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| 2 | DR. TIMOTHY AKINBOWALE OLUSA (Orcid ID : 0000-0001-9853-4788) |
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| 17 | Authors: Timothy, A.O. Olusa ^{1*} ; Sa'ad, M.Y. Ismail ¹ ; Christina, M. Murray ¹ & Helen, M.S. |
| 18 | Davies ¹ |
| 19 | |
| 20 | Institution affiliations: ¹ Faculty of Veterinary and Agricultural Sciences, University of Melbourne, |
| 21 | Werribee VIC 3030. Australia |
| | |
| 22 | |
| 23 | *Corresponding author: Timothy A.O. Olusa, |
| 24 | Faculty of Veterinary and Agricultural Sciences, |
| 25 | University of Melbourne, Werribee VIC 3030, Australia |
| 26 | E-mail: timolusa1@gmail.com & olusat@unimelb.edu.au |
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1 ABSTRACT

- Carpal conformation is often considered as a contributory factor to performance and lameness in the horse; however, few attempts have been made to objectively measure radiographic variations of carpal conformation in horses due to insufficient measurable carpal parameters. This pilot study used carpal radiographic images acquired from 10 cadaveric equine forelimbs transected at the antebrachial
- 6 midshaft from 7 adult horses (7.2±2.6 years), positioned at "zero lateromedial" (ZLM) and "zero
- 7 dorsopalmar" (ZDP) views, to investigate the anatomy of the equine carpus and develop parameters
- 8 that could be objectively used to assess carpal conformation in horses.
- 9 Dorsal carpal angle (DCA: 176.61±0.66°), distal radial slope carpal angle (DRSCA: 145.59±2.19°),
- 10 intermediate carpal bone proximal tuberosity-radial angle (CiPxTRA: 115.69±3.15°) and third carpal
- 11 bone palmar facet angle (C3PalFCA: 84.43±1.13°) were all developed from the ZLM view while
- 12 medial carpal angle (MCA: 183.34±1.02°), disto-dorsal slope angle of the third carpal bone
- 13 (C3DDSA: $8.27\pm0.92^{\circ}$) and width ratio of distal radius to proximal metacarpus (WDR:WPM =
- 14 $1.13\pm.03$) were 3 of the 10 parameters developed from the ZDP view.
- Easy to identify and measurable parameters will help to provide quantitative assessment of carpal conformation in the horse with potential of eliminating subjective observational variation errors between clinicians. These newly developed parameters will be useful in further studies to measure variations in the conformation of the equine carpus in live horses and comparison between subjective visual assessment and objective radiographic evaluation methods.
- 20 Key words: Carpal conformation; Carpal joint; Horses; Measurable parameters; Radiographs; Equine
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28 1. INTRODUCTION

The conformation of the equine forelimb is very important to the overall athletic performance of the horse and its susceptibility to lameness as it bears over 55% of the horse's standing weight and is subjected to high compressional forces during galloping and landing phase of jumping (Clayton *et al.*, 2013; Kainer, 2002). The carpus must transmit large axial loads from the antebrachium to the distal forelimb and maintain optimum structural stability if the horse is to meet the heavy demand of training, racing, and other athletic performances (Stashak & Hill, 2002). This stability is largely
 dependent on the conformation of the carpal bony structures.

3 Although some radiographic parameters have previously been developed to assess carpal conformation in horses; only few parameters are however regularly utilized. These include measuring 4 5 "carpal angle" from both the dorsopalmar (DPa) and lateromedial (LM) radiographs (Barr, 1994; Fretz 1980); which the current authors have termed "medial carpal angle (MCA) and dorsal carpal 6 7 angle (DCA) respectively to eliminate confusion in their description and orientation. In 2011, Abdunnabi developed 37 parameters from DPa radiographs and proposed their use in the 8 9 conformational assessment of the equine carpus (Abdunnabi, 2011; Oheida et al., 2016). Although, in contrast to previous studies (Barr, 1994; Fretz 1980), Abdunnabi (2011) validated the repeatability 10 and reproducibility of specific landmarks used in developing the 37 DPa parameters, however the 11 complexity involved in measuring most of these 37 parameters might make them unsuitable for 12 routine/practical use. These complexities added to the shortcomings of objective carpal evaluation and 13 14 may partly explained why only 10 out of the 37 parameters were published (Oheida et al., 2016).

The equine carpal bones are classified as short bones (Getty, 1975) and have also been 15 16 described as wedge-like in shape with topographic angulation of their articular surfaces (Bramlage, 1988; Deane & Davies, 1995a; Kainer, 2002; Von Rubeli, 1925). The carpal bones slide into a "close 17 18 packed position" during weight bearing (a position where full congruities of all opposite and adjacent 19 articular surfaces of the carpal bones occurred) and this unique morphology is believed to assist the 20 carpus in attenuation of large axial forces by transferring some strain into the elastic intercarpal ligaments (Bramlage, 1988; Deane & Davies, 1995a; Von Boening, 1981). None of the 37 parameters 21 22 (Abdunnabi, 2011; Oheida et al., 2016) fully considered the topography of the articular surfaces of the carpal bones. Further investigation of the anatomy of the carpal DPa radiographs might therefore 23 24 produce more measurable parameters that could estimate the degree of wedge or steepness of slope of 25 these articular surfaces.

26 It would be beneficial to develop parameters from both the dorsopalmar and lateromedial 27 radiographs of the carpal joint that would measure both the morphological and alignment aspects of conformation. This would provide a more holistic assessment of the carpal conformation in horses and 28 probable predictive indices for biomechanical function and pathology of carpal joints. These 29 parameters should be easy to measure, have consistent landmarks, reliably measure carpal 30 31 conformational features, and show good repeatability (reliability) and reproducibility within and 32 between different observers. Intraclass correlation coefficient (ICC) measures the reliability or consistency of measurements between two or more observers and could also show the reproducibility 33 34 of experimental method and or agreement between two or more repeated measurements and observers 35 (Bobak et al., 2018; Koo & Li 2016; Liljequist et al., 2019). The aims of this pilot study were: i) to investigate the radiographic anatomy of the equine carpus and develop measurable parameters such as 36 37 angles and ratios that could be used to objectively measure the conformation of the carpus, ii) to

- 1 describe a detailed radiographic method for the measurement of the identified parameters, iii) to
- 2 investigate the consistency of the positions of landmarks used to establish these parameters and iv) to
- 3 investigate the reliability of the measurement protocol (parameters) between observers.

4 2. MATERIALS AND METHODS

- 5 2.1. Development of radiographic measurement techniques
- 6 Study design: This was a pilot study designed to test measurement and data collection protocol.

7 Ethical animal research: Approval from the University of Melbourne Animal Ethics Committee was

- 8 not required as specimen were collected from animals that had either died or were euthanized for9 reasons not related to the study.
- 10 Animals: 10 forelimbs (from 7 thoroughbreds) aged 7.2±2.6 years were collected from the postmortem room of the Department of Veterinary Pathology, University of Melbourne, Australia, and a 11 local knackery in Melbourne. All the horses had either died or were euthanized for conditions not 12 13 related to carpal injuries or lameness and owners' consent to use cadavers was obtained. The limbs were transected at about the midshaft of the antebrachium, wrapped in plastic bags, and preserved by 14 freezing at -20°C until needed. Only limbs with carpi that had no visible physical injury and no 15 radiographic abnormalities were included in the study. 16 17 **Limb preparation and radiography**: The limbs were defrosted in a chiller (5°C) for about 72 hours.
- 18 Thereafter, each limb was mounted in a standing position on a customised loading rig (Alrtib, 2013) 19 (Figure 1) and radiographed through lateromedial and dorsopalmar views using a portable 20 radiographic machine (Atomscope HF80/15 UltraLight, Mikasa X-ray Co Ltd, Japan) set at 80 KVp 21 and 24 secs (3.6 mAs). A common practice in our research group: Functional Anatomy and
- Biomechanics Laboratory (FABLAB), University of Melbourne, adopted for equine field radiography
 is to acquire images of the left limb in the lateromedial view and the right limb in the mediolateral
 position. This minimizes disturbance to the horses and reduces operational time per animal. A set of
 two lateral radiographs (i.e. lateromedial and mediolateral views) were therefore acquired for each of
- the 10 cadaveric limbs for comparison of carpal measurements on both lateral images.
- 27 2.1.1. Zero lateromedial/mediolateral (ZLM/ZML) carpal image
- A specific rotational (oblique) image of the lateromedial view of the carpus, where the second and fourth metacarpal bones completely overlap, was acquired by slightly rotating the limb until the desired image was produced. This specific carpal image was defined as the "zero lateromedial" (ZLM) image (Figure 2a) produced from a "zero lateromedial" (ZLM) view or position. All carpal parameters were thereafter developed, measured, and compared on both zero lateromedial "ZLM" and zero mediolateral "ZML" images/views.

34 2.1.2. Zero dorsopalmar (ZDP) carpal View/image

The zero dorsopalmar (ZDP) view or image was defined as a dorsopalmar (DPa) view of the carpus at which its rotations along the vertical and horizontal axes were at zero degrees (Figure 2b)

(Abdunnabi, 2011; Oheida *et al.*, 2016). A straight line drawn to represent the proximal edge of the
 metacarpus and referred to as the reference line (RL) was previously established by Abdunnabi (2011)
 and reported to be parallel with the ground (Abdunnabi, 2011; Oheida *et al.*, 2016). These 2
 previously established specific profiles of the DPa view (i.e ZDP and RL) were adopted for this study
 (Figure 2b).

The wedge angles of intermediate carpal bone (Ci) and the fourth carpal bone (C4) were 6 7 measured directly from the radiographs while the slopes of the articular facets of the third (C3), radial 8 (Cr) and ulnar (Cu) carpal bones were respectively used to calculate the respective slope angles for the C3, Cr and Cu. Geometrically, a wedge is a type of polyhedron (triangular prism) usually defined 9 by two right angle triangles and three trapezoid faces. Using the principle of the right-angle triangle to 10 relate to the "wedge-like" morphology of the carpal bones, if a long enough line (slope line) is drawn 11 from the point of the wedge slope of each carpal bone facet (e.g. Cr and C3), it will eventually meet 12 the continuation of the RL, and the angle thus formed would be termed the slope angle (x°) of that 13 particular carpal bone facet (Figure 3). Another line drawn perpendicularly from any position on the 14 RL to meet the wedge slope line will form another angle (y°). If angle y° was measured and then 15 added to the known constant (90°) of right-angle triangles; then, the summation of y° and 90° could 16 then be subtracted from 180° to get x° [i.e. x = 180 - (90+y)]. A parallel line to the RL on any 17 transverse plane could be drawn to form the base of the right-angle triangle for each carpal bone 18 19 wedge angle as required.

20 2.2. Radiographic measurement of carpal parameters

Selection of radiographs and development of measuring parameters (angles and ratios) were carried 21 22 out by observer 1. Measurement and data recording were carried out on separate occasions by observer 1 and 2 at intervals of not less than 2 weeks from each set of measurements. All radiographic 23 24 images were processed by Veterinary-80 CR Scanner (3D Imaging & Simulations Corp., Yuseong-Gu, Daejeon, Korea). Images were stored, analysed, and measured with an X-ray acquisition software 25 (DICOM PACS® DX-R). All measurements were carried out with the same computer hardware (Dell[®]) 26 Latitude E6530). A summary of the abbreviations and meaning of some used technical details are 27 provided in table 5 (the appendix). The following carpal parameters were developed to measure 28 different aspects of carpal conformation. 29

30 2.2.1. Carpal parameters measurable on zero lateromedial/mediolateral

31 (ZLM/ZML) radiographs

i. Dorsal carpal angle (DCA): was defined as the angle formed dorsally at the intersection of the
 long axis of the antebrachium and that of the third metacarpal bone. Although this angle was
 previously measured by Barr (1994), it was first termed/named DCA by Olusa (2018) and Olusa *et al.*, (2019). As shown in Figure 4a, the (dorsopalmar widths) of both the antebrachium and the
 metacarpus were each measured at 60mm and 120mm from the antebrachiocarpal and

1 carpometacarpal joints respectively and marked at the middle (midpoint) of these width. A straight

2 line was then drawn through these marked midpoints of the bones to represent the long axis of both

3 the antebrachium and the third metacarpus

4 ii. Distal radial slope carpal angle (DRSCA): was defined (Olusa, 2018; Olusa *et al.*, 2019) as the

5 correlated angle formed by the disto-dorsal slope of the antebrachium as it articulates with the

6 proximal row of the carpal bones (Figure 4b: ABD). Line "AB" was drawn as best fit from the most

7 dorsal point of the rim of the distal radius through the distal epiphyseal slope of the radius, while line

8 "BD" represented the dorsal height of Ci; from the distodorsal end (D) to its proximodorsal end (B).

9 iii. Intermediate carpal bone proximal tuberosity-radial angle (CiPxTRA): was measured as the
angle formed from the highest point of the proximal articular surface (tuberosity) of Ci to the dorsal
radial alignment (Figure 4b: ABC) (Olusa, 2018; Olusa *et al.*, 2019).

iv. Third carpal bone palmer facet angle (C3PalFCA): was measured as the angle formed between
an extended line from the highest point of the proximal palmar articular surface of C3 (point E on
Figure 4) to the disto-dorsal edge of the proximal carpal row alignment and a line (DB) representing
the dorsal height of Ci (Figure 4b: EDB) (Olusa, 2018; Olusa *et al.*, 2019).

16 2.2.2. Carpal parameters measurable on zero dorsopalmar (ZDP) radiographs

i. Medial carpal angle (MCA): was the angle formed medially at the intersection of two lines drawn
to represent the long axes of the radius and third metacarpal bones (Figure 4c) (Olusa, 2018; Olusa *et al.*, 2019).

ii. Disto-dorsal slope angle of the third carpal bone (C3DDSA): was the angle formed between the
RL and the distal edge of C3 (Figure 5a: FEI). A line representing the distal edge of C3 (FE) was
drawn from the most lateral end of the distal edge of C3 through to its most medial point and extended
to meet the RL to form the slope angle ("x"). A second line was drawn perpendicularly from the RL
to meet the line representing the distal edge of C3 (i.e FE) and the angle formed y° was measured and
added to the constant 90° and then subtracted from 180° to get x°.

iii. Disto-dorsal slope angle of the radial carpal bone (CrDDSA): This was the angle formed 26 27 between the RL and the dorsal aspect (slope) of the distal surface of Cr (Figure 5a: CD and Figure 5ai). A line "CD" drawn from the lateral margin of the disto-dorsal border of Cr (i.e the articulation 28 point of Cr with C1 and C3), through to its medial edge and extended long enough until it meet the 29 continuation of the RL represented the angle of the dorsal slope of the distal surface of Cr and was 30 denoted by "x" (as shown in Figure 3). A perpendicular line from the RL was drawn to meet this 31 distal slope line of Cr close to its lateral end to form the angle "y". The summation of "y" and 90° 32 when subtracted from 180° produced "x". 33

iv. Proximo-dorsal slope angle of the radial carpal bone (CrPDSA): This was the angle formed
between the RL and the dorsal aspect of the proximal surface of Cr. A line representing the dorsal
slope of the proximal articular surface of Cr was drawn medially from the highest point of the

37 proximal articular surface of Cr through to its medial edge (Figure 5a: AB and Figure 5ai). If "line

AB" was drawn long enough, it will eventually meet the continuation of the RL and form the
proximo-dorsal slope angle of Cr (Cr PDSA) denoted by "x°". A second line was drawn
perpendicularly from the RL to meet "line AB" at about its starting point to form angle "y" and was
measured, added to 90° and then subtracted from 180° get "x" (Figures 3 and 5a: AB).

v. Distal slope angle of the ulnar carpal bone (CuDSA): This was the angle formed by a Cu distal
topographic line "GH" drawn laterally from the medial edge of Cu articulation with Ci through to the
lateral edge of Cu (Figure 5a: GH) and "extended" to meet the RL. It was similarly represented as "x"

8 and calculated from [x = 180 - (90+y)] as previously described above.

- 9 vi. Disto-dorsal wedge angle of the intermediate carpal bone (CiDDWA): This was the angle 10 formed at the dorsal articular ridge between the medial and lateral distal articular facets of Ci. A line 11 "JK" was drawn laterally from the point of Ci articulation with Cr and the articular ridge between the 12 radial and intermediate facets of C3 to the dorsal meeting point of Ci, C3 and C4 (Figure 5b: point 13 "K") where it met with a second line "KL". The second line which represented the lateral articular 14 facets of Ci was drawn medially from Ci articulation point with Cu extending to the Ci inter-facet 15 articular ridge where it met with the first line to form CiDDWA (Figure 5b: JKL).
- vii. Disto-dorsal wedge angle of the fourth carpal bone (C4DDWA): This was the angle formed at the articular ridge between the dorsal and lateral distal articular facets of C4. It was formed by 2 lines (Figure 5b and Figure 5bi: a' b' c'). The first line representing the dorsal articular facet of C4 (a' b'), started from the distal meeting point of the images of C3 and C4 and extended to the articular ridge between the dorsal and lateral articular facets of C4. The second line (b' c') extended from this ridge to

21 the lateral margin of the lateral articular facet of C4.

viii. Disto-palmar wedge angle of the fourth carpal bone (C4DPWA): This was the angle formed
at the articular ridge between the palmar and lateral distal articular facets of C4 (Figure 5b and Figure
5bii: a b c'). It was represented by a line starting from medial margin of the palmar articular facet of
C4 extending to the ridge (a b) and another line from the ridge extending to the lateral margin of the
lateral articular facet of C4 (b c').

ix. Width ratio of distal radius to proximal metacarpus (WDR:WPM): This was the ratio of the
width of the distal radius as measured from its most lateral to its most medial side (Figure 5c and
Figure 5ci: AB) to the width of the proximal metacarpal bones as measured from the most lateral side
of MC4 to the medial margin of MC2 (Figure 5c and Figure 5ci: CD).

x. Width ratio of distal radius' medial articular condyle to lateral articular condyle
(DRW.MAC:LAC): This was the ratio of the width of medial articular condyle of the distal radius as
measured from its medial margin to the inter-condylar ridge (Figure 5c and Figure 5cii: aH) to the
width of the lateral articular condyle as measured from the inter-condylar ridge to its lateral margin
Figure 5c and Figure 5cii: Hb).

36 2.3. Validation of consistency of position of landmarks for radiographic carpal parameters

1 After the initial set of radiographs were acquired, the limbs were then dissected to expose the carpal 2 bones on both the dorsal and palmar aspects of the carpus and then radiographed a second time. A 3 radiopaque material (flexible metal wire) was then cut and fixed with super glue to the anatomic features used as landmarks to develop the parameters and the limbs radiographed the third time. All 4 5 the limbs were thus radiographed 3 times each at ZDP, ZLM and ZML views (i.e as intact limb before 6 dissection; immediately after dissection and lastly after fixing the markers). The outline of the dorsal 7 and palmar borders of each carpal bone was differentiated on the studied radiographs as explained in a standard radiographic anatomy text (Butler et al., 2008). 8

9 2.4. Statistical analysis

10 All data were presented as Mean \pm standard deviation (SD). One-way repeated measure ANOVA was used to compare means of each parameter measured from the three categories of carpal radiographs 11 (i.e. from intact, dissected and metal marked). A paired Student t-test was used to compare the 12 13 measurements from ZLM and ZML radiographs. Inter and intra observer reliability tests of measurements were analysed using paired t-test, intra class correlation coefficient (ICC) and Bland-14 Altman plot to chart the strength of agreement between the 2 independent observers. A Bland-Altman 15 16 plot is chatted based on calculated mean difference of 2 separate measurements for the same variables and the upper and lower 95% limit of agreement. A 95% confidence interval was used and values 17 where P < 0.05 were considered significant. All statistical tests were performed with MS Excel 2016 18 and Version 23 of IBM SPSS statistics for Windows. 19

20 **3. RESULTS**

14 parameters were developed from investigating the radiographic anatomy of the equine carpus. Four 21 22 parameters were developed from the ZLM image (view) and 10 from the ZDP image (Table 1). No significant differences (p > 0.05) were observed between measurements obtained on the lateromedial 23 24 (ZLM) and the mediolateral (ZML) images and between measurements of carpal parameters on 25 radiographs from intact, dissected and metal marked limbs (Table 2). The differences between the repeated measurements of the two observers (Table 3) were not significantly different and the inter-26 27 observer ICC were generally good ranging from 0.581 to 0.969 (Table 4) except for WDR:WPM where the ICC was below 0.5 (0.443) and considered poor. A Bland-Altman plot showing the strength 28 of agreement between the 2 observers was presented for each parameter (Figure 6a-n). 29

30 4. DISCUSSION

The data sets presented in this study for the 14 developed carpal parameters were generally well distributed except for CiPxTRA that was skewed to the left (Table 1). Graphically, the normality of a distribution (data set) is expressed by the dome shaped bell and it should appear symmetric if it looks the same to the left and to the right of the center point (Asghar & Zahediasl, 2012; Mishra et al., 2019). Skewness is the measure of lack of symmetry (i.e. asymmetry) of a normal distribution (data set). Ideally, for a symmetric distribution, the mean, median, and mode would coincide, and its skewness statistic = 0, but that hardly happens in most data set. Thus, distributions are considered

"approximate normal" if value is between -1 and +1 and considered highly skewed when less than -1 or greater than +1 (Asghar & Zahediasl, 2012; Mishra et al., 2019). A stricter value of between -0.5 and 0.5 for approximately symmetric, and between -1 and -0.5 or between 0.5 and 1 for moderately skewed is sometimes used for interpretation. It is difficult at this stage to ascertain the source or reason for the negative skewness of CiPxTRA observed in this study as it could either be a sample skewness without skewness in the population or an indication of skewness in the population.

7 The metal markers used in this study, made the landmarks used for the development of the 8 parameters to be more visible (radiopaque) and thus reduced the chance of missing these points of 9 interest. Measurements that were acquired with the aid of markers affixed to landmarks could therefore be regarded as true and accurate representations of distances or angles between two or 10 more points of interest. Since there were no significant differences between measurements of the same 11 parameters evaluated on radiographs from the marked and non marked preparations of same limb, it is 12 reasonable to suggest that the measurements acquired without markers were as reliable as those with 13 markers. This therefore validates that the location of the landmarks used on the radiographs were 14 consistent and repeatable. The neccesity for verification of new methods suggests that measurement 15 16 be taken more than once and also by more than one observer for comparison. Analysis of these 17 repeated measures validate the consistency and repeatability of the method of measurement and the 18 parameters been measured. The high intraclass correlation coefficient (ICC), found between and 19 within measurements of the 2 observers in this study, thus further suggest clarity of parameters' 20 landmarks and the ease and simplicity of the methodology.

Bland-Altman plot was introduced by Altman and Bland (1983) to describe the 21 22 correlation or agreement more accurately between 2 quantitative measurements. It constructs on a scatter plot XY, the calculated mean difference (bias), and an upper and lower limit of agreement 23 24 (LOA) between these 2 measurements. The Y axis shows the difference between the 2 paired 25 measurements while the X axis represent the average of the 2 measurements (Giavarina, 2015). 95% 26 of the data points are expected to be within ± 2 standard deviation of the mean difference (centered 27 line), represented by the 2 straight lines of upper and lower LOA respectively (Altman & Bland, 1983; Giavarina, 2015; Dogan, 2018). A strong inter-rater agreement observed in this study for all the 28 14 parameters could further affirm the accuracy, reliability, and reproducibility of measurements. 29 30 Radiographic parameters were developed with the intent of measuring different aspects of the 31 conformation of the equine carpus, so that when one or more parameters are evaluated together, a 32 more comprehensive assessment of the carpus can be achieved.

The dorsal carpal angle (DCA) was developed to measure the general alignment of the carpus as viewed from the lateral aspect of the forelimb of the horse. Although the method used to measure DCA in this study was based primarily on the procedure described by Barr (1994), the term DCA was however not used in Barr's report. Other authors (Burn *et al.*, 2006; Deane & Davies, 1995b) have differently measured "carpal angle" also from the lateromedial view while still using the intersection

1 of the long axis of the antebrachium and the third metacarpal bone. They referred to the angle formed 2 at the palmar aspect of the carpus as the "carpal angle". Confusion could therefore arise as to what 3 orientation best defined the carpal angle or its proper nomenclature. The term DCA was therefore adopted in the current study to precisely identify the anatomical plane for which the angle has been 4 5 measured. The term "hyperextension" is often used to describe overextending of a joint and carpal hyperextension has been reported to be associated with carpal damages and conformational 6 7 unsoundness of the carpus in horses (Fretz, 1980; Barr, 1994; Deane & Davies, 1995b; Kainer, 2002; Stashak & Hill, 2002; Burn et al., 2006). DCA measures the degree to which a carpus is either 8 9 conformationally hyperextended (back-at-the-knee) or flexed ("Buck-kneed"). Also, during exercise, 10 DCA could be used to either experimentally (Olusa et al., 2019) or physiologically (Burn et al., 2006; Deane & Davies, 1995b) assess the severity (degree) of hyperextension of the carpus at loading phase 11 12 of locomotion.

The third carpal bone palmar facet angle (C3PalFCA) was conceived to measure the 13 alignment of the middle carpal joint. Since the C3 palmar facet is a feature within the middle carpal 14 joint, it was thought that the angle formed by its relative height with the dorsal margin of the proximal 15 row of carpal bones, might affect either the forward or backward tilt of the proximal row of carpal 16 17 bones, the distal antebrachium during loading and subsequently the entire carpal conformation. The 18 middle carpal joint is a frequently damaged joint therefore, any parameter that can be used to assess 19 its alignment (hyperextension) might be useful in diagnosis of middle carpal joint injuries and 20 understanding of their pathogenesis. In a recent study, C3PalFCA was found useful for assessing the degree (severity) of carpal hyperextension as its values increase with increasing loading of the carpus 21 22 (Olusa et al., 2019). It also gave a more holistic evaluation of the carpus when assessed along with DCA as it was found to be inversely related to DCA (Olusa et al., 2019). 23

24 The distal radial slope carpal angle (DRSCA) was designed to measure the conformational 25 alignment of the disto-dorsal portion of the antebrachium (epiphysis) with the proximal row of carpal bones while the intermediate carpal bone proximal tuberosity-radial angle (CiPxTRA) attempts to 26 27 assess the angular alignment formed between the highest point of the proximal row of carpal bones (the palmar tuberosity of Ci) and the disto-dorsal rim and epiphyseal slope of the radius. The palmar 28 tuberosity of Ci has been reported to be more developed in the thoroughbred than in the pony 29 (Abdunnabi et al., 2011). CiPxTRA might therefore be helpful in further assessment of the degree of 30 carpal hyperextension as it relates to or originates from the antebrachiocarpal joint. 31

The term "medial carpal angle" (MCA) has not been previously used to describe the measurement of "earpal angle" from the frontal plane of live horses, or on photographs of horses and on DPa radiographs. Nevertheless, the use of the intersection or pivot point of the radius and the third metacarpal bone has long been used in the horse especially when assessing the severity of angular limb deformities in foals (Butler, 2008; Fretz, 1980; Steinman *et al.*, 2000). MCA purpose was to measure the general alignment of the forelimb at the level of the carpus as viewed in the frontal plane. 1 This can be used routinely/clinically to objectively quantify the degree of carpal valgus or varus in the
2 horse instead of the subjective method of dropping an imaginary line from the point of the shoulder
3 joint to bisect the limb (Stashak & Hill, 2002). It will also be useful in assessing the degree of
4 extension or hyperextension during loading and flexion of the carpus (Olusa *et al.*, 2019).

5 The current study measured for the first time the wedge-like angulations of the articular 6 surfaces of the equine carpal bones. Although the interlocking wedge concept of the carpal bones 7 have been described (Bramlage, 1988; Deane & Davies, 1995a; Rooney, 1969; Von Rubeli, 1925) 8 there are no published measurements of these angles. Quantifying the topographic geometry of each 9 carpal bone articular surfaces (Sledge, 1993), may however open a new area of investigation into how 10 the biomechanics of the smooth load transmission from bone to ligament has protected the carpus 11 from injury during the evolution of the horse.

The C3DDSA measures the angulation of the distal articular surface of C3. Since C3 is 12 subjected to high compressional forces during loading (Bramlage, 1988; Palmer, 1994; Young et al., 13 1991), the steepness of this angle might have a possible correlation with how the C3 is 14 conformationally stable on the MC3 during loading. In a study carried out by Abdunnabi (2011), out 15 of 5 parameters that were used to categorize two limbs into "favourable" or "less favourable" carpal 16 conformation and used to assess their stability under loading, 3 were related to the C3 (Abdunnabi, 17 18 2011). Other parameters related to C3 that were developed in the current study were CrDDSA and 19 CiDDWA. The CrDDSA measures the steepness of the radial articular facet of C3 while CiDDWA 20 partly measures the steepness of the intermediate articular facet of C3. The clinical extent of congruity maintained by Cr and Ci on C3 and on the proximal metacarpus by C3 during loading would be based 21 22 on the degree of steepness and wedgeness of their articular surfaces and facets. Measuring the shape and geometrical properties of C3 might therefore provide a useful tool for quantifying the 23 24 contributory role of C3 to the stability of the carpal joint in horses.

The wedge-like angulations of the distal surface of C4 promote its stability in-between the lateral splint bone, the third metacarpal bone and the C3 during loading. The steepness of these wedge-like angles of C3 and C4 could have important roles in the conformational stability of the distal carpal row which would be essential to the integrity of the carpometacarpal joint. On its proximal articular surface, the C4 articulates with the distal articular surface of ulnar carpal bone (Cu) during loading and thus CuDSA attempts to estimates the degree of congruity between the opposing surfaces of Cu and C4 under load.

The unique morphology of Ci has positioned it as the prime example of the wedge concept (Bramlage, 1988; Deane & Davies, 1995a; Rooney, 1969) and a clear depiction of the wedge-like angulation of the articular surfaces of the carpal bones (Bramlage, 1988). CiDDWA was conceived to measure the conformational stability of the Ci as it stabilizes/wedges between the C3 and C4 during weight bearing. The presence and degree of this angle might have an important role in the transfer of axial forces to the intercarpal ligaments between these bones. Auer et al., (1986) suggested that

1 spinning (rotational) movements occur around the long axes of the antebrachium and MC3 as the 2 carpus is moving into a close-packed position during loading and that fractures of C4 and Ci are due 3 to abnormal concentration of forces on these 2 bones. If the radius is rotating outward from medial to lateral (supination), while the MC3 is stationary or rotating lateromedially (i.e. inwardly and termed 4 5 pronation), C4 and Ci are believed to be slammed together before other carpal bones can make full contact (Auer et al., 1986). A steeper CiDDWA might therefore increase the slamming rate and 6 7 impact of collision between these bones and result in increased incidence and severity of damage. Being able to measure this angle and ultimately establishing a safe value range for conformationally 8 9 stable Ci may further help our understanding of loading, load transfer to adjacent bones and ligaments and pathogenesis of middle carpal joint damage. 10

Both the proximal and distal articular surface slope angles of Cr were measured. These 11 measurements assess the degree of congruity of the proximal surface of the Cr with the radius and the 12 13 distal surface of the Cr with the C3. The Cr is perhaps the most mobile of the carpal bones and receives high loading stress during flexion and extension of the antebrachiocarpal and middle carpal 14 joints. A suggested mechanism of injury to these joints was repeated carpal hyperextension and 15 16 resultant shortening (weakening) or microanatomic fractures of articular surfaces due to the chronic accumulation of loading stress (Bramlage, 1988). A deformed (weakened) articular surface may 17 18 perhaps be measurable by assessing changes in the wedge angles. Furthermore, an increase or 19 decrease in the steepness of these angles (CrDDSA and CrPDSA) might affect the loading stability of 20 the Cr as it wedges in between the radius and the C3.

The width of the distal antebrachium would represent the proximal boundary of the carpus while the width of the metacarpus would represent the distal perimeter of the carpus. These 2 boundaries were measured as a ratio of each other (WDR:WPM). If a large difference exists between these 2 surfaces/width, it might result in a "funnel effect" in which a load travelling from the antebrachium will exert more pressure (strain) on the metacarpus due to the smaller recipient contact area. More studies will be required to test this theory.

27 DRW.MAC:LAC measures the relative width of the distal radius condyles. In another study, a similar measurement of widths of the lateral and the medial condyles of the distal extremity of MC3 28 showed that the medial condyle width was significantly larger than the lateral condyle (Alrtib et al., 29 30 2012). This was thought to partly prevent the sliding of the proximal phalanx towards the lateral direction; a reason believed to be associated with the low incidence of fetlock luxation in horses 31 (Alrtib et al., 2012; Bertone, 2002). In the present study, the width of the medial articular condyle 32 (MAC) of the distal radius was consistently less than the width of the lateral articular condyle (LAC). 33 34 This would contribute to the conformational stability of the radius on the proximal carpal row as well 35 as the general carpal alignment.

36 5. CONCLUSION

1 This study developed a radiographic measurement protocol and proposed 14 parameters for 2 objective assessment of carpal conformation in the horse. These parameters are more holistic and yet 3 simple to measure in comparison to previous methods. 5 of these 14 parameters were already found useful/relevant for assessing carpal conformation during experimental loading and flexion of the 4 carpus (Olusa et al., 2019). This evaluation protocol can be easily incorporated into routine 5 radiographic examination of the horse such as pre purchase examination. With further studies on 6 7 larger equine populations, and establishment of ranges of normal values for these parameters in different breeds, this technique offers a potential tool for clinicians for assessing different angular 8 limb (carpal) conformation and physiological hyperextension in horses. This approach when adopted 9 10 could also help to eliminate the often-encountered judgemental errors or variation between equine practitioners using subjective visual assessment for the carpus. Further investigation will be required 11 for comparison between subjective visual examination and objective radiographic assessment 12 methods of carpal conformation. 13

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20 CONFLICT OF INTEREST

21 No conflict of interest is declared for this work.

22

23 DATA AVAILABILITY STATEMENT

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The data that support the findings of this study are available from the corresponding author upon request.

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| S/no | Measurable | Mean ± SD | Median | 95% CI | of Mean | Skewness |
|------|-------------------|-------------------------|--------|---------------|---------|-----------|
| | Parameters (n=10) | (°) | (°) | Lower | Upper | Statistic |
| 1 | DCA | 176.61±0.66 | 176.79 | 176.14 | 177.08 | -0.529 |
| 2 | DRSCA | 145.59±2.19 | 145.65 | 144.02 | 147.15 | 0.607 |
| 3 | CiPxTRA | 115.69±3.15 | 117.24 | 113.44 | 117.94 | -1.495** |
| 4 | C3PalFCA | 84.43±1.13 | 84.48 | 83.62 | 85.24 | -0.502 |
| 5 | MCA | 183.34±1.02 | 183.49 | 182.61 | 184.07 | -0.314 |
| 6 | C3DDSA | 8.27±0.92 | 8.21 | 7.61 | 8.93 | 0.638 |
| 7 | C4DDWA | 141.71±2.85 | 140.71 | 139.67 | 143.75 | 0.657 |
| 8 | C4DPWA | DPWA 128.31±5.03 | | 129.67 124.72 | | -0.219 |
| 9 | CrDDSA | 7.91±1.16 | 8.07 | 7.08 | 8.74 | 0.249 |
| 10 | CrPDSA | 13.44±0.87 | 13.48 | 12.81 | 14.06 | -0.077 |
| 11 | CiDDWA | 153.08±2.19 | 153.39 | 151.52 | 154.64 | -0.368 |
| 12 | CuDSA | 33.02±2.77 | 32.44 | 31.04 | 35.01 | 0.649 |
| 13 | WDR: WPM | 1.13±.03 | 1.13 | 1.11 | 1.15 | 0.583 |
| 14 | DRW.MAC:LAC | 0.77±0.06 | 0.79 | 0.72 | 0.81 | -0.244 |

Table 1:14 Carpal conformational parameters measured from Zero lateromedial (ZLM) and Zero dorsopalmar (ZDP) radiographs of 10 cadaveric limbs

DCA = Dorsal carpal angle; DRSCA = Distal radial slope carpal angle; CiPxTRA = Intermediate carpal bone proximal tuberosity-radial angle; C3PalFCA = third carpal bonepalmer facet angle; MCA = Medial carpal angle; C3DDSA = Disto-dorsal slope angle of the third carpal bone; C4DDWA = Disto-dorsal wedge angle of the fourth carpalbone; C4DPWA = Disto-palmar wedge angle of the fourth carpal bone; CrDDSA = Disto-dorsal slope angle of the radial carpal bone; CrPDSA = Proximo-dorsal slope angleof the radial carpal bone; CiDDWA = Disto-dorsal wedge angle of the intermediate carpal bone; CuDSA = Distal slope angle of the ulnar carpal bone; WDR:WPM = Widthratio of distal radius to proximal metacarpus; DRW.MAC:LAC = Width ratio of distal radius' medial articular condyle to lateral articular condyle. 95% C I = 95% Confidenceinterval; (°) = Degrees. The unit of measurement was in degree for all the parameters except for WDR:WPM and DRW.MAC:LAC that are ratios and had no unit. SD =Standard deviation. btw = between. ** = highly skewed **Skewness statistic** measures lack of symmetry (asymmetry) of normal distribution of a data set. perfect symmetric = 0; approximate normal/symmetric = btw -0.5 and 0.5; moderately skewed = btw -1 and -0.5 or 0.5 and 1; and highly skewed = less than -1 or greater than 1.



Table 2: Validation of the consistency of the positions of landmarks used for measuring the 14 carpal parameters from ZLM and ZDP radiographs

| S/no | Measura | ble | | | Mean ± | ± SD (°) | | | Sig. btw int, |
|------|------------|-----|--------------|---------------|-------------|---------------|-------------|---------------|-----------------------|
| | Parameters | | Intact limb/ | Sig. | Dissected | Sig. | Carpi with | Sig. | dis & mak |
| | (n = 10) | | Carpi | (p value) btw | limb/ Carpi | (p value) btw | marker | (p value) btw | carpi |
| | 0 | | | ZLM & ZML | | ZLM & ZML | | ZLM & ZML | (p<0.05)* |
| 1 | DCA | ZLM | 176.61±0.66 | 0.273 | 176.45±0.81 | 0.265 | 176.88±0.62 | 0.286 | 0.403 |
| | | ZML | 176.25±0.50 | | 176.79±0.48 | | 176.46±0.77 | | |
| 2 | DRSCA | ZLM | 145.59±2.19 | 0.789 | 144.89±1.73 | 0.643 | 145.22±1.81 | 0.828 | 0.725 |
| | | ZML | 145.87±2.09 | | 144.61±1.69 | | 145.07±1.68 | | |
| 3 | CiPxTRA | ZLM | 115.69±3.15 | 0.981 | 114.82±1.91 | 0.582 | 115.93±2.49 | 0.850 | 0.602 |
| | | ZML | 115.72±2.01 | | 115.47±2.33 | | 115.79±1.95 | | |
| 4 | C3PalFCA | ZLM | 84.43±1.13 | 0.574 | 84.71±1.95 | 0.924 | 85.26±2.03 | 0.709 | 0.567 |

| | | ZML | 84.81±1.66 | | 84.78±1.85 | | 84.95±1.58 | | |
|----|---------|----------|-------------|----|-------------|----|-------------|----|-------|
| 5 | MCA | | 183.34±1.02 | na | 183.99±1.33 | na | 183.89±1.36 | na | 0.463 |
| 6 | C3DDS | A | 8.27±0.92 | na | 8.02±0.81 | na | 8.08±0.90 | na | 0.807 |
| 7 | C4DDWA | | 141.71±2.85 | na | 141.24±3.00 | na | 142.17±3.21 | na | 0.791 |
| 8 | C4DPW | A | 128.31±5.03 | na | 128.18±4.09 | na | 128.22±5.68 | na | 0.998 |
| 9 | CrDDS | A | 7.91±1.16 | na | 7.64±0.88 | na | 8.16±1.01 | na | 0.536 |
| 10 | CrPDS | A | 13.44±0.87 | na | 13.45±1.36 | na | 13.52±1.82 | na | 0.990 |
| 11 | CiDDW | 'A | 153.08±2.19 | na | 151.62±2.76 | na | 153.63±3.11 | na | 0.250 |
| 12 | CuDSA | A | 33.02±2.77 | na | 33.19±3.00 | na | 35.05±3.27 | na | 0.269 |
| 13 | WDR:WPM | | 1.13±.03 | na | 1.13±0.02 | na | 1.13±0.03 | na | 0.821 |
| 14 | DRW.MAC | :LAC | 0.77±0.06 | na | 0.78±0.04 | na | 0.77±0.06 | na | 0.828 |

DCA = Dorsal Carpal Angle; **DRSCA** = Distal Radial Slope Carpal angle; **CiPxTRA** = Intermediate carpal bone Proximal Tuberosity-Radial Angle; **C3PalFCA** = Third carpal bone Palmer facet angle; **MCA** = Medial Carpal angle; **C3DDSA** = Disto-dorsal slope angle of the third carpal bone; **C4DDWA** = Disto-dorsal wedge angle of the fourth carpal bone; **C4DPWA** = Disto-palmar wedge angle of the fourth carpal bone; **C4DPWA** = Disto-palmar wedge angle of the fourth carpal bone; **CrDDSA** = Disto-dorsal slope angle of the radial carpal bone; **CrPDSA** = Proximo-dorsal slope angle of the radial carpal bone; **CiDDWA** = Disto-dorsal wedge angle of the intermediate carpal bone; **CuDSA** = Distal slope angle of the ulnar carpal bone; **WDR:WPM** = Width ratio of Distal radius to Proximal metacarpus; **DRW.MAC:LAC** = Width ratio of distal radius' medial articular condyle to lateral articular condyle. **95%** C I = 95% Confidence interval; **SD** = Standard deviation; na = non applicable; btw = between; * = Statistical significance (**Sig.**) at **p<0.05. int = intact, dis = dissected, mak = marked.**

 Table 3: Intra-observer repeatability (test re-test reliability) test for each of the 14 carpal parameters measured separately by 2 independent observers.

 Results showed no significant mean difference and intraclass correlation coefficient (ICC) between their (i.e. Obr 1 & 2) respective 2 repeated measurements.

| S/ | Parameters | Mst/ | | Observ | ver 1 | | Observer 2 | | | |
|----|------------|-----------------|-------------|---------------|-----------------------|----------|-------------|---------------|-----------------------|----------|
| no | (n = 10) | Read | Mean±SD | Mean Diff.±SD | Sig. | ICC | Mean±SD | Mean Diff.±SD | Sig. | ICC |
| | | ing | | | (p<0.05)* | (95% CI) | | | (p<0.05)* | (95% CI) |
| 1 | DCA | 1 st | 176.61±0.66 | 0.20±0.64 | 0.344 | 0.616 | 176.52±0.60 | -0.02±0.69 | 0.925 | 0.660 |

| | | 2 nd | 176.41±0.56 | | | (-0.464; 0.903) | 176.54±0.72 | | | (-0.542; 0.918) |
|----|----------|-----------------|-------------|-------------|-------|-----------------|-------------|------------|-------|-----------------|
| 2 | DRSCA | 1 st | 145.59±2.19 | 0.16+1.55 | 0.755 | 0.808 | 145.98±1.33 | 0.67±1.62 | 0.404 | 0.668 |
| | + | 2 nd | 145.43±1.47 | 0.10±1.55 | | (0.188; 0.953) | 145.31±1.85 | | 0.494 | (-0.356; 0.918) |
| 3 | CiPxTRA | 1 st | 115.69±3.15 | 0.07+0.92 | 0.811 | 0.975 | 116.55±1.29 | 0.32±0.81 | 0.244 | 0.895 |
| | | 2 nd | 115.62±2.46 | 0.07±0.92 | | (0.899; 0.994) | 116.24±1.39 | | 0.244 | (0.607; 0.974) |
| 4 | C3PalFCA | 1 st | 84.43±1.13 | 0.00 ± 1.00 | 0.785 | 0.744 | 84.57±1.85 | -0.18±1.78 | 0.750 | 0.620 |
| | O | 2 nd | 84.33±1.22 | 0.09±1.09 | | (-0.108; 0.938) | 84.75±1.46 | | 0.739 | (-0.709; 0.908) |
| 5 | MCA | 1 st | 183.34±1.02 | 0.04+0.78 | 0.881 | 0.852 | 183.61±1.05 | -0.42±0.73 | 0.867 | 0.753 |
| | | 2 nd | 183.38±1.08 | -0.04±0.78 | | (0.379; 0.964) | 184.03±0.94 | | | (-2.799; 0.795) |
| 6 | C3DDSA | 1 st | 8.27±0.92 | 0.26+0.31 | 0.027 | 0.949 | 8.29±0.58 | -0.09±0.55 | 0.624 | 0.852 |
| | | 2 nd | 8.52±0.80 | -0.20±0.51 | | (0.670; 0.989) | 8.38±0.88 | | | (0.401; 0.963) |
| 7 | C4DDWA | 1 st | 141.71±2.85 | 0.20+1.08 | 0.280 | 0.951 | 142.41±2.39 | -0.06±1.94 | 0.924 | 0.806 |
| | U | 2 nd | 142.10±2.15 | -0.39±1.08 | | (0.813; 0.988) | 142.47±2.26 | | | (0.166; 0.953) |
| 8 | C4DPWA | 1 st | 128.31±5.03 | 0.27+1.02 | 0.273 | 0.989 | 128.83±6.01 | 0.10±2.01 | 0.874 | 0.965 |
| | | 2 nd | 128.69±5.09 | -0.37±1.02 | | (0.960; 0.997) | 128.73±4.22 | | | (0.856; 0.991) |
| 9 | CrDDSA | 1 st | 7.91±1.16 | -0.01+0.38 | 0.909 | 0.973 | 8.14±0.77 | -0.08±0.59 | 0.664 | 0.846 |
| | | 2 nd | 7.93±1.05 | -0.01±0.56 | | (0.891; 0.993) | 8.22±0.80 | | | (0.370; 0.962) |
| 10 | CrPDSA | 1 st | 13.44±0.87 | 0.15+0.01 | 0.606 | 0.845 | 13.23±1.25 | -0.05±0.65 | 0.810 | 0.924 |
| | Ċ | 2 nd | 13.59±1.48 | -0.13±0.91 | 0.000 | (0.372; 0.962) | 13.28±1.09 | | | (0.688; 0.981) |
| 11 | CiDDWA | 1 st | 153.08±2.19 | 0.27+0.01 | 0 370 | 0.957 | 153.24±1.96 | 0.44±0.73 | 0.093 | 0.963 |
| | | 2 nd | 152.81±2.29 | 0.27±0.91 | 0.379 | (0.838; 0.989) | 152.80±2.35 | | | (0.836; 0.991) |
| 12 | CuDSA | 1 st | 33.02±2.77 | 0.36+0.63 | 0.000 | 0.985 | 32.62±2.63 | 0.18±0.71 | 0.447 | 0.982 |
| | | 2 nd | 32.66±2.86 | 0.30±0.03 | 0.077 | (0.931; 0.996) | 32.44±2.56 | | | (0.930; 0.995) |
| 13 | WDR:WPM | 1 st | 1.13±0.03 | 0.001+0.02 | 0.876 | 0.852 | 1.13±0.03 | 0.001±0.02 | 0.859 | 0.883 |
| | | 2 nd | 1.13±0.02 | -0.001±0.02 | 0.070 | (0.377; 0.964) | 1.13±0.02 | | | (0.512; 0.971) |

| 14 | DRW.MAC: | 1 st | 0.77±0.06 | -0.008+0.04 | 0.534 | 0.866 | 0.78±0.05 | 0.01+0.06 | 0.761 | 0.802 |
|----|----------|---------------------------|-----------|-------------|-------|----------------|-----------|-----------|-------|----------------|
| | LAC | 2 nd 0.77±0.05 | 0.77±0.05 | 01000_0101 | 0.001 | (0.467; 0.966) | 0.77±0.05 | 0.01_0.00 | 0.701 | (0.404; 0.885) |

Measurement (Mst) Reading refers to the separate 1st and 2nd time points (minimum of 2 weeks interval) of repeated measurement of radiographs by the two observers. 95%

CI = 95% Confidence interval. Mean Diff = Difference between 2 means. SD = Standard deviation. * = Statistical significance (Sig.) at p<0.05

Table 4: Assessment of agreement of measurement between the 2 independent observers (Inter-rater reliability test) for each of the 14 carpal parameters using calculated mean difference (bias) and 95% limit of agreement (CI) for the Bland-Altman plot

| S / | Parameters | Observers | Mean±SD | Mean | Sig | Intraclass Correlation | Calc. 95% CI for Limits of | |
|------------|-----------------|-----------------|-------------|-------------|-----------------------|------------------------|----------------------------|-------------------|
| no | | | | Diff.±SD | (p<0.05)* | Coefficient | agreement (for B | land-Altman plot) |
| | | | | | | (95% CI) | Lower | Upper |
| 1 | DCA | 1 st | 176.61±0.66 | 0.09+0.83 | 0.739 | 0.621 | -1 5324 | 1 7124 |
| | \mathbf{O} | 2 nd | 176.52±0.60 | 0.09±0.05 | | (-1.855; 0.922) | | 1./124 |
| 2 | DRSCA | 1 st | 145.59±2.19 | -0 39+0 97 | 0.844 | 0.823 | -2 3002 | |
| | 2 | 2 nd | 145.98±1.33 | 0.37±0.77 | 0.011 | (0.248; 0.957) | 2.3002 | 1.5142 |
| 3 | CiPxTRA | 1 st | 115.69±3.15 | 0.86+2.81 | 0.257 | 0.884 | 6 260/ | |
| | | 2 nd | 116.55±1.29 | -0.00±2.01 | | (0.165; 0.987) | -0.3094 | 4.6454 |
| 4 | C3PalFCA | 1 st | 84.43±1.13 | -0 14+2 03 | 0.735 | 0.732 | -4 1168 | |
| | č | 2 nd | 84.57±1.45 | 0.1122.03 | 0.755 | (-0.174; 0.820) | | 3.8408 |
| 5 | MCA | 1 st | 183.34±1.02 | -0 27+1 71 | 0.096 | 0.581 | -3 6309 | |
| | | 2 nd | 183.61±1.54 | 0.27 ± 1.71 | | (-0.547; 0.834) | 5.0507 | 3.0829 |
| 6 | C3DDSA | 1 st | 8.27±0.92 | 0.02+0.50 | 0.014 | 0.907 | 1 1020 | 1 1510 |
| | | 2 nd | 8.29±0.58 | -0.02±0.39 | 0.914 | (0.307; 0.987) | -1.1959 | 1.1519 |
| 7 | C4DDWA | 1 st | 141.71±2.85 | -0.70+1.52 | 0.177 | 0.922 | -3 6849 | 2 2769 |
| | | 2 nd | 142.41±2.39 | 0.70±1.92 | | (0.539; 0.989) | -3.00+2 | 2.2107 |

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| 8 | C4DPWA | 1 st | 128.31±5.03 | -0.52±1.27 | 0.228 | 0.989 | -3 0054 | 1 9674 |
|----|--------------|-----------------|-----------------|------------|-------|-----------------|----------|--------|
| | | 2 nd | 128.83±6.01 | 0.52-1.27 | 0.220 | (0.895; 0.998) | 5.0051 | 1.9071 |
| 9 | CrDDSA | 1 st | 7.91±1.16 | -0.22+0.55 | 0.228 | 0.916 | -1 3/73 | 0.8993 |
| | Q | 2 nd | 8.14±0.77 | -0.22±0.55 | 0.220 | (0.564; 0.987) | -1.3+73 | 0.0775 |
| 10 | CrPDSA | 1 st | 13.44±0.87 | 0 20+0 99 | 0.532 | 0.789 | -1 7406 | 2 1486 |
| | | 2 nd | 13.23±1.25 | 0.20±0.77 | 0.552 | (-0.269; 0.970) | -1.7400 | 2.1400 |
| 11 | CiDDWA | 1 st | 153.08±2.19 | -0 16+1 42 | 0.731 | 0.969 | -2 9519 | 2 6319 |
| | \mathbf{G} | 2 nd | 153.24±1.96 | -0.10±1.42 | 0.751 | (0.769; 0.995) | 2.7017 | 2.0317 |
| 12 | CuDSA | 1 st | 33.02±2.77 | 0.41+1.38 | 0.373 | 0.872 | 2 2888 | |
| | | 2 nd | 32.62±2.63 | 0.41±1.56 | 0.575 | (0.861; 0.927) | -2.2888 | 3.1048 |
| 13 | WDR:WPM | 1 st | 1.13±0.03 | -0.01+0.03 | 0.614 | 0.443 | -0.06/13 | 0.0543 |
| - | | 2 nd | 1.13±0.03 | -0.01±0.03 | 0.014 | (-2.686; 0.883) | -0.00+3 | 0.0343 |
| 14 | DRW.MAC:LAC | 1 st | 0.77±0.06 | -0.01+0.05 | 0.521 | 0.869 | -0.1029 | |
| | | 2 nd | 0.78 ± 0.05 | 0.01±0.05 | 0.321 | (0.542; 0.989) | 0.1027 | 0.0829 |

Estimates of reliability based on ICC values are categorized as follows: below 0.5 = Poor; 0.5 to 0.75 = Moderate; 0.75 to 0.9 = Good and above 0.9 = Excellent (Koo & Li

2016). * = Statistical significance (Sig.) at p<0.05

Table 5: (Appendix) Abbreviations and details of technical parameters used for imaging

| DP | Dorsopalmar: This refers to the direction of travel of the primary X-ray beam as viewed from |
|----|---|
| | |
| | the frontal plane of the horse/limb. The beam enters on the dorsal surface of the carpus and exit |
| | |
| | from the palmar side |
| | |
| LM | Lateromedial: This refers to the direction of travel of the primary X-ray beam as it enters on |
| | |
| | the lateral side of the limb and exit from the medial side |
| 1 | |

| ML | Mediolateral: X-ray beam travelled in opposite direction to LM |
|--------------|--|
| ZDP | Zero dorsopalmar: This is an oblique variation of dorsopalmar view. It is usually obtained |
| | when the direction of travel of the primary X-ray beam entered the object at between 2° to 15° |
| 0 | Dorsolateral-Palmaromedial Oblique (DL-PaMO). The angulation of the oblique depends on the |
| | conformation of each limb. The aim was to produce a radiograph of the carpus with i) a small |
| | radiolucent space between the proximo-dorsal articular facets of the radial carpal bone (Cr) and |
| \mathbf{O} | intermediate carpal bone (Ci); and ii) a contact point between the disto-lateral ends of the dorsal |
| | and the palmar borders of the third carpal bone (C3). These 2 features respectively served as the |
| | vertical and horizontal landmarks for ZDP view |
| ZLM | Zero Lateromedial: This was essentially a Palmarolateral-Dorsomedial Oblique (PaL-DMO) |
| | view. The oblique angle varied from between 5° to 20° depending on each limb's |
| | conformation. The aim of this view was to produce a radiograph in which the overlapped 4 th and |
| σ | 2nd metacarpal bones were completely superimposed; represented by a single clear margin of |
| | their palmar borders |
| ZML | Zero Mediolateral: This was opposite to ZLM as the direction of travel of the primary X-ray |
| | beam was Dorsomedial-Palmarolateral Oblique (DM-PaLO) at similar angles |
| DICOM | Digital imaging and communication in medicine |
| PACS | Picture archiving and communication system |

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C4DPWA (Mean of mst by Obr 1 & Obr 2)

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0.5 0.55 0.6 0.65 0.7 0.75 0.8 0.85 0.9 DRW>MAC:LAC (Mean of mst by Obr 1 & Obr 2)

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