hospital in Skara. We gratefully acknowledge the skilled technical assistance of Kerstin Amberger, Hillevi Gietz and Bjarne Hellmén.

References


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SECTION 4

CONDITIONS AFFECTING
THE STIFLE.

   Equine Veterinary Journal, 14, 25-30. ....................... 264

   Equine Veterinary Journal, 14, 31-39. ......................... 270

   Equine Veterinary Journal, 14, 40-46. ......................... 279

   Equine Veterinary Journal, 15, 304-311. ...................... 286

   Equine Veterinary Journal, 16, 81-88. ......................... 294
SECTION 4  CONDITIONS AFFECTING THE STIFLE

A short series of collaborative investigations into chronic stifle lameness in the horse have been published. These highlight the importance of two conditions in young horses, osteochondrosis and subchondral bone cysts. It was possible to make some headway into understanding the underlying pathogenesis of these two conditions. In particular, the importance of trauma and weight-bearing to the medial femoral condyle producing the bone cyst at one specific site. This has laid the foundation for better methods for surgical and conservative treatment of this condition.

Statement on Share of Work:

Papers 25-28 - The material for these papers was based on cases referred to me for lameness evaluation. All the clinical and radiological work was performed by myself. Dr. Kold assisted in the collation of the data and collaborated in the preparation of manuscripts for publication.

Paper 29 - In this study the source of the clinical material was the same, but the assistance and collaboration of Dr. Melsen was utilised in the processing and interpretation of histological specimens. I was chiefly responsible for the preparation of the manuscripts.
Orthopaedic Articles

Radiographic examination of the equine stifle

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Summary
A radiographic technique is described for the equine stifle joint with the horse in the standing position or under general anaesthesia. The method with the animal anaesthetised in dorsal recumbency and the leg extended was preferred because it gave greater flexibility with a better range of views and greatly reduced the safety hazards. In the standing position a useful practical tip for the lateral view was to raise and extend the limb caudally. This provides some flexion and ventral movement of the stifle allowing improved access for the cassette, a more accurate lateral view of the joint and a reduction in exposure.

Some of the features of radiographic anatomy, from birth to adulthood, of this rather complex joint are described to form a basis for radiological interpretation in cases of suspected stifle lameness.

Introduction
LESIONS of the stifle make an important contribution to the overall causes of lameness in horses (Vaughan 1965). Out of a total of 1857 cases referred for lameness to the clinical department of the Equine Research Station, from September 1972 to September 1980, 82 (4.4 per cent) had a stifle problem (Table 1).

The equine stifle is a complex anatomical structure and one that has received relatively little attention in terms of radiological examination and interpretation. Radiographic techniques, with the horse standing, have been described in the standard texts of Adams (1974), Carlson (1977), Schebitz and Wilkens (1978) and Douglas and Williamson (1980). Radiographs are usually limited to lateral, oblique angle and caudocranial views. Only Schebitz and Wilkens (1978) mention the use of general anaesthesia to obtain lateral radiographs, with the animal lying in lateral recumbency. In addition to the standard texts, some features of radiographic anatomy have been considered by O'Brien (1974), Carlson (1977), Schebitz and Wilkens (1978) and Douglas and Williamson (1980). Radiographs are usually limited to lateral, oblique angle and caudocranial views. Only Schebitz and Wilkens (1978) mention the use of general anaesthesia to obtain lateral radiographs, with the animal lying in lateral recumbency. In addition to the standard texts, some features of radiographic anatomy have been considered by O'Brien (1974), Carlson (1977), Schebitz and Wilkens (1978) and Douglas and Williamson (1980).

This paper presents a practical scheme for radiography of the stifle region and makes comment on some of the salient features of radiographic anatomy in preparation for further reports on the radiology of conditions affecting the equine stifle (Jeffcott and Kold 1982a, b).

Materials and methods

Radiographic equipment
The majority of the examinations were carried out using a Siemens Triplex Optimatic 1023 generator with an X-ray tube capable of producing 150 kV and 1250 mA mounted on a 3-D overhead suspension. The tube had a high speed rotating anode (8,000 rpm) with fine and broad focal spots of 0.6 and 1.2 mm respectively. A portable machine, Acona Super 80 (SMR, Poulton-le-Fylde, Lancs) was used for radiography of some of the foals examined.

Initially, a number of film/screen combinations were tried but latterly only Kodak Lanex Regular Rare Earth intensifying screens (RE) with Kodak orthochromatic film (Ortho G) were used. Where a grid was employed this was either a 4:1 Lucite focussed (Cuthbert Andrews, Watford, Herts) 24 lines/cm or a crosshatch parallel Lysholm (Elema-Schonander) with an 8:1 grid ratio and 75 lines/cm. All radiographs were processed using a Kodak X-Omat 100 automatic processor (Kodak, Hemel Hempstead, Herts).

Case material
A total of 230 horses of different breeds and type, with

<table>
<thead>
<tr>
<th>Reason for referral</th>
<th>1973-1980 Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back problem</td>
<td>825</td>
<td>44.4</td>
</tr>
<tr>
<td>Upper forelimb lameness*</td>
<td>161</td>
<td>8.7</td>
</tr>
<tr>
<td>Lower forelimb lameness†</td>
<td>315</td>
<td>16.9</td>
</tr>
<tr>
<td>Pelvis</td>
<td>113</td>
<td>6.1</td>
</tr>
<tr>
<td>Hindlimb lameness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stifle</td>
<td>82</td>
<td>4.4</td>
</tr>
<tr>
<td>Hock and below</td>
<td>88</td>
<td>4.8</td>
</tr>
<tr>
<td>Other‡</td>
<td>121</td>
<td>6.5</td>
</tr>
<tr>
<td>Incoordination/neck problems</td>
<td>152</td>
<td>8.2</td>
</tr>
<tr>
<td>Total</td>
<td>1857</td>
<td>100</td>
</tr>
</tbody>
</table>

* Upper forelimb — elbow and proximal
† Lower forelimb — carpus and distal
‡ Miscellaneous soft tissue injuries, no specific site of diagnosis possible

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Clinically normal stifle joints, were examined. They were referred for investigation of a thoracolumbar disorder or because of lameness, other than that due to a stifle problem. In addition, 15 newborn Thoroughbred foals were examined using the portable equipment on the studfarm and 3 near term foetuses were supplied by the department of pathology of the Equine Research Station.

Terminology

Radiographs taken in the lateral projection were designated either lateral to medial (LM) or medial to lateral (ML) according to the direction of the primary X-ray beam. Radiographs taken in the caudocranial plane were termed PA (ie, posteroanterior) for ease of abbreviation. Oblique views were termed according to the direction of the primary beam (ie, PALMO for the lateral oblique and APLMO for the medial oblique).

Radiographic technique for the standing horse

All horses examined at the Equine Research Station were restrained in stocks to prevent lateral movement and a twitch applied to the upper lip. Only occasionally was chemical restraint administered in the form of acepromazine maleate intramuscularly (0.05 mg/kg). The cassette (24 x 30 cm) was held by an attendant with protective apron and lead gloves. For the lateral (LM) view the cassette was placed as high into the inguinal region as would be tolerated by the animal (Fig 1). A focus to film distance (FFD) of 105 cm was used. Satisfactory radiographic quality was usually obtained using the RE screens but in some instances a focussed Lucidex grid was employed. A Dodger-T aluminium filter (Saab-Scania, Linkoping, Sweden) was used to attenuate the primary beam passing through the soft tissue structures on the cranial aspect of the stifle. This gave considerable improvement in image quality and also reduced the amount of scattered radiation from the object (Edholm and Jacobson 1971). An improved lateral view could be achieved if the stifle was dropped ventrally and partially flexed by extending the distal limb (Fig 2). This gave better access for the cassette and made it possible to align the central ray at right angles to the stifle joint and so achieve a more accurate lateral view.

For the PA view the animal stood squarely on both hindlimbs and the primary beam was angled downwards about 5° from the horizontal to give optimum visualisation of the femorotibial joint (Fig 3). RE screens were used and a Lucidex grid was required in many instances. The Dodger-T filter was also routinely employed. The exposure values using this system for lateral and PA views are given in Table 2.

The routine for the young foals on the studfarms was to restrain the animal by the head using a halter. The portable was used with cassettes (24 x 30 cm) and RE screens. Exposures of 70 kV and 1.8 mAs were used for the lateral view and 70 kV and 3.0 mAs were usually required for the PA radiographs. A light beam diaphragm was a considerable aid but neither a grid nor the Dodger-T were used.

TABLE 2: Approximate exposure values for the equine stifle in the standing position using Siemens Triplex Optimatic equipment and a Dodger-T compensating filter

<table>
<thead>
<tr>
<th>Type of animal</th>
<th>Approx mean bwt (kg)</th>
<th>Lateral view (LM)</th>
<th>Lateral view stifle flexed</th>
<th>Caudocranial view</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RE</td>
<td>RE + grid</td>
<td>RE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kV</td>
<td>mAs</td>
<td>kV</td>
</tr>
<tr>
<td>Foal</td>
<td>200</td>
<td>50</td>
<td>18</td>
<td>55</td>
</tr>
<tr>
<td>Adult pony</td>
<td>350</td>
<td>60</td>
<td>20</td>
<td>65</td>
</tr>
<tr>
<td>Average TB</td>
<td>450</td>
<td>60</td>
<td>20</td>
<td>65</td>
</tr>
<tr>
<td>Hunter type</td>
<td>550</td>
<td>65</td>
<td>25</td>
<td>70</td>
</tr>
<tr>
<td>Heavy hunter</td>
<td>650</td>
<td>70</td>
<td>32</td>
<td>75</td>
</tr>
</tbody>
</table>

RE = Rare earth screens and film
RE + grid = Rare earth screens and film + Lucidex grid
Radiographic technique for the anaesthetised horse

The method of anaesthesia and position of the animal in dorsal recumbency has been described previously for radiography of the pelvis and lumbosacral spine (Jeffcott 1979). Once in position the limb to be radiographed was hoisted into extension using a small pulley system fixed to an overhead steel girder (Fig 4). This gave good access to the stifle region and allowed lateral (LM or ML) oblique and PA views to be taken with ease. The RE screens and film were used in a 35 x 43 cm cassette with the 8:1 crosshatch grid. The cassette was held in an adjustable mobile holder (Cuthbert Andrews, Watford, Herts). The range of exposure values used is shown in Table 3.

For the PA view it was sometimes necessary to extend the leg further to widen the femorotibial joint space and to angle the primary beam upwards approximately 5° from the horizontal to achieve a better view of the articular surfaces and intercondyloid fossa.

Fig 3. Caudocranial (PA) view in standing horse with central ray angled slightly downwards (5°)

Fig 4. Horse in dorsal position under general anaesthesia with the leg extended for radiography of the stifle

Fig 5. Lateral (above) and PA (right) views of the stifle of a newborn Thoroughbred foal
Fig 6. Lateral view (LM) of 8-month-old Thoroughbred foal taken under general anaesthesia

Fig 7. Lateral (left) and PA (right) views of the stifle of a 4-year-old Thoroughbred mare taken under general anaesthesia

Fig 8. Radiographs of the medial and lateral ridges of the femoral trochlea and condyles from a yearling Thoroughbred colt

TABLE 3: Approximate exposure values for the equine stifle with the animal under general anaesthesia using the Siemens Triplex Optimatic equipment, RE screens and film, a crosshatch Lysholm grid and a Dodger T filter

<table>
<thead>
<tr>
<th>Type of animal</th>
<th>Approx bwt (kg)</th>
<th>Lateral or oblique views</th>
<th>Caudocranial view</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foal</td>
<td>200</td>
<td>55 32</td>
<td>65 50</td>
</tr>
<tr>
<td>Adult pony</td>
<td>350</td>
<td>60 40</td>
<td>70 64</td>
</tr>
<tr>
<td>Average TB</td>
<td>450</td>
<td>65 50</td>
<td>75 80</td>
</tr>
<tr>
<td>Hunter type</td>
<td>550</td>
<td>70 50</td>
<td>85 80</td>
</tr>
<tr>
<td>Heavy hunter</td>
<td>650</td>
<td>75 50</td>
<td>90 100</td>
</tr>
</tbody>
</table>
Normal radiographic anatomy

The major changes in the radiographic anatomy from birth to adulthood are depicted in Figs 5, 6 and 7. At birth the stifle region had 6 well-formed centres of ossification; these were the shaft and distal extremity of the femur, the proximal extremity of the tibia, the tibial tuberosity, the shaft of tibia and the patella. The cranial aspect of the femoral trochlea and the patella had the most immature appearance. They showed noticeable irregularities on the proximal borders and gradually increased in size during the first weeks of life. There was no obvious difference in the size of the medial and lateral trochlear ridges at this stage. The patella gradually lost its simple triangular shape assuming a more complex outline with the proximal and articular surfaces becoming concave and the cranial aspect convex by about 4 months of age. There was usually little evidence of ossification of the fibula at birth.

In the newly born foal the femorotibial joint space was wide and the intercondylar fossa shallow. The tibial spine was not completely formed and the ossification centre in the tibial tuberosity was some distance from the tibial shaft and proximal tibial extremity. It did not unite with the tibia until 9 to 12 months. Closure of the distal femoral and proximal tibial growth plates occurred from about 20 to 24 months and was usually complete by 30 months. The fibula began to ossify from a centre in the head which was clearly visible by 2 months. The shaft ossified separately, usually from 2 different centres which sometimes failed to fuse together leaving a small area of discontinuity. The outlines of the 2 trochlear ridges became very dissimilar after the first few weeks (Fig 8). The medial ridge was much more prominent especially at its proximal part where it was wider and more rounded. This gave a considerably greater articular surface. There was a small notch where the trochlea ended and became the medial condyle. On the lateral side there was a flattened or slightly roughened area at this transition. The distal femoral growth plate extended into each condyle and produced 2 separate lines on a lateral radiograph. These were wavy and in places could overlap one another giving an overall impression of irregularity and sclerosis.

The position of the patella when the horse was bearing weight on the limb was at the extreme proximal limit of the femoropatellar articulation (Fig 9). When the foot was picked up and the limb held with the stifle semiflexed (ie, "shoeing" position) the patella moved ventrocaudally to about the midpoint of the trochlea giving a clear view of the distal borders of the patella and the proximal part of the medial trochlear ridge. Further flexion of the stifle moved the patella to the distal extremity of the trochlea. This was not a comfortable position for the horse to maintain for radiography. Neither was full extension of the limb, although it produced a similar view of the stifle as the semiflexed position.

Fig 9. Radiographs of the stifle of a 4-year-old Thoroughbred gelding taken to show the position and range of movement of the patella: (top left) leg in weight bearing position; (top right) leg held semiflexed; (bottom left) leg held in full flexion; (bottom right) leg held in extension
Discussion

With the introduction in recent years of RE intensifying screens it is feasible to achieve good quality stifle radiographs even with low output portable machines. There are considerable advantages in performing stifle radiography with the horse under general anaesthesia, making it possible to standardise the exposure factors (FFD). There is improved ease of access to the stifle region in dorsal recumbency as well as the restriction in body movement allowing greater time for exposures. The cassette and grid can be much more accurately aligned with the primary beam and a much greater degree of radiation safety is possible, as well as protection of the equipment. The disadvantages include the logistical difficulties of anaesthesia and recovery although these can be kept to a minimum with the use of modern equipment and anaesthetics. With the leg under tension, the femorotibial joint space can be widened if required, as this allows a more accurate alignment of the central ray to the stifle and enables the exposure values to be reduced.

There are often management factors which preclude the use of general anaesthesia but satisfactory radiographs can be taken with the horse in the standing position. A useful lateral view of the femoropatellar region (ie, for osteochondrosis or osteoarthritis) can be obtained by taking X-rays in the semi-flexed position, as this allows a more accurate alignment of the femoral condyle and with reduced exposure values to achieved.

The animals included in this study were not a random sample of normal horses. Many were referred to the Equine Research Station with some lameness or back problem but were found to have normal stifle joints.

Acknowledgements

It is a pleasure to record the expert technical assistance of Miss Janet Butler. We are indebted to the Horserace Betting Levy Board who defrayed part of the costs of the study.

References


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Stifle lameness in the horse: A survey of 86 referred cases

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Summary
The clinical and radiological characteristics of stifle lameness in 86 horses are described. The majority of these cases had been lame for some weeks before referral. The most frequent diagnoses made were osteochondrosis dissecans (13 per cent) and subchondral bone cyst (38 per cent). Both of these conditions were seen principally in Thoroughbreds at or before the onset of training. The other bone lesions encountered were osteoarthrits (3 per cent), fractures (4 per cent) and epiphysitis (1 per cent). The commonest soft tissue condition was an atrophic or partial upward fixation of the patella (15 per cent), ligamentous/meniscal damage comprised 12 per cent of the cases and the remaining 13 per cent were attributed to non-specific strain of the stifle joint.

Treatment in most of these chronic stifle injuries consisted of a period of rest followed by a gradual return to exercise; in some cases this was combined with a short course of a non-steroidal anti-inflammatory drug. The prognosis in most cases of osteochondrosis dissecans was grave to hopeless, while the majority of the horses with a subchondral bone cyst improved clinically after an extended period of rest (ie, 6 months). Ligamentous/meniscal damage usually responded satisfactorily to rest, provided there was no gross tearing or rupture of the structures involved. The outcome in cases of chronic osteoarthritis was always poor and these cases did not respond satisfactorily to analgesic and anti-inflammatory medication.

Introduction
STIFLE injuries constitute an important cause of hindlimb lameness in horses (Wheat 1972), although they have received only limited attention in the literature. Vaughan (1965) recorded 63 cases out of a total of 835 horses with a hindlimb or spinal condition (8 per cent). The British Equine Veterinary Association survey (Amon 1965) reported 99 cases (2 per cent) of stifle lameness in a total of 5388 specified conditions of the musculo-skeletal system. In both of these reports the principal diagnoses were strain (osteo) or patellar fixation. Soft tissue lesions have been described by Hickman (1964) who mentioned the relationship between fitness and the tendency to upward fixation of the patella. Adams (1973) reviewed the problems of differential diagnosis in stifle lameness, while O'Brien (1973) described the radiographic findings in the normal and diseased stifle.

Most attention has been paid to the syndrome of osteochondrosis dissecans (Meagher, Pool and O'Brien 1973; Strömberg 1976, 1979; Moore and McLwraith 1977; Wyburn 1977; Rejnö and Strömberg 1978; Strömberg and Rejnö 1978). Other workers (Peterson and Sevelius 1968; Peterson and Reiland 1968; Reid 1970) have described the related condition of perarticular subchondral bone cysts or "ossus cyst-like lesions". There is some confusion concerning the nomenclature of these osteochondral lesions. Olsson (1978) reported that "osteochondritis dissecans", as it occurs in man, differs from the disease seen in animals. It is generally agreed that human "osteochondritis dissecans" is primarily a lesion of the subchondral bone, while in animals osteochondrosis is a cartilaginous lesion which only secondarily affects bone. "Dyschondroplasia" is therefore a good term because it infers faulty development of cartilage, while osteochondrosis could be misinterpreted as indicating a primary bone lesion. There is further confusion when the damage to the joint surface progresses to dissecating flaps of articular cartilage. At this stage the lesion is often referred to as "osteochondritis dissecans" because the extensive cartilaginous damage results in an inflammatory reaction within the joint (ie, synovitis with pain, swelling and restricted movement). However, this is a secondary reaction from the synovial lining and not a primary inflammatory reaction in the cartilage and subchondral bone. In this study the term osteochondrosis will be used to describe a generalised condition involving a disturbed endochondral ossification in the metaphyseal growth plates as well as in the joint cartilages, and "osteochondrosis dissecans" will be used for conditions where trauma has exaggerated the condition and resulted in dissecting lesions. The condition of subchondral bone cyst is treated as a separate entity elsewhere (Jeffcott and Kold 1962b, c).

The purpose of this paper is to report on a series of mainly chronic stifle lameness cases referred to the Equine Research Station for radiological investigation.

Materials and methods
The case material consisted of 86 horses referred for investigation of hindlimb lameness to the clinical department of the Equine Research Station between 1973 and 1980. A clinical examination was carried out and radiography of the stifle region performed with the horse in the standing position or under general anaesthesia (Jeffcott and Kold 1982a). The clinical examination involved an examination of the stifle region at rest and during exercise in hand and/or ridden. Routine haematological and biochemical examinations were undertaken as well as serological tests for Brucella abortus antibodies. Analysis of synovial fluid was carried out in only a small number of selected cases.

Follow-up examinations at the Equine Research Station were
TABLE 1: Breakdown of the diagnoses made in 86 horses with stifle lameness

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Number of cases</th>
<th>Mean age (years)</th>
<th>Age range (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone lesions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fractures</td>
<td>4 (5)</td>
<td>3.3</td>
<td>1-6</td>
</tr>
<tr>
<td>Osteoarthrosis</td>
<td>3 (4)</td>
<td>13.7</td>
<td>9-18</td>
</tr>
<tr>
<td>Osteochondrosis dissecans</td>
<td>11 (13)</td>
<td>1.8</td>
<td>0.2-6</td>
</tr>
<tr>
<td>Subchondral bone cyst</td>
<td>33 (38)</td>
<td>3.1</td>
<td>0.9-9</td>
</tr>
<tr>
<td>Epiphysis</td>
<td>1 (1)</td>
<td>1.0</td>
<td>--</td>
</tr>
<tr>
<td>Soft tissue lesions (40%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upward fixation of patella</td>
<td>13 (15)</td>
<td>5.3</td>
<td>3-9</td>
</tr>
<tr>
<td>Ligamentous/meniscal damage</td>
<td>10 (12)</td>
<td>6.7</td>
<td>3-14</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>11 (13)</td>
<td>5.7</td>
<td>2.9</td>
</tr>
<tr>
<td>Total</td>
<td>86</td>
<td>5.1</td>
<td>0.2-18</td>
</tr>
</tbody>
</table>

carried out in 14 cases (16 per cent). However, clinical information on the outcome was obtained from the referring veterinary surgeons and owners in 70 cases (81 per cent). Post mortem examinations were obtained in 12 cases (14 per cent).

Results

A breakdown of the diagnoses made and the major clinical findings have been summarised in Tables 1 and 2. The duration of signs refers to the time between onset of clinical signs and examination at the Equine Research Station. The appearance of the stifle joint regarding the presence of any swelling and/or restriction in joint movement was recorded and the degree of lameness was categorised into 3 groups — mild, moderate or severe. All horses were checked for serological evidence of brucellosis and although some were positive no cases of active infection were encountered. The haematological and biochemical profiles did not reveal any useful changes. Synovial fluid examination did not prove to be of much diagnostic value, although it was helpful in eliminating the presence of an acute primary inflammatory reaction in cases where there was gross swelling of the stifle joint (eg, osteochondrosis dissecans). Table 3 shows the results of the follow-up information obtained on 70 cases.

Fractures

Fractures of the stifle were seen on 4 occasions. They affected the proximal tibia, distal femur and the patella.

TABLE 2: Summary of some of the clinical features in 86 cases of stifle lameness

<table>
<thead>
<tr>
<th>Category of diagnosis</th>
<th>Number of cases</th>
<th>Average duration of signs (months)</th>
<th>History of trauma</th>
<th>Degree of lameness</th>
<th>Distension of stifle joint</th>
<th>Restricted range of stifle flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone lesions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fractures</td>
<td>4</td>
<td>&lt;1</td>
<td>4/4</td>
<td>--</td>
<td>1/4</td>
<td>4/3</td>
</tr>
<tr>
<td>Osteoarthrosis</td>
<td>3</td>
<td>9</td>
<td>3/3</td>
<td>--</td>
<td>2/3</td>
<td>3/1</td>
</tr>
<tr>
<td>Osteochondrosis dissecans</td>
<td>11</td>
<td>5</td>
<td>3/11</td>
<td>3/11</td>
<td>4/11</td>
<td>11/11</td>
</tr>
<tr>
<td>Subchondral bone cyst</td>
<td>33</td>
<td>4</td>
<td>1/33</td>
<td>6/33</td>
<td>25/33</td>
<td>5/33</td>
</tr>
<tr>
<td>Epiphysis</td>
<td>1</td>
<td>6</td>
<td>1/1</td>
<td>1/1</td>
<td>--</td>
<td>0/1</td>
</tr>
<tr>
<td>Soft tissue lesions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patella fixation</td>
<td>13</td>
<td>5</td>
<td>2/13</td>
<td>8/13</td>
<td>1/13</td>
<td>0/13</td>
</tr>
<tr>
<td>Ligamentous/meniscal damage</td>
<td>10</td>
<td>7</td>
<td>8/10</td>
<td>2/10</td>
<td>7/10</td>
<td>6/10</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>11</td>
<td>5</td>
<td>7/11</td>
<td>3/11</td>
<td>4/11</td>
<td>5/11</td>
</tr>
</tbody>
</table>

TABLE 3: Outcome of 70 cases of stifle lameness assessed from re-examination and/or information obtained from owners or attending veterinary surgeons

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Number of cases</th>
<th>No improvement</th>
<th>Partial improvement</th>
<th>Complete recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fractures</td>
<td>4</td>
<td>3 (75%)</td>
<td>1 (25%)</td>
<td></td>
</tr>
<tr>
<td>Osteoarthrosis</td>
<td>3</td>
<td>2 (67%)</td>
<td>1 (33%)</td>
<td></td>
</tr>
<tr>
<td>Osteochondrosis dissecans</td>
<td>6</td>
<td>5 (83%)</td>
<td>1 (17%)</td>
<td></td>
</tr>
<tr>
<td>Subchondral bone cyst</td>
<td>28</td>
<td>18/18%</td>
<td>6/22%</td>
<td>14/50%</td>
</tr>
<tr>
<td>Ligamentous/meniscal damage</td>
<td>6</td>
<td>3 (50%)</td>
<td>2 (33%)</td>
<td>1 (17%)</td>
</tr>
<tr>
<td>Other soft tissue damage</td>
<td>10</td>
<td>2 (20%)</td>
<td>1 (10%)</td>
<td>6 (60%)</td>
</tr>
<tr>
<td>Total</td>
<td>70</td>
<td>8/11%</td>
<td>18/28%</td>
<td>34/48%</td>
</tr>
</tbody>
</table>

A non-union involving the femorotibial joint and lateral tuberosity of the tibia was seen in an 8-year-old Thoroughbred gelding (Fig 1A). A fracture of the lateral condyle and proximal shaft of the tibia was present. This involved considerable damage to the femorotibial joint with ventral displacement (ie, by 1.7 cm) of the body fragment, which was 10 cm in length. There was some sign of healing at the fracture site but there was little evidence of a satisfactory bony union. The fibula was also fractured in its midshaft. There was extensive ligamentous damage, on avulsion fracture, and periosteal proliferation on the medial femoral condyle and fracture of the tibial spine indicating damage to the cranial cruciate ligament. The animal was destroyed and the radiological findings confirmed.

There were 2 young Thoroughbreds with comminuted fractures of the distal femoral shaft. The clinical signs clearly indicated the presence of a fracture. The cases are included in this series because they were referred for radiological examination to evaluate the extent of bone damage and possible involvement of the stifle joint. The injured limb was unable to support any weight, the stifle being semiflexed so that it was lower and held in a more cranial position than normal. This made it possible to take lateral radiographs in the standing position by placing the cassette on the lateral aspect of the affected stifle region and directing the primary beam beneath the abdomen from the sound side of the horse (Fig 1B). In both cases the
Fig 1A. Non-union of the lateral tuberosity (caudocranial [PA] view taken under general anaesthesia) in an 8-year-old Thoroughbred gelding with distal displacement of the lateral condyle

Fig 1B. Fracture of the distal femoral shaft (mediolateral [ML] view taken in standing position) in a 2-year-old Thoroughbred colt

Fig 1C. Fracture of the proximal aspect of the patella in a 6-year-old gelding (anteromedial [LM] view taken in standing position)

Fractures were considered inoperable, even though they did not affect the stifle joint, and both horses were humanely destroyed immediately.

A 6-year-old gelding had a fracture of the proximal tip of the patella (Fig 1C). This individual returned to full work following a 3 month rest.

Osteoarthritis

The 3 cases of osteoarthritis occurred in older horses from 9 to 18 years of age. They all showed severe lameness with muscle wastage of the affected quarter, restriction in joint movement and exacerbation of lameness after flexion of the limb (Table 2). The radiographic signs were much less dramatic (Fig 2), although evidence of periarticular new bone formation and narrowing of the joint space were detectable.

A grave prognosis was given in all 3 horses and they all eventually had to be destroyed because of lack of clinical improvement. Treatment with a prolonged course of phenylbutazone was attempted in one case but no satisfactory response was obtained.

Osteochondrosis dissecans

The 11 animals with osteochondrosis dissecans could be divided into 2 groups according to their clinical and radiographical features. In Group A there were 5 foals between 2 and 11 months of age (mean 5 months) and 4 of them had extensive marginal lesions involving the lateral trochlear ridge of the distal femur. They all showed pronounced clinical signs (Table 4) and a typical radiological appearance. One of the most consistent clinical features in the early stages was a difficulty in getting to their feet after being recumbent. Owners often described them as "getting up like a cow". There was usually a marked reluctance to trot because of the inability to flex the stifle. All 5 animals in this group showed signs of rapid growth, which in 2 instances was accompanied by severe contracted tendons on both forelegs. Four of the animals also showed marked kyphosis of the caudal thoracic and cranial lumbar spine.

Radiographic lesions were mainly confined to the lateral trochlear ridge, although the articular cartilage of the patella was also affected to some extent. The changes were suggestive of disruption and collapse of the articular cartilage and the under-
lying subchondral bone. The outline of the trochlea was irregular over a considerable distance (Fig 3A), although this was confined chiefly to the middle third of the ridge. The subchondral bone showed patchy areas of radiolucency, often lined by a narrow zone of sclerosis. The prognosis was considered to be hopeless in all cases. An example of the degree of articular

TABLE 4: Major clinical characteristics of osteochondrosis dissecans of the stifle in 11 horses

<table>
<thead>
<tr>
<th>Clinical finding</th>
<th>Group A (n = 5)</th>
<th>Group B (n = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of animal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-12 months</td>
<td>5/5</td>
<td>1/6</td>
</tr>
<tr>
<td>&gt;12 months</td>
<td>0/5</td>
<td>5/6</td>
</tr>
<tr>
<td>Clinical signs present from birth</td>
<td>3/5</td>
<td>0/6</td>
</tr>
<tr>
<td>History of injury before onset of signs</td>
<td>0/0</td>
<td>2/6</td>
</tr>
<tr>
<td>Difficulty in getting up and/or in lying down</td>
<td>5/5</td>
<td>1/6</td>
</tr>
<tr>
<td>Osteoarthritis of stifle joint</td>
<td>5/5</td>
<td>6/6</td>
</tr>
<tr>
<td>Kyphosis of lumbar spine (trochlear)</td>
<td>4/5</td>
<td>1/6</td>
</tr>
<tr>
<td>Stiff and restricted hindlimb gait</td>
<td>5/5</td>
<td>1/6</td>
</tr>
<tr>
<td>Degree of lameness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No lameness</td>
<td>2/5</td>
<td>1/6</td>
</tr>
<tr>
<td>Mild lameness</td>
<td>0/0</td>
<td>3/6</td>
</tr>
<tr>
<td>Moderate lameness</td>
<td>2/5</td>
<td>2/6</td>
</tr>
<tr>
<td>Severe lameness</td>
<td>1/5</td>
<td>0/0</td>
</tr>
<tr>
<td>Analysis of synovial fluid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reticulocyte count</td>
<td>3/4</td>
<td>1/1</td>
</tr>
<tr>
<td>Leukocyte count</td>
<td>3/4</td>
<td>0/1</td>
</tr>
<tr>
<td>Platelet count</td>
<td>2/4</td>
<td>0/1</td>
</tr>
</tbody>
</table>

Fig 3A. Radiograph of the right stifle (ML view taken under general anaesthesia) of a 10-month-old Thoroughbred colt with severe changes of osteochondrosis dissecans of the whole articular surface of the trochlea (Group A)

Fig 3B. Post mortem specimen of the lateral trochlear ridge of the same horse showing marked degeneration and cavitation of the articular surface. Damage to the trochlear ridge in a 10-month-old foal is demonstrated post mortem in Fig 3B.
Group B consisted of 6 animals which were older than the horses in Group A (mean 2.8 years) and 5 of them were in training at the time of referral. The radiographic lesions in most of these cases were much more localised and circumscribed, usually with an ossified "joint-mouse" either floating free in the femoropatellar joint or still attached to the trochlear ridge (Fig 4A). It was not always possible to assess where the piece of cartilage had become detached. The site of damage was often the lateral trochlear ridge (Fig 4B) or the distal articular surface of the patella (Fig 4C). A feature of another case was the presence of focal radiodense material or loose bodies on the periphery of the femoropatellar joint giving the appearance of synovial osteochondromatosis (Fig 4D). The clinical signs were less severe than in Group A and the main reason for referral was reduced performance ability rather than actual lameness. However, the outcome in the 2 cases followed-up was poor as both animals were destroyed because of lack of clinical improvement. One other underwent surgical treatment with curettage of the degenerated cartilage. However, the horse died following a bout of colic 6 weeks postoperatively. At post mortem examination satisfactory healing of the lesion was seen to have been taking place.

The results of synovial fluid evaluation in foals in Group A proved to be of little diagnostic value. They showed a decrease in the viscosity of the synovia with mild increase of erythrocyte, leucocyte and protein (globulin fractions) concentrations (Table 4). The only case examined in Group B showed a mild increase in erythrocyte content of the synovia.
Subchondral bone cyst

This condition, like that of osteochondrosis dissecans, was principally a problem of young horses (Table I) with 74 per cent being less than 3 years old. The bone cysts could be classified into 2 groups. Group A (28 cases) showed a large circular or dome-shaped cyst in the medial femoral condyle with a distinct communication with the femorotibial joint. Lesions were usually unilateral. In Group B (5 cases) the cysts were much more variable in shape and size and were located in the distal femur adjacent to the intercondylar fossa or in the proximal tibia just beneath the tibial spine. No evidence of typical osteochondrosis dissecans was seen in any of the cases. In general the clinical signs were much less dramatic than in osteochondrosis dissecans and the prognosis for the majority of the cases was reasonable, provided the horse was given 6 months rest (Table 3).

Epiphysitis

Epiphysitis of either the distal femoral physis or the proximal tibial physis with its separate centre of ossification was not a major differential problem in stifle lameness. Only one young horse in this study showed epiphysitis that accounted for its mild degree of lameness. The yearling was rapidly growing at the time of examination and also showed a degree of kyphosis of the cranial lumbar spine. The animal was put on a restricted diet for 3 months and made a spontaneous recovery of both the stifle lameness and the kyphosis.

Patellar fixation

There were 13 horses in which atypical upward or partial fixation of the patella was diagnosed. These cases were chronic and rarely showed demonstrable locking of the patella at clinical examination. However, they had intermittent signs of poor performance and hindlimb stiffness with a shortened stride on the affected limb. In conformation these horses often were very upright behind, with rather poorly muscled quarters. No abnormalities were found on palpation or manipulation of the stifle joint. Turning the horse in a tight circle with the affected limb innermost often revealed some stiffness or difficulty. These cases were treated conservatively by improving the animal's fitness, building up the quarter muscles or by desmotomy. The prognosis was good, provided there were no complicating lesions. No radiological abnormalities were detectable in any of the cases.

Ligamentous/ meniscal damage

In this group there were 10 cases, including 2 horses with patellar ligament strain, 6 horses with injury to the cranial cruciate ligament, 2 horses with damage to the medial collateral ligament and one horse with meniscal damage which also had a medial collateral ligament tear and secondary osteoarthritis. All the cases showed some degree of demonstrable radiological change.

Strain of the middle patellar ligament was seen as thickening and increased radiodensity or early calcification in the ligament, with some periosteal roughening at the insertion on the patella. Both horses with this condition showed a sudden onset of severe lameness with pain and swelling reported in the affected stifle. There was some improvement with rest and analgesic medication but lameness and stiffness persisted for many weeks. Flexion of the joint was resisted and this manoeuvre transiently exaggerated the degree of lameness. No specific treatment was given apart from further rest for about 3 months and the final outcome was satisfactory.

The lameness associated with cruciate ligament injury was variable but there was always a sudden onset reported. None of the 6 cases examined here showed a complete rupture of the ligament. They all involved a partial tear or injury near the ligamentous insertion. Damage chiefly occurred at the cranial attachment on the tibia, although 2 cases showed the damage to be at the caudal insertion in the intercondylar fossa.

One of these showed a loose bony fragment present at this site (Fig 5A). Clinically there was usually some dimention of the joint, obvious restriction in the range of flexion and pain when the joint was flexed. It was not possible to detect any instability of the joint or elicit a cranial draw sign (Adams 1973). Muscle wastage of the gluteal or thigh muscles depended on the degree of lameness. The radiographic findings were usually some distension of the joint with periosteal roughening and early new bone proliferation at the ligamentous insertion (Fig 5B). In one case the presence of a partially detached fragment of bone was detectable at the same site (Fig 5C). At post mortem examina-

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**Fig 5 A - C.** Left stifle of an 8-year-old showjumping pony gelding with cruciate damage involving a fragment of detached bone from the intercondylar fossa (arrow) (PA view taken in standing position); B. Right stifle of a 5-year-old Thoroughbred steeplechase gelding which had sustained severe tearing of the cranial cruciate ligament 5 weeks previously. Radiographically there was proliferation of some new bone just cranial to the tubercles of the lateral meniscus (arrow) (ML view taken under general anaesthesia); C. Left stifle of a 14-year-old large hunter gelding (18 hands) with a hock standing cruciate injury (LM view taken in standing position). There was a large bony fragment in the lateral femorotibial joint cranial to the tibial spine which was accompanied by secondary arthritic changes in the joint (arrow).
shortly after the radiological examination and no follow-up steroid therapy given. The horse was exported to Australia
Miscellaneous soft tissue injuries
There was swelling of the joint, roughening of the area of cranial cruciate ligament on the proximal tibia. The horse had
the insertion of the medial collateral ligament and extensive
view periosteal proliferation was seen at the insertion of the marginal lipping of the femorotibial joint (Fig 6). In the lateral
changes were quite distinct and could be seen in the caudo­
tation this piece of bone was found to be only loosely attached to the tibia by fibrous connective tissue. Furthermore the cranial
aspect of the femorotibial articulation was deformed, probably as a consequence of the instability of the joint following the
ligament tear. The prognosis of these cruciate injuries depended on their severity. In the 2 horses with marked and persistent
lameness, euthanasia was the only course of action. The other cases improved, becoming more or less sound but unable to
stand up to hard work.
Chronic damage to the medial collateral ligament was seen as a complicating factor in 2 horses with a subchondral bone cyst, in one fracture case and the stallion with meniscal damage referred to below. It was difficult therefore to define the specific clinical signs and prognosis in these cases. The radiographic changes were quite distinct and could be seen in the caudo­cranial (PA) radiographs as irregularity and periosteal roughening on the medial epicondyle of the femur.
The single case of suspected meniscal damage occurred in a Standardbred stallion and showed radiographically a narrowing of the medial compartment of the femorotibial joint space. There was swelling of the joint, roughening of the area of insertion of the medial collateral ligament and extensive marginal lipping of the femorotibial joint (Fig 6). In the lateral view periosteal proliferation was seen at the insertion of the cranial cruciate ligament on the proximal tibia. The horse had raced in the USA and it was reported that the joint had been drained on numerous occasions and intra-articular cortico­
sed in the affected limb. No specific radiological changes were
it was reported that the joint had been
horses would seem to be extremely low.
Arthrocentesis may also have a palliative and curative effect by relieving the local discomfort created by increased intra­
garticularly pressur...
a free "joint-mouse" was detected, it was difficult to assess precisely where the piece of cartilage had been detached from. It was not clear whether these lesions had been present since foalhood and were only made clinically significant by the increasing stress and pressure at the start of training. Alternatively, they may have arisen as an acute osteochondral fracture. Some authors have reported trauma as the major factor in the pathogenesis because of the bilateral nature and anatomical location of the lesions (Moore and McIlwraith 1977). Adams (1974) and Rooney (1975) suggested that excessive pressure on the growing cartilage produces an area of ischaemic necrosis. This would occur more frequently on the convex surface of highly curved joints and particularly in the stifle joint of horses with straight-lined conformation. Adams (1974) also thought that patellar chondromalacia was caused by partial or complete upward fixation of the patella. The distribution of the lesions in our material may lend support to the theory that repeated subclinical trauma from the patella causing pressure on the lateral trochlear ridge is the precipitating factor which leads to dissecting lesions. Patellar luxation is much more common in Standardbreds and has a higher incidence in the USA and Adams (1973) stated that if patellar chondromalacia and ligamentous rupture can be ruled out when there is distension of the stifle and pronounced lameness then medial meniscal damage should be suspected.

Acknowledgements

The authors extend their grateful thanks to their colleagues at the Equine Research Station, especially Judith Shelley and Chris Collis for their timely advice and assistance throughout this study. We also acknowledge the many practitioners who referred cases and provided follow-up information, particularly Messrs Crowhurst and Partners and Rossadale and Partners, Newmarket. We are indebted to the support of the Horserace Betting Levy Board who defrayed part of the costs involved.

References

constates lorsqu’ils furent examinés. Le diagnostic le plus fréquent fut leur fixation partielle ou atypique de la rotule. Les autres lésions osseuses rencontrées furent l’ostéoarthrite (3%), les fractures (4%) et les épiphyses (1%). L’affection la plus commune des tissus mous était la fixation partielle ou atypique de la rotule (15%). Les lésions ligamenteuses et des méninges représentaient 12% des cas, 13% furent attribués à des lésions non spécifiques de l’articulation.

Le traitement de la plus grande partie de ces lésions chroniques du grasset comporta la mise au repos avec reprise graduée de l’exercice. Dans quelques cas, on employa également des anti-inflammatoires non stéroïdiens. Le pronostic de la plupart des cas d’ostéochondrite disquante fut grave ou désespéré. Pour leur majorité les chevaux atteints de kystes osseux sous cartilagineux montrèrent une amélioration clinique après 6 mois de repos. Les dommages ligamentaires et des méninges furent influencés favorablement par la mise au repos, dans la mesure où il n’y eut point de déchirures importantes ou de ruptures des structures atteintes. Le devenir des cas d’ostéoarthrite fut toujours très médiocre et ces cas ne furent pas influencés favorablement par des médications analgésiques ou anti-inflammatoires.

Zusammenfassung


Résumé

Les caractéristiques cliniques et radiologiques des boîteries ayant leur siège au niveau du grasset sont décrites chez 86 chevaux. Pour la plupart, ces animaux étaient de plusieurs semaines lorsqu’ils furent examinés. Le diagnostic le plus fréquent fut l’ostéochondrite disquante (13%) et la présence de kystes osseux sous cartilagineux (38%). Ces deux affections furent constatées surtout chez les Pur sang avant ou au moment du début de l’entraînement. Les autres lésions osseuses rencontrées furent l’ostéoarthrite (3%), les fractures (4%) et les épiphyses (1%). L’affection la plus commune des tissus mous était la fixation partielle ou atypique de la rotule (15%). Les lésions ligamenteuses et des méninges représentaient 12% des cas, 13% furent attribués à des lésions non spécifiques de l’articulation.

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Clinical and radiological aspects of stifle bone cysts in the horse

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Summary
Thirty-three cases with subchondral bone cysts in the stifle are reported. The condition was most commonly seen in young Thoroughbreds and produced intermittent lameness of varying degree. Radiographically distinct areas of radiolucency were found in the distal femur or proximal tibia adjacent to the femorotibial joint. Lesions were usually unilateral but 5 horses had cysts in both stifles. The cases could be divided into 2 distinct groups. Horses in Group A (28 cases) had a large circular or dome-shaped cyst in the medial femoral condyle with a distinct communication with the femorotibial joint. In Group B (5 cases) the cysts were much more variable in shape, size, and location. The common sites were the distal femur adjacent to the intercondyloid fossa or the proximal tibia just beneath the tibial spine. No evidence of radiological signs typical of osteochondrosis dissecans were seen in any of the cases.

All the horses were treated conservatively with a 6 month rest period out at grass, followed by a gradual return to full training. Fourteen horses were re-examined 4 to 33 months after the initial examination and none of them showed disappearance of the cysts. There was a tendency to increased radio density of the cyst in some cases but this was only to a minor degree. The outcome of the 2 groups was different. In Group A just over half (14) made a complete recovery while a further 5 returned to full work although some persistence of mild lameness was still present. In Group B only one case was reported to have made a successful return to full work.

Materials and methods
A total of 33 horses with unilateral or bilateral involvement of the stifle joints were investigated. All of them were referred to the Equine Research Station for radiological investigation of obscure hindlimb lameness. They were subjected to a full clinical and radiological examination (Jeffcott and Kold 1982 a, b). The radiodensity of the cysts was measured using a densitometer (Sakura Densitometer PDA-81, Japan). Fourteen of the horses were made available for a follow-up clinical and radiological examination between 4 and 33 months (mean 9 months) after the initial examination. Follow-up information on the clinical progress of 16 additional cases was obtained from the referring veterinary surgeon, the trainer or the owner.

Results
The cases could be divided into 2 groups according to the radiographic features (Fig 1). In Group A there were 28 horses with a clearly defined bone cyst in the centre of the medial femoral condyle, adjacent to and communicating with the femorotibial joint. Group B consisted of 5 horses with one or more less clearly defined cysts in the region of the intercondyloid fossa of the femur and/or the proximal extremity of the tibia.

Introduction
PETTERSON and Sevelius (1968) reported on 13 horses with lesions described as "subchondral bone cysts". These cysts were found in various locations in the distal parts of the limbs although the majority were in the phalanges. Reid (1970) reported on radiographically similar lesions which he referred to as "ossceous cyst-like lesions". These were principally seen in the phalanges and carpal and tarsal regions. Other workers have described these cystic lesions in the stifle joint and have referred to them as part of the syndrome of osteochondrosis (Morgan 1972; O'Brien 1973; Rooney 1975; Strömberg 1976; 1979).

The purpose of this study is to report on the clinical and radiological features of 33 cases of subchondral bone cysts in the stifle and to assess their outcome and effect on performance. The question of the aetiology and pathogenesis of these cysts will be considered separately (Jeffcott and Kold 1982 c).

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Cent were lame at the walk. While 76 per cent showed lameness when trotted in hand (Table 3). However, there were some lameness, with stiffness and a somewhat shortened stride. At the commencement of training at the Equine Research Station only 15 per cent the onset coincided with breaking-in or the commencement of training (Table 2). Signs of intermittent lameness were reported to be intermittent, but action stiff after period of rest. There was distension of the femoropatellar joint in 3 horses in Table 3: Clinical signs noted in 33 cases of stifle bone cysts on examination at the Equine Research Station.

### TABLE 1: Details of the incidence and distribution of bone cysts in the stifle joints of 33 horses

<table>
<thead>
<tr>
<th>Breed</th>
<th>Group A number (%)</th>
<th>Group B number (%)</th>
<th>Total number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thoroughbred</td>
<td>24 (86)</td>
<td>4 (80)</td>
<td>28 (85)</td>
</tr>
<tr>
<td>Crossbred</td>
<td>5 (11)</td>
<td>1 (20)</td>
<td>6 (12)</td>
</tr>
<tr>
<td>Arab</td>
<td>1 (4)</td>
<td>0 (0)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Sex</td>
<td>Male 12 (43)</td>
<td>4 (80)</td>
<td>16 (49)</td>
</tr>
<tr>
<td>Female</td>
<td>16 (57)</td>
<td>1 (20)</td>
<td>17 (51)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>1 7 (25)</td>
<td>1 (20)</td>
<td>8 (24)</td>
</tr>
<tr>
<td></td>
<td>2 14 (50)</td>
<td>2 (40)</td>
<td>16 (49)</td>
</tr>
<tr>
<td></td>
<td>&gt;3 7 (25)</td>
<td>2 (40)</td>
<td>9 (27)</td>
</tr>
<tr>
<td>Bwt (kg)</td>
<td>300-400 1 (4)</td>
<td>0 (0)</td>
<td>1 (3)</td>
</tr>
<tr>
<td></td>
<td>400-500 19 (68)</td>
<td>3 (60)</td>
<td>22 (67)</td>
</tr>
<tr>
<td></td>
<td>500-600 8 (28)</td>
<td>1 (15)</td>
<td>9 (27)</td>
</tr>
<tr>
<td></td>
<td>&gt;600 0 (0)</td>
<td>1 (15)</td>
<td>1 (3)</td>
</tr>
</tbody>
</table>

### TABLE 2: Some features of the history in 33 cases of stifle bone cysts before examination at the Equine Research Station

<table>
<thead>
<tr>
<th>Features of clinical history</th>
<th>Number of cases (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onset of clinical signs</td>
<td></td>
</tr>
<tr>
<td>Sudden onset</td>
<td>11 (33)</td>
</tr>
<tr>
<td>Onset at start of breaking/training</td>
<td>10 (30)</td>
</tr>
<tr>
<td>Not known</td>
<td>12 (36)</td>
</tr>
<tr>
<td>Total</td>
<td>35 (100)</td>
</tr>
<tr>
<td>Characteristics of lameness</td>
<td></td>
</tr>
<tr>
<td>Not lame, but action stiff and short</td>
<td>4 (12)</td>
</tr>
<tr>
<td>Slight lameness</td>
<td>3 (9)</td>
</tr>
<tr>
<td>Moderate lameness</td>
<td>8 (24)</td>
</tr>
<tr>
<td>Severe lameness</td>
<td>4 (12)</td>
</tr>
<tr>
<td>Lameness reported to be intermittent</td>
<td>11 (33)</td>
</tr>
<tr>
<td>Total</td>
<td>30 (90)</td>
</tr>
<tr>
<td>Effect on lameness after period of rest</td>
<td></td>
</tr>
<tr>
<td>Improvement</td>
<td>8 (24)</td>
</tr>
<tr>
<td>No improvement</td>
<td>14 (42)</td>
</tr>
<tr>
<td>Not known</td>
<td>11 (33)</td>
</tr>
<tr>
<td>Total</td>
<td>33 (100)</td>
</tr>
</tbody>
</table>

### Clinical features

The distribution of the case material according to breed, age, sex and body weight (bwt) is shown in Table 1. The majority of horses were Thoroughbreds of less than 3 years old with an average bwt of 400 to 500 kg. In one third of the cases, the onset was associated with some traumatic incident and in 30 per cent the onset coincided with breaking-in or the commencement of training (Table 2). Signs of intermittent lameness were reported in 35 per cent of the horses which in some cases has responded to rest, only to reappear at resumed work.

The main presenting sign was a weight-bearing type of lameness, with stiffness and a somewhat shortened stride. At the time of examination at the Equine Research Station only 15 per cent were lame at the walk, while 76 per cent showed lameness when trotted in hand (Table 3). However, there were some distinct differences between the 2 groups.

### Radiological features

The major radiological factors are summarised in Table 4. With only one exception, the Group A cysts were confined to the medial femoral condyle (Fig 2). In this case (ref: 80/250) there was a large cyst in the femoral condyle but a second small cyst (or kissing-type lesion) could be seen on the opposite surface in the proximal tibia extremity (Fig 3). In 4 horses (16 per cent) lesions were found in both stifles. The shape of the cysts (Fig 4) varied. They were either circular (34 per cent), dome-shaped (47 per cent), oval (13 per cent) or had a more irregular outline (6 per cent). There was visible communication between the cyst lumen and the femorotibial joint in all cases and in 72 per cent an obvious neck or channel could be clearly demonstrated (Figs 2 and 3). The size of the cysts was also...
variable, although the majority (72 per cent) measured between 1 and 2 cm on the radiographs. The cysts were always clearly defined and 19 per cent had a narrow zone of sclerosis at the periphery at the initial examination.

In Group B the cysts tended to have a more irregular outline and could be variable in number (Fig 6). This gave the affected area of the femoral condyle or tibia a rather moth-eaten appearance. A visible communication with the femorotibial joint was much less commonly noted and this was also true of the peripheral zone of sclerosis. The sites of cysts were either adjacent to the intercondylar fossa on the lateral side and/or in the proximal extremity of the tibia just beneath the tibial spine. In 2 cases cysts were present in both these locations. Most of the cysts measured 1 to 2 cm on the radiographs and only one animal had lesions in both stifles.

**Follow-up study**

The outcome of 30 cases was determined from information obtained at follow-up examinations at the Equine Research Station and from the referring veterinary surgeons, owners and trainers (Tables 5 and 6). The horses in Group A showed a much better recovery rate than those in Group B, even though only a small number of cases were involved in the latter group. Complete recovery was seen in 14 Group A horses (56 per cent) and 16 horses (64 per cent) returned to full work. In 2 cases the animals were not completely sound when trotted in hand but improved dramatically on being ridden at faster paces. Only one case in Group B (20 per cent) showed a good clinical recovery.

A follow-up radiographic examination was carried out in 14 horses and 3 cases were also examined on a third occasion. The time interval between examinations varied from 4 months to almost 3 years. In none of the animals was complete resolution or radiographic disappearance of the cyst noted. In Group A there was only one case in which the cyst appeared to have reduced in size at the second examination, whereas in 4 other horses (all 2-year-olds) a measurable increase in the cyst size was observed.

**TABLE 4: Radiological appearance of subchondral bone cysts in the stifle joint of 33 horses**

<table>
<thead>
<tr>
<th>Radiographic features</th>
<th>Group A number (%)</th>
<th>Group B number (%)</th>
<th>Total number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Position of lesion</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial femoral condyle</td>
<td>32 (100)</td>
<td>0 (0)</td>
<td>32 (84)</td>
</tr>
<tr>
<td>Intercondylar fossa region</td>
<td>0 (0)</td>
<td>2 (33)</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Proximal tibia</td>
<td>0 (0)</td>
<td>2 (33)</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Intercondylar fossa region + proximal tibia</td>
<td>0 (0)</td>
<td>3 (33)</td>
<td>3 (5)</td>
</tr>
<tr>
<td><strong>Shape of cyst</strong></td>
<td>Circular</td>
<td>11 (34)</td>
<td>3 (10)</td>
</tr>
<tr>
<td>Domed</td>
<td>15 (47)</td>
<td>0 (0)</td>
<td>15 (39)</td>
</tr>
<tr>
<td>Oval</td>
<td>4 (13)</td>
<td>2 (33)</td>
<td>6 (16)</td>
</tr>
<tr>
<td>Others</td>
<td>2 (6)</td>
<td>0 (0)</td>
<td>2 (6)</td>
</tr>
<tr>
<td><strong>Visible communication of the cyst with femorotibial joint</strong></td>
<td>Present with visible neck</td>
<td>23 (72)</td>
<td>2 (33)</td>
</tr>
<tr>
<td>Present without visible neck</td>
<td>9 (28)</td>
<td>1 (17)</td>
<td>10 (26)</td>
</tr>
<tr>
<td>No visible communication</td>
<td>0 (0)</td>
<td>3 (50)</td>
<td>3 (8)</td>
</tr>
<tr>
<td><strong>Zone of sclerosis around cyst</strong></td>
<td>Present</td>
<td>6 (19)</td>
<td>5 (16)</td>
</tr>
<tr>
<td>Absent</td>
<td>26 (81)</td>
<td>1 (17)</td>
<td>27 (71)</td>
</tr>
<tr>
<td><strong>Diameter of cyst</strong></td>
<td>&lt;1 cm</td>
<td>2 (6)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>1-2 cm</td>
<td>23 (72)</td>
<td>5 (16)</td>
<td>28 (74)</td>
</tr>
<tr>
<td>2-3 cm</td>
<td>7 (22)</td>
<td>1 (17)</td>
<td>8 (21)</td>
</tr>
</tbody>
</table>
A subjective visual appraisal of the alteration in radiodensity of cysts was made (Table 6) but this was difficult to evaluate accurately because of the differences in exposures, quality of the radiographs and size and positioning of the horse. It was decided to compare radiodensity of the cyst by taking densitometric readings from the radiographs. A point in the centre of the cyst was measured (Co) and a second reading was then taken at a fixed point just outside the cyst (Cy). The ratio of these 2 measurements was termed the radiodensity index (RDI) of the cyst. By subtraction of the RDI on successive occasions a figure for the alteration in cyst density, termed ARDI, was obtained. An increase in density of the cyst was shown as a negative reading of ARDI (Table 7). There were 7 horses which demonstrated some increase in radiodensity. These horses made satisfactory recoveries and 4 of them proved to be winners.

Discussion

Subchondral bone cysts in the stifle constitute an important cause of stifle lameness, particularly in young Thoroughbreds. However, other authors have found bone cysts more commonly in the distal limbs (Petterson and Reiland 1969; Reid 1970). For example, in Reid's series of 69 cysts in 64 horses, only 14 (12 unilateral and one bilateral) were recorded in the stifle. The rest were found in, or distal to, the carpal and tarsal joints. The unusually high predilection for this site in our material was probably explained by the type of cases referred to the Equine Research Station, the investigation of obscure upper hindlimb lameness being a particular interest and specialty.

The division of the stifle cysts into 2 distinct categories has not previously been recorded, nor has the single instance of a "kissing-type" of cyst in the medial proximal extremity of the tibia (Fig 3). The Group A cysts were always in the distal extremity of the medial femoral condyle adjacent to the joint surface with a clearly visible communication with the femoro-tibial joint space. They showed no apparent tendency to regress or fill in with new bone as may occur at other sites (Petterson and Reiland 1969). However, a mild degree of increased radiodensity was seen in half of the cases followed up and all these...
Fig 5. Sequential radiographs (left to right) taken in a Thoroughbred filly at 20, 26 and 32 months to show the increase in size and change in shape that can occur. Other features include the obvious communication of the cyst lumen with the femorotibial joint and the zone of peripheral sclerosis which has developed at 32 months.

TABLE 5: Outcome of 30 cases of stifle bone cysts

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Group A</th>
<th>Group B</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>number (%)</td>
<td>number (%)</td>
<td>number (%)</td>
</tr>
<tr>
<td>No improvement</td>
<td>6 (24)</td>
<td>3 (60)</td>
<td>9 (30)</td>
</tr>
<tr>
<td>Retired</td>
<td>0 (0)</td>
<td>1 (20)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Sent to stud</td>
<td>3 (12)</td>
<td>1 (20)</td>
<td>4 (13)</td>
</tr>
<tr>
<td>Destroyed</td>
<td>3 (12)</td>
<td>1 (20)</td>
<td>4 (13)</td>
</tr>
<tr>
<td>Partial improvement</td>
<td>5 (20)</td>
<td>1 (20)</td>
<td>6 (20)</td>
</tr>
<tr>
<td>Not able to return</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to full work</td>
<td>3 (12)</td>
<td>1 (20)</td>
<td>4 (13)</td>
</tr>
<tr>
<td>Performing satisfactorily</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>despite mild recurrence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of clinical signs</td>
<td>2 (8)</td>
<td>0 (0)</td>
<td>2 (7)</td>
</tr>
<tr>
<td>Complete clinical recovery</td>
<td>14 (56)</td>
<td>1 (20)</td>
<td>15 (50)</td>
</tr>
</tbody>
</table>

TABLE 6: Results of follow-up radiographic examination of 14 bone cyst cases

<table>
<thead>
<tr>
<th></th>
<th>Group A</th>
<th>Group B</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=11 (%)</td>
<td>n=5 (%)</td>
<td>n=16 (%)</td>
</tr>
<tr>
<td>Change in size of cyst Increase</td>
<td>4 (36)</td>
<td>0 (0)</td>
<td>4 (25)</td>
</tr>
<tr>
<td></td>
<td>1 (9)</td>
<td>0 (0)</td>
<td>1 (7)</td>
</tr>
<tr>
<td>No change</td>
<td>6 (55)</td>
<td>3 (100)</td>
<td>9 (56)</td>
</tr>
<tr>
<td>Change in position of cyst Yes</td>
<td>2 (18)</td>
<td>0 (0)</td>
<td>2 (14)</td>
</tr>
<tr>
<td></td>
<td>3 (27)</td>
<td>3 (100)</td>
<td>6 (38)</td>
</tr>
<tr>
<td>Change in shape of cyst Yes</td>
<td>4 (36)</td>
<td>0 (0)</td>
<td>4 (25)</td>
</tr>
<tr>
<td></td>
<td>7 (64)</td>
<td>3 (100)</td>
<td>10 (62)</td>
</tr>
<tr>
<td>Increase in sclerosis around the cyst Yes</td>
<td>5 (45)</td>
<td>1 (33)</td>
<td>7 (45)</td>
</tr>
<tr>
<td></td>
<td>6 (55)</td>
<td>2 (67)</td>
<td>8 (50)</td>
</tr>
<tr>
<td>Increased radiodensity of the cyst Yes</td>
<td>5 (45)</td>
<td>0 (0)</td>
<td>5 (31)</td>
</tr>
<tr>
<td></td>
<td>6 (55)</td>
<td>3 (100)</td>
<td>9 (56)</td>
</tr>
</tbody>
</table>

n = Number of horses in each group, on which follow-up radiographs were obtained.

There is considerable disagreement over the likely pathogenesis or aetiology of stifle bone cysts. Most of the Swedish and American workers (Morgan 1972; O'Brien 1973; Rejnö and Stromberg 1978; Stromberg 1979) suggest that the cysts form part of the osteochondrosis syndrome (ie, the central form of osteochondrosis dissecans on a weight-bearing surface), whereas Rooney (1975) thinks they may arise from previous joint-ill (suppurative arthritis) during foalhood. However, the exact aetiology is unknown and probably multifactorial but consideration of this aspect and details of the histopathology of bone cysts will be dealt with in a subsequent report (Jeffcott and Kold 1982 c).
Various lines of therapy for stifle bone cysts have been attempted but most authors have relied on a conservative approach (Pettersen and Sevelius 1968; Reid 1970). Evans and Jenny (1970) described a surgical approach for enucleation of the cyst, followed by packing of the cavity with cancellous bone chips. The single case report involved performing the technique for bilateral carpal cysts. The animal was rested for 6 months postoperatively and remained sound. Evans and Jenny (1970) also reported on 2 other cases, which were given forced exercise combined with intra-articular anti-inflammatory medication, suggesting that forced exercise caused the cyst to fill in with new bone. Both animals became sound enough to train and stood up to racing. Our results tend to confirm the other reports for the Group A cysts, there being a 64 per cent return to full work, with a number of the horses having done extremely well on the racecourse for successive seasons, although some of them were not completely sound at follow-up examination.

The cysts did not appear to ossify and showed only little change in radiodensity, even though there may have been complete clinical improvement. There were 7 horses that showed some increase in radiodensity at follow-up examination and 5 of them have performed very well on the racecourse since, while only 2 of the 6 horses with decreased radiodensity have shown satisfactory results. The majority of the horses that showed an increase in radiodensity were Group B. The cysts in these horses may have been partially or completely filled with cancellous bone chips and thus may not have filled in with new bone. The cysts in Group A horses may have been more completely filled with new bone, which may have resulted in a decrease in radiodensity.

### Table 7: Alteration in radiodensity of subchondral bone cysts in the stifle joint between successive examinations in 13 horses

<table>
<thead>
<tr>
<th>Horse</th>
<th>Category of cyst</th>
<th>Clinical recovery of the case</th>
<th>Radiodensity index (RDI)</th>
<th>Time between first and last examination (months)</th>
<th>Alteration in radiodensity in cyst (RDI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Examination 1</td>
<td>Examination 2</td>
<td>Examination 3</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>Complete</td>
<td>1.69</td>
<td>1.74</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>Complete</td>
<td>1.94</td>
<td>2.13</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>Complete</td>
<td>1.38</td>
<td>1.75</td>
<td>—</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>Partial</td>
<td>1.65</td>
<td>2.28</td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>A</td>
<td>Complete</td>
<td>1.42</td>
<td>1.41</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>A</td>
<td>Complete</td>
<td>1.75</td>
<td>1.54</td>
<td>—</td>
</tr>
<tr>
<td>7</td>
<td>A</td>
<td>Complete</td>
<td>1.57</td>
<td>1.23</td>
<td>—</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>Complete</td>
<td>2.25</td>
<td>1.67</td>
<td>—</td>
</tr>
<tr>
<td>9</td>
<td>A</td>
<td>Initial</td>
<td>2.98</td>
<td>2.94</td>
<td>1.71</td>
</tr>
<tr>
<td>10</td>
<td>A</td>
<td>Initial</td>
<td>3.94</td>
<td>1.29</td>
<td>—</td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>No improvement</td>
<td>1.09</td>
<td>1.18</td>
<td>—</td>
</tr>
<tr>
<td>12</td>
<td>B</td>
<td>Partial</td>
<td>1.21</td>
<td>1.21</td>
<td>1.30</td>
</tr>
<tr>
<td>13</td>
<td>B</td>
<td>No improvement</td>
<td>1.82</td>
<td>1.43</td>
<td>—</td>
</tr>
</tbody>
</table>

RDI = Radiodensity index = \( \frac{\text{radiodensity of cyst (Cy)}}{\text{radiodensity of condyle (Co)}} \)
increased zone of sclerosis at the follow-up radiographs have performed extremely well. Generally, a mild increase in cyst radiodensity in Group A cases was associated with good subsequent performance and a prominent zone of sclerosis also seems to be a good prognostic sign. On the other hand, the outcome for the Group B cysts on conservative treatment was generally very poor, so perhaps these types of cyst would be the ones in which surgery should be attempted.

Acknowledgements

The authors acknowledge the expert technical assistance of Miss Janet Butler and thank their colleagues Judith Shelley and Chris Colles for advice and encouragement. The costs of the project were supported by the Horserace Betting Levy Board.

References


Résumé


Tous les chevaux furent soumis à un repos de six mois, avec mise à l’herbe, poursuivi par une reprise progressive de l’entraînement. 14 chevaux furent examinés de nouveau entre 4 et 33 mois après la première consultation et l’on ne put constater la disparition des kystes sur aucun. La radiodensité du kyste parut être augmentée chez certains mais à un faible degré. Le devenir des deux groupes fut différent: dans le groupe A, 14 soit la moitié, guérirent complètement, tandis que 5 autres reprirent un entraînement complet avec persistance d’une boiterie moyenne. Dans le groupe B, un seul animal put reprendre un entraînement normal.

Zusammenfassung


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General Articles

Aspects of the pathology of stifle bone cysts in the horse

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Summary
The gross and histological appearance of subchondral bone cysts in six Thoroughbred or partbred horses is described. The lesions were all situated in the centre of the medial femoral condyle and were not associated with any other damage to the articular surface of the femorotibial or femoropatellar joints. In three cases the cysts were unilateral but had an early non-cystic lesion present in the opposite stifle. All the cysts had a narrow channel at their distal extremity which communicated with the femorotibial joint. The more recently developed ones were fluid filled and contained fibrous strands, while those in the older horses contained dense fibrotic detritus. No signs of significant ossification of the cysts were detected. The likely pathogenesis of these lesions is discussed in the light of the pathological findings.

Introduction
THE importance of stifle bone cysts as a cause of hindlimb lameness in young Thoroughbred horses has been clearly established and the clinical and radiological features reported (Jeffcott and Kold 1982a, b; Stewart and Reid 1982; Verschooten and De Moor 1982). Most cases respond to a prolonged period of rest but, in those that do not, encouraging results have been achieved from surgery involving curettage and packing of the cyst with an autogenous cancellous bone graft (Kold and Hickman 1983). The underlying aetiology of these lesions is generally considered to form part of the syndrome of osteochondritis dissecans (Morgan 1972; O’Brien 1973; Rooney 1975; Strømberg 1979; McLwraith 1982). However, we noticed that no other signs of osteochondritis-like lesions were detectable in horses with stifle bone cysts. Similarly, cases with classical signs of osteochondritis dissecans, involving extensive degeneration of the articular surfaces, did not have clearly defined single cystic lesions in the medial femoral condyle (Jeffcott and Kold 1982a). It may be erroneous, therefore, to include stifle bone cysts as part of the osteochondritis dissecans syndrome without more substantial evidence than is currently available. The purpose of this paper is to describe some of the pathological features of stifle bone cysts in order to consider the possible pathogenesis.

Materials and methods
A total of six horses were included in the study. The diagnosis of a subchondral bone cyst in the stifle was made in life in five cases, while the remaining horse was found to have an early lesion at post mortem examination. All five clinical cases with stifle bone cysts had been lame for at least two months at the time of referral to the Equine Research Station (Table 1).

After euthanasia both stifle joints were opened and the articular surfaces of the femoropatellar and femorotibial joints examined. The distal femurs were then sectioned longitudinally (ie, cranio-caudally) with a bone cutting saw through the midpoint of the cyst. A thin slice (3 to 5 mm) through the communication of the cyst to the femorotibial joint was then radiographed using high definition intensifying screens and film (Min-R, Kodak Ltd, Hemel Hempstead) at exposures of approximately 45 kV and 20 mAs.

Bone specimens from selected cases were fixed in buffered formalin and then decalcified using Cutsa’s fluid. Decalcification was monitored radiographically and was usually completed in four weeks. The specimens were then embedded in Fibrowax (R. A. Lamb, London) and sections were cut at 10 μm using a Reichert Jung Autocut microtome with a tungsten carbide knife. The staining methods used were haematoxylin and eosin, Harris and Van Gieson, safranin and miltius scarlet blue.

Results
The animals were all destroyed at their owners’ request because of persistent or recurrent hindlimb lameness. In Cases 1, 2, 3 and 6, the lameness was attributed solely to the presence of a subchondral bone cyst. Case 4 was euthanased because of extensive gluteal muscle degeneration following a severe attack of paralytic myoglobinuria (exertional rhabdomyolysis). In Case 5 there was some additional damage present associated with chronic strain of the medial collateral ligament of the femorotibial joint and a longstanding thoraco-lumbar condition. All six horses were in fair to good bodily condition at post mortem examination. Apart from Case 1, which was very fat, they were judged to be of average size and showed no signs of any serious conformational deformities. All the subchondral bone cysts detected were Group A in type (Jeffcott and Kold 1982b), situated in the centre of the medial femoral condyle.

Apart from the indentation and wrinkling of the articular cartilage which marked the channel of communication into the cyst (Fig 1), no other visual cartilaginous damage nor any signs of peripheral osteochondritis dissecans were found. The channel was identically sited in all cases, being the most distal...
and central point of the medial femoral condyle, not covered by the medial meniscus but in apposition to the articular surface of the tibia.

Macroscopic appearance

The gross findings in all six cases are summarised in Table 2 as well as in line drawings of the cysts traced from radiographs (Fig. 2). In Case 1 the central region of the left medial femoral

<table>
<thead>
<tr>
<th>Case number</th>
<th>Age at post mortem examination</th>
<th>Breed</th>
<th>Sex</th>
<th>Body weight (kg)</th>
<th>Character of lameness</th>
<th>Duration of lameness (months)</th>
<th>At time of referral</th>
<th>At time of euthanasia</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21 months</td>
<td>TB</td>
<td>Colt</td>
<td>518</td>
<td>Intermittent LH, variable in degree</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>21 months</td>
<td>TB</td>
<td>Filly</td>
<td>—</td>
<td>Persistent moderate RH lameness</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>30 months</td>
<td>TB</td>
<td>Gelding</td>
<td>472</td>
<td>Persistent and severe LH</td>
<td>7</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4 years</td>
<td>TB</td>
<td>Colt</td>
<td>502</td>
<td>Severe bilateral lameness and muscle wastage</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5 years</td>
<td>Partbred</td>
<td>Gelding</td>
<td>434</td>
<td>Intermittent moderate LH</td>
<td>2</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>7 years</td>
<td>TB</td>
<td>Gelding</td>
<td>483</td>
<td>Persistent RH lameness</td>
<td>7</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

LH Left hindlimb  
RH Right hindlimb  
TB Thoroughbred

Fig. 1. Distal aspect of the left medial femoral condyle of Case 5 (A) and right medial condyle of Case 3 (B), both cases showing the depression in the articular surface which communicates with the lumen of the subchondral bone cyst.

Fig. 2. Diagram of the mid section outline of the subchondral bone cysts drawn from contact radiographs.

Fig. 3. Macroscopic appearance of the lesion in the medial femoral condyles (A-left, B-right) of a 21-month-old Thoroughbred colt (Case 1).
TABLE 2: Macroscopic appearance of subchondral bone cysts in six horses at post mortem examination

<table>
<thead>
<tr>
<th>Case number</th>
<th>Shape</th>
<th>Character of lesion</th>
<th>Diameter of cyst (mm)</th>
<th>Area (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Left Circular</td>
<td>Cyst filled with strands of fibrous tissue; channel of communication lined with articular cartilage and extending to centre of cyst</td>
<td>205 195 261</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right Triangular</td>
<td>Small pale area in subchondral bone, not cystic</td>
<td>- - -</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Left Domed</td>
<td>Small pale area in subchondral bone, not cystic</td>
<td>- - -</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right Domed</td>
<td>Cyst contained a mixture of dense fibrous and inspissated material</td>
<td>160 140 167</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Left Oval</td>
<td>Cyst filled with semi-solid material which blocked the internal opening of the communicating channel</td>
<td>200 160 278</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right Oval</td>
<td>Cyst contained much semi-solid material but had a central fluid filled space</td>
<td>200 5 279</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Left Domed</td>
<td>Small discoloured zone of subchondral bone beneath the area of roughened articular cartilage</td>
<td>4.5 4.0 11</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Right Circular</td>
<td>Cyst lumen completely filled in with dense fibrous-like material</td>
<td>235 230 283</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Right Oval</td>
<td>Cyst filled with fibrous looking material of varying consistency</td>
<td>260 160 286</td>
<td></td>
</tr>
</tbody>
</table>

condyle showed a 60 x 30 mm depression in the articular surface, but no discoloration nor any apparent articular degeneration was seen. From the centre of the indentation, the layer of articular hyaline cartilage made a narrow channel into the cavity of the subchondral bone cyst (Fig 3a). The thickness of the cartilage in and around the communicating channel was not different from that over the rest of the femorotibial articular surface. The cyst itself was more or less circular and had a clearly defined edge. The periphery was lined with fibrous-looking material and there were many strands of this crossing the cyst giving it a multiloculate appearance. No demonstrable macroscopic changes were detectable in the

Fig 4. Radiographic appearance of thin slices through four cysts showing the likely progression of changes in subchondral bone cyst development in the medial femoral condyle (A-Case 4; B-Case 1, right; C-Case 1, left; D-Case 5)
subchondral and surrounding bone of the distal femoral epiphysis.

In the same position in the opposite stifle (ie, right medial femoral condyle) there was a slight protuberance and yellowish discoloration of the articular surface instead of a depression. The cut surface of the lesion was not cystic but beneath it there was a triangular area of abnormal pale looking subchondral bone which had an irregular outline (Fig 3b). The overlying hyaline cartilage was apparently not further affected.

The articular surface of the medial condyle in the right stifle of Case 2 showed quite a large indented region from which a narrow cleft extended into the cyst beneath. The bone cyst itself was dome-shaped and situated close to the femorotibial surface. The contents had the appearance of a mixture of semi-solid detritus and fibrous tissue, no central cavity was present and no peripheral zone of sclerosis was detectable. In the left medial condyle a small, slightly raised and discoloured area of articular cartilage was present overlying a small dome-shaped region of abnormal subchondral bone. No cavity was present in this lesion.

Case 3 was bilateral and there were similar wrinkled indentations in the articular surfaces of the medial femoral condyles. The one in the right stifle was a little longer and appeared deeper. The midsection revealed the cyst in this limb to be oval-shaped and extending a little further into the epiphysis than the previous cases (Fig 2). The cyst lumen was filled with a mixture of fibrous-looking material and near its centre there were three focal areas of amorphous detritus. In the left stifle, the cyst was similar in size and shape but there was a central fluid-filled cavity surrounded by dense fibrous material. No gross damage to the articular cartilage was seen and both channels which communicated with the cysts were filled with fibrous-like tissue.

The distal articular surface of the left medial condyle in Case 4 showed a circular area of roughened, discoloured cartilage (10 mm in diameter). No detectable communicating channel could be seen and no obvious cystic cavity was found but a dome-shaped area of pale subchondral bone was present, which on the contact radiograph appeared radiolucent (Fig 4b).

In Case 5 an elongated slit running in a craniocaudal direction (approximately 15 mm in length) was present in the articular surface of the medial condyle. Beneath the articular surface the channel and cyst lumen were filled with dense fibrous-looking tissue. This had a whorled appearance, comprising numerous concentric rings. The cyst extended deeper into the epiphysis than previous cases and there was a narrow zone of peripheral sclerosis present (Fig 5a).

The cyst in Case 6 was more or less oval-shaped and was situated very close to the joint surface. It was filled with fairly dense looking bundles of fibrous material. A more obvious zone of peripheral sclerosis was noted. The articular cartilage of the femorotibial joint appeared normal but the communicating channel was considerably wider than previous cases and the cyst contents could be seen protruding slightly from the joint surface (Fig 5b).

**Histological features**

The histological findings are reported in the sequence of their likely severity and chronicity. In the normal medial femoral condyle, slight thickening of the articular cartilage was occasionally seen over the central point (ie, weight bearing area). The basal chondrocytes were arranged in a columnar pattern and had normal staining ability as well as an intact osteochondral junction. The bone immediately subchondral was thin and, under polarised light, displayed smooth-surfaced vascular canals and a more or less irregular collagen pattern and osteocyte distribution. Further away from the articular cartilage the trabeculae showed a regular lamellar structure with well-defined trabecular units indicating remodelling.

The small non-cystic lesion in the right stifle of Case 1 showed thickening of the subchondral bone plate, which consisted of many small Haversian-like systems. The vascular canals exhibited signs of remodelling and osteoclastic resorption; only a small amount of primitive woven bone was seen as interstitial bone between the Haversian-like systems. The overlying articular cartilage was slightly thickened but the basal layers displayed the normal columnar arrangement of chondrocytes without clone formation or disruption of the osteochondral junction (Fig 6a).

Case 4 had an obvious defect macroscopically in the left stifle and histologically showed central thickening of the articular cartilage. There was fibrillation in the transitional zone but the basal layer of chondrocytes was still in its normal columnar arrangement although mild central hypertrophy was noticed. At the osteochondral junction some disruption and separation had occurred with vacuole formation in the basal layers of cartilage. Immediately beneath this, the subchondral bone was thickened, comprising principally a primitive woven structure with irregular collagen and osteocyte pattern.
Fig 6a. The weight-bearing area of the right medial femoral condyle of a 2-month-old Thoroughbred (Case 1) showing thickening of the subchondral bone plate with slight thickening of the overlying articular cartilage. Haematoxylin and eosin x 3

Fig 6b. Case 4. Left femur of four-year-old Thoroughbred showing thickening of the articular cartilage centrally, together with osteochondral disruption and separation. The subchondral bone plate is thickened. Marrow fibrosis and early cyst formation are present. Increased formation is present in the surrounding bone. Haematoxylin and eosin x 3

Fig 6c. Close up of the communicating canal between the cyst and the joint lumen in Fig 6d. Incomplete osteochondral junction with normal endochondral ossification indicates the vitality of the articular cartilage. Marlius scarlet blue × 28

Fig 6d. Case 1. Twelve-month-old Thoroughbred, left stifle. A fully developed multicameral cyst is present. The articular cartilage is of even thickness throughout. A connective tissue membrane is seen to line the periphery of the cyst and to divide the cyst into multiple chambers. Marlius scarlet blue × 4

Fig 6e. Close-up of the communicating canal between the cyst and the joint lumen in Fig 6d. Incomplete osteochondral junction with normal endochondral ossification indicates the vitality of the articular cartilage. Marlius scarlet blue × 35

Fig 6f. Close-up of an intracystic area of Fig 6d. Fragments of non-vital bone and apparently vital cartilage are seen to be incorporated surrounded by a connective tissue membrane. Marlius scarlet blue × 20

Fig 6g. Case 6. Right stifle of seven-year-old Thoroughbred showing the most pronounced stage of cyst formation and repair with the cyst lumen occupied almost entirely by a highly vascular connective tissue with fragments of woven bone. Significant peripheral osteoclastosis is present. Marlius scarlet blue × 25

Fig 6h. Close-up of an intracystic area of Fig 6g showing a fragment of apparently vital cartilage with endochondral ossification, indicating functional capacity of incorporated cartilage fragments. Marlius scarlet blue × 20

However, there were interspersed areas of more lamellar-type bone structure with typical Haversian systems.

Another feature was the presence of marrow fibrosis and, in one site immediately beneath the disrupted cartilage, a cystic marrow cavity was found which was filled with low cellular connective tissue (Fig 6b). This was a site of increased bone formation caused by a slight increase in bone mass locally with thickening of trabeculae, which also showed increased surface resorption and osteoblast covering. Accumulation of bone dust was observed between the trabeculae. Much of this was artificial, being attributed to the sawing before histological preparation, but in several sites foci of non-vital bone were incorporated in the bone marrow. These were characterised by empty osteocytic lacunae, absence of collagen structure and a ground glass appearance and were suggestive of previous microfractures (Fig 6c). These findings were not demonstrable in sections of normal bone.

In the cystic lesion itself, the articular cartilage present was of normal thickness even where it was invaginated into the communicating channel (Fig 6d). The histological appearance of the cartilage in this border area had the normal columnar arrangement of chondrocytes and calcification of its basal layers, although some focal areas of subnormal calcification were noted. There was endochondral ossification with an intact osteochondral junction all along the cartilage lining of the channel, indicating that the cartilage was viable (Fig 6e). The superficial layers bordering the channel showed some degeneration with a moderate degree of fibration. The subchondral bone was sclerotic and exhibited a noticeable amount of remodelling. The sclerotic bone had a mainly lamellar structure although some small areas of woven bone formation were found.

Central to the sclerotic bone was the main cystic cavity which was made up of multiple chambers. At the periphery there was highly vascular connective tissue while in the lumen multiple fragments of non-vital bone were present, each surrounded by a zone of connective tissue (Fig 6f). A few fragments of apparently vital cartilage were also noticed. Thin collagen septae, which subdivided the cystic cavities, were present but no cellular lining was noted. All bone surfaces in the border between the pericystic connective tissue and the surrounding sclerotic bone were undergoing remodelling.

Because of the decalcifying procedure and lack of intra-vital staining, it was difficult to decide whether this activity expressed genuine expansion of the cyst or if it simply reflected an increased amount of bone deposition. In the neighbouring bone the trabeculae were thickened and seen to be undergoing increased resorption and formation. In the narrow cases a loosely arranged connective tissue was often present even at some distance from the lesion.

In Case 6, which had a more chronic appearance, the communicating channel from the articular surface to the cyst was only partially covered with cartilage. The neighbouring cartilage was thickened, but of normal structure, and degeneration was only seen at the very limits of the cyst. In this case, the cyst contained a large amount of connective tissue, highly vascularised and almost completely filling the cavity (Fig 6g). In this connective tissue fragments of non-vital bone were seen and in a few areas vital cartilage with evidence of ossification was detectable, indicating that incorporated fragments of cartilage could be functional (Fig 6h). The surrounding bone was sclerotic even within the cyst. The surface of the bone and the marrow showed a wider zone of sclerosis than the previous case.

Discussion

Cysts in the medial femoral condyle are most frequently found in young horses. Jeffcott and Kold (1982b) reported on 28 cases of a subchondral bone cyst in the medial femoral condyle, of which 70 per cent were less than three years old. Stewart and Reid (1982) also described a similar predilection in young horses (75 per cent less than four years) with this type of lesion, while Verschooten and De Moor (1982) reported a higher mean age in the case of 12 femoral cysts in 10 horses. Subchondral bone cysts have been described in various sites (Pettersson and Reiland 1969; Reid 1970; Verschooten and De Moor 1982). However, the majority of previous studies have lacked a detailed histological report. Pettersson and Reiland (1969) gave a histological description of two cysts in the first and third phalanges. The articular cartilage was considered normal, except for one area showing degenerative and reparative changes. Inagination of the cartilage into the cyst channel was described and viable cartilage was found deep in the cyst. Strömberg (1976) and Rejnér and Strömberg (1978) described histopathological changes in two (four) irregularly outlined subchondral cysts in the femoral condyle and described similar changes to those found in 30 cases of osteochondritis dissecans of the lateral trochlear ridge. These involved degenerative changes of the articular cartilage, observed as thickening, loss of columnar arrangement of chondrocytes, fissures in the cartilage, cluster formation of chondrocytes and abnormal cartilage protruding into the subchondral bone. These findings have since been confirmed by Olson, Reiland, Pettersson and Strömberg (1983).

Degenerative changes in the articular cartilage underlying the cysts were not seen in the cases reported here. The minor
thickening and low grade degenerative changes were thought to be compensatory, mechanical and secondary to changes in the subchondral bone. Peterson and Reiland (1969) described two cysts to be empty but lined and subdivided by fibrous tissue with a distinct cellular lining. No distinct lining of an empty cystic cavity was mentioned by Strömberg (1976) or Rejnö and Strömberg (1978). In this study, fully developed cysts were lined and subdivided by a connective tissue, but without a cellular lining. Our finding of non-vital bone fragments within the cysts has not been described previously. Peterson and Reiland (1969) noted remodelling at the periphery of the cysts with osteoblastic apposition of bone on the surface of pre-existing trabeculae with some osteosclerosis, but no evidence of bone necrosis was found. Strömberg (1976) described thickened bone trabeculae with subchondral defects filled with necrotic cartilage and with marrow fibrosis. These changes were attributed to be secondary to a primary cartilage lesion with disturbance of endochondral ossification.

Our material also reveals increased bone mass with thickened trabeculae and increased remodelling activity. The finding of fragments of non-vital bone in the cyst lumen is considered to be of histological importance, whereas the minor degenerative changes in the overlying cartilage are thought to be caused by mechanical changes and are secondary. The trabecular microfractures in the subchondral bone plate in the area of maximum weight-bearing might be the initiating lesion; the continued loading at the site could cause fatigue and lead to segmental collapse. The presence of non-vital fragments in the narrow spaces leads to cystic resorption with collapse of cortical cartilage. There are some comparative studies in man to corroborate this theory. Rhaney and Lamb (1955) described the changes at a focus of recent injury to the articular surface as a disruption of the articular surface, destruction of the subchondral bone plate and fractures of the subjacent trabeculae; but loss of part of the trabecular system beneath an unbroken surface might take place. Eggers, Evans, Butler and Blumel (1959) also suggested that cyst formation could result from repetitive minor trauma to a localised area of bone and Murray and Jacobson (1971) described the effects of traumatic or fatigue fractures as a result of prolonged exposure to minor, but repeated, mechanical insults. Verschooten and De Moor (1982) suggested that cystic lesions in horses could be caused by joint trauma producing focoi of subchondral ischaemia or pressure necrosis which were subsequently revascularised with removal of the dead trabeculae, although this is not the view of Olsson et al. (1983).

It would appear that there may be more than one underlying pathological process involved in the development of subchondral bone cysts. It seems likely, from this study, that mechanical trauma at the point of load bearing in the joint is the initiating factor, whereas other reports have described cysts to be associated with the cartilaginous damage in osteochondritis dissecans. This latter condition is much more prevalent in young horses in Sweden (Hoppe, Philippson and Jeffcott 1983) than in the UK. Further investigation on the pathogenesis is obviously required and experimental studies are currently underway involving attempts to surgically induce cyst formation while following the sequence of events in the bone using intra-vital bone marking with tetracycline (S. Kold, J. Hickman and F. Melsen, unpublished data).

Acknowledgements

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References


Résumé

On décrit les aspects microscopique et histologique que de kystes osseux sous cartilagineux tels qu’ont les rencontre chez les Pur Sang et Demi Sang. Toutes les lésions étaient situées dans le centre du condyle fémoral médial (interne); elles n’étaient pas asso cées à d’autres lésions de la surface articulaire des articulations fémoro tibiale ou fémoro rotulienne. Aucun signe évident d’ossification de ces kystes ne fut constaté. La pathogénie de la plus vraisemblable de ces lésions est étudiée en fonction des constitutions pathologiques. Dans trois cas, les kystes étaient unilatéraux mais déjà une lésion précoce, non kystique existait sur l’articulation symétrique. Tous les kystes présentaient à leur extrémité distale un étroit canal établissant une communication avec l’articulation fémoro tibiale. Les plus récents étaient remplis de liquide et contenaient du matériel fibreux. Ceux des chevaux les plus âgés renfermaient des débris fibreux.
Zusammenfassung

Das makroskopische und das histologische Aussehen subchondraler Knochendysmen bei sechs Vollblut — oder Warmblutpferden wird beschrieben. Die Läsionen lagen alle im Zentrum des medialen Condylus des Femurs; es bestanden kein gleichzeitiger Schaden der Gelenksoberfläche in den demorotibialen und femoro-patellaren Gelenken. In drei Fällen waren die Zysten unilateral, aber im gegenüberliegen-

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Commissioned Article

Interpreting radiographs 3: Radiology of the stifle joint of the horse

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Radiographic technique

There are definite advantages in performing stifle radiography under general anaesthesia, including better standardisation of exposure factors, reduction in movement unsharpness, a greater range of possible projections and much improved radiation safety. In practice these factors have to be balanced against the inconvenience and potential hazards of anaesthesia.

A piece of equipment that can be used with both the standing and recumbent animal to improve radiographic quality is the Dodger-T aluminium filter (Saab-Scania, Linkoping, Sweden). This attenuates the primary beam and provides some flexion and ventral movement of the stifle allowing improved access for the cassette, a more accurately aligned LM projection of the joint and a reduction in exposure.

Radiographic anatomy and incidental findings

The equine stifle is the largest joint in the body and a complex anatomical structure so it is vital to have a sound understanding of its radiographic anatomy.

At birth, ossification is incomplete and the radiographic appearance is very different from that of the mature horse. Incidental findings that can complicate radiographic interpretation of the stifle region. A list of these and their differential diagnoses is shown in Table 1.

Leo Jeffcott graduated from the Royal Veterinary College, London in 1967. He spent the following 14 years at the Equine Research Station, during which time he obtained his PhD on perinatal studies in Equidae and a Fellowship of the RCVS for his thesis on disorders of the thoracolumbar spine. He was appointed Professor of Veterinary Clinical Sciences, University of Melbourne in 1982. Professor Jeffcott was Honorary Editor of the Equine Veterinary Journal from 1975 to 1979

Table 1: Details of the time of appearance of ossification centres in the stifle and the times of closure and maturation

<table>
<thead>
<tr>
<th>Site</th>
<th>Time of appearance (days of gestation)</th>
<th>Closure time (months after birth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femur Diaphysis</td>
<td>60-70</td>
<td>21-42</td>
</tr>
<tr>
<td>Distal epiphysis</td>
<td>220-245</td>
<td></td>
</tr>
<tr>
<td>Tibia Proximal epiphysis</td>
<td>265-300</td>
<td>36-42</td>
</tr>
<tr>
<td>Tibial tuberosity</td>
<td>300-320</td>
<td></td>
</tr>
<tr>
<td>Diaphysis</td>
<td>60-70</td>
<td></td>
</tr>
<tr>
<td>Fibula Proximal epiphysis and diaphysis</td>
<td>After birth</td>
<td>40</td>
</tr>
</tbody>
</table>

* Data derived from Getty 1975

The outlines of the two trochlear ridges become very dissimilar after the first few weeks of life. The medial ridge is much larger, especially proximally, where it is wider and more rounded. A small notch is usually present at the distal extremity of the trochlea where it becomes the medial condyle. At this site on the lateral side there is a flattened and slightly roughened area at the transition (Fig 4a and b). In the PA projection, the outline of the medial epicondyle can be seen as a relatively smooth concave surface. The surface of the lateral epicondyle appears more convex and is often rather irregular and roughened in appearance. The adult, the cranial surface of the patella often shows some irregularity and roughening which should not be confused with evidence of patellar ligation strain. There are relatively few incidental findings that complicate radiographic interpretation of the stifle region.
Radiological conditions

There is a wide range of radiological conditions which may affect the stifle and a list of the more important ones is given in Table 3.

Fractures

Severe and comminuted fractures of the stifle region do not usually present any difficulties in diagnosis. They most commonly involve the distal shaft of the femur and the patella. The affected limb is often held semiflexed so that the stifle drops down and forward because the animal is unable to bear any appreciable weight on the limb. In these circumstances it is possible to obtain satisfactory standing radiographs with the minimum discomfort to the patient by directing the X-ray beam beneath the abdomen from the sound side, thus achieving a mediolateral view.

Osteochondrosis

Osteochondrosis dissecans may affect the stifle joint, especially in young animals between two months and two years of age. In general, the earlier the onset of clinical signs, the more severe is the radiological picture and the worse the prognosis. Radiographically, lesions tend to be confined to the femoropatellar joint. The lateral ridge of the trochlear is principally involved but the medial ridge and the distal articular surface of the patella can also be affected. There is marked irregularity of the articular outline with patchy areas of radiolucency and local sclerosis resulting from disruption and collapse of the cartilage and underlying subchondral bone (Fig 5a).

When the condition is less severe the clinical signs are often not apparent until the animal starts work or training (ie, at two years old or older). The radiographic lesions are more localised and circumscribed but again principally involve the cranial midportion of the lateral trochlear ridge (Fig 5b). There is frequently an ossified “joint mouse” floating free in the femoropatellar joint or still attached to the trochlear ridge. In the more longstanding cases flattening of the trochlear ridge can be seen. The prognosis in these cases of osteochondrosis dissecans is more hopeful and some of them respond to surgical treatment with curettage of the degenerated cartilage.

Fig 1. Some features of the radiographic anatomy of the stifle of newborn foal in (a) lateromedial (LM) and (b) caudocranial (PA) views.

Fig 2. The radiographic anatomy (LM view) of a five-month-old foal.
Subchondral bone cysts

The presence of large cystic lesions associated with the femorotibial joint of the horse constitutes an important cause of lameness, principally in young animals. There appears to be two types of lesions which can easily be differentiated radiographically. The commonest type of cyst (Group A) occurs as the solitary, clearly defined area of radiolucency, 1 to 2 cm in diameter, in the centre of the medial femoral condyle adjacent to the femorotibial joint (Fig 6a and b). Other cystic lesions (Group B) are occasionally seen near the intercondylar fossa and the proximal extremity of the tibia just beneath the tibial spine (Fig 6c and d).

In Group A the location of the cysts is remarkably constant. Only very rarely is a second smaller cyst (i.e., kissing type lesion), seen on the opposite surface in the proximal tibia (Jeffcott and Kold 1982c). In some instances (less than 20 per cent) bilateral cysts are found even though lameness is unilateral. The shape of these cysts may be circular, dome or oval shaped. There is always a communication between the cyst lumen and the femorotibial joint and often a sclerotic
TABLE 2: Some of the incidental radiographic findings of the equine stifle region

<table>
<thead>
<tr>
<th>Incidental finding</th>
<th>Differential diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prominent wavy line of distal femoral epiphysis sometimes with mild sclerosis at 6 to 12 months</td>
<td>Epiphysitis</td>
</tr>
<tr>
<td>Before 12 months of age there is complete or partial separation of the ossification centre of the tibial tuberosity</td>
<td>Fracture of proximal tibia</td>
</tr>
<tr>
<td>Incomplete ossification of fibula at any age</td>
<td>Fibula fracture</td>
</tr>
<tr>
<td>Flattening of trochlea at the distal extremity of the femoropatellar joint</td>
<td>Osteochondrosis</td>
</tr>
<tr>
<td>Roughening on cranial aspect of patella</td>
<td>Strain of patellar ligaments</td>
</tr>
<tr>
<td>On PA view when animal is weight bearing the patella will appear above or slightly lateral to the lateral trochlear ridge</td>
<td>Patella luxation</td>
</tr>
<tr>
<td>Roughening and irregularity on lateral surface of lateral epicondyle</td>
<td>Strain of lateral collateral ligaments</td>
</tr>
<tr>
<td>On PA view radiolucency on upper lateral aspect of intercondyloid fossa and beneath tibial spine in proximal tibial epiphysis</td>
<td>Subchondral bone cyst</td>
</tr>
<tr>
<td>In young foals roughening and irregularity on cranial proximal aspect of patella and trochlea</td>
<td>Suppurative arthritis</td>
</tr>
<tr>
<td>Early spur formation on the medial condyle of the tibia which is clear of the femorotibial joint</td>
<td>Secondary joint degeneration</td>
</tr>
<tr>
<td>Apparent femorotibial joint space collapse produced by improper radiographic technique</td>
<td>Meniscal damage or secondary osteoarthritis</td>
</tr>
</tbody>
</table>

TABLE 3: Some of the important radiological conditions of the equine stifle

<table>
<thead>
<tr>
<th>Condition</th>
<th>Epiphysitis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture</td>
<td>Distal femoral epiphysis</td>
</tr>
<tr>
<td>Femur - distal shaft</td>
<td>Other joint lesions</td>
</tr>
<tr>
<td>Patella - osteochondral fractures of trochlea</td>
<td>Osteoarthritis</td>
</tr>
<tr>
<td>Tibia - proximal epiphysis and tibial spine</td>
<td>Suppurative arthritis</td>
</tr>
<tr>
<td>Fibula - shaft</td>
<td>(“joint ill”)</td>
</tr>
<tr>
<td>Osteochondrosis dissecans</td>
<td>Meniscal injury</td>
</tr>
<tr>
<td>Trochlear ridges</td>
<td>Ligamentous damage</td>
</tr>
<tr>
<td>Patella</td>
<td>Middle patella ligament</td>
</tr>
<tr>
<td>Subchondral bone cyst</td>
<td>Cranial cruciate ligament</td>
</tr>
<tr>
<td>Medial femoral condyle (Group A)</td>
<td>Medial collateral ligament</td>
</tr>
<tr>
<td>Intercondyloid fossa and proximal tibia (Group B)</td>
<td>Miscellaneous</td>
</tr>
<tr>
<td></td>
<td>Lateral luxation of the patella</td>
</tr>
<tr>
<td></td>
<td>Calcinosis circumscripnte</td>
</tr>
</tbody>
</table>

A roughening and irregularity on lateral surface of lateral epicondyle

---

zone is a useful indication of a hopeful prognosis. The cysts do not ossify or disappear completely but some increase in radiodensity does often occur with the passage of time.

The Group B cysts tend to have a more irregular outline and can vary in number and size (less than 2 cm in diameter). This can give the affected area of the femoral condyle or tibia a rather moth-eaten appearance. A visible connection with the femorotibial joint is not always present; neither is sclerosis around the cyst periphery.

The prognosis for the Group A cysts is usually quite good, especially in animals of two years or less, more than 60 per cent returning to soundness. In those with persistent or severe lameness recourse to surgical treatment, involving currenting the cyst and packing it with bone chips, is a possibility (Kold and Hickman 1983). There is a much poorer chance of recovery in horses with Group B cysts and they rarely return to full work.

The pathology of these subchondral bone cysts is uncertain, although some authors include them in the osteochondrosis complex (Strömberg 1979). There may be a more complicated pathogenesis of the Group A cysts associated with other factors, such as focal articular damage followed by abnormal pressure or loading in the joint (Jeffcott, Kold and Meiken 1983) or simply trauma (Verschooten and De Moor 1982). The Group B cysts may develop secondarily to chronic damage to the insertion of the cruciate ligaments on to the proximal tibia or intercondyloid fossa. It is hoped that these points will be clarified following the completion of current research.
Epiphysitis

In the stifle, it is the growth plate in the distal femur that is usually affected. However, the incidence at this site is very low compared with the distal radial and distal tibial growth plates. When it does occur (Fig 7) these other, more radiographically accessible sites are also affected. The condition manifests itself clinically at nine to 12 months of age with a very upright conformation of the hindlimbs, a restricted stiff hindlimb gait and mild to severe acquired kyphosis (ie, roach back) of the lumbar vertebral column. No specific treatment is usually necessary other than limiting the rate of growth for a few months.

Other joint lesions

Osteoarthritis of the stifle occurs much less commonly than in joints of distal limbs. It principally affects the femorotibial
joint in older animals which show marked muscle atrophy, chronic stiffness and lameness that is not responsive to anti-inflammatory medication. The radiographic signs are usually less dramatic than the clinical picture. When the condition is apparently primary in origin the lateral aspect of the joint is more severely affected, with periarticular new bone formation (Fig 8). The condition also occurs secondarily to other causes of chronic femorotibial joint damage (e.g., cruciate or meniscal injury) when new bone deposition, marginal lipping and narrowing of the joint space may be seen.

Suppurative arthritis of young foals ("joint-ill") is associated clinically with heat, swelling and acute lameness. Radiographic changes are not seen until there has been extensive damage to the articular surfaces, subchondral bone or growth plate (Dik 1981). These should not be confused with the irregular outlines of the ossification centre in newborn foals and radiography of the opposite limb must always be performed if the condition is unilateral. Radiographically significant lesions are initially seen as minor defects which progress to obvious radiolucency sequestration, collapse and fragmentation of weakened bone. These changes can develop rapidly but take a minimum of a week.

Meniscal damage is associated with chronic lameness and distension of the femorotibial joint. Radiographically there is narrowing of the affected compartment of the joint, usually the medial one. There is frequently some medial collateral ligamentous damage and this is seen in longstanding cases as roughening at the attachment of the ligament with marginal lipping of the femorotibial joint (Fig 9). This is one instance when radiography must be performed in the standing position (i.e., weight bearing) if the joint space is to be evaluated. Meniscal injuries are rarely encountered in the United Kingdom and Europe but are more commonly seen in the USA. Prognosis is poor in these horses because secondary degeneration and osteoarthritis develop as a result of the instability of the femorotibial joint. Surgical treatment by meniscectomy is the only available recourse (Valdez and Adams 1978).
Fig 9 (a and b above). Meniscal damage shown as collapse of medial compartment of femorotibial joint space and spur formation at the joint margin (b)

Fig 10 (right). Middle patellar ligament strain with soft tissue swelling over the patella and roughening of its cranial and ventral aspects

Ligamentous damage

The middle patellar ligament is the most prone to injury. Radiographically there may be thickening and increased radiodensity in the ligament with periosteal roughening at its attachment to the patella in more longstanding cases (Fig 10). Provided an adequate period of rest is given, prognosis in these cases is usually quite good.

A more serious problem is caused by damage to the cranial cruciate ligament. Tearing of its attachment, from the proximal tibia or the intercondylar fossa, resulting in instability of the stifle is more common than complete rupture of the ligament. Radiographically there may be a bony fragment in the intercondylar fossa or separated from the tibial spine. In more chronic cases there is periosteal roughening and new bone at the cranial insertion (Fig 11). The prognosis depends on the severity of the ligamentous damage and the likelihood of secondary joint degeneration and osteoarthritis. Milder cases return to soundness but are usually left with an inability to stand up to hard work.

Injury to the medial collateral ligament of the femorotibial joint occurs with other joint and soft tissue damage. The radiographic signs are periosteal roughening at the attachment of the ligament to the medial epicondyle, usually with associated changes on the medial tibial condyle.

Miscellaneous conditions

Lateral luxation of the patella is rare in adult horses. It is usually traumatic in origin and unilateral. It can occur in ponies as a congenital condition and is frequently bilateral. Apart from the moveable position of the patella there are no other diagnostic radiographic signs.

Calcinosi c circumspecta or tumoral calcinosi s (O'Connor and Lucey 1977) is another rare condition of the equine stifle. There is a large circumscribed radiodense mass close to, but not actually involving, the stifle joint. The aetiology of the condition is unknown. The animals are usually not very lame and surgical removal of the lesion is the most satisfactory line of treatment.

References and recommended further reading

Radiographic technique and aspects of radiographic anatomy
Radiological Conditions


Accepted for publication 16.9.83


Accepted for publication 16.9.83
SECTION 5
NONINVASIVE BONE MEASUREMENT


SECTION 5 NONINVASIVE BONE MEASUREMENT

The assessment of noninvasive measurement of bone quality in the horse has traditionally involved the use of radiography, but there are now two other modalities available for critical evaluation of cortical bone strength and quality. These utilise single photon absorptiometry and ultrasound velocity. Investigations using photon absorptiometry have provided a direct measurement of bone mineral content by using a monoenergetic radionuclide source, while the technique of transmission ultrasound velocity in bone gives a measure of bone stiffness or elasticity. They can both be conveniently used on the metacarpus of the conscious horse.

Both cortical ultrasound velocity and bone mineral content can be used as accurate indicators of skeletal maturity. In addition, the effects of disuse on bone and certain types of lameness also can be accurately monitored. Preliminary data show an association with exercise in both young and mature horses. In addition there appears to be considerable scope for research of bone changes in vivo in horses produced by immobilisation, weightlessness, exercise and nutrition.

Statement on Share of Work:

Papers 30-31 - These two papers reported the development in our laboratory of the two techniques for noninvasive bone measurement. I planned the work, carried out the bulk of the measurements and prepared the papers for publication. R.N. McCartney's collaboration was essential to the success of this project through his knowledge and input of applied physics to both techniques of transmission ultrasound velocity measurement and single photon absorptiometry.

Paper 32 - This paper involved the validation of the ultrasound method in vitro and provided an additional parameter of cortical cross sectional area. The work was carried out jointly in my laboratory and the manuscript
was jointly prepared for publication.

**Paper 33** - This was the first paper from our group involving *in vivo* application of noninvasive bone measurement. I played the major part in carrying out the work involved, but was assisted with some of the measurements in training yards and at the University of Sydney by S. Buckingham. I prepared the manuscript for publication.

**Paper 34** - This study forms part of a PhD project being undertaken by S. Buckingham. I initiated and supervised the work and assisted in its preparation for publication.

**Paper 35** - This project was performed jointly at RMIT and the University of Melbourne by myself and Mr. McCartney. The results were presented by Mr. McCartney to an international conference in the USA and the paper published in the proceedings was prepared by both authors.

**Papers 36-37** - These two papers form part of a PhD project being undertaken by R. McCarthy. I initiated and supervised both studies and assisted in the preparation of both manuscripts for publication.

**Paper 38** - This investigation was planned and directed by myself although E. Scotti performed the majority of the actual measurements. I prepared the manuscript for publication.
Ultrasound as a tool for assessment of bone quality in the horse

L. B. Jeffcott, R. N. McCartney

A simple non-invasive method is described for calculating the transverse apparent velocity of sound of horse bone. This was achieved, both in vivo and at post mortem examination using the metacarpal bone and its covering soft tissue. On 34 post mortem specimens (ie, 68 limbs) from horses older than one year an average measurement of 2802 ± 37 (1 sd) m/sec was obtained. There were changes noted according to age and at different sites on the shaft of the metacarpus. The highest readings were obtained in the proximal shaft where the cortex was thickest. The velocity values gradually decreased towards the distal end where the cortex was thinner, particularly in animals less than 12 months old. The soft tissue component of the velocity measurement was uniform throughout the length of the metacarpus and effectively decreased the apparent velocity of the bone alone by about 170 m/sec (6 per cent). The shortest flight path of the ultrasound beam was found to be through the midcortical region of the metacarpal shaft. A good correlation was obtained between velocity of sound measurements and bone mass. Furthermore partial demineralisation of specimens from the mid-metacarpal region caused a considerable reduction in the apparent velocity of sound. In a series of young thoroughbreds (n = 52) measured in vivo the apparent velocity of sound increased from around 2650 m/sec at six months to approximately 2880 m/sec at three years.

Thirty-four horses with clinical signs of bone problems (ie, sore shins, splints, fractures) or serious tendon damage showed a reduction in apparent velocity readings of 100 m/sec or more from the expected normal value at one or more sites.

Assessment of bone quality can be derived from measurements of bone mineral density, compact bone density and the modulus of elasticity (Greenfield and others 1981). In this regard a method that has received some attention is the evaluation of ultrasonic energy transmission through cortical bone (Benirschke and Hyatt 1970) because the velocity of an ultrasonic wave (c) through a material is related to the modulus of elasticity (E) and its mass density (p) by the equation:

\[ c^2 = \frac{E}{p} \]

The clinical application of this technique in osteoporosis or metabolic bone disease seems to have considerable potential in man (Greenfield and others 1975) but has not yet been applied to veterinary medicine.

Racehorses are subjected to ever increasing levels of competition and great biomechanical stress to their skeletons. In spite of this and the considerable advances in exercise physiology, little is known about the effects on bone of training, fatigue, concussion and trauma. Pratt (1980) reported on a modification for horses of the ultrasonic method used in man to assess the elastic properties of bone and this work has been extended by evaluation in a series of racehorses by Rabin and others (1983). It would seem that this could prove a valuable clinical aid to diagnosis and perhaps ultimately a means of assessing performance potential or at least the limit that bone can accept (ie, fracture threshold).

The purpose of the present preliminary study is to establish a practical and reproducible method for determining the apparent velocity of sound through the third metacarpal bone and to assess variation with age and its clinical application in different types of lameness. The ultrasonic properties of the metacarpal diaphysis, including the path of the sonic beam, were also investigated as well as the effect of the soft tissues surrounding the bone.

Materials and methods

Animals
A total of 184 horses was investigated (Table 1). There were 83 horses examined at the Veterinary Clinical Centre under general anaesthesia or in the standing position. These were principally horses (n = 61) referred for respiratory problems (eg, functional airway obstruction) or other non-orthopaedic conditions (eg, colic) including seven thoroughbred weanlings and were designated as 'normals'; the rest (n = 22) had some forelimb skeletal abnormality. Another 46 horses were young thoroughbreds 17 to 42 months old from training stables in the Melbourne area. The remaining 55 were horses which had died or were euthanased and referred for necropsy to the department of pathology. They were examined within 24 hours of death, but were kept in a cold room at 5° C until that time.

Equipment
A pulse module (Panametrics Model 5055), a preamplifier (Panametrics Model 5660B), two 2-25 MHz, 13 mm diameter ultrasound transducers mounted on an electronic digital caliper (Jocal; C. E. Johansson) and a digital storage oscilloscope with signal averaging capability (Tektronix Model 468) were used. However, some of the earlier measurements, particularly on post mortem material, were made with equipment of slightly lesser quality.

Technique of ultrasonic measurement
The transverse apparent velocity of sound was calculated for the shaft of the third metacarpal bone by measuring the time of flight of an ultrasonic beam between two transducers.
TABLE 1: Breakdown of the material in this study used to measure the apparent velocity of sound of the forelimb metacarpal bones

<table>
<thead>
<tr>
<th>Material</th>
<th>Total</th>
<th>Normals</th>
<th>Abnormals</th>
<th>Age range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horses at Veterinary Clinical Centre</td>
<td>55</td>
<td>37</td>
<td>18</td>
<td>6 months to 13 years</td>
</tr>
<tr>
<td>Under general anaesthesia</td>
<td>28</td>
<td>24</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Standing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horses in training</td>
<td>37</td>
<td>36</td>
<td>1</td>
<td>17 to 42 months</td>
</tr>
<tr>
<td>Stable A</td>
<td>9</td>
<td>9</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Stable B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadaver specimens</td>
<td>55</td>
<td>44</td>
<td>11</td>
<td>0 to 26 years</td>
</tr>
<tr>
<td>Total</td>
<td>184</td>
<td>150</td>
<td>34</td>
<td></td>
</tr>
</tbody>
</table>

a known distance apart measured by an electronic digital caliper (Fig 1). The term 'apparent velocity' is used because the shortest time of flight is known to be an ultrasound path which is not directly from one transducer to the other (Fig 2). However, the velocity calculations used the separation of the probes which were placed on the lateral and medial aspects of the cannon.

For the post mortem specimens the hair was clipped from the area of measurement, the leg clamped into a retort stand and a needle inserted into the carpometacarpal joint to act as a marker from which measurements at 1·0 cm intervals could be made down the shaft of the metacarpal bone. All sites were related to the midpoint of the metacarpus. For all measurements a liberal quantity of coupling medium (Aquasonic 100; Parker), was used to ensure good sound transmission. It was only possible to obtain consistent transmission of sound over the region of the metacarpal shaft that had reasonably parallel sides. Poor readings were obtained if there was incomplete contact of the probes due to the widening of the metacarpus at the proximal and distal epiphysis. This meant that readings from an average bone of 24 cm in length were confined to a central region of 8 to 17 cm. A total of 10 readings at 1·0 cm intervals was taken in most specimens and two ultrasound determinations were made at each site. Once the readings had been taken with the skin intact, the procedure was repeated directly onto the bone after dissection of the soft tissues.

An estimate of the sonic pathway was made using 1·0 cm thick segments from the midshaft of the metacarpus. The pathway was disrupted through areas of the cortex and medulla by cutting with a small hand saw or a file. In the live animals a total of five approximately equally spaced readings was taken from each forelimb between the proximal and distal limits of the measurable part of the metacarpal shaft. The hair was not clipped but coupling gel applied a few minutes before readings were taken, ensured good sound transmission. In the foals it was often necessary to increase the ultrasound intensity by reducing the attenuation to 20 to 24 decibels (dB) and to increase the number of sweeps on the signal averaging capabilities from 32 to 64 to obtain a satisfactory trace on the oscilloscope (Fig 3). For subsequent examination of the envelope of the ultrasound trace on the oscilloscope a Polaroid camera was used.

BONE MASS MEASUREMENT

After calculation of the apparent velocity an estimate of bone mass was derived from determination of the specific gravity (n = 18), ash weight, calcium and phosphorus content (n = 8) of the mid-metacarpal bone. The effect of partial demineralisation of bone was achieved by placing small segments (1·0 cm thick) of midshaft metacarpus from a four-year-old standardbred mare into a formic acid decalcifying solution. Ultrasound readings and radiographs were taken at various intervals over 21 days.
The Veterinary Record, March 30, 1985

DENSITOMETRY MEASUREMENT

Radiographic densitometry was used as a means of comparing bone density with apparent velocity in 11 of the post mortem cases. This was achieved by cutting 1-0 mm transverse sections of metacarpal bone which were radiographed at 45 kV and 90 mAs on nonscreen film (Mammoray: Agfa-Gevaert) with a Toshiba X-ray machine. The films were processed in an automatic processor (Cronex T3; Dupont) and an estimate of optical density (OD) of the midcortical region calculated using a small portable densitometer (Shikura PDA-81; Konishiroku Photo Ind).

Results

VARIATION IN APPARENT VELOCITY ALONG METACARPUS

In the post mortem specimens from 17 normal horses there was no significant difference in apparent velocity (= 1sd) for the bone with its surrounding soft tissue between the left (2015 ± 38 m/sec) and right (2706 ± 44 m/sec) limbs. There was, however, a gradual reduction in the mean apparent velocity recorded from the proximal to the distal ends of the metacarpal shaft (Fig 4). The soft tissue thickness did not vary significantly over different parts of the cannon shaft and an approximate velocity of sound in the soft tissue, calculated from 200 readings from 10 limbs was 1610 ± 290 m/sec. The accepted average value of ultrasound velocity in human tissue is 1540 m/sec.

The mean value for all 10 sites on the 34 specimens from these 17 horses was 2973 ± 33 m/sec for bone alone and 2802 ± 37 m/sec with the skin and soft tissue intact (ie, a reduction of 5-8 per cent). In 10 foals there was found to be a much greater variation over the distal shaft region (Fig 4). The average standard deviation of all readings for the foals was ± 210 m/sec. From these results it was concluded that a mean taken from a number of measurements along the metacarpal shaft gave a good measure of the apparent velocity. However, in foals measurements from the midpoint and towards the proximal end were preferred.

VARIATION IN APPARENT VELOCITY WITH AGE

Considerable variation was found according to age in the normal post mortem material (Fig 5). There was a marked increase in the apparent velocity from birth up to approximately 12 months. After this the values levelled off considerably and an analysis of velocity (c) versus age (x) in years for horses over one year old gave a regression line of \(c = 2843 - 3.9x\). The variance about the regression line was ± 61

FIG 3: Polaroid photograph of the recorded trace of sound transmission through the mid-metacarpus of A, an eight-year-old standardbred and F, a six-month-old thoroughbred foal (\(t_1\) is the path through cortex alone; \(t_2\) the path through cortex and medullia)

FIG 4: Graph of apparent velocity of sound (m/sec) along the metacarpal shaft in the post mortem specimens from 17 normal horses and 10 normal foals. The normal horse specimens were measured both with the skin and soft tissue intact and after it had been dissected away

FIG 5: Results of apparent velocity of sound (m/sec) in post mortem specimens from 45 normal horses according to age
The transverse velocity of sound measured through specimens of cortical bone alone was approximately 3000 m/sec and through the medullary cavity it was approximately 1500 m/sec. If the flight path were to go straight from one transducer to the other (i.e., through both cortices and medulla) the reading of velocity for a diameter consisting of 2/3 cortex and 1/3 medulla would be approximately 2250 m/sec. The measured apparent velocity was considerably in excess of this and so the ultrasound beam for the shortest time of flight could not follow a direct path between the two transducers. It was possible to confirm experimentally that the preferred pathway was through the midcortex (Fig 2). This was done by taking specimens of midmetacarpus and filing away specific areas of the cortex adjacent to the medulla and periosteum and checking the effects on the velocity of sound.

The character of oscilloscope readings of the sound transmitted through the bone was also examined. For example, it was possible to identify (Fig 3) the first arrival pulse (t1) that travelled around the cortex alone from that taking the route through the medulla and cortex. In young foals the envelope of the sound trace around the cortical bone alone appeared of lower amplitude and less distinct than that transversing the central medullary bone compared to that of

**TABLE 2: Results of in vivo measurement of apparent velocity of sound (m/sec) of the metacarpal shaft including skin and soft tissue from 61 normal horses according to age**

<table>
<thead>
<tr>
<th>Age range</th>
<th>Horses</th>
<th>Proximal</th>
<th>Mid</th>
<th>Distal</th>
<th>Proximal</th>
<th>Mid</th>
<th>Distal</th>
<th>Mean of all sites for both legs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 5 months</td>
<td>4</td>
<td>±68</td>
<td>±45</td>
<td>±73</td>
<td>±126</td>
<td>±86</td>
<td>±86</td>
<td>±91</td>
</tr>
<tr>
<td>6 - 11 months</td>
<td>7</td>
<td>±95</td>
<td>±76</td>
<td>±60</td>
<td>±115</td>
<td>±82</td>
<td>±47</td>
<td>±90</td>
</tr>
<tr>
<td>12 - 23 months</td>
<td>5</td>
<td>±107</td>
<td>±57</td>
<td>±84</td>
<td>±24</td>
<td>±44</td>
<td>±37</td>
<td>±71</td>
</tr>
<tr>
<td>24 - 47 months</td>
<td>16</td>
<td>±86</td>
<td>±86</td>
<td>±73</td>
<td>±59</td>
<td>±62</td>
<td>±77</td>
<td>±81</td>
</tr>
<tr>
<td>4 - 5 years</td>
<td>14</td>
<td>±92</td>
<td>±59</td>
<td>±74</td>
<td>±84</td>
<td>±71</td>
<td>±71</td>
<td>±77</td>
</tr>
<tr>
<td>6 - 10 years</td>
<td>9</td>
<td>±59</td>
<td>±48</td>
<td>±46</td>
<td>±61</td>
<td>±23</td>
<td>±61</td>
<td>±56</td>
</tr>
<tr>
<td>Over 10 years</td>
<td>6</td>
<td>±70</td>
<td>±60</td>
<td>±59</td>
<td>±82</td>
<td>±43</td>
<td>±44</td>
<td>±61</td>
</tr>
</tbody>
</table>
The measured speed of sound was reduced in a bone from a four-year-old standardbred mare from 2924 to 1650 m/sec within 21 days.

**APPARENT VELOCITY MEASUREMENTS IN VIVO**

The apparent velocity measurements in 61 normal horses examined at the Veterinary Clinical Centre followed the same pattern as the post mortem material. Table 2 illustrates the readings (± 1sd) according to age obtained in this group for three of the five sites down the metacarpal shaft. The mean (± 1sd) apparent velocity for 45 of the horses aged from 24 months to over 10 years was 2799 ± 60 m/sec. No differences were found between the horses measured standing or under general anaesthesia. The values recorded for seven weanlings and 45 young thoroughbreds in training confirmed the trend of increasing velocity with advancing age to maturity (Fig 10). A correlation coefficient of \( r = 0.8665 \) was calculated and a variance about the regression line of 34.75 m/sec.

A total of 23 horses was examined which were classified as

**FIG 9:** Radiographic appearance of a specimen of midshaft metacarpus (A) before immersion in decalcifying fluid with a velocity of sound measurement of 2924 m/sec and (B) 21 days later when the velocity of sound had decreased to 1650 m/sec

being abnormal because of clinical signs of sore shins, splint formation, metacarpal or fetlock fracture or flexor tendon rupture. A reduction in the apparent velocity of sound of 50 to 200 m/sec at one or more sites in the metacarpal shaft was recorded. Similar results were obtained in another 11 abnormal horses examined post mortem. In a 26-year-old gelding with radiographic evidence of senile osteoporosis there were marked reduced velocity readings throughout the shaft.

**Discussion**

This ultrasonic technique for the in vivo study of equine bone has proved to be simple, cheap and not hazardous. The results compare well with the studies reported in USA by Rabin and others (1983). The metacarpus was a good choice of bone to use because of its shape, accessible position, thin but uniform surrounding soft tissue and susceptibility to biomechanical injury (Adams 1966, Rooney 1969). Reliability of the method is satisfactory, although some experience using the equipment improved the measurements. In general horses tolerated the technique extremely well and did not require any form of restraint or tranquillisation apart from the need for picking up the other forefoot. The measurements were conveniently made either in the stable or out in the paddock. No serious behavioural problems were encountered even with the weanlings and unbroken yearlings. Some horses resented the procedure, but with the opposite forelimb restrained they tended to move or sink backwards and this gave the operator warning to release the transducers and get the adults. The much thinner cortex in foals and therefore lower corticomedullary ratio gave a longer \( t_2 \) reading. In the examples shown in Fig 3, for the adult horse \( t_2 \) gave an apparent velocity 2807 m/sec and \( t_1 \) gave 2292 m/sec while for the six-month-old foal \( t_2 \) gave 2600 m/sec and \( t_1 \) only 1750 m/sec.

**RELATIONSHIP OF ULTRASOUND MEASUREMENT TO BONE MASS**

The measurements made of specific gravity, ash (mg/mg dry bone), calcium and phosphorus content (mg/100 mg ash) indicated that there was a correlation between bone mass and the apparent velocity of sound according to the examples shown in Figs 6 and 7. The two neonatal foals with low apparent velocity readings gave correspondingly low ash, calcium and phosphorus results. The 26-year-old horse, which exhibited signs of senile osteoporosis, had normal ash although abnormal calcium and phosphorus levels and reduced apparent velocity compared to normal adults. The remaining samples of bone were from normal horses and their apparent velocity readings grouped well with those of bone mass. The results of the radiographic optical densitometry of the midcortical metacarpal region followed the same trend and showed increasing velocity of sound with decreasing optical density (Fig 8).

It was also possible to demonstrate a marked reduction in the velocity of sound by partial demineralisation of bone after immersion of midmetacarpal specimens in a formic acid solution (Fig 9). The decalcification was not particularly evenly distributed, but the velocity of sound was reduced in a bone from a four-year-old standardbred mare from 2924 to 1650 m/sec within 21 days.

The apparent velocity of sound in 11 normal horses examined at the Veterinary Clinical Centre followed the same pattern as the post mortem material. Table 2 illustrates the readings (± 1sd) according to age obtained in this group for three of the five sites down the metacarpal shaft. The mean (± 1sd) apparent velocity for 45 of the horses aged from 24 months to over 10 years was 2799 ± 60 m/sec. No differences were found between the horses measured standing or under general anaesthesia. The values recorded for seven weanlings and 45 young thoroughbreds in training confirmed the trend of increasing velocity with advancing age to maturity (Fig 10). A correlation coefficient of \( r = 0.8665 \) was calculated and a variance about the regression line of 34.75 m/sec.

A total of 23 horses was examined which were classified as

**FIG 8:** Comparison of radiographic optical densitometry (OD) according to the apparent velocity of sound (m/sec) in 11 normal horses.
them quickly out of the way. It was very rare for a horse to attempt to strike suddenly or lunge forward and so damage the equipment.

It was unnecessary to clip the hair from the cannon region provided a liberal quantity of transmission gel was applied and sufficient time given for it to penetrate down to the epidermis (i.e., usually within five minutes). Thoroughly wetting the forelimbs also ensured good passage of the ultrasound beam through the limb. The transducers were applied with light finger pressure which was kept as constant as possible. It was always more difficult to obtain good ultrasonic traces in the younger horses (i.e., under 20 months old). This was presumably associated with the much narrower cortex compared with mature horses. Readings where the cortex was thinnest, down towards the distal metacarpal shaft, took longer to obtain good oscilloscope traces (i.e., 10 to 30 seconds). In this situation enhancement of the ultrasound trace could be achieved by reducing the attenuation in the pulse module but it also increased the background noise on the base line. This problem could largely be overcome by increasing the signal averaging capability of the oscilloscope. However, a sweep rate of 64 was the upper limit for in vivo measurements as the time involved was approximately four seconds per trace. A higher sweep rate of 128 involved eight second traces which was too long for the operator to be able to hold the transducers absolutely still. Increased pressure of the transducers on the sides of the cannon could usually help improve the ultrasonic trace to some extent.

The soft tissues surrounding the metacarpus reduced the apparent bone-only velocity by about 170 m/sec. For practical purposes this could be ignored as it was consistent at approximately 6 per cent of the total apparent velocity throughout the length of the cannon bone. However, if there was local inflammation or subcutaneous oedema of the metacarpal region there was difficulty in obtaining a satisfactory ultrasound trace and the apparent velocity measurement was significantly reduced depending on the thickness of the soft tissue swelling involved.

It was important to keep the transducers to the lateral aspects of the metacarpus where the sides of the bone were flattest and parallel. Minor deviations from this did not affect the apparent velocity measurement provided there was good contact of the transducers with the skin. Sometimes there were difficulties in obtaining the most proximal readings because of the lateral digital extensor tendon lying over the outer cortex at its maximum diameter. This problem was usually only encountered with animals under general anaesthesia lying in dorsal recumbency. It was usually possible to push the tendon a little further lateral to obtain a satisfactory trace. Other problems encountered were horses which did not have parallel-sided metacarpal bones or where there were small periosteal swellings and split formation. Here it was difficult to get complete contact of the transducers.

At sites where equivocal or poor readings were obtained it was important to repeat the measurements until a consistent trace was obtained. By routinely taking five measurements down each metacarpus it was possible to space out evenly the individual measurements by utilising the position of the imprint left in the transmission gel by the transducers.

The equipment for determining apparent velocity of sound in bone is relatively inexpensive compared to other modalities used for assessing bone quality (e.g., radiography, nuclear medicine and computed tomographic scanning). A fairly sophisticated oscilloscope was used here but more economical versions could probably be used in practice. The running costs are negligible and involve only transmission gel. A major disadvantage of the present system was that the mains operation limited its portability and the apparent velocity was not obtained directly during the recording. This had to be calculated afterwards from the micrometer value and the oscilloscope reading of the time of flight. This problem appears to have been overcome by Rabin and others (1983) who used a digital caliper interfaced with a computer, from which a direct reading of velocity was obtained and software incorporated for soft tissue correction.

The apparent velocity of sound is essentially a measurement of the modulus of elasticity and density of the bone which is related to its strength. It was therefore encouraging to find such a useful correlation here between velocity and bone mass (i.e., density) in the post mortem specimens. It was also possible to reduce velocity readings by demineralisation in the laboratory which confirms the potential to assess clinical osteoporosis as has been done in man (Greenfield and others 1981).

The difficulties of accurately measuring bone mineral content in vivo could be overcome by using photon absorptiometry. This technique has become a standard method in man (Sorensen and Cameron 1967) and has been used in ponies (Wentworth and others 1971). A commercially available bone mineral analyser will shortly be available for horses (R. Myers, personal communication). In association with ultrasound this should provide a new dimension for the sequential assessment of skeletal maturity and bone metabolism in racehorses.

In conclusion there appears to be considerable potential for the use of ultrasonic measurement in the horse as a means of assessing bone quality. The shape of the envelope of the ultrasonic trace looks as if it has a role to play in the evaluation of the density and thickness of the cortex and this may assist in further understanding the pathway of the beam of sound. It may be possible to demonstrate changes or trends in bone density or elasticity that are a prelude to the onset of lameness or reduced racing performance. This could extend the studies of Pratt (1980) and Rabin and others (1983) who recorded lowered velocities in horses with metacarpal fracture and the authors’ own observations of more than 100 m/sec reduction in some of the common orthopaedic problems of young racehorses (i.e., sore shins, splints and tendon injuries).

Acknowledgements. — We gratefully acknowledge the technical assistance of Tracy Waters and also wish to thank C. Fahier, T. Hughes and H. McNamara for their kindness, cooperation and permission to take readings from their horses. We are also most grateful to Dr. A. MacLean for his help in providing clinical material and J. Darke for assistance with measuring the horses in training.

References


Papers and Articles

Single photon absorptiometry for the measurement of bone mineral content in horses

L. B. Jeffcott, R. N. McCartney, V. C. Speirs

A safe, non-invasive method for the accurate measurement of bone mineral content in the third metacarpal bone of the horse is described. The technique involves scanning the bone with a single photon beam from an Americium-241 source. Data were obtained from the excised metacarpal bones from both forelimbs of 50 normal and seven lame horses. Measurements were made in vivo on eight normal and seven lame horses and on one experimental horse with osteopenia induced by partial weightlessness. The contribution of the splint bones to the total bone mineral content was less than 2 per cent distal to the mid-point of the metacarpus, but in the proximal shaft it increased to 12 per cent. No significant differences were noted either between right and left limbs, or between male and female animals. A reduction in bone mineral content was demonstrated in the affected leg of horses with chronic lameness and with osteopenia induced by weightlessness. The bone mineral content (g/cm²) correlated well with the apparent transverse velocity of ultrasound (m/sec) through the bone. A measure of bone mineral density (g/cm²) was calculated from the bone mineral content and cross sectional area of the bone to overcome the individual differences in size of the metacarpus.

SINGLE photon absorptiometry was developed by Cameron and Sorensen (1963) in the USA following unsuccessful attempts to measure bone mineral content accurately by using conventional X-ray film and a system of optical densitometry. The principle of their technique was to scan a bone with a narrow beam of low energy photons from a monenergetic radionuclide source (e.g. 208Tl, 125I or 241Am) and to measure the degree of attenuation of the beam by bone, relative to its attenuation by tissue, by means of a scintillation detector system. A direct relationship was established between the number of extra photons absorbed and the bone mineral content.

The limb containing the bone being scanned must be surrounded by a soft tissue equivalent material so that the surfaces facing the source and the detector are flat and parallel. Both the photon source and the radiation counting equipment move at a fixed rate to scan the bone transversely. The transmitted intensity of the beam is reduced as it scans the bone, and a logarithmic plot of counts per second shows a typical absorption curve (Fig. 1). The area within the bone profile (ie, the sum of the logarithm of counts per second absorbed) is used to calculate the bone mineral content. Equipment for single beam photon absorptiometry is available commercially for human medicine, although specific adaptations for veterinary use are at present limited. The estimate of bone mineral content obtained by scanning is much better than that obtained by direct radiography or radiographic densitometry and an accuracy of better than 2 per cent can be achieved.

In man, the measurement of bone mineral content by single photon absorptiometry is one of the most widely used techniques for assessing skeletal changes in vivo (Griffiths and Zimmerman 1978, Chesney and Store 1982, Wataner and others 1983). Most of the involutional changes recorded are associated with ageing and exercise (Aloia and others 1978, Aloia 1981). There have also been investigations to establish a specific relationship between bone mineral content measured by photon absorptiometry and the mechanical properties of bone (Bartley and others 1966, Currey 1969a, 1969b, 1970, Horsman and Currey 1983). In veterinary medicine, photon absorptiometry has been used to a limited extent in laboratory animals (Sanchez and others 1981) and in companion and farm animals. There are references to its use in dogs (Wentworth and others 1971, Fisher and others 1974, Stoliker and others 1976, Jorck and others 1982), in cattle (Zeiterholm 1974) and in sheep (Siemom and others 1974). In horses photon absorptiometry using a 10 mCi 241Am source has been employed as a quick method of evaluating skeletal maturity (Pezzo and others 1977).

There is great potential for the application of photon absorptiometry in racehorses for monitoring bone quality in relation to age, health, diet and training. It can also provide another non-invasive technique for the investigation of bone. To supplement the measurement of ultrasound velocity, which has already been shown to be a valuable indicator of in vivo bone strength (Jeffcott and McCartney 1985). The aims of this paper are to report on the application of photon absorptiometry in the horse by establishing base line data: to examine the feasibility of performing the technique routinely in the standing horse: to establish that bone mineral content

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FIG 1: Printout of bone scan of the metacarpal bone of a standing horse using the Norland digital bone densitometer, Large Animal Scanning System.
measured by photon absorptiometry. In a true measurement of bone mass in the horse, to compare the results of bone mineral content measured by photon absorptiometry with the results obtained by measuring the apparent transverse velocity of sound, and to investigate the role of photon absorptiometry in the evaluation of lameness and metabolic bone disturbances.

**Materials and methods**

**Animals**

**Excised bones.**—The metacarpal bones from both forelimbs of 50 Thoroughbred and Standardbred horses were collected. These animals had been referred for post mortem examination but were considered to have normal skeletal systems. Their ages ranged from newborn to 17 years and they were divided into four groups: Group 1 from newborn to three months \((n = 30)\); group 2 from four to 11 months \((n = 5)\); group 3 from 12 to 25 months \((n = 13)\); group 4 two years and over \((n = 24)\). A further group of seven horses which showed chronic unilateral lameness before post mortem examination was also investigated. The bones from all these horses were measured by photon absorptiometry and ultrasound velocity techniques. Bone mineral content was measured by photon absorptiometry alone in eight horses from 11 different bone sites - occipital bone, mandible, thoracic vertebral body \((T1)\), rib \((R_b)\), scapular vertebral body \((C_y)\), tuber coxae, third carpal bone, mid-metacarpal and metaepiphyses, proximal sesamoid bone and tuber calcaneus. The cross sectional area and specific gravity of these bones were also estimated.

**Live horses.**—Bone mineral content was measured in vivo in eight normal horses aged from four months to nine years and in three horses showing unilateral leg lameness. Photon absorptiometry and ultrasound velocity measurements were carried out sequentially on a three-year-old crossbred mare subjected to two weeks of partial weightlessness in a flotation tank.

**Photon absorptiometry**

Bone mineral content was determined using a Norland digital bone densitometer (Prototype model 2741, Large Animal Scanning System; Norland Corporation, Fort Atkinson, Wisconsin) incorporating an \(^{109m}\)Rh source. The excised bones from groups 2 to 4 were scanned transversely (Fig. 2) in a water bath at 15 sites along the metacarpus. The foals in group 1 were scanned at 14 sites along the metacarpus. The instrument was programmed with a search threshold of 95 per cent, horizontal scale of 9.0 cm, multiple scan setting for five scans at each site with a calibration slope and intercept of 2.380 and 0.130, respectively. Each site was scanned five times with an estimated mean SD of 1.8 per cent.

In the live animals bone mineral content was measured either in the standing position (Fig. 3) or in lateral recumbency under general anaesthesia. A uniform soft tissue equivalent was achieved around the metacarpus by wrapping the leg with either a fluid-filled sponge bag (Equi-Kool Flex-wrap, Equi-Best), or a water-filled bag and then enclosing this in a square polythene scanning jig. The same horizontal scale, calibration slope and intercept were used as with the excised bones, but the search threshold was set at 85 per cent with the scan setting fixed for a single scan. The absorptiometer was mounted on a portable stand and single scans were made of the mid-metacarpal shaft in a caudal to cranial direction.

In three post mortem specimens the bone mineral content was measured at 20 sites down the length of the third metacarpal bone before and after removal of the splint bones (ie, second and fourth metacarpal bones).

**Ultrasound velocity**

The transverse apparent velocity of ultrasound \((m \text{ sec})\) was calculated for the shift of the metacarpus after the method of Jeffcott and McCartney (1965) using a pulse module with a preamplifier, two 2.25 MHz transducers mounted on a digital caliper and a digital storage oscilloscope. Measurements on post mortem specimens were taken at 1.0 cm intervals at 10 different sites along the mid-shaft of the metacarpus for photon absorptiometry. In the live horses five sites were measured over the same region of the metacarpus.

**Bone mass measurements**

An approximately 1.0 cm thick section was cut with a bone-cutting band saw from the mid-shaft of 15 metacarpal bones. The bone mineral content of these specimens ranged from 1.4 to 11.0 g cm\(^{-3}\). The volume, specific gravity and ash content (mg/100 mg dry defatted bone) were determined by standard methods for each section (Anderson 1982).

**Results**

**Bone mineral content in normal excised bones**

The mean bone mineral contents of the 15 sites measured for both left and right metacarpal bones are shown in Fig. 4. There was a marked increase in bone mineral content during the first few months of life. The rate of increase slowed down gradually and peak values were observed at about six years of age. Thereafter there was a slight fall with advancing years.
A similar pattern of differences was demonstrated (ie, non-weight-bearing) limb in all II sites (mean appreciable decrease II(jollyollly,horses referred) and this was dependent between the two limbs. The bone mineral content also varied from proximal to distal shaft with higher values in the distal epiphysis. The foals in group 1 showed very little variation along the metacarpal shaft. Bone mineral content did not differ significantly between the left and right limbs or between entire males, females or geldings.

The presence of the split bones (second and fourth metacarpals) made a difference of approximately 12 per cent in the bone mineral content at the most proximal site (Fig 6). However, the difference was reduced to less than 2 per cent at the level of the mid-metacarpal site and distal to this it was only about 0.5 per cent.

_Bone mineral content of excised bones of lame horses_

The mean bone mineral content of each metacarpal of seven horses with a moderate to severe degree of chronic unilateral lameness is shown in Fig 7. There was an appreciable decrease in the bone mineral content of the lame (ie, non-weight-bearing) limb in all 11 sites (mean 7.1 ± 2.4 per cent) and this was dependent on the degree and duration of the lameness. In the 50 normal horses the differences between the two limbs was less than 1.0 per cent. A similar pattern of differences was demonstrated with ultrasound velocity (mean 3.1 per cent) and it was possible in some cases to identify a difference using a simple radiographic photometry technique (Jeffcott and McCartney 1985), but this was not nearly so precise a method.

**Ultrasound velocity in normal excised bones**

The mean apparent ultrasound velocity for all 10 sites measured in both limbs of 50 horses are shown in Fig 8. The data for the individual sites in the four age groups are illustrated in Fig 9. The pattern of these results was very similar to that obtained for bone mineral content, but there was a steeper decline to the distal metacarpal shaft particularly in the young foals in group 1. From a comparison of both apparent ultrasound velocity and bone mineral content in the 50 horses a correlation coefficient of r = 0.829 was obtained with a variance about the regression line of 0.089 (Fig 10).

**Bone mineral density in excised bones**

Bone mineral content, ash content (mg 100 mg dry defatted bone) and the other bone measurements recorded on 15 sections of mid-metacarpal shaft are listed in Table 2. The cross sectional area of the cortex (CSA [mm^2]) was derived from the measurement of volume and thickness. This was
TABLE 1: Specific gravity and calculated bone mineral density (BMD), or bone mineral content adjusted for cross sectional area, for 11 different skeletal sites in eight horses aged from nine months to seven years.

<table>
<thead>
<tr>
<th>Site</th>
<th>n</th>
<th>BMD g/cm²</th>
<th>Specific gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metatarsus (midshaft)</td>
<td>6</td>
<td>1.027</td>
<td>0.049</td>
</tr>
<tr>
<td>Metacarpus (midshaft)</td>
<td>7</td>
<td>0.992</td>
<td>0.079</td>
</tr>
<tr>
<td>Mandible (ramus)</td>
<td>8</td>
<td>0.703</td>
<td>0.120</td>
</tr>
<tr>
<td>Proximal sesamoid</td>
<td>8</td>
<td>0.588</td>
<td>0.116</td>
</tr>
<tr>
<td>Rf (R1a)</td>
<td>8</td>
<td>0.579</td>
<td>0.045</td>
</tr>
<tr>
<td>Third carpal bone</td>
<td>6</td>
<td>0.563</td>
<td>0.106</td>
</tr>
<tr>
<td>Tubercalaris (mucal crest)</td>
<td>8</td>
<td>0.412</td>
<td>0.047</td>
</tr>
<tr>
<td>Occipital bone (nuchal crest)</td>
<td>8</td>
<td>0.363</td>
<td>0.054</td>
</tr>
<tr>
<td>Thoracic vertebra (T12)</td>
<td>8</td>
<td>0.293</td>
<td>0.073</td>
</tr>
<tr>
<td>Coccygeal vertebra (C2,3)</td>
<td>8</td>
<td>0.249</td>
<td>0.030</td>
</tr>
<tr>
<td>Tubercollae</td>
<td>8</td>
<td>0.234</td>
<td>0.025</td>
</tr>
</tbody>
</table>

BMD1 (g/cm³) = bone mineral content (g/cm) / CSA(cm²)

The measured bone mineral density (BMD1) was determined by dividing the ash mass of each specimen by its volume.

BMD1 (g/cm³) = ash mass (g) / volume of cortex (cm³)

Fig 11a shows the result of plotting BMD1 against BMD1. There was a correlation coefficient of 0.994 and a variance of 0.030 cm². A significant correlation was obtained when bone mineral content was compared directly with specific gravity (Fig 11b).

Fig 11b shows the result of plotting BMD1 against BMD1. There was a correlation coefficient of 0.994 and a variance of 0.030 cm². A significant correlation was obtained when bone mineral content was compared directly with specific gravity (Fig 11b).

Bone mineral content in vivo

A limited number of in vivo measurements of bone mineral content taken at the mid-metacarpal site showed the same pattern of increasing levels with age as was obtained for the excised bones (Table 3). In a small group of lame horses there were marked differences between the two limbs in two animals with chronic non-weightbearing on one limb, but no difference in a yearling with a recent fracture of the elbow joint (Table 4).
TABLE 3: Bone mineral content (g/cm) measured in vivo in both forelimbs of eight normal horses at the mid-metacarpal site

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Type</th>
<th>Bone mineral content (g/cm)</th>
<th>% difference between limbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.75 months</td>
<td>STB RF</td>
<td>4.355</td>
<td>4.216</td>
</tr>
<tr>
<td>5 months</td>
<td>STB RF</td>
<td>5.254</td>
<td>5.223</td>
</tr>
<tr>
<td>6 months</td>
<td>STB RF</td>
<td>5.206</td>
<td>4.786</td>
</tr>
<tr>
<td>8 months</td>
<td>STB RF</td>
<td>5.206</td>
<td>4.907</td>
</tr>
<tr>
<td>15 months</td>
<td>TB RF</td>
<td>6.673</td>
<td>7.179</td>
</tr>
<tr>
<td>2 years</td>
<td>TB LF</td>
<td>7.983</td>
<td>7.957</td>
</tr>
<tr>
<td>3 years</td>
<td>TB</td>
<td>10.188</td>
<td>10.190</td>
</tr>
<tr>
<td>5 years</td>
<td>STB LF</td>
<td>10.285</td>
<td>10.576</td>
</tr>
</tbody>
</table>

RF Right fore metacarpus
LF Left fore metacarpus
STB Standardbred
TB Thoroughbred

TABLE 4: Bone mineral content (g/cm) measured in vivo in three horses with unilateral forelimb lameness, both forelimbs measured at the mid-metacarpal site

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Status</th>
<th>Bone mineral content (g/cm)</th>
<th>% difference between limbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Chronic RF</td>
<td>9.391</td>
<td>11.779</td>
</tr>
<tr>
<td>1</td>
<td>Chronic RF</td>
<td>5.777</td>
<td>8.248</td>
</tr>
<tr>
<td>1</td>
<td>Acute RF/lameness from healing elbow fracture</td>
<td>6.544</td>
<td>6.377</td>
</tr>
</tbody>
</table>

RF Right fore metacarpus
LF Left fore metacarpus

FIG 11a: Estimated and measured bone mineral densities (g/cm³) of 15 sections of mid-metacarpal shaft

FIG 11b: Bone mineral content (g/cm) compared with specific gravity for the same 15 sections of mid-metacarpal shaft

FIG 12: Bone mineral content (g/cm) and transverse apparent ultrasound velocity (m/sec) in a horse subjected to 14 days partial weightlessness in a flotation tank

The effect of induced weightlessness was investigated in a three-year-old healthy crossbred mare. The animal was confined in a small stall (2 x 3 m) for 14 days and then transferred to a specially designed flotation chamber. This tank was filled with water at 38°C effectively reducing the bodyweight by three quarters. The mare was taken out of the tank after 14 days and returned to the small stall for 14 days, and then turned out in a small paddock for the last three weeks of the study when it was made to take walking and trotting exercise for about 30 minutes per day. Weekly evaluation by photon absorptiometry and ultrasound velocity was performed on the metacarpal shafts. The bone mineral contents and apparent transverse velocity for the nine week period of investigation are shown in Fig 12. There was a decrease in bone mineral content from 9.31 to 8.22 g/cm³ during the first seven days of flotation and the decrease continued to a minimum of 7.42 g/cm³ after 14 days. When taken out of the tank there was an increase after seven days to 7.94 g/cm³. No further increase occurred by 14 days, but once exercise was instituted the bone mineral content increased to 8.2 g/cm³. The apparent transverse velocity results showed a similar pattern, but the changes were delayed compared with the changes in bone mineral content.

Discussion

Lameness remains one of the most important causes of lost performance in racehorses (Jeffcott and others 1982, Rossdale and others 1985). Its underlying pathogenesis is still not fully understood and the determination of in vivo bone mineral content to evaluate bone condition and skeletal development could have particular relevance. Photon absorptiometry appears to have a number of advantages over previous methods used to assess skeletal maturity in the horse. Radiography has been the traditional method, by determining the time of growth plate closure, particularly that of the distal radial epiphysis (Mason and Bourke 1973). The time taken for growth plate closure has been correlated with soundness in two-year-old Thoroughbred racehorses, but this takes no account of the cortical density of the metacarpal diaphysis.

Based on the method of Eckman and others (1970), Meakin and others (1981) have used radiographic photometry to estimate bone mineral density in the third metacarpal bone in terms of the radiographic bone aluminium equivalent. They also made radiographic measurements of cortical thickness, medullary cavity width and bone diameter. These two techniques would appear to be useful, non-destructive and inexpensive methods for excised bones, but are hardly applicable to sequential field studies. The results
obtained from a series of 17 metacarpal bones showed a pattern of progressive mineralisation comparable to that recorded here by photon absorptiometry. The ash content of the metacarpus was determined in 41 Thoroughbreds and Quarterhorses by el Shurafa and others (1979) who found that levels increased to a maximum at four to seven years of age. They also reported increasing cortical thickness and increasing failure stress values of the bone over the same period. These changes correlate well with the data on ultrasound bone mineral measurements over the same age range (Jeffcott and McCarron 1985).

Bone mineral density as estimated by the bone mineral content divided by the cross sectional area (BMD/SA) gave an excellent correlation with the measured bone mineral density (BMDa). This supports the need for an accurate measurement of cross sectional area. However, a good correlation was also obtained by plotting the bone mineral content directly against the specific gravity for each specimen. It appears, therefore, that specific gravity provides a simple and precise assessment of bone density in the horse as it does in other species (Siemon and others 1974). In the series of 50 normal horses no differences were observed between the sexes, but the numbers involved were probably too small to make any definite judgement. No significant differences were observed between the right or left forelimbs. However, in seven cases of chronic lameness there was a 7-1 per cent difference between the bone mineral contents of lame and sound metacarpal bones.

A useful correlation between bone mineral content and ultrasound velocity was obtained in the exsanguinated, but not in the exercised, horses, but no relationship between these parameters and exercise and training has so far been established. It is well documented that disuse osteoporosis results from reduced mechanical loading of the skeleton as a whole or a particular site (Yester and Martin 1964). It has also been demonstrated that increased mechanical loading leads to increased bone mass and strength. In man it has been shown that athletes have significantly denser bone in the distal end of the femur than non-athletes (Nilsson and Westlin 1971). Long distance runners also showed increased bone mineral content of the os calcis, provided that they continue marathon training (Williamson and others 1964). In racing sled dogs, "paralytic" (no BMDa) was suggested as a useful predictor of susceptibility to fracture and lameness (Stoliker and others 1976). It has been observed in beagles that exercise and food craving significantly increase the mineral content of the tibia (Martin and others 1981). Furthermore, Schein and Martin (1978) have demonstrated increased strength in the long bones of dogs when their limbs were rapidly loaded by controlled jumping.

Weightlessness and immobilisation result in accelerated bone loss and osteoporosis (Alvina 1981) and it is now clear that mechanical, hormonal and dietary factors, acting singly or in concert, can cause senile osteoporosis to be accelerated or retarded (Yester and Martin 1964). Exercise is the most important factor in the reversal of osteoporosis, but dietary factors and hormonal influences must also be considered. Judging from the preliminary results obtained by maintaining weightlessness by flotation, the horse is subject to the same sort of factors. A significant degree of osteopenia was induced in 14 days and involved a reduction in bone mineral content of about 15 per cent. Similar alterations in calcium homeostasis have been reported in astronauts during space flight (Wirowski and Morrey 1983). This effect has been reported experimentally in rats by simulating weightlessness (Globus and others 1984) and it appears that local factors within the weightless bones may have a greater impact on bone mass and turnover than systemic regulation of bone mineral homeostasis.

Single photon absorptiometry is applicable in the field, but a number of practical difficulties still exist. For example the bone scans lasted approximately 90 seconds, which is a long time for a horse to stand absolutely still. The fluid-filled bandages used as a soft tissue equivalent were difficult to use and expensive. They were reusable, but easily damaged, and they could trap small air pockets that affected the baseline counts. The small water-filled bag developed as an alternative appeared to be more acceptable.

For the meaningful interpretation of bone mineral content it was important to know the exact site on the metacarpal bone being scanned because different values were recorded at different sites and the values were affected by the size of the splint bones (Figs 5 and 6). However, the most important drawback in employing this system of photon absorptiometry is that no account of bone size or geometry can be taken. It merely provides a value of bone mineral content across an entire bone-scan and takes no account of differences in skeletal size. It is, therefore, only useful for monitoring sequential changes in an individual (Fig 12) and comparisons between individuals require some kind of standardisation with cross sectional geometry. Ruff and Hayes (1984) demonstrated that age related changes in compact cortical bone in children appeared to be mainly volumetric and not densitometric. One way of determining in vivo the cross sectional area or the cortical/cancellous ratio is by using ultrasound (McCarry and Jeffcott 1985), and it may be possible to obtain a value for BMDa, in horses in vivo by using a combination of photon absorptiometry and ultrasound velocity.

The role of the metacarpus as a 'sentinel' bone looks encouraging: its bone mineral content changes with age and with effects of chronic lameness and weightlessness. However, for generalised skeletal changes it is likely that a site consisting mainly of trabecular bone would be a better indicator than the chiefly cortical bone of the metacarpus. In cattle Zetterholm (1974) and Siemon and others (1974) have used the bone mineral content of the coccygeal vertebrae and this might be possible in horses. In dogs, Krook and others (1971) have successfully used photon absorptiometry of the mandible to monitor the skeletal changes (and their reversibility) caused by nutritional osteopenia. In the horse the mandible has a BMDa value only a little below those of the metacarpal and metatarsal shafts.

There would seem to be considerable potential for using single photon absorptiometry in combination with ultrasound velocity as a diagnostic and a research tool. Further studies are needed to extend the baseline data into different breeds and types of horse and the effects of exercise, diet and different methods of training young horses, as well as racehorse ergonomics, should be investigated. Finally, the use of flotation to simulate weightlessness provides a valuable model to study bone metabolism and the response to the effects of osteopenia.

Acknowledgements.—We have pleasure in acknowledging the technical assistance of Tracey Waters and Julie Green throughout the investigation and we thank Dr Simon Buckland for his timely help with the measurements of bone mineral content. The project was supported in part by the Australian Equine Research Foundation. We also acknowledge the advice and assistance of Dr T. V. Sanchez and the Norland Corporation, Fort Atkinson, Wisconsin, USA.

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Physiological measurement

Combined 2.25 MHz ultrasound velocity and bone mineral density measurements in the equine metacarpus and their in vivo applications

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Abstract—A simple noninvasive ultrasound method is described for estimating the transverse cortical bone ultrasound velocity and the cross-sectional area of the equine third metacarpal bone (MC3). The method relies on measuring the time of flight of the ultrasound for each of two pathways, via the cortical shaft and through the central medulla. Ten metacarpal bones of approximately the same dimensions were selected to evaluate the method and to determine the practical correction factors. Factors were established for the ovality of the external cortical boundary and the medullary cavity as well as corrections for the presence of the splint bones (second and fourth metacarpal bones, MC2 and MC4) which influence the total cortical cross-sectional area. Conventional single-photon absorptiometry was used to measure the bone mineral content which, together with the cross-sectional area determined ultrasonically, was then used to estimate the bone mineral density. The bone mineral density was also determined for some bone sections from ash weight and volume. The compact bone density (i.e. relative density) together with the ultrasound velocity were then used to estimate a modulus of elasticity in the transverse direction.

Keywords—Bone mineral content, Bone mineral density, Compact bone density, Cortical bone, Equine bone, Modulus of elasticity, Ultrasound velocity

List of symbols

- $f$: factor to relate cortical pathway length to diameter of cortex
- $X$: path length of ultrasound beam through cortex of MC3
- $K$: ovality factor for external perimeter of cortex of MC3
- $L$: ovality factor for medulla of MC3
- $M$: factor to compensate for area of splint bones MC2 and MC4
- $R$: ratio of medulla to cortex of MC3 = $Y/X$
- $R_c$: corrected ratio of medulla to cortex (R)
- $X$: external diameter of cortex of MC3 (lateral)
- $Y$: diameter of medulla of MC3 (lateral)
- $BMC$: bone mineral content (kg m$^{-3}$)
- $BMD_M$: measured bone mineral density (kg m$^{-3}$)
- $BMD_E$: estimated bone mineral density (kg m$^{-3}$)
- $C$: velocity of ultrasound (m s$^{-1}$)
- $C_b$: transverse cortical bone ultrasound velocity (m s$^{-1}$)
- $C_{bM}$: measured transverse cortical bone ultrasound velocity (m s$^{-1}$)
- $C_{bE}$: estimated transverse cortical bone ultrasound velocity (m s$^{-1}$)
- $C_m$: ultrasound velocity through medulla (m s$^{-1}$)
- $CBD_M$: measured compact bone density or specific gravity (kg m$^{-3}$)
- $CBD_E$: estimated compact bone density or specific gravity (kg m$^{-3}$)
- $CSA_M$: measured cross-sectional area (m$^2$) (volumetric)
- $CSA_E$: estimated cross-sectional area (m$^2$) (ultrasound)
- $J$: modulus of elasticity
- $J_{M}$: estimated modulus of elasticity using $CBD_M$ and $C_{AM}$ (GN m$^{-2}$)
- $J_E$: estimated modulus of elasticity using $CBD_E$ and $C_{AE}$ (GN m$^{-2}$)
- $P_m$: microscopic bone mineral density (kg m$^{-3}$)
- $P_c$: collagen density (kg m$^{-3}$)
- MC2, MC3 and MC4 second, third and fourth metacarpal bones of the horse
- $T_{m}$: time of flight for corticomedullary path (s)
- $T_{s}$: shortest time of flight of ultrasound transmission (s)
- $V$: mean velocity of ultrasound through cortex and medulla (m s$^{-1}$) = $X/T_{m}$
1 Introduction

Assessment of bone quality can be derived from measurements of bone mineral density \(BMD\) (kg m\(^{-2}\)), compact bone density \(CBD\) (kg m\(^{-3}\)) and a modulus of elasticity \(J\) (GN m\(^{-2}\)) (Greenfield et al., 1981). \(BMD\) can be derived from the bone mineral content \(BMI\) (kg m\(^{-2}\)) if the cross-sectional area is known (Greenfield et al., 1981; Jeffcott et al., 1986). BMI can be determined using single-photon absorptiometry (Cameron and Sorensen, 1963; Sorensen and Cameron, 1967) with the ability to detect changes of less than 3 per cent. Compact bone density \(CBD\) (kg m\(^{-3}\)) can be estimated using a bone model (Greenfield et al., 1981) from BMI, cross-sectional area \(CSA\) (m\(^2\)) and estimated constants of the microscopic bone mineral density \(\rho_m\) (kg m\(^{-3}\)) and collagen density \(\rho_c\) (kg m\(^{-3}\)) by the equation

\[
CBD = \rho_c + (1 - \rho_c/\rho_m)BMI/CSA
\]

(1)

The modulus of elasticity cannot be easily determined in vitro. A method that has received some attention involves the transmission of ultrasound through bone (Abendshen and Hyatt, 1970; Greenfield et al., 1981) because the velocity of sound \(C\) (m s\(^{-1}\)) through a material is related to a modulus of elasticity and \(CBD\), provided dispersive and attenuating effects are ignored by assuming the use of the Helmholtz equation

\[
J = CBD \times C^2
\]

(2)

In bone both the density and modulus change with alteration of mineral content (Currey, 1969). However, it would appear that the change in ultrasound velocity reflects the change in modulus of elasticity more than the change in density (Jeffcott and McCarter, 1985). There are reports (Van Buskirk et al., 1981) of the anisotropic nature of bone which is illustrated by different velocities of ultrasound in the axial, radial and tangential directions by Lees et al. (1979) who reported ratios of approximately 1:2:1.08:1. In this study it is assumed that it is the transverse velocity that is mainly being estimated. An ideal bone for the development of these measurement techniques and for subsequent clinical testing is the third metacarpal bone of the horse. It is a reasonably large bone, easily accessible, has minimal surrounding tissues, is subjected to considerable biomechanical strain and has had its geometric (Pirotrowski et al., 1983) and biomechanical (Badoux, 1973) properties studied.

The purpose of this paper is to establish a practical and reproducible method for estimating the transverse cortical bone ultrasound velocity and the cross-sectional area which can then be used with absorptiometry measurements to make estimates of bone quality in vivo.

2 Materials and methods

2.1 Theory

The estimate of ultrasound velocity is gained from knowing the distance between two transducers and measuring the time of flight of the transmitted beam. However, as the velocity of sound in the medulla is of the order of 1500 m s\(^{-1}\) and that in the cortical bone of the order of 3000 m s\(^{-1}\) it is readily seen that the shortest time of flight must be for the sound to travel around the cortex (Fig. 1).

The mathematical relationship of this pathway should be able to be specified as a factor of the total diameter \(D\) and also as a mathematical function of the ratio \(R\) of the diameter of the medulla \(Y\) to the diameter of the cortex \(X\):

\[
\text{path length} = fX = \text{function}(R)
\]

(3)

Another pathway, the corticomedullary pathway (Fig. 1), can be determined for the sound travelling through the cortical walls and the centre of the medulla in a straight line (Jeffcott and McCarter, 1985). For this second pathway a mean velocity \(V\) can be determined, and this is related to the bone velocity \(C_1\), the medullary velocity \(C_m\) and the ratio of medulla to cortex \(R\) by the formula:

\[
R = Y/X = (C_1/V - 1)/(C_1/C_m - 1)
\]

(4)

From the apparent velocity \(C_1\), which is the velocity deter-

\[\text{Fig. 1 Diagrammatic representation of assumption of orality for cortex and medulla area formulae:}\]

\[
\text{ellipse} = \frac{\pi}{4} AB
\]

\[
\text{medulla} = \frac{\pi}{4} YLY
\]

\[
= \frac{\pi}{4} LY^2
\]

\[
\text{cortex} = \frac{\pi}{4} XKK - \text{area of medulla}
\]

\[
= \frac{\pi}{4} (KX^2 - LY^2)
\]

\[
= \frac{\pi}{4} X^2(K - LR^2)
\]

\[\text{Fig. 2 Diagrammatic representation of assumption of orality for cortex and medulla area formulae:}\]

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mined from the shortest time of flight $T$, and the cortical diameter $X$, an estimate of the transverse cortical bone velocity $C_{tX}$ can be made if the path length $fX$ is taken into account.

$$C_{tX} = fX/T = fJ_{Ct}$$  \hspace{1cm} (5)

$C_{t}$ is the first estimate of the transverse bone velocity. As the bone velocity must be greater than the apparent velocity, by iteration (Appendix 2) it is possible to calculate both $C_{tX}$ and $R$. Seeing that the diameter of the bone $X$ is known and the ratio $R$ estimated, the cross-sectional area of the cortex can also be estimated using the formula

$$CSA = M\pi X^2(K - LR^2)/4$$  \hspace{1cm} (6)

where $K$ is an ovality factor for the external cortical bone cross-section and $L$ is an ovality factor for the medulla. These ovality factors are derived from the bone cross-sections on the assumption that the sections approximate ellipses, as shown in Fig. 2. $M$ is a factor to include the area of the split bones (MC2 and MC4), as these bones were included in the determination of BMC. Using this cross-sectional area, BMC can be corrected to give an estimate of the bone mineral density $BMD_B$ by

$$BMD_B = BMC/CSA_E$$  \hspace{1cm} (7)

Another estimate of the bone mineral density, $BMD_M$, can be determined from direct measurements by

$$BMD_M = \text{ash weight}/\text{volume of wet bone}$$  \hspace{1cm} (8)

The compact bone density $CBD_B$ is estimated using eqn. 1. For this series the constant for $\rho_c$ was 3120 kg m$^{-3}$ and that for $\rho_s$ was 1310 kg m$^{-3}$ as published for bovine bone by LEBES et al. (1979).

$CBD_M$ can also be determined from direct measurement by

$$CBD_M = \text{mass of wet bone}/\text{volume of wet bone}$$  \hspace{1cm} (9)

The modulus of elasticity $J_M$ is determined using eqn. 2. $CBD_M$ and $C_M$. The modulus of elasticity $J_E$ is determined with the same equation but using $CBD_E$ and $C_{tE}$.

2.2 Equipment

The ultrasound time of flight measurements were obtained using a pulse module (Panametrics Model 5055), a preamplifier (Panametrics Model 5660B), two 2-25 MHz, 13 mm diameter ultrasound transducers mounted on an electronic digital caliper (Max-cal Model 950-101) connected to the computer via an interface (Max-cal Model 960-101) and a digital storage oscilloscope with signal averaging capacity (Tektronix Model 468). An Apple II Plus microcomputer was used to apply the various iterative and calculative algorithms.

The BMC values were determined using a Norland Digital Bone Densitometer (Prototype Model 2781, Large Animal Scanning System, LASS) with an Americium source ($\text{^{241}Am}$).

2.3 Perspex bone simulation

A series of 15 regular Perspex cylinders of diameter 50 mm and with central holes ranging from 15 to 35 mm in 2 mm steps were machined to simulate bone cross-sections. Perspex was chosen because its ultrasound velocity of about 2800 m s$^{-1}$ is close to that of bone at about 3000 m s$^{-1}$. The circular central hole was initially left empty to ensure transmission occurred only through the Perspex. Later it was filled with water which has a velocity of about 1500 m s$^{-1}$ closely approximated medullary tissue. Time-of-flight measurements were made on this group of cylinders to establish the best empirical relationship between pathway and ratio of medulla to cortex. Measurements taken with air in the central cavity confirmed that the pathway for the minimum time of flight was only through the Perspex. When filled with water two distinct pathways could be verified.

2.4 Bone measurements

Ten metacarpal bones of approximately the same size were selected from the left forelimbs of thoroughbred horses aged from 2 to 5 years. After removal of all soft tissues, the bones were stored at $-15^\circ$C until examined. The lateral bone diameter, the times of flight through both the cortex alone and the corticomedullary pathways (Fig. 3) and the BMC were determined at ten sites along the shaft of the bone as shown in Fig. 4. From these measurements $C_{t}, R, C_{tE}$ and $CBD_E$ (using factors determined later) were estimated. The bones were then cut to provide ten transverse cross-sections (Fig. 4). The transverse sections 1, 3, 5, 7 and 9 were cut using a band saw to provide approximately 1 cm thick sections and radiographed to record the cross-sectional profile. From these radiographic cross-sectional profiles estimates of the ovality ratio of the

![Diagramatic representation of typical ultrasound traces used to determine time of flight measurements](image1)

![Diagramatic representation of the ten measurement sites and sections for the ten selected left metacarpal bones](image2)
cortical exterior \( K \) and the ovality ratio of the medulla \( L \) were determined to allow corrections to be made to estimate the cross-sectional area from the ultrasound measurements.

The area of the split bone (MC2 and MC4) relative to the area of the main shaft (MC3) was also estimated from the radiographs. For these sections the thickness (longitudinal length) was measured by digital calipers, the volume measured by a water-displacement method and the cross-sectional area \( CSA_M \) calculated. On the same sections \( CBD_M \) (kg m\(^{-2}\)), ash mass (kg) and ash weight (kg per 100 kg dry defatted bone) were measured. Out of sections 2, 4, 6, 8 and 10, dorsal segments, of as large a size as practical, were cut to allow direct transverse cortical bone velocity \( C_{bM} \) measurements to be made. The bone marrow was removed as a plug from all bone sections and the ultrasound velocity of the bone marrow was determined in the dorsopalmar, lateral and longitudinal directions using the same ultrasound equipment.

The modulus of elasticity \( J \) was determined using eqn. 2 from two sets of measurements. The first estimate \( J_M \) is from the directly measured \( C_{bM} \) and the directly measured \( CBD_M \). The other estimate \( J_E \) was made from \( C_{bE} \) and the \( CBD_E \) from eqn. 1. Both determinations are made in this paper.

### Results

3 Results

The pathway length determined on the Perspex blocks was compared with several mathematically derived theoretical pathways, two of which are shown in Fig. 5. A suitable theoretical pathway based on physical principles has not been achieved. Various mathematical correction factors were then tested to find an empirical formula to allow estimation of the path length.

The best empirical formula so far determined is

\[
f = \sqrt{1 - R_s^2} + R_c \arcsin R_s \tag{10}
\]

where

\[
R_s = 0.788 R
\tag{11}
\]

This formula was used for all calculations on the selected bones. Eqn. 10 is shown with the experimental values in Fig. 6.

The measurements from the 100 bone marrow samples to determine the average medullary velocity \( C_{bM} \) are summarised in Table 1. The average value of \( 1444 \pm 14 \text{ m s}^{-1} \) was used for subsequent calculations.

A comparison of \( C_{bM} \) and \( C_{bE} \) is summarised in Table 2. From the radiographs of the individual bone segments an estimate of ovality of the medulla and the ovality of the external cortical boundary was made. The average ovality

\[
\text{Table 1 Results of ultrasound velocity of the medulla (} C_{bM} \pm 1 \text{ SD) measured in dorsopalmar, lateral and longitudinal directions of ten metacarpal bones}
\]

<table>
<thead>
<tr>
<th>Bone</th>
<th>Dorsopalmar</th>
<th>Lateral</th>
<th>Longitudinal</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1439</td>
<td>1451</td>
<td>1438</td>
<td>1443</td>
</tr>
<tr>
<td>2</td>
<td>1430</td>
<td>1441</td>
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<td>1436</td>
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<tr>
<td>3</td>
<td>1461</td>
<td>1469</td>
<td>1454</td>
<td>1459</td>
</tr>
<tr>
<td>4</td>
<td>1444</td>
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<td>1430</td>
<td>1439</td>
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<td>5</td>
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<td>6</td>
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<td>1453</td>
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<td>1456</td>
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</tr>
<tr>
<td>10</td>
<td>1442</td>
<td>1460</td>
<td>1433</td>
<td>1445</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>1444 ± 14</strong></td>
<td><strong>1453 ± 13</strong></td>
<td><strong>1438 ± 16</strong></td>
<td><strong>1444 ± 14</strong></td>
</tr>
</tbody>
</table>

\[
\text{Table 2 Results obtained for directly measured } C_{bM} \text{ and estimated } C_{bE} \text{ transverse cortical bone velocity (± 1 SD) in ten metacarpal bones}
\]

<table>
<thead>
<tr>
<th>Bone</th>
<th>( C_{bM} ) directly measured</th>
<th>( C_{bE} ) estimated</th>
<th>Percentage difference between ( C_{bM} ) and ( C_{bE} )</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>3161 (-14)</td>
<td>3155 (-35)</td>
<td>-0.19</td>
</tr>
<tr>
<td>2</td>
<td>3115 (-62)</td>
<td>3164 (-51)</td>
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<td>3</td>
<td>3044 (-46)</td>
<td>3150 (-29)</td>
<td>3.48</td>
</tr>
<tr>
<td>4</td>
<td>3127 (-38)</td>
<td>3104 (-43)</td>
<td>0.74</td>
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<td>3171 (-47)</td>
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</tr>
<tr>
<td>6</td>
<td>3050 (-27)</td>
<td>3060 (-30)</td>
<td>0.33</td>
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<td>3142 (-54)</td>
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<td>3115 (-37)</td>
<td>2.07</td>
</tr>
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<td>3046 (-42)</td>
<td>3082 (-29)</td>
<td>1.18</td>
</tr>
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<td>10</td>
<td>3050 (-37)</td>
<td>3061 (-20)</td>
<td>0.36</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>3109 (-56)</strong></td>
<td><strong>3133 (-61)</strong></td>
<td><strong>0.83 (-1.75)</strong></td>
</tr>
</tbody>
</table>

Fig. 6 Comparison of the best empirical formula for ultrasound pathway length with experimental values

Fig. 5 Comparison of preliminary empirical pathways and experimental values (●) for development of pathway lengths

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factor for the medulla $J$ of each bone ($n = 10$) ranged over the ten bones from 0.65 to 0.90 with a mean of 0.76. The average ovality factor for the cortex $K$ ranged from 0.75 to 0.90 with a mean of 0.81. From the same radiographs the areas of MC2, 3 and 4 were estimated by counting squares and average correction factors were determined for the sections along the bones. Using these correction factors the cross-sectional areas were estimated from the ultrasound measurements. Fig. 7 shows $CSA_x$ and $CSA_M$ for various positions along the shaft. Fig. 8 shows the result of a comparison for the 50 bone sites for sections 1, 3, 5, 7 and 9. For the same sections ($n = 5$), Tables 3 and 4 summarise for each bone the average $BMC$ (five readings at each site), $BMD_M$, $BMD_x$, $CBD_M$, $CBD_x$, $J_M$ and $J_x$.

![Fig. 7](image)

**Fig. 7** Comparison of $CSA_x$ (○) and $CSA_M$ (△) for positions along the metacarpal shaft including contribution from the splint bones

![Fig. 8](image)

**Fig. 8** Comparison of $CSA_x$ and $CSA_M$ for the 50 bone sections

<table>
<thead>
<tr>
<th>Bone</th>
<th>$BMC$, kg m$^{-1}$</th>
<th>$BMD_M$, kg m$^2$</th>
<th>$BMD_x$, kg m$^2$</th>
<th>$CBD_M$, kg m</th>
<th>$CBD_x$, kg m</th>
<th>Ash weight, kg per 100 kg dry bone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.029 (±0.045)</td>
<td>1020 (±20)</td>
<td>990 (±50)</td>
<td>1890 (±10)</td>
<td>1880 (±20)</td>
<td>63.2 (±1.4)</td>
</tr>
<tr>
<td>2</td>
<td>0.926 (±0.048)</td>
<td>1100 (±40)</td>
<td>1030 (±60)</td>
<td>1920 (±30)</td>
<td>1910 (±30)</td>
<td>64.7 (±0.2)</td>
</tr>
<tr>
<td>3</td>
<td>0.899 (±0.048)</td>
<td>1050 (±10)</td>
<td>1010 (±80)</td>
<td>1880 (±30)</td>
<td>1900 (±30)</td>
<td>63.7 (±0.07)</td>
</tr>
<tr>
<td>4</td>
<td>0.895 (±0.057)</td>
<td>1050 (±130)</td>
<td>1000 (±80)</td>
<td>1890 (±10)</td>
<td>1890 (±40)</td>
<td>63.6 (±0.2)</td>
</tr>
<tr>
<td>5</td>
<td>0.957 (±0.045)</td>
<td>1050 (±20)</td>
<td>1050 (±40)</td>
<td>1910 (±20)</td>
<td>1920 (±20)</td>
<td>64.2 (±0.2)</td>
</tr>
<tr>
<td>6</td>
<td>0.698 (±0.041)</td>
<td>1050 (±10)</td>
<td>990 (±20)</td>
<td>1890 (±10)</td>
<td>1880 (±10)</td>
<td>63.1 (±0.1)</td>
</tr>
<tr>
<td>7</td>
<td>0.118 (±0.042)</td>
<td>1060 (±10)</td>
<td>1080 (±30)</td>
<td>1900 (±10)</td>
<td>1940 (±10)</td>
<td>62.3 (±0.05)</td>
</tr>
<tr>
<td>8</td>
<td>0.104 (±0.029)</td>
<td>1060 (±20)</td>
<td>1060 (±40)</td>
<td>1890 (±10)</td>
<td>1920 (±20)</td>
<td>64.1 (±0.02)</td>
</tr>
<tr>
<td>9</td>
<td>0.851 (±0.030)</td>
<td>1060 (±10)</td>
<td>1080 (±30)</td>
<td>1890 (±10)</td>
<td>1940 (±10)</td>
<td>62.8 (±0.02)</td>
</tr>
<tr>
<td>10</td>
<td>0.715 (±0.045)</td>
<td>1030 (±20)</td>
<td>1000 (±30)</td>
<td>1890 (±10)</td>
<td>1910 (±20)</td>
<td>61.7 (±0.6)</td>
</tr>
</tbody>
</table>

**Table 3** Results (±1 SD) of bone mineral content $BMC$, measured and estimated bone mineral density $BMD_M$ and $BMD_x$ measured and estimated compact bone density $CBD_M$ and $CBD_x$ and ash weight in the metacarpal bones from ten horses

### 3.1 Estimate of precision of the methods

Estimates of the precision were obtained for $C_u$, $C_{BF}$, $CSA_x$ and $BMC$ from multiple independent measurements taken at the same site of a bone. Using eqns. 1, 2, 7, 8 and 9 and estimates of the precision of the measurement of mass and length, further estimates using the method of propagation of errors were made for $CSA_M$, $BMD_M$, $BMD_x$, $CBD_M$, $CBD_x$, $J_M$ and $J_x$. These estimates are shown in Table 5.

<table>
<thead>
<tr>
<th>Bone</th>
<th>$J_M$, GN m$^{-2}$</th>
<th>$J_x$, GN m$^{-2}$</th>
<th>Percentage difference between $J_M$ and $J_x$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.8 (±0.2)</td>
<td>18.7 (±0.6)</td>
<td>-0.53</td>
</tr>
<tr>
<td>2</td>
<td>18.6 (±0.6)</td>
<td>19.1 (±0.9)</td>
<td>2.69</td>
</tr>
<tr>
<td>3</td>
<td>17.4 (±0.5)</td>
<td>18.9 (±0.6)</td>
<td>8.62</td>
</tr>
<tr>
<td>4</td>
<td>18.5 (±0.3)</td>
<td>18.2 (±0.9)</td>
<td>-1.62</td>
</tr>
<tr>
<td>5</td>
<td>19.2 (±0.4)</td>
<td>19.6 (±0.6)</td>
<td>2.08</td>
</tr>
<tr>
<td>6</td>
<td>17.6 (±0.2)</td>
<td>17.6 (±0.4)</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>18.8 (±0.5)</td>
<td>20.5 (±0.5)</td>
<td>9.04</td>
</tr>
<tr>
<td>8</td>
<td>19.1 (±0.3)</td>
<td>18.6 (±0.6)</td>
<td>-2.62</td>
</tr>
<tr>
<td>9</td>
<td>17.5 (±0.3)</td>
<td>18.4 (±0.3)</td>
<td>5.14</td>
</tr>
<tr>
<td>10</td>
<td>17.4 (±0.3)</td>
<td>17.7 (±0.3)</td>
<td>1.72</td>
</tr>
</tbody>
</table>

**Table 4** Measured $J_M$ and estimated $J_x$ modulus of elasticity of the third metacarpal cortex from ten horses

### 4 Discussion

The accuracy and precision of the methods used here for determining both transverse cortical bone velocity and bone mineral content are encouraging and correlate well with those of GREENFIELD et al. (1981). These workers used the human radius and employed the same single-beam photon absorptiometry, but used a pulse echo technique for cortical velocity measurement instead of the transmission method. Both of these ultrasound methods give similar results for cortical bone velocity. In man the cortical velocity of the radius was $3235 ± 300$ m s$^{-1}$, whereas for the equine metacarpus the velocity was measured at $3109 ± 56$ m s$^{-1}$. The advantage of the transmission method is that a lateral radiograph to measure cortical...
thickness is not required and an estimate of the cross-sectional area is obtained at the same time. Greenfield's estimate of uncertainty for cross-sectional area was 2–10 per cent, whereas by our transmission method the uncertainty for the equine metacarpus is about 5 per cent. The variation of cross-sectional area with site and area of splint bones correlated well with the results published by Pro-towski et al. (1983).

The estimation of cross-sectional area by the ultrasound method was considered good (correlation coefficient \( r = 0.92 \)) and proved to be better than just using an estimate of cross-sectional area based on diameter squared (\( r = 0.82 \)).

The values for bone mineral content in the horse differed from those in man because of the size of the bone being measured. An \( 114 \) Am source was used instead of \( 125 \) I. However, when the readings for bone mineral density \((1060 \pm 20 \text{ kg m}^{-2})\) were compared with Greenfield \((1120 \pm 150 \text{ kg m}^{-2})\) they were similar. The measurement of bone mineral density to this precision helps to overcome the volumetric problems identified by Ruff and Hayes (1984) found in using just bone mineral content.

The calculated estimates for transverse cortical bone velocity, bone mineral density, compact bone density and modulus of elasticity compared favourably with the measured values for the same parameters. Schryver (1978) measured the bending properties of the metacarpals of ponies and found the elastic modulus to be \( 18.4 \pm 0.14 \text{ GN m}^{-2}\) for the cranial cortex of the mid-shaft. He obtained values of \( 16.2 \) to \( 20.2 \text{ GN m}^{-2}\) for different parts of the cortex of the radius and femur and was able to show that diet, exercise and sex of the pony affected the elastic modulus, ultimate strength and energy absorption of the bone.

In this study transverse cortical bone velocity has been determined rather than the apparent transverse velocity (Jeffcott and McCartney, 1985) because it is more uniform along the shaft, is less subject to geometrical effects, allows an estimation of a modulus of elasticity and should provide better correlation between individuals. These methods, having been developed on post mortem specimens, are now being applied to live animals. Ultrasound measurements (five sites) take about 10 min per limb and absorptiometry (five readings) takes about 20 min per limb. Using these combined techniques it will be possible to establish better parameters for skeletal maturity (Buckingham and Jeffcott, 1987) and to measure the effects of exercise on bone (Jeffcott et al., 1987). As these methods are being implemented in equine medicine there appears no reason why the same principles cannot be applied in humans.

**References**


Appendix 2

The iterative procedure applied in a simple computer program involves eqns. 4, 5 and 10. \( C_n, V \) and \( C_m \) are known leaving \( f, C_n \) and \( R \) to be determined. The only restriction to the iterative process is imposed by eqn. 4, where

\[
\begin{align*}
R &= -\infty \text{ when } C_n = C_m \\
R &< 0 \text{ when } V > C_n > C_m \\
R &= 0 \text{ when } C_n = V \\
R &> 0 \text{ when } C_n > V
\end{align*}
\]

Provided the starting point of the iteration is with the first estimate of \( C_n > V \) then the correct value is determined. \( C_n \) is always greater than \( V \) and is used as the first estimate of \( C_n \). The first estimate of \( R \) is then determined (eqn. 4), followed by the first estimate of \( f \) (eqn. 10). Eqn. 5 then gives a revised estimate of \( C_n \). This process is continued until the change in \( C_n \) per cycle is less than some chosen value e.g. 1 m s\(^{-1}\). It takes only five cycles on average to achieve a suitable result.

Authors' biographies

Ronald McCartney is Australian and has been a lecturer for over 20 years in the Department of Applied Physics at the Royal Melbourne Institute of Technology. He received the M.Sc. degree from Surrey University (UK) in 1976. His major interest is in medical sonography.

Leo Jeffcott was born in Tiverton, Devon, UK in 1942. He graduated from the Royal Veterinary College, University of London in 1967 and obtained his Ph.D. from there in 1972. His research interests have always been with horses, in the UK, Sweden and currently as Professor of Veterinary Clinical Sciences in the Faculty of Veterinary Science, University of Melbourne. He is Chairman of the Department and Director of the Veterinary Clinic and Hospital. His research interests have recently concentrated on the evaluation of bone quality by noninvasive means. He is a Fellow of the UK Royal College of Veterinary Surgeons.
Noninvasive Measurement of Bone Quality in Horses and Changes Associated with Exercise

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Summary

Two techniques were developed for assessing in vivo bone quality. Ultrasound velocity, which is related to density and modulus of elasticity, was measured through the cortex of the third metacarpal bone and bone mineral content was determined by single photon absorptiometry. Values for bone mineral density were calculated from bone mineral content and the cross sectional area of the metacarpal shaft which was estimated ultrasonically. It was also possible to estimate compact bone density and modulus of elasticity. The study involved four groups of horses: 5 Thoroughbred weanlings at pasture (group 1); 25 Thoroughbred racehorses in training (group 2); 4 mature Standardbreds undergoing an 8 week lunging exercise program (group 3); 7 mature Thoroughbred racehorses interval trained for 12 weeks on a treadmill (group 4). Group 1 foals showed a gradual increase in apparent transverse velocity from 2683 m/sec at 7 months to 2745 m/sec at 17 months of age. The horses in training (Group 2) showed a more substantial increase in ultrasound velocity with increasing levels of work from 2731 m/sec at the onset of training to 2882 m/sec at 3+ years. Values dropped transiently or remained static if the horses became shin sore. Mature horses (Group 3), given lunging exercise, did not show any increase in ultrasound velocity or bone mineral content. The racehorses (Group 4) showed an increase in ultrasound velocity of 40 to 66 m/sec with training, but no significant changes in bone mineral content or bone mineral density. These preliminary results demonstrate that changes in bone associated with age and exercise can be accurately monitored noninvasively.

Index terms: cortical bone; third metacarpal bone; ultrasound velocity; photon absorptiometry; bone mineral; bone density.

Introduction

The assessment of bone quality in vivo in horses has not yet been successfully achieved, although it plays a vital role in the understanding of normal skeletal development, ex-
exercise physiology and bone disease. In this regard, the measurement of bone mineral content and bone elasticity provide valuable information on skeletal status as both density and modulus of elasticity change with alteration in mineral content (Currey, 1969a,b). The elastic properties, density and composition of bone can be measured in vivo by a variety of means including radiography, photon absorptiometry, ultrasound velocity and nuclear medicine.

The purpose of this paper is to report on some preliminary data to determine bone quality of the third metacarpus in racehorses. Two techniques, ultrasound velocity and single photon absorptiometry, have been used to show the potential of these methods for studying skeletal maturity and to monitor the effects of exercise on bone. Initially ultrasound velocity was used alone, but later this was combined with photon absorptiometry. By utilizing both techniques (McCartney and Jeffcott, 1986) it is possible to determine noninvasively:-

\[
\begin{align*}
C_a &= \text{"apparent" transverse velocity of ultrasound (m/sec)} \\
C_b &= \text{"true" transverse velocity of ultrasound (m/sec)} \\
CSA &= \text{cross sectional surface area of the metacarpal cortex measured ultrasonomically (cm}^2) \\
BMC &= \text{bone mineral content (g/cm)} \\
BMD &= \text{bone mineral density (g/cm}^3) \\
CBD &= \text{compact bone density (g/cm}^3) \\
E &= \text{estimate of transverse modulus of elasticity (GN m}^2) \\
\end{align*}
\]

The measurement of the velocity of an ultrasonic wave through cortical bone can be used to accurately determine such physical properties of bone as the modulus of elasticity (Abendschein and Hyatt, 1970). Ultrasound velocity \( (C) \) in bone is related to stiffness or modulus of elasticity \( (E) \) and its density \( (\rho) \) by the formal \( E = \rho C^2 \). The clinical application of this technique in osteoporosis or metabolic bone disease has considerable potential in man (Greenfield et al., 1981) and has the added advantage of reducing the use of ionizing radiation. A transmission method is used in the horse to measure the apparent transverse velocity of ultrasound in the metacarpal cortex (Pratt, 1980). This measurement is termed "apparent" velocity as it utilizes a beam of ultrasound which takes an indirect path through the cortex around the medulla (Jeffcott and McCartney, 1985). For the measurement of the "true" transverse cortical ultrasound velocity it is necessary to know the exact length of this pathway. Preliminary work with perspex blocks to simulate bone cross sections indicate that reasonable estimates of both transverse cortical ultrasound velocity and the dimensions of the medullary cavity can be achieved (McCartney and Jeffcott, 1985). The transverse cortical ultrasound velocity together with the density can give a good estimate of the modulus of elasticity (McCartney and Jeffcott, 1986), which is related to bone strength and ultimately to fracture threshold (Sedlin and Hirsch, 1966).

The determination of bone mineral content (BMC) by photon absorptiometry has become an important diagnostic and research tool in human medicine (Chesney and Shore, 1982; Wahner et al., 1983). It has been used to investigate a wide range of metabolic and skeletal conditions, and there is a wealth of relevant literature on the subject (Griffiths and Zimmerman, 1978). Bone mineral content is related to age (Yates and Martin, 1984) and to bone strength or the ability to withstand stress (Bartley et al., 1966). It has been widely used to monitor age-related bone loss (osteoporosis)
and the assessment of fracture risk at specific bone sites particularly in middle-aged women (Wahner et al., 1983). Significant reduction in bone mineral (i.e. osteopenia) can also be demonstrated in inactive patients, those on prolonged bed rest (Mazess and Whedon, 1983) and from weightlessness in space flight (Wronski and Morey, 1983). It has also been reported that exercise can materially assist in overcoming such involutional bone losses (Aloia et al., 1978). In the field of sports medicine it has been demonstrated that athletes in general have a higher BMC than non-athletes (Nilsson and Westlin, 1971), and in particular, long distance runners show a significant increase in BMC compared to controls (Williams et al., 1984).

In veterinary medicine, photon absorptiometry has been used in laboratory animals (Sanchez et al., 1981) and to a limited extent in companion and farm animals; for example in dogs (Stoliker et al., 1976; Jorch et al., 1982); in cattle (Siemon et al., 1974; Zetterholm and Dalen, 1978); and in horses (Wentworth et al., 1971; Pezzoli et al., 1977; Tomioka et al., 1985a; Jeffcott et al., 1986). Horses, and in particular racehorses, are top class athletes and provide an excellent model to study bone metabolism because of the strict control possible of their age, diet and type of exercise. The metacarpus (i.e. cannon bone) is a good site to evaluate because of its accessibility, fairly standard size, minimal surrounding soft tissue and its susceptibility to biomechanical stresses.

There is one important limitation with single photon absorptiometry which is that the cross sectional area of the bone being scanned is not taken into consideration. This means that any changes noted may be due to volumetric rather than densitometric differences (Ruff and Hayes, 1984; Buckingham and Jeffcott, 1986). It is clear from the literature that a combination of BMC determination and ultrasound velocity, together with radiography for the assessment of bone geometry, has the potential to assess bone quality much more effectively (Greenfield et al., 1981).

Materials and Methods

Animals

A total of 41 Thoroughbred and Standardbred horses were used in this investigation:

Group 1 consisted of 5 male Thoroughbreds kept together at pasture on a local stud farm. They were being prepared for the yearling sales and were in good bodily condition. They had been halter broken, but given no training or exercise program during the period of investigation. The apparent transverse velocity was measured at monthly intervals from 7 to 17 months of age.

Group 2 was made up of 25 Thoroughbreds, aged 16 to 47 months, in training in two stables in the Melbourne area. Apparent transverse velocity was measured sequentially at approximately monthly intervals over an 18-month period. Five of the animals showed clinical signs of shin soreness during the period of investigation and were taken out of training for 4 to 6 weeks. The training regimes were similar in both stables. The horses were broken in initially and then kept in light work before being turned out for approximately a month. Subsequently, they returned to a progressive training schedule and preparation for trials and races, unless they became shin sore.

Group 3 consisted of 4 mature Standardbreds kept at the Veterinary Clinical Centre as experimental horses. Two were controls and the other two were given 8 weeks of lunging exercise in a sand ring. The distances worked and heart rates were monitored...
and the horses were never severely fatigued. Initially, approximately 3 km of trotting was given daily at a speed of about 3.5 m/sec, and this progressed to >12 km of trotting and cantering at an average of 4.2 m/sec. Apparent and transverse cortical ultrasound velocity were determined, as well as photon absorptiometric measurements before, during and after the exercise program.

Group 4 comprised of 7 mature Thoroughbred racehorses that had been out of training for at least 3 months, on pasture, and were then kept at the Department of Veterinary Clinical Studies, University of Sydney. Ultrasonic and photon absorptiometric measurements were performed before the animals underwent a 12-week controlled training program on a treadmill. They started with 20 minutes trotting per day at 4 m/sec and this was increased to 40 minutes per day by 3 weeks. An incremental exercise test to assess maximal heart rate was performed in week 2 of the program (Evans and Rose, 1986). The next 3 weeks consisted of higher intensity exercise with the horses working at 90% of maximal heart rate. The final 6 weeks consisted of intense interval training at 100–120% of maximal heart rate. The bone measurements were repeated at peak fitness at the end of 12 weeks.

**Ultrasound velocity measurements.** For the horses in Groups 1 and 2, the apparent transverse velocity of ultrasound ($C_a$) was calculated for the third metacarpal bone by measuring the time of flight of an ultrasonic beam between two transducers a known distance apart (Jeffcott and McCartney, 1985). The equipment used was a pulse module (Panametrics, Model 5055), a preamplifier (Panametrics, Model 5660B) two 2.25 MHz, 13mm diameter ultrasound transducers mounted on an electronic digital caliper (Jocal, CE Johansson) and a digital storage oscilloscope with signal averaging capability (Tektronix, Model 468).

For Group 3 and 4, in addition to measuring $C_a$, the transverse cortical ultrasound velocity ($C_b$) was determined. This technique involved making a correction for the cortical path of the ultrasound beam by determining the velocity of a second slower path of sound which passed through both the cortex and medulla (i.e. straight through the bone). From these data it was possible to calculate the corticomedullary ratio and the cross sectional surface area (CSA) of the metacarpal cortex (McCartney and Jeffcott, 1987). A different electronic digital caliper (Max-cal, Model 950-101) was used in this part of the study in association with an Apple II plus microcomputer to apply the various iterative and calculative algorithms.

In all horses examined, a total of five lateral-to-medial readings were taken for each forelimb along the part of the metacarpal shaft where the cortical surfaces are parallel. A liberal quantity of coupling medium (Aquasonic 100, Parker) was used to ensure good sound transmission. The time of flight of the cortical ultrasound path could usually be simply calculated from the sharp deviation of the first arrival pulse from the baseline on the oscilloscope. An amplification of the signal of approximately 90 decibels (dB) was necessary to achieve an adequate signal on the oscilloscope. The first arrival pulse of the ultrasound via the path straight through the cortex and medulla was often more difficult to pinpoint. A better estimate of this point was often achieved by displaying a second trace of the same signal with a reduction of 20 dB.

The precision of the method on cadaver specimens ($n = 41$) has been calculated at $C_a = \pm 0.32\%$, $C_b = \pm 0.59\%$ and CSA = $\pm 3.6\%$ (McCartney and Jeffcott, 1987).

**Photon absorptiometry.** Bone mineral content (g/cm) was estimated using a Norland digital bone densitometer (Prototype Model 2781, Large Animal Scanning System, Nor-
In Vivo Measurement of Bone Quality

land Corporation) incorporating a 45 mCi source of $^{241}$Americium (Jeffcott et al., 1986). With the horse in the standing position the mid-metacarpal shaft of each forelimb was transversely scanned 5 times in a caudal-to-cranial direction. Stocks were used for restraint as well as mild intravenuous tranquilization with a combination of acepromazine and xylazine. The leg was wrapped in a water-filled bag, which was held in place with adhesive tape and then enclosed in a polythene scanning jig. This acted as a soft tissue equivalent which was necessary to provide a uniform mass absorption coefficient around the bone. Individual bone scans took approximately 60 seconds. The whole procedure usually took about 30 minutes to complete for each horse. Readings were always repeated if any movement or swaying of the horse took place during a scan.

In addition to BMC for Groups 3 and 4, bone mineral density (BMD g/cm$^3$) was calculated from BMC (g/cm) and CSA (cm$^2$). Also, the compact bone density (CBD g/cm$^3$) was estimated using a bone model after the method of Greenfield et al. (1981) and transverse modulus of elasticity (E GN m$^2$) from CBD and C$_b$ (McCartney and Jeffcott, 1987).

The precision of the method on cadaver specimens ($n = 20$) has been calculated at BMC = $\pm 1.15\%$, BMD = $\pm 0.44\%$, CBD = $\pm 0.42\%$ and E = $\pm 1.4\%$ (McCartney and Jeffcott, 1986).

Statistical analysis. Regression analysis was used to compare slopes and intercepts of C$_a$ versus age to distinguish if differences existed between sexes, and left and right forelimbs. The Student's paired t-test was used to compare pre- and post-exercise measurements.

Results

The weanling Thoroughbreds (Group 1) showed a gradual increase in C$_a$ from a mean of $2683 \pm 76$ m/sec after weaning to $2745 \pm 35$ m/sec at 16 to 17 months (Fig. 1). The regression gave an increase of 7.9 m/sec per month of age ($P < 0.01$). From the time that the horses in Group 2 started training (16–18 months) they showed a progressive increase in C$_a$ from approximately $2731 \pm 32$ to $2882 \pm 56$ m/sec once they were over 3 years old (Fig. 2). This was an increase of 5.9 m/sec per month of age ($P < 0.001$). Combined over all ages, the left forelimb was 12.4 m/sec lower than the right (Fig. 3) ($P < 0.001$). This difference decreased by 1.0 m/sec per month of increasing age ($P < 0.05$) and was not dependent on the sex of the horse. There was no difference between males and females in the rate of increase of C$_a$ with age (females 7.13 m/sec per month, males 5.51 m/sec per month; $P > 0.05$) (Fig. 3). A representative pattern of increasing C$_a$ with age and work is shown in a 2-year-old colt (Fig. 4).

The changes in C$_a$ in a group of 5 horses that showed clinical signs of sore shins and were rested for 4 to 6 weeks are illustrated in Fig. 5. Instead of the progressive rise seen in the sound horses there was a fall in C$_a$ which only increased again after the animal was put back into work.

In the horses given only lunging exercise (Group 3) there were no differences in ultrasound velocity or photon absorptiometric measurements between the controls and the exercised horses. Figure 6 illustrates the ultrasound velocity and bone mineral data from one of the exercised horses. A slight fall in C$_a$ and C$_b$ was seen in both exercised horses in the first 2 weeks of exercise, but levels did not rise above the baseline levels.
We also investigated whether there was a detectable change in ultrasound velocity immediately after lunging exercise. The two horses were measured on two occasions before and immediately after 25 minutes of lunging. There was no significant change in $C_a$ or $C_b$ with either fast (approximately 5 m/sec cantering) or slow (approximately 3.5 m/sec trot) lunging (Table 1).

The racehorses exercised on the treadmill for 12 weeks (Group 4) showed a mean increase of 40 m/sec in $C_a$ ($P < 0.001$) and 66 m/sec in $C_b$ ($P < 0.001$) in the post-exercise period (Table 2). There were no significant differences in the values for BMC, CSA, BMD and CBD. An increase in $E$ of 0.55 GN/m was recorded after exercise, but this was only significant to $P < 0.1$.

Discussion

The response of bone to the effects of exercise in horses has been largely overlooked in contrast to major advances of knowledge in other areas of equine exercise physiology. The skeleton of the horse is subjected to enormous biomechanical stresses in order to perform in today’s exacting levels of competition (e.g. racing, endurance, jumping,
Racehorses for example, commence training soon after they are 18 months old, which is long before they attain full skeletal maturity. It is not surprising that lameness associated with sore shins, splints, stress fractures and tendon injuries (Jeffcott et al., 1982; Rossdale, et al., 1985) is such an important cause of lost performance.

The mechanical properties of cortical bone in vitro have been extensively investigated (Reilly and Burstein, 1974) and it is generally accepted that intrinsic and bending strength of bone is positively correlated to ash content (Vose and Kubala, 1959; Currey, 1969a). However, Melick and Miller (1966) found no correlation between ultimate strength and ash content of fresh human femoral bone. Nevertheless the medical literature is clear in providing confirmation in vivo that continued exercise produces increased cortical and trabecular bone mass (Nilsson and Westlin, 1971; Dalen and Olsson, 1974; Jones et al., 1977; Huddleston, et al., 1980; Williams et al., 1984). Exercise will also slow
FIGURE 3. Mean results in group 2 of apparent transverse velocity of ultrasound (\(C_m \text{ m s}^{-1}\)) against age according to a) sex, and b) left/right metacarpus.
the demineralization process in age-related osteoporosis (Aloia et al., 1978).

Little work has been done so far in animals, although Martin et al. (1981) reported that long term exercise associated with load carrying produced a significant increase in tibial bone mineral content in adult beagles. Woo et al. (1981) also showed an increase in cortical thickness in young pigs subjected to prolonged treadmill exercise and concluded that exercise significantly affected the quantity of bone rather than its quality. The results reported here for apparent transverse velocity and bone mineral content compare favorably with other studies in the United States and Japan (Rabin et al., 1983; Tomioka et al., 1985a; Hasegawa et al., 1985; Tomioka et al., 1985b). There was a positive correlation between ultrasound velocity in cortical bone and the effects of exercise. The mineral content of the metacarpus appeared to be more related to skeletal maturity than to the effects of training or exercise. However, more detailed and controlled studies of bone development during growth (Buckingham and Jeffcott, 1986) are required before definite conclusions can be drawn.

Previous investigations on cadaver specimens of equine metacarpi have validated the
FIGURE 5. Mean results of apparent transverse velocity of ultrasound ($C_a$ m s$^{-1}$) in 5 young Thoroughbreds in group 2 before and after showing clinical signs of shin soreness.

noninvasive methods used here for bone measurement (Jeffcott and McCartney, 1985; Jeffcott et al., 1986; McCartney and Jeffcott, 1986). The data presented in this study highlights the potential for their use as a research tool in the live animal. Initially the ultrasonic technique was employed for apparent velocity alone (Pratt, 1980; Rabin et al., 1983; Jeffcott and McCartney, 1985), but has since been extended to include measurement of transverse cortical bone velocity and cross sectional area of the metacarpal shaft. With the associated use of photon absorptiometry the range of measurements now includes bone mineral content, bone mineral density, compact bone density and the transverse modulus of elasticity.

Apart from the additional information on bone quality that can be gained by combining ultrasound and photon absorptiometry, there are disadvantages to using apparent transverse velocity alone. These involve the inherent problems of the anisotropic properties of cortical bone (Reilly and Burstein, 1975), the alterations in geometry of the metacarpal shaft (Piotrowski et al., 1983) and the variability of soft tissue thickness (Buckingham and Jeffcott, unpublished observations). Even a small increase in soft tissue thickness from edema (i.e. < 3 mm) can lead to a considerable drop in apparent
FIGURE 6. Results of apparent transverse velocity of ultrasound (Cₐ m s⁻¹), transverse cortical ultrasound velocity (Cₐ m s⁻¹), bone mineral content (BMC g cm⁻³) and bone mineral density (BMD g cm⁻³) in a 9-year-old Standardbred gelding given an 8 week program of lunging exercise.
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TABLE 1. Results (± SD) of apparent transverse velocity ($C_a$) and transverse cortical bone velocity ($C_b$) in two Standardbred horses.

<table>
<thead>
<tr>
<th>Type of work</th>
<th>Horse</th>
<th>Ultrasound velocity readings (m/sec)</th>
<th>Pre-exercise</th>
<th>Post exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STEADY WORK</td>
<td>A</td>
<td>$C_a$</td>
<td>2911 ± 12</td>
<td>2866 ± 30</td>
</tr>
<tr>
<td>(approx. 3.5 m/sec trot)</td>
<td></td>
<td>$C_b$</td>
<td>3295 ± 21</td>
<td>3251 ± 29</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>$C_a$</td>
<td>2837 ± 24</td>
<td>2812 ± 14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$C_b$</td>
<td>3165 ± 27</td>
<td>3140 ± 13</td>
</tr>
<tr>
<td>FAST WORK</td>
<td>A</td>
<td>$C_a$</td>
<td>2852 ± 19</td>
<td>2872 ± 17</td>
</tr>
<tr>
<td>(approx. 5 m/sec canter)</td>
<td></td>
<td>$C_b$</td>
<td>3223 ± 23</td>
<td>3259 ± 20</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>$C_a$</td>
<td>2795 ± 9</td>
<td>2793 ± 18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$C_b$</td>
<td>3109 ± 14</td>
<td>3115 ± 9</td>
</tr>
</tbody>
</table>

Measurements were made prior to and immediately after 25 minutes lunging exercise in a sand ring.

Transverse velocity from 2800 to 2650 m/sec. While there is no dispute that there is a good correlation between ultrasound velocity and elastic modulus (Abendschein and Hyatt, 1970), only preliminary and superficial investigations have so far been reported in horses to demonstrate the changes associated with fracture or breaking strength of bone (Pratt, 1980). The data presented by Rabin et al. (1983) for prediction of fracture threshold in racehorses was performed with a correction for soft tissue variability although no details of how these were done was given. They also referred to one case of unilateral sore or bucked shins in the right forelimb which showed a similar pattern to the horses studied here. In Group 2 the apparent transverse velocity fell approximately 50 m/sec shortly before there were clinical signs of sore shins. Values remained

TABLE 2. Mean results for both forelimbs of ultrasound and photon absorptiometric measurements (±1 SD) in 7 mature Thoroughbred racehorses.

<table>
<thead>
<tr>
<th></th>
<th>Pre-training</th>
<th>Post training</th>
<th>Paired Student’s t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent transverse velocity ($C_a$ m/sec)</td>
<td>2851 ± 37</td>
<td>2891 ± 30</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Transverse cortical bone velocity ($C_b$ m/sec)</td>
<td>3210 ± 51</td>
<td>3276 ± 41</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Bone mineral content (BMC g/cm)</td>
<td>9.82 ± .65</td>
<td>9.69 ± .65</td>
<td>p &gt; 0.2</td>
</tr>
<tr>
<td>Cortical cross sectional area (CSA cm$^2$)</td>
<td>8.83 ± 1.2</td>
<td>8.75 ± 1.0</td>
<td>p &gt; 0.2</td>
</tr>
<tr>
<td>Bone mineral density (BMD g/cm$^3$)</td>
<td>1.12 ± .11</td>
<td>1.11 ± .07</td>
<td>p &gt; 0.7</td>
</tr>
<tr>
<td>Compact bone density (CBD g/cm$^3$)</td>
<td>1.96 ± .06</td>
<td>1.95 ± .04</td>
<td>p &gt; 0.6</td>
</tr>
<tr>
<td>Transverse modulus of elasticity (E GN/m$^2$)</td>
<td>20.5 ± 1.4</td>
<td>21.1 ± .8</td>
<td>p &lt; 0.1</td>
</tr>
</tbody>
</table>

(Group 4) before and at the completion of a 12 week training program on a treadmill.
lower than normal until they were back in full training again. Unfortunately photon absorptiometry was not performed on these animals to monitor the mineral content of the metacarpus over this period. It is likely that no measurable change in BMC would have been detectable, but further investigations are currently underway to confirm this.

Bone is considered to be a two phase system of hydroxyapatite and collagen (Currey, 1964). Lees and Davidson (1977) have shown that an alteration in the cross linking density with shortening of maximum cross link length of hydroxyapatite has the effect of increasing elastic modulus. This means that there could be an increase in ultrasound velocity, and therefore modulus of elasticity, without change in bone mineral content, a feature seen in the racehorses in Group 4 following the treadmill exercise. There were significant increases (p < 0.001) in ultrasound velocity while the increase in modulus of elasticity was less significant (p < 0.1). The difference noted between lunging and treadmill exercise may be explained by the relative lack of concussive stress produced in a sand ring rather than on the hard surface of a treadmill. Furthermore if there is excessive and repetitive concussion then this could lead to alteration of the normal viscoelastic properties of cortical bone by reduction in cross linking density of hydroxyapatite crystal structure and microfracture production. This may be the situation that occurs in young horses with shin soreness. Carter and Hayes (1977) showed that repeated loading of bone in vitro causes progressive loss of stiffness and ultimate strength.

This appears to be the first report of an in vivo determination of the transverse modulus of elasticity in the horse and its change with exercise. The data obtained is encouraging as it compares well with the in vitro studies of Schryver (1978) and data from human (Greenfield et al., 1981) and bovine bone (Reilly et al., 1974). Further studies to establish more conclusively the effects of different training regimens are clearly justified from the preliminary data presented in this report.

Acknowledgments

Funding for this project was defrayed in part by grants from the Rowden White Fund and the Australian Equine Research Foundation. We are indebted to Harry McNamara, Cliff Fahler and Tommy Hughes for permitting us to take measurements from their horses at stud or in training and to Professor Rose of University of Sydney for allowing access to the racehorses exercised on the treadmill. The technical assistance of Tracy Waters is gratefully acknowledged and thanks are due to Dinah Mason for her help with the lunging exercise study. We are most grateful to Garry Anderson for his assistance with the statistics.

References


In Vivo Measurement of Bone Quality


Equine Exercise Physiology


Changes in Bone Strength and Density in Standardbreds from Weaning to Onset of Training

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Summary

Sequential determinations of growth rate and bone quality were made on five 5- to 18-month-old foals. Measurements included growth rate, plasma alkaline phosphatase, radiographic optical density, ultrasound velocity, cortical cross sectional area, bone mineral content, bone mineral density, compact bone density and modulus of elasticity. All foals showed a steady growth rate during the 11-month investigation. Plasma alkaline phosphatase concentrations remained static at 200-350 U/L throughout the study period. Radiographic photodensitometry measurements of the mid-metacarpal cortex exhibited a gradual trend to increased optical density of bone with age. The apparent transverse ultrasound velocity at 6 months was 2607 m/sec and increased by 112 m/sec over the next 10 months, while the transverse cortical ultrasound velocity exhibited less change (3028 to 3081 m/sec) over the same period. The ultrasonic estimate of the cross sectional area of the mid-metacarpal cortex increased from 4.7 to 7.5 cm². Bone mineral content showed a marked increase in values from 4.9 to 7.1 g/cm, whereas those for bone mineral density and compact bone density remained static at 0.98 and 1.87 g/cm³, respectively. Values for modulus of elasticity also remained constant at 17.8 GN/m². These preliminary results provide baseline data for assessing skeletal maturation in young horses and for further studies in evaluating the effects of exercise and nutrition in the post-weaning period. Metacarpal cross sectional area, estimated ultrasonically, produced a good indication of growth rate. Radiographic photodensitometry was not judged to be a sufficiently sensitive method, but ultrasound velocity and single photon absorptiometry appear to be safe, accurate and reliable indicators of bone density and strength in young horses.

Index terms: Horse; foal; skeletal maturity; bone quality; cortical bone; third metacarpal bone; ultrasound velocity; modulus of elasticity; photon absorptiometry; bone mineral; radiographic photodensitometry; plasma alkaline phosphatase.

Introduction

Until recently, skeletal maturity in young horses has been assessed by subjective visual appraisal of the animal and by the radiographic closure of various growth plates (Mason
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and Bourke, 1973). This paper presents the results of a study aimed at monitoring the changes in bone quality and bone strength in 5 Standardbred foals kept at the Veterinary Clinical Centre over an 11 month period. Two non-specific means of assessing bone development were used. The growth rate was monitored by weekly measurements of various bodily dimensions. Plasma alkaline phosphatase levels were investigated in an attempt to provide an indication of bone formation or turnover (Krabb et al., 1980).

Radiographic photodensitometry was the first of three more specific and non-invasive techniques used to investigate bone quality. It is simple to perform and requires no special equipment apart from an aluminium alloy stepwedge, an optical densitometer and standard radiographic facilities. This technique has been widely used in human medicine (Mack et al., 1959; Schraer, 1966), although it has been largely superseded by more accurate and sophisticated methods including photon absorptiometry and computed tomography. Radiographic photodensitometry has also been successfully used in horses to measure the progressive mineralization of the third metacarpal bone in weanling foals (Meakim et al., 1981).

The measurement of the velocity of ultrasound through cortical bone provides a means of determination of its modulus of elasticity and its mass density (Abenschein and Hyatt, 1970). The modulus of elasticity (E) is a property of the bone related to its stiffness or strength and ultimately its fracture threshold. It can be determined by measurement of the ultrasound velocity (C) and the bone density (ρ), using the equation: \[ E = \rho \times C^2. \] The technique used for the measurement of apparent transverse ultrasound velocity has been described previously (Pratt, 1980; Jeffcott and McCartney, 1985). With an understanding of the pathway of the ultrasound beam, good estimates of the true transverse cortical ultrasound velocity and the cross sectional area of the cortical bone can be achieved (McCartney and Jeffcott, 1985).

Bone mineral content (BMC) can be accurately estimated by single photon absorptiometry. This method, pioneered by Cameron and Sorenson (1963), has been widely used as a diagnostic and research tool in human medicine (Chesney and Shore, 1982; Wahner et al., 1983), however its application in horses has been somewhat limited (Wentworth et al., 1971; Pezzoli et al., 1977; Tomioka et al., 1985; Jeffcott et al., 1986). Bone mineral content is of interest since the strength of bone largely depends on the degree of mineral reinforcement, in the form of hydroxyapatite, of what is essentially a fibrous scaffold of collagen.

The objective of this study is to gain a better understanding of the development of skeletal maturity and to non-invasively quantify the associated changes in bone strength and density. This is of particular interest since many horses begin serious training long before they are skeletally mature. In view of the tremendous biomechanical forces involved in high level equestrian competition, it is hardly surprising that lameness is such a critical cause of lost performance (Jeffcott et al., 1982). An increased knowledge of skeletal development is hopefully the first step in a long process of investigating the cause of some of these skeletal problems and instituting preventive measures.

Materials and Methods

Animals. A group of 5 Standardbred foals, 4 colts and 1 filly, was used. The foals were prospective racehorses acquired on loan from their owners and were returned for breaking in and training at the end of an 11-month period of examination. The foals
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arrived at the Veterinary Clinical Centre immediately after weaning and the first few weeks were spent on handling and familiarization with the surroundings and techniques. They were between 5 and 6 months old when bone measurements began.

During the investigation the foals were kept on a controlled diet aimed at providing a steady growth rate. This ration consisted of lucerne hay and a concentrate pellet. They were initially kept in yards and then later in a small paddock so that their level of exercise was limited to their own activity.

Growth rate. Weekly measurements were made of body weight, height at withers, girth, left humeral length from the greater tuberosity of the humerus to the olecranon and the circumference of the left fore cannon region at the midsite.

Plasma alkaline phosphatase (AP). Weekly blood samples were taken throughout the period of investigation and analyzed for alkaline phosphatase using a Roche Uni-Kit on a Roche Cobas Mira biochemical analyzer.

Radiographic photodensitometry. Lateral radiographs of the left and right third metacarpal bones were taken at monthly intervals to monitor any changes in radiographic optical density with age. An aluminium alloy stepwedge was included in each radiograph after the method of Schraer (1966). A Phillips XC2031 mobile x-ray machine was used with Kodak T-Mat G films and Kodak Lanex Regular rare earth screens. The films were processed using a Dupont Cronex Processor T3. Optical density was measured from a lateral radiograph at three sites in the midregion of the metacarpus using a Sakura PDA-81 optical densitometer (Konishiroku Photo Ind.). These sites were the dorsal cortex, the palmar cortex and a site between these over the medullary cavity.

Ultrasound velocity measurements. Five latero-medial readings were taken covering the part of the metacarpal shaft where the cortical surfaces are parallel. Both left and right forelimbs were measured at weekly intervals (Jeffcott and McCartney, 1985; Jeffcott et al., 1987). In addition to measuring the apparent transverse velocity (C_a m/sec), a correction was made to determine the transverse cortical ultrasound velocity (C_b m/sec) which takes into account the pathway of the ultrasonic beam around the medullary cavity (McCartney and Jeffcott, 1985). The C_b consequently provides a better estimate of the modulus of elasticity in vivo. A good estimate of the cross sectional area (CSA cm^2) of the cortical bone can also be achieved (McCartney and Jeffcott, 1987).

Single photon absorptiometry. Five measurements of the bone mineral content (BMC g/cm) at the mid-site of both left and right metacarpal were made at monthly intervals. General anesthesia was used for the first 2 sessions on each foal, but later a combination of acepromazine and xylazine provided satisfactory tranquilization to keep the animal still enough for scanning. The technique used has been documented (Jeffcott et al., 1986; 1987) and involves the passage of a beam of photons from a 45 mCi radiation source (^241 Americium) through the bone in the direction of a scintillation detector. The degree of absorption of photons is related to the bone mineral content and an estimate of the amount of bone mineral in a 1 cm thick transverse slice of the mid-metacarpal shaft is achieved.

Combination of photon absorptiometry and ultrasound velocity data. Monthly estimates of bone mineral density, compact density and modulus of elasticity for the left and right metacarpal were made.

Bone mineral density (BMD g/cm^3). Changes in BMC after birth are largely volumetric since the 1 cm thick slice of bone measured will be constantly increasing in size (Ruff and Hayes, 1984). Despite the physiological importance of this increasing bone
volume, BMC alone provides very little information about the degree of mineralization per unit volume of bone and its density. In order to compensate for growth, a value for bone mineral density can be calculated from the BMC and the ultrasonic estimate of the cortical cross sectional area (McCartney and Jeffcott, 1987):

$$BMD = \frac{BMC}{CSA}$$

**Compact bone density** ($CBD \, g/cm^3$), or specific gravity, can be estimated using a bone model (Greenfield *et al.*, 1981) from BMC, CSA and estimated constants of microscopic bone mineral density ($\rho_m, g/cm^3$) and collagen density ($\rho_c, g/cm^3$) by the equation:

$$CBD = \rho_c + (1 - \frac{\rho_c}{\rho_m}) \frac{BMC}{CSA}$$

The modulus of elasticity ($E \, GN/m^2$) or Young's modulus is related to density ($\rho$) and ultrasound velocity ($C$) can be estimated in *vivo* by the equation from McCartney and Jeffcott (1987):

$$E = CBD \times C_b^2$$

### Statistical analysis
Regression analyses were performed for all ultrasonic and photon absorptiometric measurements to estimate relationships with age. Student’s one sample t-tests were used to test whether the percentage change per month was significantly different from zero for all seven measurements.

### Results
All 5 foals exhibited similar trends throughout the period of examination. The mean results, for left and right legs, for one foal (D) are presented to illustrate these trends with time. A summary of the results for all 5 foals is presented later in tabular form. All calculations are based on the assumption of a linear regression, and percentage change per month is calculated at 52 weeks of age.

The foals all exhibited a steady growth rate throughout the investigation as illustrated by the change in girth and mid-cannon circumference for foal D (Fig. 1). Plasma alkaline phosphatase concentrations remained fairly stable in all the foals throughout the period of study with foal D being approximately 150-250 U/L (Fig. 2).

A progressive increase in optical density of the third metacarpal bone was measured by radiographic photodensitometry as seen for foal D (Fig. 3), although in the other foals the trend was not as apparent due to large variations. The dorsal cortex was always slightly more dense than the palmar cortex and both these sites were more dense than the site overlying the medullary cavity.

Foal D showed an increase in $C_a$ of 0.39% per month ($P < 0.001$), which meant a change from 2602 m/sec at 5 months to 2720 m/sec at 16 months (Fig. 4). On the other hand, $C_b$ increased at a much lower rate (0.11% per month, $P < 0.05$) with a change from 3044 to 3084 m/sec over the same period (Fig. 4).

The ultrasonic estimate of the cortical cross sectional area (CSA), critical in the estimation of BMD, CBD and E, also proved to be an excellent indicator of growth rate. The typical pattern of steady increase in CSA is shown for foal D (Fig. 5). In this case CSA increased at 4.73% per month ($P < 0.001$) from 3.83 cm$^2$ at 5 months to 7.22 cm$^2$ at 16 months.

BMC at the mid-site of the metacarpal shaft, as measured by single photon absorp-
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FIGURE 1. Growth rate as measured by change in girth and mid-cannon circumference in Standardbred foal D over an 11 month period.

FIGURE 2. Plasma alkaline phosphatase (U/L) concentrations in Standardbred foal D over an 11 month period.
FIGURE 3. Changes in bone density, as measured by radiographic photodensitometry, at the mid-site of the third metacarpal bones of Standardbred foal D. The sites measured were the dorsal cortex (Site 1), the palmar cortex (Site 3), and over the medullary cavity (Site 2). Bone density is expressed as equivalent thickness of aluminium alloy LM4.

tometry, exhibited an increase (3.65% per month, \( P < 0.001 \)) in foal D from 4.196 to 6.741 g/cm over the period of examination (Fig. 6). This increase was considered to reflect the volumetric increase of the bone and closely matches the increase in CSA. The BMD showed a slight decrease in this foal (−1.25% per month, \( P < 0.01 \)), remaining fairly static at approximately 0.96 g/cm³ (Fig. 7). CBD exhibited an even smaller decline (−0.41% per month, \( P < 0.01 \)) remaining almost constant at 1.86 g/cm³ (Fig. 7), while the estimate of the modulus of elasticity, \( E \), was constant at 17.6 GN/m² (Fig. 8).

A comprehensive summary of all values determined in the study for the 5 foals is given in Table 1. The average values for the 5 foals, meaned for left and right legs, have been standardized (using the appropriate regression line) to 52 weeks of age and are given with 1 standard deviation. The variation with time for each measurement is expressed as a percentage change per month (28 days) and the level of significance for the change is listed. For the four direct measurements which showed significant variation, Table 2 presents more detailed information. Table 2 lists the mean values (±SD) of \( C_a \), \( C_b \), CSA and BMC for the 5 foals standardized for different ages.

Discussion

Despite its obvious importance in equestrian athletics, there has been very little sequential information on bone quality with respect to skeletal maturation in horses. Safe,
Figure 4. Changes in apparent transverse ultrasound velocity ($C_a$ m s$^{-1}$) and transverse cortical ultrasound velocity ($C_b$ m s$^{-1}$) with age for Standardbred foal D.

Figure 5. Change with age in the ultrasonic estimate of the cortical cross sectional area (CSA cm$^2$) of the mid-metacarpal site in Standardbred foal D.
FIGURE 6. Mean results of bone mineral content (BMC g cm\(^{-1}\)) at the mid-metacarpal site against age for Standardbred foal D.

FIGURE 7. Change in bone mineral density (BMD g cm\(^{-3}\)) and compact bone density (CBD g cm\(^{-3}\)) in Standardbred foal D as derived from bone mineral content and cortical cross sectional area.
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FIGURE 8. Change with age in the modulus of elasticity (E GN m$^{-2}$) of the mid-metacarpal site in Standardbred foal D.

reliable and accurate techniques for the objective measurement of bone quality are now available in man (Greenfield et al., 1981; Wahner et al., 1983), and some have been applied to the horse in this study.

Plasma alkaline phosphatase concentrations provide only a crude indication of osteoblastic activity, unless the bone-specific isoenzyme can be assayed (R. A. Melick, personal communication). It may be that plasma osteocalcin (or bone Gla protein) is a more sensitive indicator since various studies have suggested that it is released into the circulation during bone formation (Nishimoto and Price, 1979; Slovik et al., 1984; Melick et al., 1985). In this study plasma alkaline phosphatase concentrations remained fairly stable which is probably a reflection of a constant rate of bone formation, consistent with the steady growth rate observed.

The rate of increase in bone density as measured by radiographic photodensitometry was inconsistent. However, the main problem with this technique is that the bone density measured radiographically must necessarily increase as the foal grows. The bone will increase in size and therefore contain more total mineral and consequently will appear more dense on the radiograph. Thus, much of the apparent increase in density measured by this technique is probably only a reflection of volumetric increase, and not of true bone density. This technique was consequently not judged to be sufficiently accurate or informative.

Despite the gradual increase (0.38% per month, $P < 0.001$) in $C_a$, consistent with the observations of Jeffcott et al. (1987), $C_a$ increased at a lower rate (0.16% per month) with a lower level of significance ($P < 0.05$). This is probably due to the changing geometry of the bone being considered, since $C_a$ is corrected for the pathway around
TABLE 1. The mean values (± SD) of the ultrasound, photon absorptiometric and derived measurements for the 5 foals.¹

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Mean (at 52 weeks)</th>
<th>% Change/month (at 52 weeks)</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent transverse velocity (Ca m s⁻¹)</td>
<td>2674 ± 50</td>
<td>0.38 ± 0.05</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Transverse cortical ultrasound velocity (Cb m s⁻¹)</td>
<td>3060 ± 60</td>
<td>0.16 ± 0.11</td>
<td>P &lt; 0.05</td>
</tr>
<tr>
<td>Cortical cross sectional area (CSA cm²)</td>
<td>6.36 ± 0.25</td>
<td>4.08 ± 0.82</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Bone mineral content (BMC g cm⁻¹)</td>
<td>6.227 ± 0.307</td>
<td>3.23 ± 0.41</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Bone mineral density (BMD g cm⁻³)</td>
<td>0.98 ± 0.02</td>
<td>-0.81 ± 0.44</td>
<td>P &lt; 0.05</td>
</tr>
<tr>
<td>Compact bone density (CBD g cm⁻³)</td>
<td>1.87 ± 0.01</td>
<td>-0.21 ± 0.21</td>
<td>NS</td>
</tr>
<tr>
<td>Modulus of elasticity (E GN m⁻²)</td>
<td>17.8 ± 0.7</td>
<td>-0.07 ± 0.44</td>
<td>NS</td>
</tr>
</tbody>
</table>

¹Both left and right legs are standardized to 52 weeks of age. The variation with time for each measurement is expressed as a percentage change per month (28 days) and the level of significance for this change is listed.

The increase in BMC at the mid-metacarpal site was considered to be volumetric and this suspicion was confirmed when the BMD was found to be fairly constant throughout the period of study. The CBD, or specific gravity, was also constant. This suggests there was no real change in the degree of mineralization of the bone over the period of investigation. There was also negligible change in the elastic bone strength or modulus of elasticity at the mid-site of the third metacarpal bone.

The total strength of any cylinder is a function of its cross sectional area and the

# TABLE 2. The mean values (± SD) of apparent transverse velocity (Ca), transverse cortical ultrasound velocity (Cb), cortical cross sectional area (CSA) and bone mineral content (BMC) for all 5 foals standardized to different ages.

<table>
<thead>
<tr>
<th>AGE (months)</th>
<th>Ca (m s⁻¹)</th>
<th>Cb (m s⁻¹)</th>
<th>CSA (cm²)</th>
<th>BMC (g cm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>2607 ± 46</td>
<td>3028 ± 41</td>
<td>4.68 ± 0.47</td>
<td>4.927 ± 0.404</td>
</tr>
<tr>
<td>8</td>
<td>2630 ± 48</td>
<td>3039 ± 46</td>
<td>5.24 ± 0.38</td>
<td>5.362 ± 0.371</td>
</tr>
<tr>
<td>10</td>
<td>2651 ± 49</td>
<td>3049 ± 53</td>
<td>5.80 ± 0.30</td>
<td>5.791 ± 0.339</td>
</tr>
<tr>
<td>12</td>
<td>2674 ± 50</td>
<td>3060 ± 60</td>
<td>6.36 ± 0.25</td>
<td>6.227 ± 0.307</td>
</tr>
<tr>
<td>14</td>
<td>2696 ± 52</td>
<td>3070 ± 67</td>
<td>6.92 ± 0.23</td>
<td>6.656 ± 0.276</td>
</tr>
<tr>
<td>16</td>
<td>2719 ± 54</td>
<td>3081 ± 74</td>
<td>7.48 ± 0.25</td>
<td>7.092 ± 0.246</td>
</tr>
</tbody>
</table>
elastic strength of the material of which it is made (Case and Chilver, 1971). If the cannon bone is considered as being essentially a cylinder, it can be seen from these results that its cross sectional area is increasing while the elastic strength \( E \) of the bone itself remains constant. Thus the total weight bearing capacity of the whole bone has increased, solely due to the increase in cross sectional area, presumably to compensate for the increasing mass of the animal.

There is an association between ultrasound velocity and exercise (Jeffcott et al., 1986a), and so the level of exercise for this group of foals was intentionally limited. The gradual increase in \( C_a \) associated with growth is very similar to the trend found in a group of Thoroughbred weanlings at pasture by Jeffcott et al. (1987). Expansion of this research will have important clinical applications. The measured bone quality of any foal could be compared with what is normal for the age group. There is also the possibility of defining critical points of bone quality as an indication of when training should commence, and what levels and types of work are appropriate. These baseline data are also critical to further research into the effects of exercise and nutrition on bone quality in the post weaning period.

Single photon absorptiometry and ultrasound velocity measurements, used alone and in combination, are safe and informative techniques for the objective assessment of skeletal maturation in horses. They are already important research tools and these results, and the work of others (Pezzoli et al., 1977; Pratt, 1980; Rabin et al., 1983; Hasegawa et al., 1985; Tomioka et al., 1985; Jeffcott et al., 1986; 1987), show their clinical importance in the in vivo determination of bone quality in the horse.

**Acknowledgments**

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COMBINED ULTRASOUND VELOCITY AND PHOTON ABSORPTIOMETRY MEASUREMENTS OF BONE QUALITY

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ABSTRACT

This paper describes the initial in vivo applications of methods developed for measuring the transverse cortical bone velocity, bone mineral content, compact bone density and modulus of elasticity on the equine metacarpal bone. It also gives a comparison of the modulus of elasticity estimated by this method with that determined by standard compression testing.

KEYWORDS

Equine bone; cortical bone; ultrasound velocity; bone mineral density; bone mineral content; compact bone density; modulus of elasticity.

INTRODUCTION

A simple non-invasive transmission method of measuring the transverse ultrasound velocity and estimating the cross sectional area in the equine metacarpal bone has been developed (McCartney and Jeffcott, 1985). The bone mineral content measured by photon absorptiometry (Cameron and Sorenson, 1963) together with the cross sectional area allows the estimation of the bone mineral density. A model of cortical bone (Greenfield et al 1981) uses the bone mineral content and the cross sectional area together with estimates of the microscopic bone mineral density and the collagen density to estimate the compact bone density. By using this compact bone density and the ultrasound velocity the modulus of elasticity (Young's modulus) is estimated.

The method was developed initially on perspex phantoms and 10 post mortem bones and is now being applied in vivo. The equine metacarpal bone is an excellent bone for assessing the usefulness of this technique as it is large, accessible, has minimal surrounding tissue and is subjected to considerable biomechanical strain, particularly in equestrian sports.

THEORY

The ultrasound measurements give an estimate of the apparent cortical bone velocity of sound Ca (Jeffcott and McCartney 1985), the transverse
cortical velocity of sound, $C_b$ (McCartney and Jeffcott 1985) and the cross sectional area of the cortical shaft, $CSA$. The single photon absorptiometry measurements give the bone mineral content, $BMC$. The bone mineral density, $BMD$, is then calculated from:

$$BMD = \frac{BMC}{CSA}$$

(1)

The compact bone density, $CBD$, is estimated using a bone model (Greenfield et al. 1981) which involves assumed constants for the microscopic bone mineral density, $\rho_b$, and the collagen density, $\rho_c$, in the equation:

$$CBD = \rho_c + (1 - \rho_c/\rho_b) \cdot \frac{BMC}{CSA}$$

(2)

The transverse modulus of elasticity, $E$, is estimated using the equation:

$$E = CBD \cdot C_b$$

(3)

EQUIPMENT

The ultrasound measurements were made using two 2.25 MHz, 13 mm diameter transducers mounted on an electronic digital caliper (Max-cal Model 950-101), pulse modules and preamp (Panametrics Models 5055 and 5660B) and a digital storage oscilloscope (Tektronix Model 468). An Apple II Plus microcomputer was used to apply the algorithms.

The BMC values were determined using a Norland Digital Bone Densitometer (Prototype Model 2781, Large Animal Scanning System, LASS). The compressive tests were conducted on an MTS Universal Servo-controlled Testing machine.

METHODS

Ultrasound measurements were taken approximately weekly on a Thoroughbred weanling from an age of 4 months through to an age of 16 months. Estimates of BMC were also made approximately monthly over the same period. All ultrasound measurements were made with the weanling standing, whereas the first three BMC measurements were made under anaesthesia with only the latter taken standing.

A group of 7 mature Thoroughbred racehorses were measured before and after 3 months of training by treadmill exercise.

A group of 10 post mortem metacarpal bones measured for ultrasound velocity, cross sectional area and bone mineral content were then compression tested to estimate the longitudinal Young's modulus. Each bone was sawn on a milling machine using two slitting blades to produce parallel ends on the central 164 mm of the shaft. The compression was applied along the shaft and the longitudinal Young's modulus calculated from the steepest straight line section of the stress / strain curve.

RESULTS

Figure 1 records $Ca$ and $Cb$ against age in days for the weanling whereas
Fig. 2 records the BMC variation over the same period. Figure 3 shows the estimated CSA which was then used with the BMC to produce the CBD, BMD (Fig. 4) and E (Fig. 5).
TABLE 1 Results from Racehorses Before and After Training

<table>
<thead>
<tr>
<th>Units</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>2851 (+/- 40)</td>
<td>2891 (+/- 33)</td>
</tr>
<tr>
<td>Cb</td>
<td>3210 (+/- 54)</td>
<td>3276 (+/- 47)</td>
</tr>
<tr>
<td>BMC</td>
<td>9.82 (+/- 0.65)</td>
<td>9.69 (+/- 0.68)</td>
</tr>
<tr>
<td>BMD</td>
<td>1.12 (+/- 0.11)</td>
<td>1.11 (+/- 0.07)</td>
</tr>
<tr>
<td>CBD</td>
<td>1.96 (+/- 0.06)</td>
<td>1.95 (+/- 0.04)</td>
</tr>
<tr>
<td>E</td>
<td>20.5 (+/- 1.3)</td>
<td>21.1 (+/- 0.9)</td>
</tr>
</tbody>
</table>

The mean (+/- 1SD) results of Ca, Cb, BMC, BMD, CBD and E for the 7 mature Thoroughbred racehorses before and after a 3 month training regime are listed in Table 1.

The estimates of the transverse Young's modulus from the ultrasound and absorptiometry measurements are compared with the direct compression measurements of the longitudinal Young's modulus in Fig. 6.

CONCLUSIONS

These preliminary results are encouraging in demonstrating that changes in some strength parameters can be measured in vivo noninvasively. As anticipated the results for apparent velocity, which is dependent on the ultrasound pathway increased with age for the weanling, whereas the transverse bone velocity remained almost constant. The bone mineral content also rose with age whereas again the compact bone density and the bone mineral density were constant. The cross sectional area estimations not only showed the anticipated increase but also illustrate the precision of the technique. There is very little change in Young's modulus with age in this case.

A statistical analysis of the results from the 7 racehorses indicated that there was no significant difference in bone mineral content, bone mineral density and compact bone density between the before and after measurements. There was a significant difference in the apparent velocity (p < 0.001) and the cortical bone velocity (p < 0.001). The confidence was not as definite for the increase in the transverse Young's modulus (p < 0.1).

ACKNOWLEDGEMENTS

Our thanks to other members of the team, Dr S. Buckingham, Dr R. McCarthy and Miss T. Waters and to Mr B. Hutchinson (RMIT) for his assistance with the compression tests.
REFERENCES

Ultrasonic transmission velocity and single photon absorptiometric measurement of metacarpal bone strength: An in vitro study in the horse

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Department of Applied Physics, Royal Melbourne Institute of Technology, Latrobe Street, Melbourne, Victoria, 3000, Australia

Summary
Ten pairs of third metacarpal bones from Thoroughbred horses aged two to 12 years were used to estimate bone strength. Measurements of transverse cortical ultrasound velocity, cortical cross sectional area and bone mineral content were made using ultrasonic transmission velocity and single photon absorptiometry. These data were used to determine bone mineral density, compact bone density and modulus of elasticity. The results were compared with those measured by direct means or chemical analysis and satisfactory correlations were obtained between estimated and measured values. Single photon absorptiometry was found to be more accurate than dual photon absorptiometry. The estimated modulus of elasticity in the transverse direction correlated well with the measured longitudinal value obtained by compression testing. This investigation confirmed the value and precision of using a combined ultrasonic and photon absorptiometric technique for non-invasive measurement of bone strength.

Introduction
The mechanical properties of equine bone have been investigated by various techniques, although few of these are readily applicable to the live animal (Ryman, Ledbetter, Boyd and Roy 1971; Cheney, Linn and Wheat 1973; Schreyer 1978; Pratt 1980). There is great potential, therefore, for methods that can be used to measure bone strength in vivo and assess the effects of exercise and locomotory stress.

Bone strength can be estimated by measuring the transmission velocity of ultrasound and by determining an index of bone density (eg. mineral density or specific gravity). Ultrasound velocity in bone is dependent on a number of important factors including its density, water content, the orientation of fibres in the bone matrix and the direction of the ultrasound path (Lee, Ahern and Leonard 1983). Lee,

Barnard and Churchill (1987) related ultrasound velocity (C) and wet density of bone (p) to the longitudinal elastic modulus (k) by the following equation:

\[ k = \rho C^2 \]

Bone mineral content (g/cm) can be measured accurately in vivo by single photon absorptiometry in the horse (Jeffcott, McCartney and Speirs 1986). The bone mineral density (g/cm\(^3\)) can then be estimated if the cross sectional area of the bone is known (Huff and Hayes 1984; McCartney and Jeffcott 1987).

A method has been described to estimate equine bone strength by the use of combined transmission ultrasound and photon absorptiometry (McCartney and Jeffcott 1987). This study was based on the investigation of 10 metacarpal bones deliberately selected for the uniformity of their dimensions and recorded cortical bone ultrasound velocity and mineral content. In addition, the cortical cross sectional area of the metacarpal shaft was estimated ultrasonically using factors established for the ovality of the external cortical boundary and the medullary cavity. However, one important consideration not properly accounted for in the preliminary study, was the considerable variation that occurs in the cross sectional profile of the third metacarpal bone in horses (Fig 1). This investigation is an extension of the previous work by McCartney and Jeffcott (1987) which establishes further baseline values for equine bone strength in vivo and provides an improved ultrasonic estimate of cross sectional area. In addition the modulus of elasticity, as estimated by the combined use of ultrasound velocity and photon absorptiometry, is compared to actual bone strength derived from compression of the metacarpal shaft.

Materials and methods

Bone specimens

The metacarpal bones from 10 Thoroughbred racehorses...
Fig 1. Transverse section of the mid-metacarpal site from two Thoroughbreds demonstrating the difference of geometric profile

Fig. 1. Transverse section of the mid-metacarpal site from two Thoroughbreds demonstrating the difference of geometric profile.

TABLE 1: Protocol for the investigation of in vitro bone strength using 10 pairs of equine metacarpal bones

<table>
<thead>
<tr>
<th>Metacarpal bones from 10 horses (ie, 10 pairs of bones)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonic and single photon absorptiometric techniques performed on all 20 bones</td>
</tr>
<tr>
<td>10 bones (1 from each pair) cut into 11 equal transverse sections on a milling machine</td>
</tr>
<tr>
<td>9 bones used for rectilinear scanning by dual photon absorptiometry</td>
</tr>
<tr>
<td>10 bones used for ultrasound velocity measurement at medulla at 11 sites</td>
</tr>
<tr>
<td>10 bones (one from each pair) cut into 160 mm lengths and subjected to compression testing</td>
</tr>
<tr>
<td>10 bones used for determination of cortical cross sectional area, volume and specific gravity</td>
</tr>
<tr>
<td>5 sections of bone numbers 2, 4, 6, 8 and 10 (n = 50) used for ash determination and Ca and P estimation</td>
</tr>
<tr>
<td>6 sections of bone (numbers 1, 3, 5, 7, 9 and 11) (n = 60) had 1.5 cm dorsal cortex removed for ultrasound velocity measurement</td>
</tr>
</tbody>
</table>

and soft tissues were removed, wrapped in clear plastic food wrapping (Glad-Wrap; Glad Products, Australia) to minimise dehydration and stored at -9°C until the time of examination. The bones were of approximately the same length, but the cross sectional profile varied considerably (Fig 1). The protocol for examination of the bones involved a range of techniques and measurements to assess bone strength as shown in Table 1.

Ultrasonic measurements

The bones were thawed for 24 h before any measurements were carried out. The lateral bone diameter (X), time of flight of ultrasound transmitted through the cortex alone (Cc) and through the corticomedullary pathway (V) were determined at 11 sites on the metacarpal shaft (McCartney and Jeffcott, 1987). Each measurement was repeated five times at each site. From each measurement, values for transverse cortical bone velocity (Cc) and the corticomedullary ratio (Rc) were estimated. The measured transverse cortical bone velocity (Cc) was performed on six small sections (approximately 10 x 10 x 15 mm) cut from the dorsal cortex of 10 bones.

The estimate of cortical cross sectional area (CSA) was adapted from that described by McCartney and Jeffcott (1987), by correcting for the outline of the metacarpal not being a true ellipse. Many of the bones were noted to have dorsomedial enlargement of the diaphysis, and a triangulation technique was used to estimate the effect of this enlargement on the assumed ovality, by taking measurements from the radiographs of the sectioned bones. The method involved measuring three sides of a triangle, M, L and P (Fig 2), from which a dimension of the metacarpal bone in the dorsopalmar direction (H) can be estimated using the following equation:

\[ H = M^2 - \left(\frac{M^2 + P^2 - L^2}{4} \right)^2 \]

The ultrasound velocity of the medullary tissue (Cc) was determined by removing the medulla as a plug from all 11 sites of the 10 bones, and was measured at each site in three planes (ie, dorsopalmar, mediolateral and proximal to distal).

Fig 2. Formula used for the estimation of the dorsopalmar diameter of the third metacarpal bone

Photon absorptiometry

Single photon absorptiometry – The bone mineral content
(BMC) was estimated by single photon absorptionmetry using a Norland bone densitometer with an americium radionuclide (241 Am) source (Jelfcott et al. 1984). The same 11 sites were used and five readings taken at each site.

**Combined ultrasonic and single photon absorptiometry data** - Values were estimated for bone mineral content (BMC), cortical bone density (CHb), and modulus of elasticity (E1), after the method of McCarter and Jelfcott (1987).

**Dual photon absorptiometry** - The bone mineral content (BMC) of nine bones, one from each of nine pairs, was determined by dual photon absorptiometry using a BMC-Lab 22a (Novo, USA). The same area of the metacarpal shaft as covered by the 11 single photon absorptiometry measurements was scanned rectilinearly.

**Compression testing**

Ten of the metacarpal bones were cut on a milling machine (Shimpe and Adcock, UK) to obtain a central portion of the shaft, 160 mm in length with parallel ends. Each portion was tested to yield point on an MTS Universal Servocontrolled testing machine under longitudinal compression at a strain rate of 0.1/sec. The longitudinal elastic stiffness coefficient (Eak) was calculated and the force required for yielding was recorded.

**Other bone measurements**

The other metacarpus from each pair of bones was cut on a milling machine to provide 11 transverse sections, the average thickness of each was determined at 12 independent points using a digital micrometer. The sections were then radiographed and the lateral and dorso-palmar diameters of the medulla and cortex were measured to provide the corticomedullary ratio (Rcm) and the ovality factors.

The medulla was removed from each section and the compact bone cleaned of peristeum and endosteum. Each section was weighed in air and before and after removal of the split bone, to determine the volume and the specific gravity (CBDa). The cross-sectional area of compact bone (CSAa) was derived by dividing the volume of each section by its measured thickness.

**Chemical analyses**

Five of the sections (1, 2, 4, 6, and 10) were defatted in a mixture of diethylether, acetone and petroleum ether (ratio 1: 1: 1) using a Soxhlet apparatus for 48 h. They were drained for 24 h at 60°C and then ashed at 600°C for 24 h to provide a measure of bone mineral content (BMCa). The ash was dissolved in 50 ml of 28% hydrochloric acid. Calcium was assayed using an atomic absorption spectrophotometer at 422.7 nm, and phosphorus was measured on a standard colorimeter using a standard phosphatic kit (bioMerieux, Charbonnieres-les-Bains, France).

**Preparation of standard phantom**

A section (approximately 1 cm) from the mid-shaft of a separate third metacarpal bone was embedded in polyester resin for use as a bone standard to monitor the precision of the Norland bone densitometer. The BMC of the phantom was measured 50 times and was also scanned five times once a week to identify any long-term variation in the technique.

**Statistical analyses**

The variations of ultrasound velocity and bone mineral content from the mid-site of each bone were analysed using a Students t test. The correlation of the estimated and directly measured bone parameters were analysed using paired two-tailed t-tests.

**List of abbreviations**

- C = apparent transverse ultrasound velocity (m/sec)
- Cm = ultrasound velocity through medulla (m/sec)
- Cc = transverse cortical bone ultrasound velocity (m/sec)
- Ck = estimated transverse cortical bone ultrasound velocity (m/sec)
- Cb = bone mineral content (g/cm

<table>
<thead>
<tr>
<th>Cm</th>
<th>Cc</th>
<th>Ck</th>
<th>Cb</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>200</td>
<td>300</td>
<td>400</td>
</tr>
</tbody>
</table>

**Results**

The results of the measured and estimated ultrasound velocity values are shown in Table 2. The overall mean apparent ultrasound velocity (Cm) for all sites of the nine bones was 3064 ± 61 m/sec, but there was variation between sites along the metacarpal shaft. The more proximal sites gave significantly higher apparent velocities than the distal sites (Table 3). The mean ultrasound velocity through the medulla (Cm) was 1470 ± 27 m/sec and did not vary with site or the direction of the ultrasound path.

The mean transverse cortical ultrasound velocity (Ck) measured through the small sections of dorsal cortex was 3217 ± 55 m/sec, whereas Cc was 3261 ± 73 m/sec. The relationship between Cc and Ck showed a correlation of r = 0.46 (Fig 3). There were no significant differences in Cm between sites along the metacarpal shaft.

The corticomedullary ratio (R1) estimated ultrasonically tended to be a little greater than that measured (R2) on the radiographs of the bone sections (Table 2). The correlation coefficient between the two techniques was 0.66. The cortical cross-sectional area (CSAa) for most bones tended to decrease from the most proximal site to the mid-site and then fall sharply towards the more distal sites where there was an increasing amount of trabecular bone in an enlarged medullary

<table>
<thead>
<tr>
<th>R1</th>
<th>R2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cb</th>
<th>Cm</th>
<th>Cc</th>
<th>Ck</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>200</td>
<td>300</td>
<td>400</td>
</tr>
</tbody>
</table>

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TABLE 2: Results of ultrasound velocity measurements from the third metacarpal bones of 10 horses

<table>
<thead>
<tr>
<th>Measured values</th>
<th>Estimated values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_a$ - apparent transverse cortical velocity (m/sec)</td>
<td>$C_{at}$ - transverse cortical velocity (m/sec)</td>
</tr>
<tr>
<td>$C_b$ - ultrasound velocity through medulla (m/sec)</td>
<td>$R_a$ - corticomedullary ratio</td>
</tr>
<tr>
<td>$C_{am}$ - transverse cortical velocity (m/sec)</td>
<td>$CSA$ - cortical cross sectional area (cm$^2$)</td>
</tr>
<tr>
<td>$R_a$ - corticomedullary ratio</td>
<td></td>
</tr>
<tr>
<td>$CSA$ - cortical cross sectional area (cm$^2$)</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3: Variation (per cent change $\pm$ sd) in apparent transverse cortical velocity ($C_a$, m/sec) at different sites in the metacarpal shaft of 20 bones

<table>
<thead>
<tr>
<th>Site on metacarpal shaft</th>
<th>Mean percent change from midsite value</th>
<th>SD</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal 5 cm</td>
<td>-0.01</td>
<td>$\pm$ 0.53</td>
<td>P &gt; 0.5</td>
</tr>
<tr>
<td>Proximal 4 cm</td>
<td>+0.08</td>
<td>$\pm$ 1.39</td>
<td>P &gt; 0.5</td>
</tr>
<tr>
<td>Proximal 3 cm</td>
<td>-0.03</td>
<td>$\pm$ 1.06</td>
<td>P &gt; 0.5</td>
</tr>
<tr>
<td>Proximal 2 cm</td>
<td>+0.01</td>
<td>$\pm$ 0.77</td>
<td>P &gt; 0.5</td>
</tr>
<tr>
<td>Proximal 1 cm</td>
<td>+0.17</td>
<td>$\pm$ 0.51</td>
<td>P &gt; 0.1</td>
</tr>
<tr>
<td>Midsite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal 1 cm</td>
<td>-1.06</td>
<td>$\pm$ 0.79</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Distal 2 cm</td>
<td>-2.12</td>
<td>$\pm$ 0.89</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Distal 3 cm</td>
<td>-3.19</td>
<td>$\pm$ 1.38</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Distal 4 cm</td>
<td>-4.11</td>
<td>$\pm$ 2.49</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Distal 5 cm</td>
<td>-4.48</td>
<td>$\pm$ 3.26</td>
<td>P &lt; 0.001</td>
</tr>
</tbody>
</table>

Data on the bone phantom

The coefficient of variation for 50 scans of the bone phantom was 1.42 per cent. There was no significant variation in the BMC of the phantom over a period of four months.

Discussion

The transverse cortical ultrasound velocity ($C_{am}$) of the dorsal cortex of the equine metacarpus compared well with the measurements, and as measured by compression are shown in Table 4.

The mean calcium content of the bone ash was 41.33 $\pm$ 1.90 mg Ca/100 mg ash. The mean phosphorous content of the bone ash was 12.52 $\pm$ 1.83 mg P/100 mg ash. No significant relationship was found when the calcium content was compared to $C_{at}$ or $C_{am}$.
TABLE 4: Results of bone mineral and elastic modulus measurements from the third metacarpal bones of 10 horses

<table>
<thead>
<tr>
<th>Measured values</th>
<th>n</th>
<th>Mean</th>
<th>Estimated values</th>
<th>n</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BMC&lt;sub&gt;M&lt;/sub&gt;</strong></td>
<td>Bone mineral content (g/cm)</td>
<td>50</td>
<td>9.94 ± 1.08</td>
<td><strong>BMC&lt;sub&gt;E&lt;/sub&gt;</strong></td>
<td>Bone mineral content (g/cm)</td>
</tr>
<tr>
<td>Ashing</td>
<td></td>
<td></td>
<td>a) Single photon absorptiometry</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BMD&lt;sub&gt;M&lt;/sub&gt;</strong></td>
<td>Bone mineral density (g/cm)</td>
<td>40</td>
<td>1.150 ± 0.040</td>
<td><strong>BMD&lt;sub&gt;E&lt;/sub&gt;</strong></td>
<td>Bone mineral density (g/cm)</td>
</tr>
<tr>
<td><strong>CBD&lt;sub&gt;M&lt;/sub&gt;</strong></td>
<td>Compact bone density (g/cm)</td>
<td>89</td>
<td>1.987 ± 0.030</td>
<td><strong>CBD&lt;sub&gt;E&lt;/sub&gt;</strong></td>
<td>Compact bone density (g/cm)</td>
</tr>
<tr>
<td><strong>E&lt;sub&gt;M&lt;/sub&gt;</strong></td>
<td>Modulus of elasticity (GN/m&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>10</td>
<td>13.48 ± 1.15</td>
<td><strong>E&lt;sub&gt;E&lt;/sub&gt;</strong></td>
<td>Modulus of elasticity (GN/m&lt;sup&gt;2&lt;/sup&gt;)</td>
</tr>
</tbody>
</table>

Values measured in other species (Table 6) and with those previously measured in the horse (McCarty and Jeffcott 1987). Other reports of cortical ultrasound velocity in the equine metacarpus have concentrated on the apparent transverse cortical velocity (C<sub>T</sub>) through the mid-metacarpal shaft (Pratt, 1980; Tomioka, Hasegawa, Koneko and Oikawa 1985; Glade, Luba and Schyver 1986). Tomioka et al (1985) found that C<sub>T</sub> in the metacarpal shaft had a significant negative correlation to the size of the medullary cavity and was also positively correlated to the amount of interstitial lamellar bone. The velocities measured in this study are dependent on the cross-sectional profile and area of the cortex, the size of the medullary cavity, the density and histological type of bone present.

The data here showed that C<sub>T</sub> measured through the dorsal cortex was uniform throughout the length of the metacarpal shaft in horses of this age group. This reflects the uniformity of the density of compact bone from the metacarpal shaft. Previous reports of directly measured bone velocity tend to be greater than that recorded here, but this is because ultrasound of higher frequencies (ie. 5 to 10 MHz) was used and its velocity was often measured in a longitudinal rather than a transverse direction (1.04c). This variation emphasizes the anisotropic and bone-elastic properties of bone.

Values for C<sub>T</sub> were higher than those recorded by direct measurement. The correlation between the directly measured and estimated ultrasound velocity was low (r = 0.46), although still significant (P < 0.01). The ultrasound path through the metacarpal cortex is in a partially radial, but predominantly transverse direction, so the estimation of the transverse cortical ultrasound velocity will combine both of these directions. The measured ultrasound velocity was made in a transverse direction. Although the velocity of ultrasound in radial and transverse directions tend to be the same (Lang, 1979), the attenuation of the ultrasound beam in the radial direction is much greater (James, Yont and Katz 1985). This may explain some of the discrepancies between the measured and estimated transverse cortical ultrasound velocity. The cortical ultrasound velocity measurements may have been improved if the cut surfaces of the bone cubers could have been made perfectly parallel. This correlation may be expected to improve if a wider range of values for C<sub>T</sub> was used. Only 20 bones were used here and the preliminary report of McCartney and Jeffcott (1987) involved only 10 adult metacarpal bones. A much larger sample will be required to approximate more accurately the normal population and to identify any differences due to training or other effects.

It was not possible in this study to measure both the cortical and corticomedullary pathways at all 11 sites as was described by McCartney and Jeffcott (1987). The ability to detect both pathways was poor in the distal metacarpal shaft and this corresponded with increasing amounts of trabecular bone in the medullary cavity tends to disperse and attenuate the ultrasound travelling by the corticomedullary pathway. The measurement, when achieved, of the ultrasound velocity through the metacarpal shaft was found to be very reproducible. Forty repeat measurements of C<sub>T</sub> at one site gave a coefficient of variation of 0.32 percent.

The ultrasonic estimation of cross-sectional area (CSA<sub>T</sub>) was greatly improved by considering the asymmetrical profiles of the cortical shaft. The triangulation technique to estimate the dorsal enlargement of the metacarpus significantly improved the estimate of CSA<sub>T</sub>. The correlation of CSA<sub>M</sub> to CSA<sub>E</sub> was increased from 0.27 to 0.68. This technique was chosen because it is easily conducted on the live horse and does not require standardised lateral radiographs for radiomometry. However, there was still a tendency to underestimate CSA in some bones and overestimate it in others (Fig 4A). For individual bones the correlation of CSA<sub>M</sub> to CSA<sub>E</sub> was often excellent. The error in the ultrasonic estimate of CSA reduced the sensitivity of the subsequent calculations of BMD, CBD and E. Thus, the variability in the estimates of CSA may affect the variability in the subsequent calculations of BMD and E.

TABLE 5: Variation (per cent change ± SD) in bone mineral content (BMC g/cm<sup>2</sup>) measured by single photon absorptiometry at different sites in the metacarpal shaft

<table>
<thead>
<tr>
<th>Site on metacarpal shaft</th>
<th>Mean per cent change from midsite value</th>
<th>sd</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal 5 cm</td>
<td>+11.00</td>
<td>2.06</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Proximal 4 cm</td>
<td>+8.76</td>
<td>2.53</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Proximal 3 cm</td>
<td>+7.28</td>
<td>1.81</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Proximal 2 cm</td>
<td>+4.66</td>
<td>1.05</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Proximal 1 cm</td>
<td>+2.40</td>
<td>0.67</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Midsite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal 1 cm</td>
<td>-2.18</td>
<td>1.17</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Distal 2 cm</td>
<td>-4.11</td>
<td>1.56</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Distal 3 cm</td>
<td>-6.03</td>
<td>1.59</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Distal 4 cm</td>
<td>-7.57</td>
<td>1.60</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Distal 5 cm</td>
<td>-9.65</td>
<td>1.86</td>
<td>P &lt; 0.001</td>
</tr>
</tbody>
</table>
BMD, CBD and E are primarily a reflection of the variability of the estimate of CSA. The uncertainty of the estimated ratio of medullary to cortex in the medial to lateral direction accounts for some of the inaccuracy of CSA, which is based on the assumption that the cross sectional profile of the bone approximates an ellipse. The cross sectional profile of many of the bones used did not approximate an ellipse, with many bones showing marked dorsal and craniomedial enlargement of the diaphysis (Fig 1), which will also account for some of the discrepancies of the estimation of CSA. This type of enlargement is seen in many Thoroughbred metacarpal bones and is presumably a bone modelling response to concussion during exercise and may be related to a previous episode of shin soreness.

BMC, as estimated by single photon absorptiometry, was shown to be a precise indicator of the mineral content, but tended to underestimate the real value as determined by ashing. Tomioka et al. (1985) have shown similar results when scanning equine metacarpal bones using the same type of equipment. Subsequent work has shown a very good correlation coefficient between BMC and ash has content ($r = 0.99$), but the ratio of BMC to ash was about 0.91 (R. N. McCarthy and L. B. Jeffcott, unpublished data). A possible explanation for this underestimation of BMC may be the use of incorrect linear mass absorption coefficients for BMC calculation. The equipment used here for single photon absorptiometry was initially designed for the measurement of human bone.

It was interesting that the dual photon and single photon absorptiometry results were not directly comparable. The average BMC result for the 11 sites, as estimated by single photon absorptiometry, was used to compare with the linear mean of the dual photon absorptiometry. This showed that dual photon absorptiometry underestimated BMC when compared to single photon absorptiometry and the ash content. The reason for this marked difference by the dual photon technique is not known.

The recorded calcium content of the bone ash was consistent with values reported for equine compact bone (Blitz and Pellegrino 1969; Schryver et al. 1974; Jeffcott and McCartney 1985; Tomioka et al. 1985), although the values reported by Jeffcott and McCartney (1985) seem unusually low for adult cortical bone. The phosphorus content measured in this study is low when compared to values previously reported for equine bone (Blitz and Pellegrino 1969; Schryver et al. 1974; Jeffcott and McCartney 1985; Tomioka et al. 1985). This technique did not always produce consistent results. There appears to have been a systematic error in phosphorus estimation when results are compared to reported values for bone ash phosphorus, although the specific error could not be identified. The results for the phosphorus content of bone ash reported in the

**Fig 4.** Cortical cross sectional area (CSA) as measured from radiographs compared with the results obtained by ultrasonic means (CSA') a) data for all 20 bones; b) results from two individual metacarpal bones.

**Fig 5.** Bone mineral content measurement (BMC) a) comparison of BMC derived from single photon absorptiometry with that measured by ashing [BMC]; b) comparison of single and dual photon absorptiometry.
literature also exhibit a range. This may be due to the different techniques used and the different sites harvested for compact bone.

There was some discrepancy between the estimated value of modulus of elasticity (E₂) and the measured value (Eₐ). The difference may be explained by considering the viscoelastic properties of bone and therefore the value reflects two extremes of strain rate: very low at 0.1 Hz for compression and very high at 2.25 MHz for ultrasound (Lappi, King and LeMay 1979). This feature was also noted by Abendschein and Hyatt (1970), who demonstrated a good correlation between E₀ and E₂ when using normal and markedly osteoporotic bone samples. The ultrasound determination of E₂ reflects the intrinsic stiffness of compact bone, but does not account for overall bone morphology which would have influenced the results gained from compression testing. The modulus of elasticity was measured by compression in a longitudinal direction whereas it was estimated in a transverse direction using ultrasound. The anisotropy of E of bone has been well demonstrated (Lang 1970) and it is thought that estimation in a transverse direction correlates well with estimation along the major axis. Therefore the results of E by the two methods are not expected to give the same value, but should correlate well. The results show very uniform ultrasound velocity and density for compact bone from the metacarpal shaft, and indicate that the elastic modulus for these bones should also lie in a narrow range. In future experiments we intend to use small cubes of bone in compression to determine E for comparison with the ultrasound velocity.

The method for estimating C and CSA using the ultrasound technique has been based on constants measured from the metacarpal bones of horses older than two years. The application of this technique to horses less than two years of age may require alteration of these constants as the morphology of the metacarpus changes during growth. Measurement of these constants from young horses is currently being carried out.

It is clear that for a meaningful assessment of bone maturity the overall bone size relative to the size of the animal should be considered, as well as the intrinsic bone strength, as estimated by ultrasound velocity. Therefore to assess the ability of the equine metacarpal bone to resist the rigors of intensive exercise it will also be necessary to evaluate its inertial properties (i.e., the distribution of bone around its long axis) as well as its intrinsic bone strength.

Acknowledgements

The authors would like to thank Mr T. Anderson for expert technical assistance; Simon Buckingham for his assistance and advice and Drs E. Seeman and J. MacKay for allowing us use of their Dual Photon Absorptiometer.

References


...
Monitoring the effects of treadmill exercise on bone by non-invasive means during a progressive fitness programme

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Summary

Six Standardbred horses underwent a 14-week training programme on a treadmill. The training schedule consisted of five weeks of slow work of six to 12 km/day at 5 m/sec. This was followed by a nine week interval programme increasing in its intensity so that for the last three weeks the horses did three to four intervals/day from 600 to 1000 m at or above maximum heart rate. Ultrasound velocity through the third metacarpus showed a significant increase as a result of training. There was also a significant increase in modulus of elasticity, but no change in bone mineral content, bone mineral density or compact bone density. A decrease in ultrasound velocity was noted immediately after a session of trotting on the treadmill for 6 km. These changes reflected the potential to alter the viscoelastic properties of cortical bone through treadmill exercise, but did not explain the mechanism involved.

Introduction

It is well recognised that an increase in bone mass can be induced by exercise in both man and animals. However, the intensity of the exercise must be sufficiently higher than normal and be applied for a long enough period to provide the necessary stimulus for bone deposition. Exercise has been shown to increase bone mineral content or limit the involutional loss of bone in osteoporotic patients (Nilsan and Westin 1971, Smith, Reckedal and Smith 1984, Williams, Wagner, Wasmich and Heilbrun 1984). Studies on immature animals have demonstrated an increase in bone mass and bone density (Kiskinnik 1977, Van et al 1981). If the exercise is intense enough, an increase in bone mineral mass has also been shown to occur in a remarkably short time. However, this can also involve a significant risk of fatigue failure of bone (Marinques et al 1980).

Schuyler (1978) reported that the effect of exercise in the horse is to increase the strength of cortical bone as measured by three point bending. It has also been found that a short term intense treadmill exercise programme can increase ultrasound velocity in the third metacarpal bone without any change in the mineral content (Jeffcott, Buckingham and McCarthy 1987).

The aim of this study was to investigate more closely the alterations in ultrasound velocity through the third metacarpal bone caused by a standardised training programme on a treadmill.

Materials and methods

Animals and exercise programme

Six mature Standardbred horses, four females and two geldings, aged from five to 10 years were trained for a period of 14 weeks on a treadmill (Beltingh: Bondi Bottom, Euroa, Victoria). None of the horses had been trained within the previous two months. Exercise consisted of four weeks of slow exercise starting with 6 km/day at 5 m/sec working up to 12 km a day at 5 m/sec in the fourth week. The horses were exercised six days a week. This was followed by a nine week interval training programme in which the horses did three to four intervals a day at about 80 to 90% of heart rate maximum (HR max) with 5 mins of slow trotting between each interval. The horses did this interval training four days a week and did 12 km of slow exercise for two days a week. The interval speeds were increased during the nine weeks so that in the final three weeks the horses were doing intervals at or above HR max. The interval distance varied from 600 to 750 m depending on the speed at which it was covered. The treadmill was set at an incline of 3%.

Ultrasound velocity measurement

Ultrasound velocity measurements were made for each horse through left and right metacarpal shafts (Jeffcott and McCarthy 1985). Measurements were taken weekly before, during and after training. The routine was to take five latensono readings covering the part of the metacarpal shaft where the cortical surfaces are parallel. In addition, five measurements were made at the mid-metacarpal site at the times when photon absorptiometry was performed.

As well as measuring the apparent transverse velocity (Cₐ, m/sec) a correction was made to estimate the transverse cortical ultrasound velocity (Cₐ, m/sec) which takes into account the pathway of the ultrasonic beam around the medullary cavity. Cₐ provides a better estimate of the modulus of elasticity in vivo. An estimate of the cross sectional area (CSA cm²) of the cortical bone can also be achieved by this technique (McCarthy and Jeffcott 1987).

The immediate changes to the apparent transverse velocity at the mid-site, due to an exercise session, were also investigated. The mid-site was marked prior to the exercise period and five readings were taken before and immediately
after five or 20 mins of trotting at 5 m/sec. The ultrasound velocity data from an exercise session were analysed using formulae to correct for any changes in skin thickness (Rubin et al. 1987).

Correction for post exercise swelling

\[ V_c^{\text{post}} = V_0^{\text{post}} - \frac{1}{2} \frac{V_0^{\text{meas}} - V_0^{\text{meas}}}{[W_0/W_1]/150]} \]

Correction for pre exercise swelling

\[ V_c^{\text{pre}} = V_0^{\text{pre}} - \frac{1}{2} \frac{V_0^{\text{meas}} - V_0^{\text{meas}}}{[W_0/W_1]/150]} \]

Where \( V_c^{\text{post}} \) and \( V_c^{\text{pre}} \) are the corrected velocities after and before the exercise session, \( V_0^{\text{post}} \) and \( V_0^{\text{pre}} \) are the measured velocities after and before the exercise session, and \( W_0 \) and \( W_1 \) are the weights of the horse before and during the exercise session.

The long term ultrasound velocity data were not corrected for changes in skin thickness because the mid-site was not marked from week to week.

Single photon absorptiometry

Single photon absorptiometry was used to measure the bone mineral content (BMC g/cm²) of both left and right metacarpus (Jeffcott, McCartney and Spiers 1986). Five measurements were made at the mid-site at two-weekly intervals. Xylazine was used when necessary to tranquilise the horses so that they stood still enough for scanning.

Combination of ultrasound velocity and photon absorptiometry

Bone mineral density (BMD g/cm³), compact bone density (CBD g/cm³), and modulus of elasticity (E: GN/m²) were estimated by combining the ultrasound velocity and photon absorptiometry data. BMD is calculated by dividing BMC by the ultrasound estimate of CSA (McCartney and Jeffcott 1987).

\[ \text{BMD} = \frac{\text{BMC}}{\text{CSA}} \text{ g/cm}^3 \]

CBD (i.e. specific gravity) can be estimated by using the bone model of Greenfield et al. (1984). BMC, CSA, and estimated constants of microscopically bone mineral densities (g/cm³) and collagen densities (g/cm³) are related to CBD by the following equation:

\[ \text{CBD} = \text{pc} + 1 \cdot \text{pe} \text{ (g/cm}^3) \]

The modulus of elasticity, related to density and transverse cortical ultrasound velocity, can be estimated in vivo by the equation from McCartney and Jeffcott (1987):

\[ E = \text{CBD} \cdot C_e^2 \text{ GN/m}^3 \]

Radiograph photodensitometry

Lateral radiographs of both third metacarpal bones were taken before and after the exercise period to monitor any changes in optical density with exercise. An aluminium alloy step wedge was included in each radiograph after the method of Schmutz (1966). A Phillips XC2031 mobile x-ray machine was used with Kodak T-Mat G films and Kodak Lanex regular rate earth screens. The films were processed using Dupont Cronex Processor T3. Optical density was measured from a lateral radiograph at three sites in the mid-region of the metacarpus using a small optical densitometer (Sakura PDA-81, Komori Kikko Photo Ind.). These sites were the dorsal cortex, the palmar cortex and a site between these over the medullary cavity.

Standardised exercise tests

Nine standardised exercise tests were carried out during and after the training programme. These consisted of four to six stages during which there was an increase in speed from stage to stage. The stages consisted of two mins at five and six m/sec and one min at 7, 8, 9, 10, 11 and 12 m/sec. Heart rate was monitored during and after the test using either a horse tester (PLH 100 Polari-Electro Ky; Finland) or a custom made heart rate monitoring belt integrated into the treadmill computer (Modulatek, Brisbane, Queensland). These tests were used to measure \( V_{\text{max}} \) and HR max and were conducted in Weeks 2, 3, 4, 5, 7, 8, 11, 14 of training and five weeks after the completion of the programme.

Plasma lactate levels

Blood samples were collected prior to, and 5 mins after, a standardised exercise test for lactate determination on Weeks 4, 8, 14 of training and five weeks after the finish of training. The venous blood samples were placed in sodium fluoride tubes and stored on ice until deproteinised with perchloric acid usually within 2 h. The samples were then assayed for lactate using a blood lactate kit (Sigma Diagnostics; St Louis, Missouri USA).

Statistics

The data were analysed using a paired Students t test to compare the training and post training results with the pre-training data. The weekly ultrasound velocity and photon absorptiometry data were averaged over each period (i.e. four weeks pre-training, 14 weeks training, and four weeks post training).

Results

Only four of the horses were able to finish the training schedule. One horse was retired from work because of a recurrence of lameness due to a previous teno-ositis. Another horse developed a foot abscess from which it recovered satisfactorily. However, when re-introduced to work this horse suffered a severe bout of exertional myopathy and was retired.

Ultrasound velocity

An increase in ultrasound velocity (\( C_e \) and \( C_s \)) at the mid-metacarpal site of both forelimbs was recorded in the post training period compared to both the pre-training and training periods (Table 1). A significant decrease in \( C_e \) of both forelimbs was measured immediately after the 20 min exercise session, provided that values were corrected for changes in skin thickness. No change was noted after 5 mins of exercise, or if no correction was made for changes in skin thickness (Table 3).

Bone mineral content and other bone measurements

No change in BMC of the mid-metacarpus was detected during the training and post training periods (Table 1). There were no alterations detected in BMC or CBD as measured during the training and post training periods (Table 2). An
TABLE 1: Changes in ultrasound velocity and single photon absorptiometry data at the metacarpal mid-site in the training, and post training periods as compared to the pre-training period in four horses

<table>
<thead>
<tr>
<th></th>
<th>Apparent transverse limb velocity (Cm m/sec)</th>
<th>Transverse cortical bone (Cm m/sec)</th>
<th>Bone mineral density (BMD g/cm²)</th>
<th>Transverse cortical bone (BMD g/cm²)</th>
<th>Bone mineral density (BMD g/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training</td>
<td>L -11.26 ± 19.6 0.25 ± 32.9 0.04 ± 0.22</td>
<td>R 12.0 ± 21.6 13.0 ± 26.1 -0.15 ± 0.38</td>
<td>L 43.3 ± 14 * 51 ± 24.2 * -0.01 ± 0.47</td>
<td>R 48.3 ± 21.8 * 60 ± 25.9 * -0.04 ± 0.19</td>
<td>L 41.5 ± 12.8 * 51 ± 16.8 * 0.09 ± 0.24</td>
</tr>
<tr>
<td>Pre-training</td>
<td>R 12.0 ± 21.6 13.0 ± 26.1 -0.15 ± 0.38</td>
<td>L 43.3 ± 14 * 51 ± 24.2 * -0.01 ± 0.47</td>
<td>R 48.3 ± 21.8 * 60 ± 25.9 * -0.04 ± 0.19</td>
<td>L 41.5 ± 12.8 * 51 ± 16.8 * 0.09 ± 0.24</td>
<td>R 35.8 ± 11.0 * 47 ± 14.5 * 0.10 ± 0.24</td>
</tr>
<tr>
<td>Post training vs</td>
<td>R 12.0 ± 21.6 13.0 ± 26.1 -0.15 ± 0.38</td>
<td>L 43.3 ± 14 * 51 ± 24.2 * -0.01 ± 0.47</td>
<td>R 48.3 ± 21.8 * 60 ± 25.9 * -0.04 ± 0.19</td>
<td>L 41.5 ± 12.8 * 51 ± 16.8 * 0.09 ± 0.24</td>
<td>R 35.8 ± 11.0 * 47 ± 14.5 * 0.10 ± 0.24</td>
</tr>
<tr>
<td>Pre-training</td>
<td>R 12.0 ± 21.6 13.0 ± 26.1 -0.15 ± 0.38</td>
<td>L 43.3 ± 14 * 51 ± 24.2 * -0.01 ± 0.47</td>
<td>R 48.3 ± 21.8 * 60 ± 25.9 * -0.04 ± 0.19</td>
<td>L 41.5 ± 12.8 * 51 ± 16.8 * 0.09 ± 0.24</td>
<td>R 35.8 ± 11.0 * 47 ± 14.5 * 0.10 ± 0.24</td>
</tr>
<tr>
<td>Post training vs</td>
<td>R 12.0 ± 21.6 13.0 ± 26.1 -0.15 ± 0.38</td>
<td>L 43.3 ± 14 * 51 ± 24.2 * -0.01 ± 0.47</td>
<td>R 48.3 ± 21.8 * 60 ± 25.9 * -0.04 ± 0.19</td>
<td>L 41.5 ± 12.8 * 51 ± 16.8 * 0.09 ± 0.24</td>
<td>R 35.8 ± 11.0 * 47 ± 14.5 * 0.10 ± 0.24</td>
</tr>
</tbody>
</table>

* (P<0.05)

increase in E was measured in the post training period when compared to both the pre-training and training periods (Table 2).

The radiographic photodensitometry of the dorsal cortex, palmar cortex, or medulla showed no change in optical density due to training (Table 4).

Exercise testing

The speed at a heart rate of 200 beats/min did not show any appreciable change during the training period (Table 5). Plasma lactate accumulation after a standardised exercise test only decreased markedly in one horse, as a result of training (Table 5).

Discussion

The increase in ultrasound velocity (C and C.) after a short-term training programme in these Thoroughbreds compared to Table 3: Changes in apparent ultrasound velocity (C) at the mid-metacarpal site immediately after 1.5km and 6km of trotting.

<table>
<thead>
<tr>
<th>Limb</th>
<th>Alteration in C (m/sec)</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training</td>
<td>5 2.6 ± 16.7 P=0.745</td>
<td></td>
</tr>
<tr>
<td>Pre-training</td>
<td>R 5 12.4 ± 13.8 P=0.115</td>
<td></td>
</tr>
<tr>
<td>Post training vs</td>
<td>5 3.6 ± 24.4 P=0.758</td>
<td></td>
</tr>
<tr>
<td>Pre-training</td>
<td>R 5 0.4 ± 22.6 P=0.970</td>
<td></td>
</tr>
<tr>
<td>After 6km of trotting</td>
<td>6 -16.3 ± 28.6 P=0.236</td>
<td></td>
</tr>
<tr>
<td>Post training vs</td>
<td>R 6 -38.9 ± 21.1 P=0.029</td>
<td></td>
</tr>
<tr>
<td>Pre-training</td>
<td>R 6 -38.0 ± 20.7 P=0.0065</td>
<td></td>
</tr>
<tr>
<td>Post training vs</td>
<td>R 6 -38.0 ± 22.9 P=0.0016</td>
<td></td>
</tr>
</tbody>
</table>

well with the results of the earlier exercise study in Thoroughbreds (Jeffcott et al 1987). The change in the ultrasound velocity occurred predominantly in the post training period although there was a general trend to increasing levels throughout the training period. Wide fluctuations in ultrasound velocity occurred during the training period and this may be due to some short term variations that have been noted with exercise on the treadmill. The short term decrease of ultrasound velocity after an exercise session was not recorded in horses lunged on sand at 3.2 and 5 m/sec (Jeffcott et al 1987). It was found that marathon running can result in an increase in ultrasound velocity through the human tibia (Rubin et al 1987). There are many possible explanations for these short term changes in ultrasound velocity. For example, the changes in the visco-elastic behaviour of bone, bone temperature and interstitial fluid pressure due to exercise are possibilities which warrant further investigation. It has been shown that the ultrasound velocity in bone is reduced with an increase in temperature (Bonthefeld and Jolly 1982) and this is the most likely cause of the short term reduction in velocity that was measured after a 20 min session of trotting. It is unlikely that the long term change is due to a temperature effect as the training ended in the warmest month of the year.

The longer term increase in ultrasound velocity may have a similar basis, but might also reflect a change in the porosity of bone. This would involve a change in the wet density, which is thought to have a direct effect on the transmission of ultrasound velocity in bone (Leces, Ahern and Leonard 1983). No change was detected in the density of the bone due to exercise. However, any change in mineral content that might have occurred with this sort of exercise programme may have variations that have been noted with exercise on the treadmill.

Table 4: Results of change in radiographic optical densitometry at the end of training compared to pre-training.

<table>
<thead>
<tr>
<th>Site</th>
<th>Limb</th>
<th>Mean change in steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsal</td>
<td>Left</td>
<td>-0.135 ± 0.22</td>
</tr>
<tr>
<td>Cortex</td>
<td>Right</td>
<td>+0.103 ± 0.28</td>
</tr>
<tr>
<td>Medulla</td>
<td>Left</td>
<td>-0.183 ± 0.22</td>
</tr>
<tr>
<td>Cortex</td>
<td>Right</td>
<td>+0.008 ± 0.261</td>
</tr>
<tr>
<td>Palmer</td>
<td>Left</td>
<td>-0.073 ± 0.21</td>
</tr>
<tr>
<td>Cortex</td>
<td>Right</td>
<td>+0.19 ± 0.31</td>
</tr>
</tbody>
</table>

* (P<0.05)
been too small to be determined with single photon absorptometry. These immediate and longer term changes in the ultrasonic velocity due to exercise and training must be taken into consideration if routine monitoring of horses in training is to be carried out. The use of the formula (Rubin et al. 1987) to account for changes in skin thickness may not be feasible with routine use of the ultrasound technique as care must be taken to reduce repose errors.

Bone mineral content in these horses did not change with training which is consistent with the previous results in Thoroughbreds (Jeffcott et al. 1987). Neither was any change noted in the optical density of lateral radiographs of the metacarpal bones which compares favourably with the BMC result. BMC can be affected following a short period of exercise if it is intense enough (Marquie et al. 1988). In this study the increase in bone mineral content due to exercise also entailed a high risk of fatigue fractures, and the change in bone mineral may be the result of remodelling activity after microdamage to the bone.

The heart rate response to a standardised exercise test did not change during the training period which concurs with the result of Church, Evans, Evans and Rose (1986) who conducted a similar training schedule using Thoroughbreds. Gabel et al. (1987) conducted a similar training schedule using Standardbreds, and did not demonstrate a significant change, in the heart rate response to exercise. The accuracy and precision of the PIH 100 was demonstrated by Evans and Rose (1986), who showed a very good correlation of the PIH 100 read out and values with LCG. The present authors own tests, comparing the PIH 100 to LCG during exercise, have also shown a very good correlation (r = 0.988) R.N. McCarthy, unpublished data.

Table 5: Plasma lactate accumulation as measured in weeks 2, 8, 14 and 19 (five weeks after end of training) and weeks 4, and 12, respectively

<table>
<thead>
<tr>
<th>Time of measurement</th>
<th>Plasma lactate accumulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horse 1</td>
<td>7.9 9.8 10.0 9.9</td>
</tr>
<tr>
<td>Horse 2</td>
<td>9.1 9.7 9.8 9.8</td>
</tr>
<tr>
<td>Horse 3</td>
<td>9.1 9.9 9.9 9.9</td>
</tr>
<tr>
<td>Horse 4</td>
<td>7.5 7.7 7.5 7.0</td>
</tr>
</tbody>
</table>

References


The hock as a potential site for non-invasive bone measurement

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Summary

An in vitro study on the calcaneus of adult horses (n = 5) and foals (n = 10) was carried out using radiographic photodensitometry, single photon absorptiometry, transmission ultrasound velocity and chemical analysis. Data for trabecular bone content, ash, calcium and phosphorus levels were obtained. As techniques for assessing bone quality, ultrasound velocity was not sufficiently sensitive nor accurate and radiographic photodensitometry was found to be of limited value. Photon absorptiometry was both accurate and reproducible, although some variation in bone mineral content and bone mineral density was observed along the length of the calcaneus. Bone mineral content was estimated in a second series of fibular tarsoal bones from 23 horses ranging in age from less than six months to 16 years. The photon absorptiometry technique was also applied to the hocks of four hind limbs at post mortem and two horses under general anaesthesia. It was concluded that the calcaneus was a feasible site for photon absorptiometry, but that the present equipment would require considerable modification for use in the standing horse.

Introduction

There have been a number of recent reports concerning techniques for non-invasive measurement of cortical bone quality in the horse (Pratt 1980, Jeffcott and McCartney 1985; Tomioka et al. 1985, Jeffcott, McCartney and Speirs 1986; McCartney, Jeffcott and McCartney 1988). This has led to further work on the application of non-invasive techniques to assess skeletal maturity (Huckingham and Jeffcott 1987), the effects of training (McCarty and Jeffcott 1988) and fractures (Rubin et al. 1983). However, no attempt has yet been made to identify a predominantly trabecular bone site in the horse which is suitable for non-invasive bone measurement. The most widely used trabecular site in man is the vertebral column (Marez 1983) although the calcaneus has also been used (Shiokawa et al. 1986). In the veterinary field, successful methods for single photon absorptiometry of the bovine coxal bone (Zetterholm and Dalen 1978) and the bovine and ovine tarsus (Siemen, Moodie and Robertson 1974) have been reported.

In the horse, the calcaneus or fibular tarsoal bone of the hock, is a potential site for the assessment of trabecular bone quality. It also plays a key role in the dynamics of hindlimb locomotion and the biomechanical stresses of exercise might produce important changes in bone growth and remodelling. The purpose of the preliminary study was first, to investigate some aspects of the bone structure and mineral content of the calcaneus in vitro using the techniques of radiographic photodensitometry, single photon absorptiometry and transmission ultrasound velocity; and secondly to assess the feasibility of using this site in the live horse for non-invasive bone measurement.

Materials and methods

Excised bones

The fibular tarsoal bones of 38 horses (n = 76) were obtained for investigation. These horses were aged from one day to 16 years. The specimens were collected as soon after death as possible, the skin and soft tissues were removed and they were wrapped in clear plastic food wrapping (Glad-Wrap, Glad Product, Australia) to minimize dehydration and were stored at -20°C until examined.

Radiographic photodensitometry

Radiographs of five pairs of bones from adult horses aged two to five years, and 10 pairs from both aged one day to 12 months, were taken in the lateral plane at a focus to film distance of 109 cm, using high definition film (Min-R; Kodak Ltd) and incorporating an aluminium alloy wedge as a standard to compare optical densities of different specimens (Jeffcott et al. 1988). The exposure values for the adult bones were 70 kVp and 42 mAs. The final bones required a different range of exposures from 55 to 62 kVp and 42 mAs and a different aluminium standard was used. Measurements were made at five different sites along the length of the calcaneus (Fig 1) using a small optical densitometer (Sakura PDA-81; Komishiroku, Photo Ind.). Results were expressed as optical density units of equivalent aluminium thickness (mm).

Single photon absorptiometry

Excised bones – The bone mineral content (BMC) of specimens examined was estimated using a Norland bone densitometer (Norland Large Animal Scanning System, Model 278); Norland Corporation Fort Atkinson, Wisconsin (Jeffcott, McCartney and Speirs 1988). Two radionuclide sources, americium (241Am) and iodine (125I) were used. Each calcaneus from the adult group of horses was scanned with 241Am in two planes, (i.e. cranio-caudally and lateromedially) at five sites approximately 1 cm apart from the most proximal aspect of the tuber calcis to the level of the susten-
taclum tali. No significant difference was found between the two scanning planes. The foal specimens were scanned in the lateromedial direction and at two to four sites only because of their smaller size. They were scanned with both radionuclide sources.

Isolated limbs: The tocks from three horses were scanned with the densitometer to simulate the in vivo method. Each limb was first placed in a plastic jig and frozen in order to fix the position of the trabeculated point in the x-ray beam. The beam was also used to maintain a constant limb position for scanning. Soft tissue equivalent material was provided by two soft plastic bags half-filled with water, which were placed above and below the tock, ensuring that the bone was surrounded as evenly as possible. Each specimen was scanned twice; the first site (A) corresponding to the largest lateral diameter of the calcaneus and the second (B) at about the midpoint of the bone (Fig 2).

Isolated - The tocks of two adult horses were scanned in lateral recumbency under general anesthesia. The scanning method was identical to that described for the isolated limbs, except that only site B was measured.

Fig 2. Diagrammatic representation of the method of scanning the tock using an isolated hindlimb retained in a plastic jig. The arrows show the direction of the photon beam for the two sites A and B.

Bone mass and morphometric measurements

The isolated tarsal bones were cut into approximately 1 cm transverse sections using a milling machine (Shipley and Adcock, UK) (Fig 3). Each section was then radiographed at an exposure of 38 to 45 kVp and 60 to 90 mA (Fig 4). The relative proportion of trabecular to cortical bone was measured in the adult group (n = 5) only from the radiograph on a digitizing tablet (Videoplan, Carl Zeiss Inc, New York).

The thickness of each section was determined using a digital caliper (Jocal, Johansson, Sweden) and the volume measured by a water displacement technique. The measured bone sectional area (CSA) of each section was determined by dividing the volume of the section by its measured thickness. The specific gravity (SG) was then calculated. A crude estimate of...
cross-sectional area (CSA) was obtained from the radiographs of the cut sections of the calcaneus. This involved calculating the area within a quadrangle (ABCD) made by four points on the bone (Fig 5).

The bone specimens were dried at 77 °C for 24 h, deattered for 48 h in a solution of acetone and ether, dried for a further 48 h at 100 °C and then weighed. The bones were ashed for 24 h at 600 °C and reweighed. Ash was calculated as a percentage of wet bone weight. A determination of the bone mineral density (BMD) was made by dividing ash by the volume of the sections. Measured bone mineral content (BMC) was determined by dividing ash by thickness of the section. The ash was then dissolved in 50 ml of 2N HCl for determination of calcium and phosphorus content. Phosphorus was determined by the direct phosphomolybdate reaction without deproteinisation at 340 nm using an automated method (Corbas-Mir; Roche, Switzerland). Calcium was determined by atomic absorption spectrophotometry (GBC-992 Double Beam Atomic Absorption Spectrophotometer; Australia).

Ultrasound velocity measurement

Transmission ultrasound velocity through the proximal portion of the calcaneus was measured in the lateral-medial plane in one pair of bones. The method of Jeffcott and McCarter (1985) was used initially with 2.25 MHz transducers directly applied to the lateral and medial sides of the calcaneus. A second technique was employed using 1 MHz transducers and placing the bone in a water bath (R. N. McCarteny and L. B. Jeffcott, unpublished data). One bone was tested in this way, the other had the outer surfaces cut on a band saw in order to have a portion of trabecular bone with parallel sides and no outer cortical shell.

Results

Radiographic photodensitometry

The results of radiographic photodensitometry for the adult group of horses expressed as optical density units (ODU) of equivalent aluminium thickness are shown in Table 1. The overall pattern of bone density varied between individuals, but Sites 1, 2, 3, 4, 5, 6 and 7 respectively contained larger amounts of cortical bone. A similar trend was noted in the foal specimens. However, the results of ODU from the adult and foal groups are not directly comparable, as different exposures and aluminium alloy standards were used.

![Fig 5. Method of estimating the cross-sectional area (CSA) of the sections of calcaneus from the radiograph. The maximal cranial-medial (OD) and mediolateral (AB) lengths were measured and the area within the quadrangle (ABCD) calculated.](image)

**TABLE 1: Results of radiographic photodensitometry expressed as optical density units (ODU) equivalent to mm of aluminium for five sites in the calcaneus of five adult horses and 10 foals.**

<table>
<thead>
<tr>
<th>Site</th>
<th>Adult group Mean ODU</th>
<th>Adult group sd</th>
<th>Foal group Mean ODU</th>
<th>Foal group sd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>20.76 ± 2.9</td>
<td>20</td>
<td>3.44 ± 1.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Site 2</td>
<td>18.53 ± 1.3</td>
<td>20</td>
<td>3.98 ± 1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Site 3</td>
<td>12.2 ± 1.7</td>
<td>10</td>
<td>2.39 ± 1.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Site 4</td>
<td>17.11 ± 1.1</td>
<td>20</td>
<td>3.01 ± 1.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Site 5</td>
<td>13.63 ± 2.4</td>
<td>20</td>
<td>2.73 ± 1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Right hock</td>
<td>16.86 ± 3.7</td>
<td>45</td>
<td>3.28 ± 2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Left hock</td>
<td>16.13 ± 3.7</td>
<td>45</td>
<td>3.08 ± 2.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

TABLE 2: Results of single photon absorptiometry (BMC(g/cm²)) in the calcaneus of 18 adult horses and two horses under general anaesthesia.

<table>
<thead>
<tr>
<th>Category</th>
<th>Age (months)</th>
<th>n</th>
<th>BMC(g/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excised bones</td>
<td></td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>1 to 6</td>
<td>6</td>
<td>2.12 ± 0.3</td>
<td>1.89 ± 0.4</td>
</tr>
<tr>
<td>6 to 12</td>
<td>3</td>
<td>4.37 ± 1.66</td>
<td>4.65 ± 1.5</td>
</tr>
<tr>
<td>12 to 18</td>
<td>7</td>
<td>4.42 ± 0.62</td>
<td>4.47 ± 0.65</td>
</tr>
<tr>
<td>18</td>
<td>10</td>
<td>7.21 ± 0.76</td>
<td>6.93 ± 0.84</td>
</tr>
<tr>
<td>Isolated hindlimbs</td>
<td></td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>Post mortem</td>
<td></td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>2 to 5 yrs</td>
<td>7</td>
<td>7.04 ± 0.77</td>
<td>6.36 ± 0.63</td>
</tr>
<tr>
<td>6 to 16 yrs</td>
<td>10</td>
<td>6.62 ± 0.80</td>
<td>6.60 ± 0.92</td>
</tr>
</tbody>
</table>

TABLE 3: Mean results (±sd) of bone mineral content (BMC(g/cm²)) in the calcaneus as determined by single photon absorptiometry with 241Am and 153Gd radionuclide sources and measured by ashing (BMCash).

<table>
<thead>
<tr>
<th>Bone mineral content</th>
<th>All Sites (n = 56)</th>
<th>Right hock (n = 28)</th>
<th>Left hock (n = 28)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMC(g/cm²) 241Am</td>
<td>4.39 ± 2.37</td>
<td>4.46 ± 2.37</td>
<td>4.32 ± 2.41</td>
</tr>
<tr>
<td>BMC(g/cm²) 153Gd</td>
<td>4.52 ± 2.38</td>
<td>4.54 ± 2.43</td>
<td>4.49 ± 2.39</td>
</tr>
<tr>
<td>BMCash</td>
<td>4.58 ± 2.56</td>
<td>4.60 ± 2.58</td>
<td>4.57 ± 2.59</td>
</tr>
</tbody>
</table>
There was a good correlation (r = 0.996) between the BMC \( \text{g/cm}^3 \) as measured from ash and that obtained by single photon absorptiometry (BMC \( _{\text{sp}} \)) for the foal bones (fig 6); for the adult group a correlation of \( r = 0.90 \) was obtained. The values for the isolated hindlimbs and two horses examined under general anaesthesia are given in Table 2. These results compare well with those recorded above for the adult and foal groups. In one of the isolated hindlimbs of a seven-month-old Thoroughbred foal, two series of 20 measurements, each comprising five scans, were carried out for the two sites. BMC \( _{\text{BMD}} \) measurements obtained at site A ranged from 5.06 to 5.84 g/cm\(^3\) with a mean of 5.31 ± 0.22 g/cm\(^3\). The densitometer also recorded the width of the bone (BW). This parameter was used to confirm that the bone was scanned in the same position for all 20 measurements. The mean BW was 5.2 ± 0.14 cm with a mean ratio BMC \( _{\text{g/cm}^3} \)/BW of 1.021 ± 0.03 g/cm\(^3\). The results of BMC \( _{\text{BMD}} \) at site B ranged from 4.6 to 5.34 g/cm\(^3\) with a mean of 5.11 ± 0.19 g/cm\(^3\). A mean BW of 4.77 ± 0.17 cm and a mean ratio BMC \( _{\text{BMD}} \)/BW of 1.071 ± 0.05 g/cm\(^3\) were recorded.

**Bone mass and morphometric measurements**

The results of specific gravity, ash content and calcium and phosphorus levels are given for adult (Table 4) and foal specimens (Table 5). The cross sectional area of specimens obtained by volumetric measurement (CSA \( _{\text{BMD}} \)) and that estimated by calculation (CSA \( _{\text{BMD}} \)) correlated well for the adults (r = 0.961) and the foals (r = 0.985) (fig 7), although there was a tendency to underestimate the area by calculation from the radiograph.

Values for bone mineral density (BMD \( _{\text{BMD}} \)) were calculated by dividing BMC \( _{\text{BMD}} \) by CSA \( _{\text{BMD}} \) and a second value for bone mineral density.

---

**TABLE 4: Results of bone mineral density estimated (BMD \( _{\text{BMD}} \)) and measured (BMD \( _{\text{BMD}} \)), bone mineral density (g/cm\(^3\)), percentage ash, specific gravity (g/cm\(^2\)) and calcium and phosphorus (mg/100 mg ash) from five sites in the calcaneus of five adult horses**

<table>
<thead>
<tr>
<th>Site</th>
<th>n</th>
<th>BMD ( _{\text{BMD}} ) (g/cm(^3))</th>
<th>BMD ( _{\text{BMD}} ) (g/cm(^3))</th>
<th>Ash (%)</th>
<th>SG (g/cm(^2))</th>
<th>Ca (mg/100 mg ash)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>10</td>
<td>0.425 ± 0.056</td>
<td>0.463 ± 0.05</td>
<td>42.5 ± 7.07</td>
<td>1.291 ± 0.58</td>
<td>41.61 ± 2.67</td>
<td>19.43 ± 2.52</td>
</tr>
<tr>
<td>Site 2</td>
<td>10</td>
<td>0.449 ± 0.067</td>
<td>0.484 ± 0.06</td>
<td>45.47 ± 7.47</td>
<td>1.393 ± 0.58</td>
<td>42.85 ± 2.36</td>
<td>18.73 ± 1.28</td>
</tr>
<tr>
<td>Site 3</td>
<td>10</td>
<td>0.529 ± 0.073</td>
<td>0.569 ± 0.06</td>
<td>47.82 ± 5.69</td>
<td>1.372 ± 0.070</td>
<td>40.07 ± 1.75</td>
<td>19.17 ± 1.19</td>
</tr>
<tr>
<td>Site 4</td>
<td>10</td>
<td>0.602 ± 0.080</td>
<td>0.667 ± 0.07</td>
<td>50.65 ± 4.58</td>
<td>1.469 ± 0.078</td>
<td>41.43 ± 2.98</td>
<td>19.11 ± 0.8</td>
</tr>
<tr>
<td>Site 5</td>
<td>10</td>
<td>0.710 ± 0.087</td>
<td>0.745 ± 0.07</td>
<td>52.95 ± 3.58</td>
<td>1.564 ± 0.075</td>
<td>40.73 ± 3.02</td>
<td>18.71 ± 0.8</td>
</tr>
<tr>
<td>Right hock</td>
<td>25</td>
<td>0.546 ± 0.116</td>
<td>0.583 ± 0.12</td>
<td>48.16 ± 6.77</td>
<td>1.391 ± 0.128</td>
<td>41.37 ± 2.52</td>
<td>19.62 ± 1.13</td>
</tr>
<tr>
<td>Left hock</td>
<td>25</td>
<td>0.539 ± 0.137</td>
<td>0.583 ± 0.13</td>
<td>47.67 ± 6.86</td>
<td>1.404 ± 0.125</td>
<td>41.13 ± 2.43</td>
<td>19.94 ± 1.70</td>
</tr>
<tr>
<td>All Sites</td>
<td>50</td>
<td>0.543 ± 0.126</td>
<td>0.583 ± 0.12</td>
<td>47.88 ± 6.74</td>
<td>1.398 ± 0.12</td>
<td>41.25 ± 2.66</td>
<td>19.63 ± 1.43</td>
</tr>
</tbody>
</table>

**TABLE 5: Results (±sd) from the foal bones of bone mineral density (BMD \( _{\text{BMD}} \) g/cm\(^3\)) for both radionuclides courses bone mineral density measured by ashing (BMD \( _{\text{BMD}} \) g/cm\(^3\)), percentage ash, specific gravity (g/cm\(^2\)) and calcium/phosphorus content (mg/100 mg ash) for both bone mineral density**

<table>
<thead>
<tr>
<th>Site</th>
<th>n</th>
<th>BMD ( _{\text{BMD}} ) (g/cm(^3))</th>
<th>BMD ( _{\text{BMD}} ) (g/cm(^3))</th>
<th>Ash (%)</th>
<th>SG (g/cm(^2))</th>
<th>Ca (mg/100 mg ash)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>All sites</td>
<td>56</td>
<td>0.453 ± 0.103</td>
<td>0.470 ± 0.171</td>
<td>45.6 ± 4.53</td>
<td>1.091 ± 0.33</td>
<td>42.16 ± 3.62</td>
<td>17.8 ± 0.8</td>
</tr>
<tr>
<td>Right hock</td>
<td>28</td>
<td>0.458 ± 0.165</td>
<td>0.467 ± 0.175</td>
<td>45.5 ± 4.26</td>
<td>1.089 ± 0.33</td>
<td>41.86 ± 3.22</td>
<td>17.8 ± 0.92</td>
</tr>
<tr>
<td>Left hock</td>
<td>28</td>
<td>0.449 ± 0.164</td>
<td>0.472 ± 0.169</td>
<td>45.7 ± 4.85</td>
<td>1.093 ± 0.33</td>
<td>42.46 ± 4.02</td>
<td>17.8 ± 0.8</td>
</tr>
</tbody>
</table>

---

**Fig 6.** Graph showing the comparison of bone mineral content as measured by ashing (BMC \( _{\text{BMD}} \) with that estimated (BMC \( _{\text{BMD}} \)) from single photon absorptiometry with a \( ^{14} \)C source for the foal group of specimens (\( n = 56 \)).

**Fig 7.** Comparison of measured (CSA \( _{\text{BMD}} \)) to estimated (CSA \( _{\text{BMD}} \)) cross sectional area of the sections of calcaneus for the foal group of specimens (\( n = 56 \)).
density (BMD*9) was derived from the ash content (Tables 4 and 5). A good correlation between BMD*9 and BMD*9 was obtained for adult (r = 0.975) and foal (r = 0.983) bones. For the adult group the results for BMD*9 ranged from 0.32 to 0.86 g/cm² with a mean of 0.54 g/cm². A gradual increase in bone density from Site 1 to Site 5 was found. This trend was also confirmed from the results of specific gravity measurements. A similar trend was noted in the specimens examined from the foal group, but the values were lower and more variable.

The trabecular bone content of the sections of adult bone showed variation between sections and between bones, but there was a trend to decreased trabecular content towards the more distal sites (Table 6).

**Ultrasound velocity**

No useful results were obtained using the 2.25 MHz transducers. It was possible to get adequate readings of the ultrasound beam by placing the bone in a water bath and using 1 MHz transducers. A series of 22 readings were made on one bone which gave a mean ultrasound velocity of 2300 ± 66 m/sec. A second series of 20 readings on the same bone gave 2313 ± 21 m/sec and on a third occasion the mean of 21 readings was 2324 ± 23 m/sec. The result from the section of trabecular bone without cortex was similar (2300 m/sec).

**Discussion**

Trabecular bone has a turnover rate approximately eight times higher than that of cortical bone. It is preferable, therefore, to use a trabecular site to evaluate metabolic and nutritional bone disorders, osteoporosis and some aspects of skeletal maturity. In man, the most commonly used site is the vertebral column, which contains about 66 per cent trabecular bone. The spine is not a feasible site in the horse as the equipment necessary is not readily available (Jeffcott et al 1988). The data presented here confirm that there is an appreciable content of cancellous bone in the equine calcaneus (Table 6).

The calcaneus is not as accessible as the metacarpus in the standing horse and it is covered with a greater and more variable thickness of soft tissues. Radiographic photodensitometry lacked precision and the bone density equivalent (ODU) did not correlate well with BMD*9, even though the technique was carried out in vivo without the covering of soft tissues and with the minimum of variation in radiographic procedure. However, a fairly good correlation was obtained with BMC*9 (r = 0.911 for the adult and r = 0.989 for the foal group) by plotting the mean ODU of the five sites versus BMC*9 for each bone (Fig 8). Radiographic optical density, like BMC*9, was influenced more by the mass of the bone than by its actual mineral density. A better estimate of bone density could be obtained by dividing ODU by CSA. It was concluded that radiographic photodensitometry was not a sufficiently reliable technique for bone quality prediction.

**TABLE 6: Trabecular bone content in the adult group of horses expressed as a percentage of the total cross-sectional area of the calcaneus at each site.**

<table>
<thead>
<tr>
<th>Site 1</th>
<th>10</th>
<th>72.3</th>
<th>± 5.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 2</td>
<td>10</td>
<td>75.0</td>
<td>± 6.0</td>
</tr>
<tr>
<td>Site 3</td>
<td>10</td>
<td>69.0</td>
<td>± 7.0</td>
</tr>
<tr>
<td>Site 4</td>
<td>10</td>
<td>62.7</td>
<td>± 8.1</td>
</tr>
<tr>
<td>Site 5</td>
<td>10</td>
<td>64.2</td>
<td>± 9.2</td>
</tr>
<tr>
<td>Right hock</td>
<td>25</td>
<td>67.1</td>
<td>± 10.0</td>
</tr>
<tr>
<td>Left hock</td>
<td>25</td>
<td>66.0</td>
<td>± 10.9</td>
</tr>
<tr>
<td>All Sites</td>
<td>50</td>
<td>66.5</td>
<td>± 10.4</td>
</tr>
</tbody>
</table>

The technique of single photon absorptiometry proved to be accurate and reproducible, although there were variations noted between horses and between the different sites. There was a trend to increasing BMC*1 with age (Table 2). Values in man for measurements taken at one point in the calcaneum over a wide age range varied from 0.8 to 3 g/cm² (Soresson and Cameron 1967; Goldsmith et al 1971; Kleinn, Banyer and Schneider 1976). Specific gravity, percentage ash and BMD*9 showed similar changes from site to site as BMC*1. The correlation of SG against BMD*9 was used as an indirect verification of the reliability of the volumetric measurements and ashing. For the adult bones a correlation coefficient of r = 0.96 was obtained and r = 0.98 for the foal bones.

The measurements of CSA*9 in the adult group (n = 5) showed the section of the right calcaneus to be somewhat larger and more irregular than the left. In this small series no statistical significance between left and right was established (p = 0.466) with a paired students t test and no differences in BMD*9 was demonstrated. Calcium and phosphorus values were consistent with those reported for the equine femur and tibia (Blitz and Pellegrino 1969; Schreyer et al 1974), the third metacarpus (Tomioka, Hasegawa, Kaneko and Okawa 1985; McCarthy et al 1986) and human trabecular bone (Obrant and Odsellus 1986). However, there were significantly higher values (r = 0.014) recorded for phosphorus in the adult bones (19.03 ± 1.43 mg/100 mg ash) than for the foal bones (17.8 ± 8 mg/100 mg ash).

The BMC*1 of adult bones was underestimated by 7.0 per cent compared to that measured from ash (BMC*9). In the foal bones the underestimation was lower at 2.0 per cent for 241Am with an overestimation of 0.02 percent for 125I. It was not possible to explain these differences, but they may have been partly related to the shape of the bone section being scanned. The densitometer may work somewhat differently according to the geometry of the bone (ie, rounded or sharp edges) (R. J. McCarthy, personal communication). Differences between BMC*9 and BMC*1 were also noted when scanning the metacar- pus both by single and dual photon absorptiometry (McCarthy et al 1986). Both radiouclide sources employed here gave satisfactory results. The bone profile was better defined using
due to the greater absorption of its lower energy photons (35.5 keV) compared to 241Am (59.5 keV), but there was incomplete penetration of larger specimens. The 241Am source was found, therefore, to be more suitable for the smaller rodent bones whereas 241Am was more suitable for the larger adult specimens.

The technique used here to measure ultrasound velocity was not found to give a satisfactory indication of bone density. The results obtained using the fluid immersion method with 1 MHz transducers gave poorly defined traces on the oscilloscope compared to those obtained for cortical bone (Jeffcott and McCartney 1985). It was not clear whether this failure was due to the different ultrasonic properties of trabecular bone, the shape of this particular bone or the technique used. The ultrasonic dispersion and attenuation in trabecular bone is markedly different from that in cortical bone (Barger 1979; Langton, Palmer and Porter 1984; Lees 1986). Some more basic information on frequency dependent behaviour of ultrasound in trabecular bone is required and it is likely that a different approach to assess trabecular bone quality by ultrasound is required.

Single photon absorptiometry of the hock in vivo requires equipment that can be used safely and simply around the hindlimb. It was possible to use the Nurland densitometer with the horse under general anaesthesia, but not in the standing position. The other problem was ensuring a reliable and reproducible scanning site. This was tested using the isolated limb of one foal and scanning it after reposing on 20 occasions. This gave a coefficient of variability of BMC of about 4 per cent, but could be improved to 3 per cent by recording the length of the scanning path (BW). In man, the technique has been improved by rectilinear transmission scanning (Vogel and Anderson 1972) and a technique to overcome the problems of positioning with irregular shaped bones has also been proposed (Hevlin, Black and Oliver 1976). Siemsen et al (1974) have used a small portable unit to investigate sheep and cattle under field conditions by using a point source and measuring the y-ray absorption at a single site in the bone. In conclusion, this study demonstrates the potential of single photon absorptiometry to estimate bone quality of an essentially trabecular bone site, such as the calcaneus. However, for it to be used on conscious, standing horses the equipment would need to be substantially adapted. This is considered a feasible proposition and could be done while retaining the level of accuracy obtained here.

Acknowledgements

It is a pleasure to acknowledge the technical assistance of Mrs T. Anderson and the most valuable advice of Simon Buckingham, Ron McCarthy, Ron McCartney and Garry Anderson.

References


SECTION 6

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2. Perinatal Pathology (10 papers)
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6.1 Perinatal Physiology and Pathology

6.1.1 Passive Transfer of Immunity


6.1.2 Perinatal Pathology


6.1.3 Reproduction of early pregnancy


6.1.4 Prematurity and induction of parturition


6.2 Medicine and Pathology


6.3 Radiological Conditions


6.4 Miscellaneous Publications


Hall, L.M., JEFFCOTT, L.B. and Moss, M.S. (1972) Poisoning of dogs by horse meat containing chloral hyd Veterinary Record, 89, 480.


Linzell, J.L., Annison, E.F., Bickerstaffe, R. and JEFFCOTT, L.B glucose, acetate and palmitate in the lactating horse. Proc
Investigations of vertebral and other skeletal abnormalities causing lameness and loss of performance in horses

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