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Solar angle of the distal phalanx is associated with scintigraphic evidence of subchondral bone injury in the palmar/plantar aspect of the third metacarpal/tarsal condyles in Thoroughbred racehorses

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Summary

Background: Subchondral bone injury at the palmar/plantar aspect of the condyles of the third metacarpal/metatarsal bone (MC/MT3) commonly causes lameness and poor performance in racehorses. Injury occurs due to repetitive loading, the magnitude of which may be influenced by the position of the distal phalanx relative to the ground surface, i.e. the solar angle. The association of solar angle and injury at the palmar/plantar condyles of distal MC/MT3 therefore warrants investigation.

Objectives: Investigate the relationship between solar angle and radiopharmaceutical uptake at the palmar/plantar aspect of distal MC/MT3 on scintigraphic images of racehorses.

Study design: Retrospective case-controlled study.

Methods: Scintigraphic images of Thoroughbred racehorses presented for poor performance or lameness were graded for intensity of radiopharmaceutical uptake in the palmar/plantar aspect of distal MC/MT3. Solar angle was graded (positive, neutral or negative), referring to the angle of the solar plane of the distal phalanx relative to the ground surface. Repeatability of solar angle (n = 1226 limbs) and agreement with objective radiographic evaluation (n = 52 limbs) were evaluated. Pre-scintigraphy performance data was collected from race records. Associations between solar angle, performance and radiopharmaceutical uptake were investigated using multivariable logistic regression.

Results: Repeatability of scintigraphic solar angle grading ($\kappa = 0.89$, 95% CI 0.87-0.91) and agreement of scintigraphic and radiographic solar angle ($\kappa = 0.88$, 95% CI 0.75-0.97) were excellent. Horses that performed best prior to presentation were more likely to have both greater radiopharmaceutical uptake and a neutral/negative solar angle. When controlling for prior performance, horses with neutral/negative forelimb solar angle were twice as likely to have moderate/marked radiopharmaceutical uptake than horses with positive solar angle ($P<0.02$). Horses with negative hindlimb solar angle were six times more likely to have moderate/marked radiopharmaceutical uptake than horses with positive/neutral solar angle ($P<0.001$).

Main limitations: Population bias due to pre-selected hospital population.

Conclusions: Both solar angle and race performance are independently associated with increased bone activity in the palmar/plantar aspect of the third metacarpal/tarsal condyles.

Introduction

Subchondral bone injury of the palmar/plantar aspect of the condyles of the third metacarpal/tarsal bone (MC/MT3) is a common cause of lameness in Thoroughbred racehorses and is considered a bone fatigue injury [1,2]. Fatigue of subchondral bone is influenced predominantly by the number of cycles of load and the magnitude of load applied [3]. During locomotion, load exerted on the metacarpal condyles is generated mostly by the forces developed by superficial digital flexor tendon and the suspensory apparatus whilst the metacarpophalangeal joint is hyperextended [4]. The magnitude of this load is influenced by the lever arm created by the distance between the point of application of ground reaction force and the centre of rotation of the metacarpo(tarso)phalangeal joint (MCP/MTPJ). The point of application of the ground reaction force is the centre of pressure of the foot [5]. In a musculoskeletal model based on data derived from instrumented horses galloping on a treadmill, a 1 cm change in the centre of pressure of the foot, in a dorsal direction, increased loads predicted by the model at the MCP/MTPJ surface by 5% [6].

Nuclear scintigraphy is a sensitive method for detection of fatigue induced bone injuries [7,8]. Differentiation between normal radiopharmaceutical uptake and radiopharmaceutical uptake likely to be associated with load-related alteration or pathology is challenging since there is a continuum of change without definitive end points. However, subchondral bone injuries in the palmar/plantar aspect of the condyles of MC/MT3 are associated with focal areas of radiopharmaceutical uptake in Thoroughbred racehorses [9,10] and, greater intensity of radiopharmaceutical uptake in this location is associated with a poorer post-diagnosis performance [11].

A long toe/low heel conformation is common in Thoroughbred racehorses [12,13]. Different foot conformations have been shown to influence the position of the centre of pressure [14,15]. The experimental application of toe wedges which would acutely decrease the solar angle of the distal phalanx resulted in the centre of pressure moving dorsally [15]. As a consequence of natural hoof growth over 8 weeks, the centre of pressure becomes farther from the centre of rotation of the DIPJ [16] and the moment arm to it increases [14]. Similarly, the solar angle of the distal phalanx was negatively correlated with the DIPJ moment arm throughout stance [17]. It is therefore logical to suspect that changes in solar angle may influence the magnitude of load experienced at the MC/MT3 condyle and therefore occurrence of injury at that site.

The aim of this study is to determine if there is a relationship between the position of the distal phalanx relative to the ground surface, i.e. the solar angle of the distal phalanx and scintigraphic evidence of subchondral bone injury at the palmar/plantar aspect of the condyles of the third metacarpal/metatarsal bones in Thoroughbred racehorses. Solar angle was classified relative to the horizontal plane as positive (>0 degrees), neutral (0 degrees) or negative (<0 degrees). We hypothesised that there would be a positive association between the intensity of radiopharmaceutical uptake at the palmar/plantar aspect of the condyles of the third metacarpal/metatarsal bones and neutral or negative solar angle.

Materials and Methods

Records from Thoroughbred racehorses undergoing scintigraphic evaluation at The University of Melbourne Equine Hospital for lameness or poor performance over nine years were collected retrospectively. A standard scintigraphic protocol was used for each horse. An 18 gauge catheter was placed in a jugular vein and 12.7 - 15 MBq/kg of ^{99}Tc-HDP administered. Static delayed phase standing lateral and dorsal (forelimb) or plantar (hindlimb) images were obtained three hours after radiopharmaceutical injection. Images were acquired with a large field of view gamma camera (Phillips Argus Epic[a]) using a 256·256 matrix and transferred to a workstation for processing (Sun Ultra Workstation[b]). The camera was mounted on a gantry, on a section of floor that could be lowered so that lateral images of the distal aspect of the limbs were acquired with the camera in a fixed vertical position, partially below floor level, thereby avoiding the need for the horses to stand on blocks.

<u>Validation of using scintigraphic images to evaluate the orientation of the distal phalanx</u>

All feet were graded using scintigraphic images for the orientation of the distal phalanx, by the same observer (E.A.W.) on two occasions, six months apart so repeatability could be evaluated. The method of evaluation is detailed below.

Horses that had scintigraphic evaluation and foot radiographs at the same veterinary evaluation were used as a gold standard to assess correctness of the scintigraphic classification of solar angle. Scintigraphic images were graded for solar angle subjectively, prior to objective evaluation of radiographs. Digital radiographs (Atomscope Tough Ray TR9030[c]) were obtained with the horse standing square on custom made[d] wooden blocks, 6 cm in height with a radiodense marker embedded within the block to identify the ground surface. The radiographic solar angle was determined objectively using the ‘angle’ tool in proprietary software[e].

Grading of scintigraphic radiopharmaceutical uptake at the palmar/plantar aspect of the condyles of the MC/MT3 and grading of solar angle

Using lateral images of the distal limbs, radiopharmaceutical uptake intensity at the palmar/plantar aspect of the condyles of MC/MT3 was graded as being normal, mildly, moderately or markedly increased. All grading of radiopharmaceutical uptake was performed by the same observer (R.C.W.) experienced in the evaluation of scintigraphic images. Images were graded at the time the horse was presented for imaging and therefore prior to the conception of this study. Horses were then categorised for radiopharmaceutical uptake as normal/mild or moderate/marked referring to the subjective assessment of intensity of radiopharmaceutical uptake; region of interest analysis was not performed. Although there is no way to determine the cut off between normal, load related and pathologic radiopharmaceutical uptake, we used this simple arbitrary cut off for our classification of horses in order to exclude horses with mild changes as being unlikely to represent pathology. This is supported by the findings of others [11].

The angle of the solar plane of the distal phalanx relative to the ground surface was graded subjectively as positive, neutral or negative. Measurement of specific angles was not attempted. A ruler was held horizontally at the level of the toe of the distal phalanx on scintigraphic images. Since image orientation is not manipulated during image acquisition and processing, the perimeter of the image as viewed on the workstation, is therefore representative of the true ground surface on which the horse was standing and can be used as a reference for the horizontal. Images where the palmar/plantar processes extended below the horizontal were graded as negative (<0 dgrees), above as positive (>0 degrees) and, in those where they were parallel to it, were classified as neutral (0 degrees). Horses whose MC3/MT3 bone was not oriented approximately perpendicular to the ground surface on scintigraphic images (n = 1), and those with poor distal limb uptake of radiopharmaceutical (n = 2) were excluded.

Performance data

Data for race performance prior to scintigraphic evaluation was obtained from an online database (www.racingaustralia.com). This included whether horses started in a race, number of starts, places, and prize money. Prize money per start and places per start were calculated. Prize money earned and prize money per start were log transformed (log(dollars+1)) for analysis.

Data analysis

Repeatability

Repeatability of scintigraphic image evaluation for reading one versus reading two, and between scintigraphic and radiographic evaluation of solar angle were determined using the Kappa statistic (κ) [18]. The κ was interpreted as <0.40 poor agreement, 0.40-0.75 fair to good agreement and >0.75 excellent agreement [19].

For a comparison to be made with performance, a single solar angle grade for forelimb and for hindlimbs was required. Horses were assigned a single grade for the forelimb and for the hindlimb corresponding to the grade of the foot, left or right, closest to a negative solar angle. The perceived 'worst case' foot was used for the classification based on previous studies employing similar methodology [20-22] and based on evidence that a negative solar angle (or more long toe/low heel conformation where solar angle was not evaluated), may be detrimental in regards injury, joint forces or 'balance' [17, 23-26]. Grouping of radiopharmaceutical uptake as normal/mild and moderate/marked was based on data which demonstrated a significant reduction in post diagnosis performance in horses with moderate/marked radiopharmaceutical uptake in previous work from our hospital [11].

<u>Descriptive statistics</u>

Continuous variables (age, number of starts and places, prize money in Australian dollars (AUD), prize money per start and places per start) are reported as median (25th percentile [Q1]- 75th percentile [Q3]), while categorical variables (radiopharmaceutial uptake, solar angle, sex and whether the horse started in a race) are reported as the number (proportion) present. Results are reported for all horses, grouped by forelimb and hindlimb solar angle, and grouped by forelimb and hindlimb radiopharmaceutical uptake.

<u>Association between solar angle and race performance before scan</u>

Association between solar angle and race performance was examined using logistic regression for binary data (whether the horse started a race); negative binomial regression for count data (number starts and places) and analysis of covariance for continuous variables (percentage of starts placed, prizemoney, prizemoney per start). The horses' sex and age were forced into all models.

<u>Multivariable analysis</u>

Univariable logistic regression was used to screen solar angle, horse signalment and race performance variables for association with increased radiopharmaceutical uptake in forelimbs and hindlimbs, with P-value <0.2 resulting in inclusion of the variable in the multivariable regression model building. Separate multivariable regression models were built for forelimbs and for hindlimbs. If the likelihood ratio test was <0.05 variables were retained in the multivariable regression model [27]. All variables not included in the final model were evaluated as potential confounders by resubmission into the model one at a time. Variables were retained in the model if the odds ratio (OR) was changed by >20% [28]. The Hosmer-Lemeshow goodness-of-fit test was used to assess the fit of the final multivariable models [29]. Stata 12.1[f] was used for all analyses.

Results

Horses

A total of 359 horses were included in the study. Of these 11% (40/359) were entire males, 45% (161/359) geldings and 44% (158/359) females. The median age at scan was 3 years (Q1; 3- Q3; 4).

Repeatability

From the 359 horses examined, scintigraphic images were obtained for 1026 feet. Of these 7.1% (73/1026) changed solar angle grade by 1 degree from the first to the second assessments (positive to neutral [n = 22]; neutral to positive [n = 10]; neutral to negative [n = 6]; negative to neutral [n = 35]). Repeatability of scintigraphic solar angle grade was excellent (κ = 0.89, 95% CI 0.87-0.91).

There were 53 feet with both scintigraphic and radiographic images. Forty-nine of these feet (94%, 49/53) were classified as the same solar angle using each modality. In the four misclassifications, horses were graded scintigraphically as neutral but were radiographically negative by 1 degree (n = 2), positive by 1 degree (n = 1) or were scintigraphically negative but were radiographically neutral (n = 1). Agreement of scintigraphic and radiographic solar angle grade was excellent (κ = 0.88, 95% CI 0.75-0.97).

Scintigraphic examination

Horses underwent scintigraphic examination of the hindlimbs (n = 111), forelimbs, (n = 94) or both fore and hindlimbs (n = 154). Radiopharmaceutical uptake in the palmar/plantar aspect of the condyle of MC/MT3 was classified by horse as normal/mild (n = 137 fore/n = 156 hind) or moderate/marked (n = 111 fore/n = 109 hind) based on the more intense grade when left and right were graded differently.

Solar angle and radiopharmaceutical uptake grades

The majority of horses had the same solar angle grade in both forelimbs (74%, 183/248). Of the 26% (65/248) with differing solar angle grade, only 15% (10/65) differed by more than one grade (solar angle positive and solar angle negative). Similarly, in the hindlimbs, most horses had the same solar angle in left and right (71%, 189/265), and of the 29% (76/265) with differing solar angle grade, only 5% (4/76) differed by more than one grade (solar angle positive and solar angle negative).

A greater proportion of forelimbs were classified as having a positive solar angle (52% [130/248]), than neutral (34% [84/248]) or negative (14% [34/248]). Of horses with a negative forelimb solar angle, 70% (24/34) also had moderately/markedly increased radiopharmaceutical uptake. The distribution was reversed in hindlimbs with the solar angle positive in 14% (38/265), neutral in 26% (68/265) and negative in 60% (159/265). Of horses with negative hindlimb solar angle, 57% (91/159) also had moderately/markedly increased radiopharmaceutical uptake (Table 1).

Performance data

In total 72% (259/359) of horses had started in at least one race prior to scintigraphic examination. The median (Q1-Q3) number of race starts was 3 (0-9), places 1 (0-4), places per start 27 (0-50), prize money earned $5400 (0-47,209) and prize money per start $2998 (800-7839) (Table 2).

Association between solar angle and race performance before scan

Horses with a neutral or negative forelimb solar angle were more likely to have started a race (OR 3.3; 95%CI 1.5-7.4; P = 0.004 and OR 18.2; 95%CI 2.2-146.7; P = 0.007 respectively), earned more prize money (Geometric mean [GM] ratio 1.9; 95%CI 1.2-3.2; P = 0.007 and GM ratio 2.2; 95%CI 1.1-4.3; P = 0.027) and prize money per start (GM ratio 1.9; 95%CI 1.2-2.8; P = 0.003 and GM ratio 2.1; 95%CI 1.2-3.7; P = 0.010) compared to horses with a positive forelimb solar angle. While horses with a negative forelimb solar angle had placed in a higher proportion of starts (Difference. 12.0; 95%CI 2.6-21.3; P = 0.012) than horses with a positive forelimb solar angle, there was no association between solar angle and the absolute number of starts or places (P>0.05).

Horses with a negative hindlimb solar angle were more likely to have started a race (OR 3.0; 95%CI 1.3-7.2; P = 0.013), had a higher number of places (OR 1.7; 95%CI 1.1-2.7; P = 0.021), places per start (Diff. 11.4; 95%CI 1.3-21.5; P = 0.027), earned more prize money (GM ratio 2.1; 95%CI 1.1-4.0; P = 0.031) and prizemoney per start (GM ratio 2.1; 95%CI 1.2-3.7; P = 0.007) than horses with a positive hindlimb solar angle. There was no association between a neutral hindlimb solar angle and performance (P>0.05).

Forelimb multivariable analysis

Of the nine variables screened for association with increased radiopharmaceutical uptake in the forelimbs; solar angle, age at scan and prize money per start were retained in the final model.

Horses with neutral (OR 2.14, 95%CI 1.2-3.9, P = 0.014) or negative solar angle (OR 2.76, 95%CI 1.2-6.3, P = 0.015), horses that were older at the time of scan (OR 1.32, 95%CI 1.0-1.7, P = 0.043) and horses that earned more prize money per start (OR 1.39, 95%CI 1.2-1.7, P = 0.001) had greater odds of an association with moderate/marked forelimb radiopharmacutical uptake (Table 3).

Hindlimb multivariable analysis

Five of nine variables were retained in the final hindlimb model. Of these, two were associated with greater odds of an association with moderate/marked hindlimb radiopharmaceutical uptake: negative solar angle (OR 6.10, 95%CI 1.2-6.3, P<0.0001), and earning more prize money (OR 1.45, 95%CI 1.2-1.7, P<0.0001). Horses with a neutral solar angle had no greater odds of an association with increased radiopharmaceutical uptake, nor with a greater number of starts, places or greater age at scan (Table 3).

Discussion

We have shown that a common foot imbalance observed in Thoroughbred racehorses, characterised by a neutral (forelimb) or negative (fore and hindlimb) solar angle of the distal phalanx, is associated with increased radiopharmaceutical uptake at the palmar/plantar aspect of the condyles of the MC/MT3. In addition, horses with better performance prior to presentation, were more likely to have a neutral or negative forelimb solar angle, a negative hindlimb solar angle, and increased radiopharmaceutical uptake.

Our findings are similar to those of previous studies that have identified an association between various measurements relating to foot shape or 'balance' and injury more proximally in the limb [24,30-32]. Catastrophic suspensory apparatus failure was 6.75 times more frequent in horses with a 10 degree difference between toe-heel angle [24] in Thoroughbred racehorses examined as part of the California Horse Race Board Postmortem Program. Similarly, severely underrun heels (determined through comparison of toe and heel angle) were a significant risk factor for suspensory apparatus failure in racehorses in Oklahoma [31]. Neither of these studies included performance data in their analysis so it is not possible to determine whether racing ability or speed were contributing factors. Mansmann *et al.* [32] demonstrated that a negative solar angle in a hindlimb was associated with prominent gluteal pain, and correction of that dorsoplantar imbalance, resulted in resolution of pain. Despite these studies, there has been limited work to date on a possible relationship between any measurement that may be considered a contributor to foot 'balance' and injury of the metacarpo(tarso)phalangeal joint (MCP/MTPJ). The most detailed study of subchondral bone injury in the region of the MCP/MTPJ of Thoroughbred racehorses did not examine foot characteristics as a risk factor [33].

There are at least two possible explanations for the observed association between solar angle and intensity of MC/MT3 condylar radiopharmaceutical uptake; a neutral (forelimb) or negative (fore and hindlimb) solar angle may contribute to MCP/MTPJ injury or subchondral bone adaptation, most likely because solar angle affects biomechanics more proximally in the limb or, the causes of the increased radiopharmaceutical uptake and solar angle are the same. The centre of pressure of the foot relative to the centre of rotation of the MCP/MTPJ affects joint surface loads in cantering horses at midstance [6]. For faster gaits, modelling data indicate maximum loads at the palmar (plantar) condyles of the third metacarpal (metatarsal) bones occur around midstance when the MCP/MTP joint is in extension [4]. Moving the centre of pressure at this point forward increases the lever arm generating torque around the MCP/MTPJ and resulting in higher load on its palmar(plantar) condyles of the third metacarpal (metatarsal) bones generated by the contact force applied by the proximal sesamoid bones and generated wholly by the superficial digital flexor tendon and the suspensory apparatus whilst the joint is hyperextended [6]. Differences in dorsopalmar/plantar foot 'balance' occurring naturally with foot growth [16] and evaluated using solar angle in individual horses [17] affect the moment arm of the DIPJ [14, 17] and may therefore also have an effect on MCP/MTP joint contact loads. Over an 8 week cycle of growth, a decrease in hoof angle occurred and resulted in the centre of pressure at mid stance moving farther dorsally from the centre of rotation of the DIPJ [14] and at 15, 50 and 86% of the stance phase, solar angle was negatively correlated to the DIPJ moment arm [17]. Higher joint loads result in a shorter fatigue life of the subchondral bone and therefore increase the risk of subchondral bone injury [3]. Alternately, factors leading to increased MC/MT3 condylar radiopharmaceutical uptake may also cause the solar angle of the distal phalanx to become more negative. For example, superior performing horses may compete at faster speeds and/or for longer resulting in both MC/MT3 bone injury and the development of a negative solar angle. In the current study, horses which had superior performance records prior to presentation were more likely to have increased radiopharmaceutical uptake.

The association of solar angle with superior race performance is interesting. Measurement of forelimb dorsal hoof wall angle on the day of a race was not associated with performance in that race [34] however dorsal hoof wall measurements are only moderately correlated with solar angle [35]. Previous work disputed an old but popular theory that farrier modifications, to promote a long toe low heel conformation increased stride length and consequently, velocity [36,37]. Our data may support the association of a negative solar angle and superior performance. Better performing horses may stay in work longer and have greater opportunity for the angulation of the distal phalanx to change in response to farrier intervention [38], environmental or workload factors, which are speculated to contribute to changes in solar angle [39, 40, 41] rather than the solar angle per se, being advantageous for performance. Although whether our finding also reflects the wider population of Thoroughbred racehorses is unknown. Mechanical load is considered to be one a several stimuli which may result in alteration of hoof morphology although experimental evidence for a significant response to this form of stress is limited [39]. It is generally accepted, that due to the hoof mechanism, the heel region is more prone to wear than the toe [42]. The result of this wear is thought to result in a more sloping hoof angle over time although there are few studies demonstrating this [16].

There were no significant changes in hoof morphology of Standardbreds exposed to moderate speed trot work over a number of weeks [43] and morphological responses of the distal phalanx to exercise are also minimal [44]. It is possible these studies did not expose the subjects to sufficient magnitude or duration of exercise to produce notable responses in morphology. Greater force has been measured at the heel region of the long toe/low heel foot [45]. It has been suggested that in horses working at high speeds, the forces applied in the heel region may result in a cycle of tissue injury and hoof deformation through chronic overload [46] although scientific evidence is lacking.

The age of the horse has also been shown to be influential in hoof conformation [47] with a change toward long toe/low heel conformation in 2-3-year-olds versus younger horses. The authors of that study attributed the change to farrier intervention. In our study the age range was 2-9 years so all horses would have been trimmed and shod for a reasonable period of time before inclusion in the study. Some measurements that can be used to assess hoof 'balance', including solar angle, can be altered by farrier intervention [38] so there may be an effect of farrier on solar angle in our study population. Unfortunately, due to the retrospective nature of this study it was not possible to investigate if this was the case.

There are a number of areas where the potential for bias should be considered. All horses presented for scintigraphic evaluation due to lameness or poor performance. We do not know what proportion of racehorses, not perceived to have a problem, would fall into either of our disease (radiopharmaceutical uptake) or exposure (solar angle) categories so our findings may not be representative of a typical racehorse population. Lameness was not always localised using regional anaesthesia techniques so the contribution of moderate-severe radiopharmaceutical uptake to lameness was not definitively determined for every horse. However, it was not the purpose of this study to differentiate radiopharmaceutical uptake associated with pain causing lameness. Previous work from our hospital, using a subset of the horses included in this study, identified a reduction in post diagnosis race performance in horses with moderate/marked condylar uptake, compared with lesser grades [11], which supports our interpretation of the clinical importance of this finding in this study population. Disease state (moderate/marked radiopharmaceutical uptake) was determined at the time of clinical presentation. At that stage we had not considered the possibility of a relationship between the solar angle of the distal phalanx and radiopharmaceutical uptake at the MCP/MTPJ, so although the joint and distal phalanx can be seen on the same scintigraphic image, we are confident this has not influenced the radiopharmaceutical uptake grade. The subjective grading of radiopharmaceutical uptake could have been more robust by use of regions of interest (ROI) analysis [48] however, identifying a 'normal' ROI at the distal aspect of the MC/MT3 bones of racehorses can be challenging. Since a single experienced clinician graded all images, we considered a subjective appraisal was sufficient. Ideally the repeatability of radiopharmaceutical uptake grade would have been assessed, however, there was no way to perform this without concurrent visibility of the hoof pastern alignment so we did not consider 'regrading' could be performed without bias. The use of lateral images to grade intensity of radiopharmaceutical uptake could result in the potential for error in that radiopharmaceutical uptake in the medial and lateral condyles are summed, rather than described individually. A single observer graded solar angle; anatomic detail is lacking in scintigraphic images and a reference for ground surface is only extrapolated which could limit accuracy. We excluded horses that were not deemed to be standing square during image acquisition and used a ruler as a guideline to determine the solar angle classification where the perimeter of the image was considered representative of the ground surface. These steps were taken to maximise accuracy and reduce the potential for observer bias. Per Fleiss *et al*. [19] the scintigraphic solar angle assessment method showed excellent repeatability and agreement when compared with radiographically determined solar angle. This suggests the technique is robust at least within the single observer.

Conclusion

Greater awareness of the association of solar angle of the distal phalanx with increased radiopharmaceutical uptake at the MC/MTPJ, may improve the management and prevention of musculoskeletal problems in athletic horses. Further work examining the biomechanical effects of differences in the angle of the distal phalanx are warranted.

Authors' declaration of interests

None of the authors have competing interests.

Ethical animal research

Research ethics committee oversight not required by this journal: retrospective analysis of clinical data.

Owner informed consent

Explicit owner informed consent for inclusion of animals in this study was not stated.

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Authorship

The initiation, conception and planning of this study were by E. Walmsley, L. Wells-Smith and M. Jackson. Its execution by E. Walmsley, R. Whitton and M. Jackson with statistics by E. Walmsley and M. Jackson. The paper was written by E. Walmsley, R. Whitton, L. Wells-Smith and M. Jackson.

Manufacturers' addresses

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[b]Sun Ultras Workstation, Argus ADAC Systems Pty Ltd, Melbourne, Australia.

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[e]Synapse, Version 4.4.2, Fujifilm Medical Systems. www.fujifilm.com/worldwide

[f]Stata Version 12.1 for Windows, StataCorp, College Station, Texas, USA.

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Table 1: Frequency distribution of forelimb (n = 248) and hindlimb (n = 265) solar angle of the distal phalanx and radiopharmaceutical uptake at the palmar/plantar aspect of the condyles of the third metacarpal/metatarsal bone (MC/MT3)

		Radiopharmaceutical uptake MC3	
		None/Mild (n = 137)	**Moderate/Marked (n = 111)**
Forelimb solar angle	**Positive (n = 130)**	89 (68.5)	41 (31.5)
	Neutral (n = 84)	38 (45.2)	46 (54.8)
	Negative (n = 34)	10 (29.4)	24 (70.6)
		Radiopharmaceutical uptake MT3	
		None/Mild (n = 156)	**Moderate/Marked (n = 109)**
Hindlimb solar angle	**Positive (n = 38)**	32 (84.2)	6 (15.8)
	Neutral (n = 68)	56 (82.4)	12 (17.6)
	Negative (n = 159)	68 (42.8)	91 (57.2)

Table 2: Descriptive statistics of horse signalment and race performance prior to scintigraphic evaluation for all horses and grouped by solar angle of the forelimb (n = 248) and hindlimb (n = 265) distal phalanx and by radiopharmaceutical uptake at the palmar/plantar aspect of the third metacarpal/tarsal (MC/MT3) bone.

	n (%)	Sex n (%) Male	Female	Gelding	Median age at scan (Q1-Q3)	Start a race n (%)	Median number of starts (Q1-Q3)	Median number of places (Q1-Q3)	Median places per start (Q1-Q3)	Median prize money earned AUD (Q1-Q3)	Median prize money earned per start AUD (Q1-Q3)
All horses	359	40 (11)	158 (44)	161(45)	3 (3-4)	259 (72)	3 (0-9)	1 (0-4)	27 (0-50)	5400 (0-47,209)	2998 (800-7839)
Forelimb SA											
Positive	130(52)	14 (11)	49 (38)	67 (52)	3 (3-4)	90 (70)	3 (0-11)	1 (0-4)	23 (0-50)	4677 (0-44,550)	2396 (970-7839)
Neutral	84 (34)	11 (13)	35 (42)	38 (45)	3 (3-4)	70 (83)	5 (1-10)	2 (0-5)	33 (0-50)	13,000 (932-98,486)	4134 (1683-8057)
Negative	34 (14)	4 (12)	16 (47)	14 (41)	4 (3-4)	33 (97)	5 (2-11)	2 (0-4)	37 (0-54)	9000 (1000-91,600)	2327 (357-15,614)
Hindlimb SA											
Positive	38 (14)	0	16 (42)	22 (58)	3 (2-4)	22 (58)	1 (0-6)	0 (0-2)	0 (0-33)	0 (0-13,460)	1707 (0-6730)
Neutral	68 (26)	11 (16)	27 (40)	30 (44)	3 (3-4)	41 (60)	1 (0-8.5)	0 (0-4)	0 (0-51)	225 (0-32,947)	3277 (1136-6597)
Negative	159 (60)	17 (11)	74 (47)	68 (43)	3 (3-4)	128 (81)	4 (1-9)	1 (0-5)	33 (0-50)	8400 (0-62,235)	3243 (790-8184)
RU MC3											
None/Mild	137 (55)	17 (12)	59 (43)	61 (45)	3 (3-4)	90 (66)	2 (0-8)	1 (0-3)	14 (0-49)	1800 (0-21,777)	2339 (714-6730)
Moderate/Marked	111 (45)	12 (11)	41 (37)	58 (52)	4 (3-5)	103 (93)	7 (3-13)	3 (1-6)	40 (20-51)	30,725 (3052-106,575)	3416 (1469-11,450)
RU MT3											
None/Mild	156 (59)	16 (10)	73 (47)	46 (30)	3 (3-4)	94 (60)	1 (0-6)	0 (0-3)	0 (0-50)	0 (0-23,817)	2550 (333-6570)
Moderate/Marked	109 (41)	12 (11)	44 (40)	53 (49)	4 (3-5)	97 (89)	(7 (3-11)	2 (1-5)	42 (20-53)	15,325 (1450-91,600)	3927 (1252-8231)

SA = solar angle; RU = radiopharmaceutial uptake; Min = minimum; Q1 = 25th percentile; Q3 = 75th percentile; max = maximum; AUD = Australian dollars

Table 3: Univariable logistic regression and final multivariable model for association between radiopharmaceutical uptake at the palmar/plantar aspect of the condyles of the third metacarpal/metatarsal bone, and solar angle of the forelimb/hindlimb distal phalanx, horse signalment and race performance prior to scintigraphic evaluation.

Variable	Univariable			Final Multivariable		
	OR	**95% CI**	**P-value**	**OR**	**95% CI**	**P-value**
Forelimb (n = 248)						
Solar Angle						
Positive	1 (ref)			1 (ref)		
Neutral	2.63	1.49-4.63	0.001	2.14	1.17-3.92	0.02
Negative	5.21	2.28-11.89	<0.0001	2.76	1.21-6.25	0.02
Sex						
Male	1 (ref)					
Female	1.05	0.46-2.41	0.908			
Gelding	1.55	0.69-3.49	0.29			
Age	1.54	1.21-1.95	<0.0001	1.32	1.01-1.73	0.05
Started in a race						
No	1 (ref)					
Yes	6.97	3.13-15.51	<0.0001			
Number of starts	1.04	1.01-1.07	0.004			
Number of places	1.1	1.03-1.17	0.003			
Places per start	1.02	1.01-1.03	<0.0001			
Prize money earned (AUD)	1.42	1.24-1.62	<0.0001			
Prize money per start (AUD)	1.56	1.32-1.84	<0.0001	1.39	1.15-1.67	0.001
Hindlimb (n = 265)						
Solar angle						
Positive	1 (ref)			1 (ref)		
Neutral	1.14	0.39-3.34	0.807	1.13	0.36-3.55	0.9
Negative	7.14	2.82-18.03	<0.0001	6.1	2.24-16.58	<0.0001
Sex						
Male	1 (ref)					
Female	0.85	0.46-2.34	0.692			
Gelding	1.03	0.46-2.34	0.937			
Age	1.49	1.19-1.87	<0.0001	1.28	0.89-1.84	0.2
Started in a race						
No	1 (ref)					
Yes	5.13	2.61-10.07	<0.0001			
Number of starts	1.05	1.02-1.08	0.002	1.06	0.96-1.17	0.2
Number of places	1.10	1.03-1.17	0.003	0.85	0.70-1.02	0.09
Places per start	1.02	1.01-1.03	<0.0001			
Prize money earned (AUD)	1.46	1.29-1.65	<0.0001	1.45	1.20-1.74	<0.0001
Prize money per start (AUD)	1.60	1.37-1.88	<0.0001			