



Minerva Access is the Institutional Repository of The University of Melbourne

**Author/s:**

Olusa, TAO;Davies, HMS

**Title:**

Radiographic assessment of carpal conformation in the horse, part 2: Finding acceptable limits to postural and rotational variations during radiography

**Date:**

2021-05-01

**Citation:**

Olusa, T. A. O. & Davies, H. M. S. (2021). Radiographic assessment of carpal conformation in the horse, part 2: Finding acceptable limits to postural and rotational variations during radiography. *Journal of Veterinary Medicine Series C Anatomia Histologia Embryologia*, 50 (3), pp.467-492. <https://doi.org/10.1111/ahe.12651>.

**Persistent Link:**

<https://hdl.handle.net/11343/298098>

DR. TIMOTHY AKINBOWALE OLUSA (Orcid ID : 0000-0001-9853-4788)

Article type : Original Article

**ORIGINAL ARTICLE**

**Title: RADIOGRAPHIC ASSESSMENT OF CARPAL CONFORMATION IN THE HORSE, PART 2: FINDING ACCEPTABLE LIMITS TO POSTURAL AND ROTATIONAL VARIATIONS DURING RADIOGRAPHY**

**Running head: EFFECTS OF ROTATIONAL VARIATIONS ON CARPAL ANGLES**

**Authors:** Timothy, A.O. Olusa<sup>1\*</sup> & Helen, M.S. Davies<sup>1</sup>

**Institution affiliations:** <sup>1</sup>Faculty of Veterinary and Agricultural Sciences, University of Melbourne, Werribee VIC 3030, Australia

\*Corresponding author: Timothy A.O. Olusa,

Faculty of Veterinary and Agricultural Sciences,

University of Melbourne, Werribee VIC 3030, Australia

E-mail: timolusa1@gmail.com & olusat@unimelb.edu.au

This is the author manuscript accepted for publication and has undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the [Version of Record](#). Please cite this article as [doi: 10.1111/AHE.12651](https://doi.org/10.1111/AHE.12651)

This article is protected by copyright. All rights reserved

## ABSTRACT

Finding an appropriate location for perpendicular positioning of the X-ray machine to produce zero lateromedial (ZLM) and zero dorsopalmar (ZDP) carpal images (views) and an acceptable range of rotational variations for measurement of carpal conformational parameters were two major challenges identified during field radiography of equine forelimbs. 16 cadaver forelimbs transacted at antebrachial midshaft from 10 horses (aged  $9.13 \pm 4.59$  years) were axially mounted into a custom-built frame, and the radiographic machine and plate were perpendicularly aligned with the limb. Each limb was then radiographed at  $2.5^\circ$  interval of vertical rotation of the machine until ZLM and ZDP images were acquired, and at 24 other postural and rotational positions from ZLM and ZDP at  $5^\circ$  interval for comparison of measurements with the standardized ZLM and ZDP image.

ZLM radiographs were produced at a mean vertical projection angle (VPA) of  $9.84 \pm 3.47^\circ$  palmarolateral-dorsomedial oblique (PaL-DMO) while ZDP was acquired at VPA of  $6.41 \pm 2.73^\circ$  dorsolateral-palmaromedial oblique (DL-PaMO). Changes in limbs' postural tilts, vertical plate rotations (VPR) and horizontal beam rotations (HBR) had no effect on the quality of the radiographs and on carpal measurements while vertical beam rotation (VBR) of X-ray beam produced significant changes on the quality of radiographs and on measurements of carpal parameters.

It is recommended that field radiographs of equine forelimbs intended for carpal measurement be obtained within a proposed range of VPA of  $2.5^\circ$  to  $12.5^\circ$  PaL-DMO for ZLM and  $2.5^\circ$  to  $10^\circ$  DL-PaMO for ZDP in order to minimize potential errors attributable to vertical rotational movements.

**Key words:** Zero lateromedial (ZLM), Zero dorsopalmar (ZDP), Carpal radiographs, Rotational variations, Postural tilts, Carpal angles, Horses

## INTRODUCTION

Radiographs required for morphological studies should be of remarkably high quality (Abdunnabi, 2011; Oheida *et al.*, 2016). They should clearly show all the anatomical features used as landmarks for each parameter being measured. However, the conditions under which radiographs are often taken in the field are less desirable due to potential horse movements,

postural tilts of horse's limbs, rotations of radiographic plate holder and or cassette and the angle of projection of the X-ray beam. These rotations (variables) could make maintaining the focal object distance and alignment between the X-ray beam, the object, and the cassette a major challenge. Usually, 3 personnel are involved in this process. The first person restrains the horse using a hand-held halter and tries to keep the animal as calm as possible. Using a hand-held radiographic plate holder, the second operator positions the radiographic plate/cassette behind the limb to be radiographed while the third operator holds the machine, aligns it perpendicularly to the limb and aims for the best projection angle of the X-ray beams during exposure. In an effort by the operators to keep the animal as calm as much as possible and or keep pace with movements or postural tilts and simultaneously maintain perpendicular alignment between the plate and the x-ray beam, a rotation of the plate and or the projection angle of X-ray beam may occur during radiography (exposure).

Furthermore, given the large variation between individual equine forelimbs within and between breeds, the radiographic positioning at which ZLM and ZDP images/views will be obtainable may not be the same for all limbs. Thus, there appears an obvious need to determine the "limit or range of rotation" of the projection angle(s) of the primary X-ray beam along the limbs' vertical and horizontal axes that would consistently produce ZLM and ZDP radiographs. This is of utmost concern especially with regards to minimizing exposure of personnel to ionizing radiation hazard.

In addition to the above, observations from carpal radiographs in archives have shown an apparent variation in the alignment and or morphology of the carpus (Abdunnabi, 2011; Oheida *et al.*, 2017). This was thought to raise two concerns: i) "a potential obstacle in distinguishing between normal carpi morphometry and carpal pathology" and ii) "an indication of inconsistency in the taking of the radiographs" (Oheida *et al.*, 2017). Although some studies have conceptualized the potential effects of limb' rotations on carpal measurements and have investigated its effects on carpal measurements (Barr, 1994; Abdunnabi, 2011; Oheida *et al.*, 2017), the effects of plate rotation and or rotations of projection angles of the X-ray beam during acquisition of radiographs were not included in these studies. Another limitation or short coming of these studies (Barr, 1994; Abdunnabi, 2011; Oheida *et al.*, 2017), was the "assumption" that a horse could rotate a limb along its vertical or horizontal axes either inwardly or outwardly while the limb is positioned on the ground (during weight bearing/radiography). The horse seldom significantly rotates its forelimb either inwardly or outwardly along the limb's vertical or horizontal axes while standing. Except if the limb's rotations in these experimental set ups were used to mirror the

vertical or horizontal rotations of X-ray beam projections (which were not clearly stated), it would be inaccurate to suggest otherwise. The positioning of a horse's limb at rest "reflects both its intrinsic conformation and chosen posture at that particular moment" (Barr, 1994). From close observation, the horse at standing position has no rotational movement around the vertical axes of its limbs but can be seen to rather display a forward or backward and a medial or lateral postural tilt of the limb once the hoof was placed on the floor (Figure 1). Such postural tilts are what were often encountered during field radiography and thus effects of postural limb tilts should be investigated on carpal measurements.

Development and validation of measurable radiographic parameters for the carpal joint in the standing horse (Olusa, 2018; Olusa *et al.*, 2020) should therefore involve testing the potential effects of these postural tilts and rotational variations of X-ray beam and plates on carpal measurements if the developed parameters are to be useful for routine clinical and field application.

There are three objectives for this study. Firstly, to establish a "field radiographic positioning range" for which ZLM and ZDP carpal images/views could be readily acquired for two common breeds of horses (Thoroughbred and Standardbred). Secondly, to investigate the effects of the different forelimb postural tilts, plate rotations and the angles of projection(s) of the primary X-ray beam on the quality of carpal radiographs (i.e clarity of ZLM and ZDP landmarks) and carpal measurements. Thirdly, to establish a safe measurement range or limits in which rotational variations during radiographic acquisition will produce none or minimal acceptable changes or effects on carpal measurements. It is hypothesized that: i). Vertical rotation of X-ray beam projection angles above 15° affects measurements obtained from the radiographs, ii). Rotation of X-ray beams around the horizontal axis has no effect on carpal conformational parameters and iii). Rotations of the cassette around its vertical axis and limb postural tilts up to 10° have no effect on radiographic carpal measurements.

## **MATERIAL AND METHODS**

**Study design:** This was an exploratory anatomic study designed to test measurements of previously developed carpal parameters under different postural and rotational situations.

**Ethical animal research:** Approval from the University of Melbourne Animal Ethics Committee was not required as specimen were collected from animals that had either died or were euthanized for reasons not related to the study.

**Animal/test specimen:** 16 cadaver forelimbs (aged 9.13±4.59 years) consisting of 4 left and 4 right carpi from 5 Thoroughbred and 4 left and 4 right carpi from 5 Standardbred horses were collected from the post-mortem room of the Department of Veterinary Pathology,

University of Melbourne, Australia, and a local knackery in Melbourne from horses that died or were euthanized for reasons not associated with this study. The horses had no known history of carpal lameness, and no gross pathology on physical examination and radiography. The limbs were transected at the radial midshaft (about 12-15cm from antebrachiocarpal joint) and stored at -20 until required.

**Loading Rig:** A custom built compression frame for the equine limb (Altrib, 2013) previously used in part one of the study (Olusa *et al.*, 2020) was also used for the current study (Figure 2a).

**Holding platform:** A purpose built holding platform was constructed for the portable X-ray machine. The surface of the platform was calibrated in degrees ranging from -30° to +30° at 2.5° intervals and a holding base (made of transparent fiber glass) was attached to the calibrated surface so that the radiographic machine could freely rotate and be manipulated as desired around its vertical axis during radiography (Figure 2b).

**Wedges:** 4 wooden wedges with angles (2.5°, 5°, 7.5° and 10°) were used to effect horizontal rotation of the x-ray machine (beam) and the postural limb tilts (Figure 2c).

**Plate holder:** a specially designed plate holder with a calibrated rotating base was used to hold the radiographic plate/cassette during radiography. The calibration (from 2.5° to 10°) was for rotation around the vertical axis of the plate at 2.5° intervals (Figure 2d).

**Metal marker:** a small metal rod (about 12cm in length and 0.2cm diameter) was fixed to the MC3 using tape. It served as a reference point especially for the vertical rotation/axes of each limb (Figure 3).

### **Experimental technique:**

#### **Limb preparation, loading and alignment at 0° position**

The limbs were defrosted in the chiller at 4° for 48 -72 hours. The limbs were each vertically mounted into the custom-built compression frame and aligned along the vertical axis of the frame to mimic a natural standing position in the horse and at 0° with the X-ray beam and plate. The radiographic machine and plate were then perpendicularly aligned with the limb and this position was termed initial 0° alignment position.

To consistently align the X-ray beam on the limbs, a consistent reference line on the limbs was developed using a metal marker (Figure 3a and b). For the dorsopalmar view, the limb was placed horizontally on a flat surface on its palmar side with the two bulbs of the heel evenly placed. Using a Vernier calliper, the medial to lateral width of MC3 was then measured on its dorsal side at two points (about 5 and 20 cm from the carpometacarpal joint), the midpoint of the width was marked, and a small metal rod (metal marker) was attached by

tape down the middle of the MC3. The marked mid-line on the MC3 was then extended to the front of the hoof in a straight line using a pen marker or chalk (Figure 3a).

For the lateromedial view, a similar procedure was carried out on the lateral side of the limb, to place the metal marker for alignment on it (Figure 3b). A small load (loading the limb until a 145° dorsal fetlock angle was achieved), was applied as required on each limb to ensure even loading of the carpal specimens at about standing/walking gait in horses (Holmstrom *et al.*, 1990; Weller *et al.*, 2006; Alrtib *et al.*, 2015; Olusa *et al.*, 2019). The radiographic plate was placed as closely as possible directly behind the limb using the custom-built plate holder set at 0° vertical rotation.

The compression frame and the X-ray platform were positioned at 100cm away from each other. Parallel line markings were drawn at the edges of both the frame and X-ray platform and a perpendicular line was drawn to align them (Figure 4a). These lines and the metal marker on the limbs were used for the perpendicular alignment of the carpus to the primary X-ray beam projections (Figure 4b). The height of the radiographic machine was adjusted as required to ensure that the primary beam of the X-ray was directed at a right angle to the middle carpal joint. A combination of measuring plumb, right angle ruler, 1-meter ruler, laser light (pointer) and visual observation were used to ensure that this initial 0° alignment position was accurate (and this positional set up was referred to as Position 0°). The first radiograph was then taken at this position. Each limb was kept in the frame at its aligned and loaded position 0° for the entire duration (period) required for the radiographs in the various rotations and postural tilts to be taken. The limbs were intermittently moistened with drapes soaked in water to keep them hydrated. All radiographs were acquired using a portable radiographic machine (Atomscope HF80/15 UltraLight, Mikasa X-ray Co Ltd, Japan) set at 80 KVp and 24 secs (3.6 mAs).

### **Radiographic positioning for ZLM and ZDP carpal images (views)**

From the initial 0° alignment position of plate, limb, and X-ray beam (i.e. Position 0°), using the rotating mechanism of the custom-built holding platform for the X-ray machine, each limb was serially radiographed at 2.5° intervals on palmarolateral-dorsomedial oblique (PaL-DMO) and dorsolateral-palmaromedial oblique (DL-PaMO) angles until ZLM and ZDP radiographs were respectively produced. To achieve these (ZLM and ZDP) positions for the left limbs, the radiographic machine was rotated along its vertical axis to the left (anticlockwise) denoted by a negative (-ve) sign direction on the platform while the right limbs were rotated in the opposite direction. The radiographic position at which the ZLM and

ZDP view of each limb was obtained was then recorded (as Position ZLM and ZDP respectively).

### **Vertical and Horizontal rotations of the angle of projection of X-ray beam from ZLM and ZDP views**

From the recorded respective positions of ZLM and ZDP radiographic views, further radiographs were then subsequently taken at 5° intervals of vertical rotations of the angle of projection of the X-ray beam on both directions (-ve and +ve) by rotating the X-ray machine along its vertical axis (Figure 5A-F and Figure 6A-H). The calibrated platform of the x-ray machine was used to effect the exact degree of rotation of the x-ray machine along the desired direction each time. Re-alignment of the primary x-ray beam at each new location with the reference metal marker on the limb was achieved by carefully and gently dragging the base of the platform holder along the pre-marked lines on the floor.

For the horizontal rotations of the angle of projection of the X-ray beam, wooden wedges were inserted either behind or in front of the base of the platform of the X-ray machine to create a positive or negative angle inclination (of -5°, -10° and +5°, +10°) as required.

Vertical rotations of the angle of projection of the X-ray beam was termed vertical beam rotation (VBR) and horizontal rotation of the angle of projection of the X-ray beam was named horizontal beam rotation (HBR).

### **Postural limb tilts**

Starting at Position ZLM or ZDP, the 5° wooden wedge was completely inserted into the front, back, left side and right side of the base of the compression frame to produce a 5° backward limb tilt (Figure 4c), forward limb tilt, medial limb tilt (Figure 4d) and lateral limb tilt respectively. This process was also repeated for the 10° wedge and radiographs taken at these inclinations to produce the required postural tilt of the limb.

### **Plate vertical rotation (PVR)**

From Position ZLM or ZDP, the plate was rotated both inwards and outwards along its vertical axis at 5° interval (i.e., ranging from -10° to +10°) and serial radiographs were taken (Figure 4e).

### **Measurement of radiographic carpal parameters**

All the 14 carpal parameters were measured from the acquired radiographs as previously described (Olusa, 2018; Olusa *et al.*, 2020). Below is the list of 4 ZLM parameters and 10 ZDP developed on ZLM and ZDP radiographs, respectively.

#### **ZLM radiographic parameters:**

- i. Dorsal Carpal Angle (DCA)

- ii. Distal Radial Slope Carpal angle (DRSCA)
- iii. Intermediate carpal bone Proximal Tuberosity-Radial Angle (CiPxTRA)
- iv. Third carpal bone Palmer facet angle (C3PalFCA)

**ZDP radiographic parameters:**

- i. Medial Carpal Angle (MCA)
- ii. Disto-dorsal slope angle of the third carpal bone (C3DDSA)
- iii. Disto-dorsal wedge angle of the fourth carpal bone (C4DDWA)
- iv. Disto-palmar wedge angle of the fourth carpal bone (C4DPWA)
- v. Disto-dorsal slope angle of the radial carpal bone (CrDDSA)
- vi. Proximo-dorsal slope angle of the radial carpal bone (CrPDSA)
- vii. Disto-dorsal wedge angle of the intermediate carpal bone (Ci DDWA)
- viii. Disto-dorsal slope angle of the ulnar carpal bone (Cu DDSA)
- ix. Width ratio of Distal radius to Proximal metacarpus (WDR:WPM)
- x. Width ratio of distal radius' medial articular condyle to lateral articular condyle (DRW.MAC:LAC)

**Statistical analysis**

Carpal parameters were measured and expressed as Mean  $\pm$  SD. A paired t-test was used to compare each (of the 24) tested angles of rotation and postural limb changes with either the ZLM or ZDP images/view for each of the 14 parameters. A generalized linear mixed model was used to derive the regression coefficient for the effect of rotation on the parameter. The normality of the differences between pairs of angles was assessed by the Shapiro-Wilk test for Normality. Bonferroni adjusted t-tests were used to compare means effects between levels with a significant difference. A 95% confidence interval was used and values where  $P < 0.05$  were considered significant. IBM SPSS version 23.0 for and excel 365 for Windows 10 was used for data analysis.

**RESULTS**

Vertical X-ray beam rotation (VBR) had a profound effect on the clarity of the landmarks for ZLM and ZDP images as shown in Figures 5 and 6, respectively. From the limb-X-ray-plate aligned zero-degree ( $0^\circ$ ) initial position, a progressive clarity was observed as the VBR rotates at  $2.5^\circ$  intervals to a ZLM and ZDP position for each limb and progressive obscurity as the VBR rotates away from the ZLM and ZDP positions. The mean rotational position (in degrees of unit) of the vertical projection angle of the primary X-ray beam (i.e., alignment of the radiographic machine to the limbs' lateral and dorsal surfaces) that produced ZLM and

ZDP images/views in the tested specimens were respectively  $10\pm 3.54^\circ$  palmarolateral-dorsomedial oblique (PaL-DMO) and  $8.13\pm 1.77^\circ$  dorsolateral-palmaromedial oblique (DL-PaMO) for thoroughbreds and  $9.69\pm 3.64^\circ$  PaL-DMO and  $4.69\pm 2.48^\circ$  DL-PaMO for the Standardbreds (Table 1).

The quality of radiographs was progressively diminished as the vertical beam rotations/positions were further away from the ZLM and ZDP view (Figures 7 and 8). Changes (by rotation) of the projection angle of the primary X-ray beam at  $5^\circ$  intervals from the ZLM and ZDP, (i.e., VBR:  $-20^\circ$ ,  $-15^\circ$ ,  $-10^\circ$ ,  $-5^\circ$ , ZLM/ZDP,  $+5^\circ$ ,  $+10^\circ$ ,  $+15^\circ$  and  $+20^\circ$ ), produced the most significant changes to the clarity of landmarks and therefore affects carpal measurements. Horizontal beam rotations (HBR), limbs' postural tilts (LPT), and vertical plate rotations (VPR) had no effect on the quality of the radiographs (i.e., clarity of ZLM and ZDP landmarks) and subsequently minimal to no effect on carpal measurements. Table 2 showed the Mean  $\pm$  SD for each of the measured 14 parameters at either ZLM or ZDP in comparison with each of the other 24-tested rotational and postural positions.

## DISCUSSION

Acquisition of radiographs that clearly showed all landmarks needed for measurement of intending parameters can be considered the first task in objective radiographic assessment of carpal conformation. The positioning and rotations of the cadaveric forelimbs in this study was attempted to mimicked true postural changes of the equine forelimb as observed during field radiography. Horses do not significantly rotate their forelimbs along the vertical or horizontal axes but slightly tilt the limb forward, backward, laterally, or medially. In contrast to previous studies (Barr, 1994; Abdunnabi, 2011; Oheida *et al.*, 2017) that examined the effects of limb rotations on radiographic measurement, the current study investigated the effects of limbs postural changes, vertical rotation of the radiographic plate, and variations in both vertical and horizontal angles of X-ray beam projection on carpal measurement. This study therefore provided results that more closely represented true in vivo orientation and alignments between object, plate, and X-ray source. The production of ZLM radiographs within a range of  $2.5^\circ$  to  $12.5^\circ$  palmarolateral-dorsomedial oblique (PaL-DMO) and ZDP at a range of  $2.5^\circ$  to  $10^\circ$  dorsolateral-palmaromedial oblique (DL-PaMO) from direct perpendicular to the lateral or frontal (dorsal) plane of the horse provided for the first time a reference for where ZLM and ZDP radiographs can readily be acquired in live horses. The use of these references in the field by the authors has decreased the number of exposures required to obtained radiographs with clear landmarks for ZLM and ZDP images, respectively.

Vertical rotations of the projection angle of the primary X-ray beam, termed vertical beam rotation (VBR) in this study, had the most profound effect on the quality of the radiographs in terms of clarity of landmarks and on carpal measurements. This observation was not unexpected for two reasons. Vertical rotations of the X-ray beam produced firstly the most distortions of carpal images and secondly obscurity of the parameters' landmarks. Distortions are known to affect measurements because anatomical landmarks may be altered (Yoon *et al.*, 2002). Closely related to altered landmarks is the inability to locate landmarks due to obscurity. These combined factors would thus have contributed significantly to the current findings which agreed with previous reports (Yoon *et al.*, 2002; Abdunnabi, 2011; Alrtib, 2013; Oheida *et al.*, 2017) in which rotations of 5° and above were reported to have had significant effects on some measured parameters. Both dorsal and medial carpal angles (DCA and MCA) which respectively measured the general conformational alignment of the carpal region from the lateral and frontal plane were affected by a 5° change in either inward or outward vertical rotations of the x-ray beam. This meant that these two parameters probably have very minimal safe acceptable ranges or limits for which reliable measurement could be obtained from radiographs. Some carpal parameters were however still measurable on radiographs with vertically rotated images and in fact produced no significant difference in comparison with their respective ZLM and ZDP values. In addition to obscurity of landmarks for ZLM and ZDP parameters at  $\geq \pm 10^\circ$ , VBR starting from  $\geq 15^\circ$  DL-PaMO for the ZLM and  $\geq 10^\circ$  DM-PaLO for ZDP, also produced distortion of radiographic images. This cofounder introduces one of two challenges. Firstly, it means clinical carpal radiographs from archives which were primarily taken for diagnostic purposes and thus often times without much emphasis on clarity of measurement landmarks can be used for morphometrical studies with little anticipation for errors due to slight image distortion or obscurity of landmarks. On the other hand, this finding might tend to render less important the necessity to acquire good radiographs with clear and precise measurement landmarks for those parameters (such as DRSCA, CiPxTRA, C3PalFCA and CrDDSA) that were unaffected by image distortions or slight obscurity of landmarks.

Generally, a horizontal rotation of the X-ray beam (HBR) as well as postural changes of the forelimb and vertical plate rotations were found not to significantly affect carpal measurements at the tested degrees of rotation. Postural tilts of forelimb did not affect carpal measurements because lateral and medial tilts resulted in orientational (turned) changes of carpal images while forward and backward tilts resulted in slight magnification changes which were not significant at the maximal 10° that was tested. Similarly, the magnification

changes produced by horizontal rotation of X-ray beams did not produce any significant changes in most of the carpal measurements. Carpal images produced by the forward and backward postural tilts of the limb and the horizontal rotation of the X-ray beam appeared as reciprocal images as these positions were replicas of each other. A 5° backward tilt of a limb (BLT 5) from its vertical axis and a -5° inward rotation of x-ray beam along its horizontal axis (HBR -5) produced a similar image with the same magnification distortion and orientation on the radiographic plate. The distortions are limited to changes in size and position of images on the radiographic plates. The disto-dorsal wedge angle of the fourth carpal bone (C4DDWA) was however significantly affected by horizontal rotation of the X-ray beam (at HBR -5, +5 and +10) while the disto-palmar wedge angle of the fourth carpal bone (C4DPWA) was significantly different at HBR +10. This finding suggests that the distal wedge angles of C4 might be sensitive to small transverse changes in the topography of its articular surface. This might be of interest considering the stability that the C4 provides for the distal carpal row as it wedges between the third and fourth metacarpal bones.

Vertical rotation of the radiographic plate produced a change in the location of the carpal image on the plate. This rotation could be parallel to the center of the x-ray beam and thus similar to a sagittal plane or axis of the limb. Since previous reports have suggested that rotation along the sagittal axis only changed objects positions on the radiographs and did not affect its clarity or magnification (Major *et al.*, 1996; Yoon *et al.*, 2002), the lack of significant difference found in this current study for vertical plate rotation may therefore be attributable to this factor.

## **CONCLUSION**

The objectives of this study were largely achieved. A potential reference range for vertical rotation of the X-ray beam (perpendicular positioning of machine) to acquire ZLM and ZDP radiographs for reliable measurement of certain carpal parameters was established for both thoroughbred and standardbred forelimbs. Although a “cut off” guide for range of rotation where carpal measurements become unreliable was not established in this study, it would be reasonable based on the presented data, to suggest that any rotational position in which the landmarks of ZLM, ZDP and carpal parameters becomes too obscured cannot be expected to produce reliable measurements. Such radiographs should thus be avoided for carpal measurements. Since vertical rotation of the angles of the X-ray beam projection had the most significant effect on the quality of radiographs and measurements of carpal parameters, it would be essential to obtain radiographs within the proposed range of 2.5° to 12.5° palmarolateral-dorsomedial oblique (PaL-DMO) for ZLM and 2.5° to 10° dorsolateral-

palmaromedial oblique (DL-PaMO) for ZDP to minimize the errors that may be attributable to rotational movements during quantitative assessment of carpal conformational in horses.

#### **ACKNOWLEDGEMENT**

The authors would like to thank Brendan Kehoe and Dave Hobbs for assistance with samples collection and storage. Also, the expertise and input of Professor Ian Gordon, Director of Statistical Consulting Centre, University of Melbourne for assistance/consultation about choice of statistical tests, study design and analysis was duly acknowledged.

#### **CONFLICT OF INTEREST**

No conflict of interest is declared for this work.

#### **DATA AVAILABILITY STATEMENT**

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

#### **REFERENCES**

- Abdunnabi, A.H. (2011). Morphometry of the equine carpus and its relationship to carpal bone pathology. University of Melbourne (PhD Thesis), Victoria, Australia.
- Alrtib, A.M. (2013). Radiographic bone morphometry of the equine metacarpophalangeal joint and relationships to the incidence of pathology in thoroughbred racehorses. University of Melbourne (PhD Thesis), Victoria, Australia.
- Alrtib, A.M., Oheida, A.H., Abushhiwa, M.H., & Davies, H.M.S. (2015). Metacarpophalangeal joint angle measurement in equine forelimbs. *Journal of Veterinary Advances*, 5, 831- 840.
- Barr, A.R.S. (1994). Carpal conformation in relation to carpal chip fracture. *Veterinary Record*, 134, 646-650.

- Holmstrom, H., Magnusson, L.E. & Philipsson, J. (1990). Variation in conformation of Swedish warmblood horses and conformational characteristics of elite sport horses. *Equine Veterinary Journal*, 22, 186 – 193.
- Major, P.W., Johnson, D.E., Hesse, K.L., & Glover, K.E. (1996). Effect of head orientation on posterior anterior cephalometric landmark identification. *Angle Orthodontist*, 66, 51-60. DOI: 10.1043/0003-3219(1996)066<0051:EOHOOP>2.3.CO;2
- Oheida, A.H., Anderson, G.A., Alrtib, A.M., Abushhiwa, M.H., Philips, C.J., & Davies, H.M.S. (2016). Carpal parameters on dorsopalmar radiographs of the equine carpus. *Journal of veterinary advances*, 6, 1258-1268.
- Oheida, A.H., Anderson, G.A., Alrtib, A.M., Abushhiwa, M.H., Philips, C.J., & Davies, H.M.S. (2017). Effects of limb rotation on radiographic measurements of carpal parameters in the equine carpus. *Journal of veterinary advances*, 7, 1392-1402.
- Olusa, T.A.O. (2018). Radiographic assessment of bone morphometry, alignment and loading stability of the equine carpal joint in racehorses. University of Melbourne (PhD Thesis), Victoria, Australia.
- Olusa, T.A.O., Murray, C.M., & Davies, H.M.S. (2019). Radiographic assessment of the equine carpal joint under incremental loads and during flexion. *Comparative Exercise Physiology*, 1 – 12. doi.org/10.3920/CEP180044
- Olusa, T.A.O., Ismail, S.M.Y., Murray, C.M., & Davies, H.M.S. (2020). Radiographic assessment of carpal conformation in the horse: technique development and validation of the consistency of measurements. *Anatomia histologia embryologia*. DOI: 10.1111/AHE.12627
- Ware, C. Equethy Barefoot Educational Workshops (Australia). <http://www.equethy.com>  
Accessed June 2017
- Weller, R., Pfau, T., May, S.A., & Wilson, A.M. (2006). Variation in conformation in a cohort of National Hunt racehorses. *Equine Veterinary Journal*, 38, 616-621.
- Yoon, Y.J., Kim, D.H., Yu, P.S., Kim, H.J., Choi, E.H., & Kim, K.W. (2002). Effect of head rotation on posteroanterior cephalometric radiographs. *Angle Orthodontist*, 72, 36-42. DOI: 10.1043/0003-3219(2002)072<0036:EOHROP>2.0.CO;2.

**Table 1: Details of horses (forelimbs) whose carpi were used to determine the positions of vertical rotations of the angles of projection of the primary X-ray beam (i.e. the safe measurement range) to produce ZLM and ZDP radiographs.**

S/no	Thoroughbred						Standardbred						
	Limb source	Carpi position	Sex	Age (years)	ZLM° (PaL-DMO)	ZDP° (DL-PaMO)	Limb source	Carpi position	Sex	Age (years)	ZLM° (PaL-DMO)	ZDP° (DL-PaMO)	
1	KR	Left	M	12	7.5	7.5	PM	Left	G	4	10	5	
2	KR	Right	M	12	10	10	KR	Left	F	8	10	5	
3	PM	Left	F	3	5	10	KR	Right	F	8	10	2.5	
4	PM	Right	F	3	10	7.5	KR	Right	F	3	2.5	2.5	
5	KR	Left	M	14	15	7.5	KR	Left	F	12	15	10	
6	KR	Right	M	14	10	7.5	KR	Right	F	12	10	5	
7	PM	Left	F	4	15	5	KR	Left	M	14	12.5	5	
8	PM	Right	F	NA	7.5	10	KR	Right	M	14	7.5	2.5	
Mean±SD				8.86±5.24	10±3.54°	8.13±1.77°	Mean±SD				9.38±4.31	9.69±3.64°	4.69±2.48°
<b>Both breeds</b>													
Age				ZLM (PaL-DMO)				ZDP (DL-PaMO)					
9.13±4.59 years				9.84±3.47°				6.41±2.73°					

ZLM= zero lateromedial; ZDP= Zero dorsopalmar; PaL-DMO= Palmarolateral-dorsomedial oblique; DL-PaMO = Dorsolateral-palmaromedial oblique; NA = Not available; KR = Knackery; PM = Postmortem

**Table 2a: Comparison of Dorsal Carpal Angle (DCA) measured at ZLM with each of the other 24 rotational variations and postural positions.**

Parameter (Dependable variable)	Rotational Positions (°)	Descriptive statistics			Paired t-test			
		N	Mean±SD (°)	SEM (°)	Paired Samples Correlations Coeff.	Paired Mean Difference (ZLM - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) p < 0.05
Dorsal Carpal Angle (DCA)	ZLM	16	171.58±2.50	0.62				
	VBR-20	10	169.57±3.51	1.11	0.757	1.90±2.30	0.73	0.028*
	VBR-15	16	169.80±2.95	0.74	0.704	1.79±2.14	0.53	0.004*
	VBR-10	16	169.72±2.50	0.63	0.769	1.86±1.70	0.42	0.001*
	VBR-5	16	170.51±2.57	0.64	0.779	1.07±1.69	0.42	0.023*
	VBR+5	16	171.27±2.75	0.69	0.909	0.32±1.15	0.29	0.287
	VBR+10	16	170.86±2.41	0.60	0.843	0.73±1.38	0.35	0.053
	VBR+15	15	170.69±3.21	0.83	0.798	0.78±1.93	0.50	0.139
	VBR+20	14	171.19±2.85	0.76	0.915	0.36±1.15	0.31	0.270
HBR-10	16	170.28±1.88	0.47	0.856	1.30±1.32	0.33	0.001*	

HBR-5	16	170.62±1.92	0.48	0.834	0.96±1.39	0.35	0.014*
HBR+5	16	170.77±1.88	0.47	0.718	0.81±1.74	0.44	0.082
HBR+10	16	171.52±2.11	0.53	0.802	0.06±1.50	0.37	0.878
CVR-10	16	171.29±2.65	0.66	0.578	0.29±2.37	0.59	0.632
CVR-5	16	171.12±2.29	0.57	0.676	0.47±1.94	0.48	0.351
CVR+5	16	170.84±2.21	0.55	0.822	0.74±1.43	0.36	0.056
CVR+10	16	170.96±2.31	0.58	0.694	0.62±1.89	0.47	0.206
FLT5	16	170.95±2.46	0.62	0.804	0.63±1.55	0.39	0.127
FLT10	16	171.02±2.39	0.60	0.732	0.56±1.79	0.45	0.231
BLT5	16	170.69±2.00	0.50	0.827	0.89±1.41	0.35	0.023*
BLT10	16	170.71±2.69	0.67	0.598	0.88±2.33	0.58	0.154
MLT5	16	170.82±1.16	0.29	0.516	0.77±2.14	0.54	0.173
MLT10	16	170.72±2.03	0.51	0.424	0.86±2.46	0.62	0.181
LLT5	16	170.60±2.05	0.51	0.694	0.98±1.82	0.46	0.048
LLT10	16	170.72±2.29	0.57	0.746	0.86±1.72	0.43	0.064

SD = Standard deviation; SEM = Standard error of (measurement) mean; ZLM = zero lateromedial; Sig = Significance at level  $p < 0.05$ ; \*Value was significantly different at  $p < 0.05$

**Table 2b: Comparison of Distal Radial Slope Carpal angle (DRSCA) measured at ZLM with each of the other 24 rotational variations and postural positions.**

		Descriptive statistics	Paired t-test
--	--	------------------------	---------------

Parameter (Dependable variable)	Rotational Positions (°)	N	Mean±SD (°)	SEM (°)	Paired Samples Correlations Coeff.	Paired Mean Difference (ZLM - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) p < 0.05
Distal Radial	ZLM	16	146.79±3.46	0.86				
Slope Carpal angle (DRSCA)	VBR-20	10	145.16±4.13	1.31	0.430	2.50±4.13	1.31	0.088
	VBR-15	16	146.16±3.11	0.78	0.147	0.63±4.29	1.07	0.567
	VBR-10	16	147.42±2.51	0.63	0.237	-0.63±3.76	0.94	0.513
	VBR-5	16	146.85±2.78	0.70	0.457	-0.06±3.30	0.83	0.947
	VBR+5	16	147.58±3.21	0.80	0.844	-0.79±1.88	0.47	0.114
	VBR+10	16	148.25±3.70	0.92	0.666	-1.46±2.93	0.73	0.065
	VBR+15	15	148.20±3.71	0.96	0.414	-1.25±3.92	1.01	0.237
	VBR+20	14	149.60±4.10	1.10	0.501	-2.31±3.79	1.01	0.040*
	HBR-10	16	146.49±2.83	0.71	0.704	0.30±2.49	0.62	0.638
	HBR-5	16	147.20±3.56	0.89	0.835	-0.41±2.02	0.50	0.429
	HBR+5	16	147.38±3.55	0.89	0.797	-0.58±2.23	0.56	0.312
	HBR+10	16	147.53±3.06	0.77	0.887	-0.74±1.60	0.40	0.082
	CVR-10	16	146.62±2.82	0.71	0.770	0.17±2.21	0.55	0.759
	CVR-5	16	147.12±2.78	0.70	0.709	-0.33±2.46	0.62	0.600
	CVR+5	16	147.28±2.89	0.72	0.802	-0.49±2.07	0.52	0.362
	CVR+10	16	147.44±3.08	0.77	0.796	-0.65±2.12	0.53	0.240
FLT5	16	146.90±3.37	0.84	0.841	-0.11±1.93	0.48	0.821	
FLT10	16	146.59±3.44	0.86	0.785	0.21±2.26	0.56	0.720	
BLT5	16	147.41±3.15	0.79	0.921	-0.61±1.35	0.34	0.088	
BLT10	16	147.48±3.25	0.81	0.733	-0.69±2.46	0.61	0.280	
MLT5	16	147.04±2.76	0.69	0.706	-0.25±2.47	0.62	0.691	
MLT10	16	146.85±2.61	0.65	0.648	-0.06±2.66	0.67	0.932	

	LLT5	16	147.83±3.59	0.90	0.701	-1.04±2.73	0.68	0.150
	LLT10	16	147.83±3.43	0.86	0.761	-1.04±2.38	0.60	0.100

SD = Standard deviation; SEM = Standard error of (measurement) mean; ; ZLM = zero lateromedial; Sig = Significance at level  $p < 0.05$ ; \*Value was significantly different at  $p < 0.05$

**Table 2c: Comparison of intermediate carpal bone proximal tuberosity-radial angle (CiPxTRA) measured at ZLM with each of the other 24 rotational variations and postural positions.**

Parameter (Dependable variable)	Rotational Positions (°)	Descriptive statistics			Paired t-test			
		N	Mean±SD (°)	SEM (°)	Paired Samples Correlations Coeff.	Paired Mean Difference (ZLM - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) $p < 0.05$
Intermediate carpal bone Proximal Tuberosity- Radial Angle (CiPxTRA)	ZLM	16	116.22±3.26	0.82				
	VBR-20	8	116.42±2.79	0.99	-0.090	-1.19±4.21	1.49	0.450
	VBR-15	14	116.40±2.68	0.72	0.266	0.27±3.61	0.96	0.782
	VBR-10	16	116.08±3.15	0.79	0.157	0.14±4.16	1.04	0.891
	VBR-5	16	116.93±3.73	0.93	0.360	-0.71±3.97	0.99	0.486
	VBR+5	16	115.76±3.09	0.77	0.760	0.46±2.21	0.55	0.416
	VBR+10	16	115.00±3.65	0.91	0.761	1.22±2.42	0.60	0.061
	VBR+15	15	115.02±4.80	1.24	0.428	1.32±4.53	1.17	0.280
	VBR+20	14	114.93±5.57	1.55	0.502	1.35±4.83	1.34	0.334
	HBR-10	16	115.84±1.86	0.46	0.633	0.38±2.53	0.63	0.560
HBR-5	16	115.14±2.25	0.56	0.628	1.08±2.54	0.64	0.111	

HBR+5	16	115.51±2.78	0.70	0.591	0.71±2.76	0.69	0.320
HBR+10	16	115.85±2.07	0.52	0.718	0.38±2.29	0.57	0.522
CVR-10	16	115.41±2.84	0.71	0.734	0.82±2.26	0.56	0.169
CVR-5	16	114.49±2.12	0.53	0.455	1.73±2.97	0.74	0.035*
CVR+5	16	115.29±2.38	0.59	0.526	0.93±2.85	0.71	0.212
CVR+10	16	115.37±2.52	0.63	0.787	0.85±2.01	0.50	0.113
FLT5	16	115.91±1.92	0.48	0.800	0.31±2.07	0.52	0.557
FLT10	16	116.02±2.57	0.64	0.764	0.20±2.11	0.53	0.707
BLT5	16	115.72±1.73	0.43	0.516	0.51±2.79	0.70	0.480
BLT10	16	115.16±1.55	0.39	0.216	1.07±3.29	0.82	0.216
MLT5	16	116.20±1.47	0.37	0.422	0.02±2.96	0.74	0.974
MLT10	16	117.06±2.10	0.53	0.811	-0.84±1.98	0.50	0.111
LLT5	16	115.55±1.58	0.39	0.204	0.67±3.32	0.83	0.432
LLT10	16	115.34±1.43	0.36	0.107	0.88±3.42	0.85	0.317

SD = Standard deviation; SEM = Standard error of (measurement) mean; ; ZLM = zero lateromedial; Sig = Significance at; \*Value was significantly different at  $p < 0.05$  level  $p < 0.05$

**Table 2d: Comparison of third carpal bone palmer facet angle (C3PalFCA) measured at ZLM with each of the other 24 rotational variations and postural positions.**

		Descriptive statistics	Paired t-test
--	--	------------------------	---------------

Parameter (Dependable variable)	Rotational Positions (°)	N	Mean±SD (°)	SEM (°)	Paired Samples Correlations Coeff.	Paired Mean Difference (ZLM - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) p < 0.05
Third carpal bone Palmer facet angle (C3PalFCA)	ZLM	16	87.64±2.19	0.55				
	VBR-20	8	85.91±2.56	0.90	0.704	1.29±1.85	0.66	0.091
	VBR-15	15	86.88±2.22	0.57	0.547	0.43±1.96	0.51	0.406
	VBR-10	16	87.28±1.68	0.42	0.818	0.36±1.27	0.32	0.280
	VBR-5	16	87.95±2.28	0.57	0.935	-0.32±0.81	0.20	0.139
	VBR+5	16	87.38±2.52	0.63	0.724	0.25±1.78	0.44	0.577
	VBR+10	16	88.58±2.66	0.66	0.232	-0.95±3.03	0.76	0.231
	VBR+15	15	88.17±2.57	0.66	0.594	-0.51±2.20	0.57	0.383
	VBR+20	12	87.42±2.81	0.81	0.025	0.40±3.16	0.91	0.667
	HBR-10	16	87.59±1.53	0.38	0.744	0.04±1.47	0.37	0.908
	HBR-5	16	87.30±1.68	0.42	0.772	0.34±1.40	0.35	0.347
	HBR+5	16	87.43±2.26	0.56	0.905	0.20±0.97	0.24	0.417
	HBR+10	16	87.74±2.44	0.61	0.885	-0.10±1.14	0.28	0.724
	CVR-10	16	86.63±1.51	0.38	0.556	1.01±1.85	0.46	0.045
	CVR-5	16	86.86±1.55	0.39	0.818	0.78±1.29	0.32	0.028
	CVR+5	16	87.39±1.21	0.30	0.483	0.25±1.93	0.48	0.614
	CVR+10	16	87.67±1.67	0.42	0.801	-0.03±1.32	0.33	0.929
	FLT5	16	87.18±2.58	0.65	0.802	0.46±1.55	0.39	0.257
	FLT10	16	87.25±2.29	0.57	0.680	0.39±1.79	0.45	0.403
BLT5	16	87.28±1.84	0.46	0.692	0.36±1.62	0.40	0.386	
BLT10	16	87.26±1.93	0.48	0.799	0.37±1.33	0.33	0.280	
MLT5	16	87.61±2.21	0.55	0.753	0.03±1.55	0.39	0.939	
MLT10	16	87.74±2.52	0.63	0.764	-0.11±1.65	0.41	0.799	

deviation; SEM =  
(measurement)

lateromedial; Sig = Significance at level  $p < 0.05$

	LLT5	16	87.58±1.90	0.47	0.697	0.06±1.62	0.40	0.892
	LLT10	16	87.56±1.61	0.40	0.628	0.08±1.72	0.43	0.854

SD = Standard  
Standard error of  
mean; ZLM = zero

**Table 2e: Comparison of medial carpal angle (MCA) measured at ZDP with each of the other 24 rotational variations and postural positions.**

Parameter (Dependable variable)	Rotational Positions (°)	Descriptive statistics			Paired t-test			
		N	Mean±SD (°)	SEM (°)	Paired Samples Correlations Coeff.	Paired Mean Difference (ZDP - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) $p < 0.05$
Medial Carpal Angle (MCA)	ZDP	16	186.68±1.10	0.27				
	VBR-20	15	184.48±1.32	0.34	0.590	2.20±1.13	0.29	0.000*
	VBR-15	16	184.73±0.97	0.24	0.497	1.95±1.04	0.26	0.000*
	VBR-10	16	186.06±1.11	0.28	0.562	0.62±1.03	0.26	0.030*
	VBR-5	16	186.61±1.60	0.40	0.540	0.07±1.37	0.34	0.831
	VBR+5	16	187.23±1.41	0.35	0.673	-0.54±1.05	0.26	0.057
	VBR+10	16	187.46±1.71	0.43	0.480	-0.77±1.53	0.38	0.061
	VBR+15	16	187.66±1.56	0.39	0.409	-0.98±1.49	0.37	0.020*
	VBR+20	16	188.63±2.11	0.53	0.569	-1.94±1.74	0.44	0.000*

HBR-10	16	186.34±1.33	0.33	0.266	0.35±1.48	0.37	0.364
HBR-5	16	186.61±1.26	0.32	0.616	0.07±1.05	0.26	0.787
HBR+5	16	186.40±1.44	0.36	0.591	0.28±1.19	0.30	0.353
HBR+10	16	186.01±1.21	0.30	0.376	0.68±1.29	0.32	0.054
CVR-10	16	186.82±1.19	0.30	0.356	-0.14±1.30	0.33	0.680
CVR-5	16	186.28±1.19	0.30	0.162	0.40±1.48	0.37	0.295
CVR+5	16	186.20±1.55	0.39	0.268	0.49±1.64	0.41	0.255
CVR+10	16	186.72±1.26	0.32	0.380	-0.03±1.32	0.33	0.924
FLT5	16	186.35±1.17	0.29	0.365	0.34±1.28	0.32	0.308
FLT10	16	186.49±1.42	0.36	0.673	0.20±1.06	0.27	0.471
BLT5	16	186.44±1.08	0.27	0.720	0.24±0.82	0.20	0.255
BLT10	16	186.63±1.45	0.36	0.663	0.05±1.10	0.27	0.858
MLT5	16	186.53±0.94	0.23	0.457	0.15±1.07	0.27	0.583
MLT10	16	186.39±1.28	0.32	0.766	0.29±0.83	0.21	0.182
LLT5	16	186.75±1.06	0.27	0.542	-0.07±1.04	0.26	0.798
LLT10	16	186.77±1.09	0.27	0.507	-0.08±1.08	0.27	0.767

SD = Standard deviation; SEM = Standard error of (measurement) mean; ZDP = zero dorsopalmar; Sig = Significance at level  $p < 0.05$ ; \*Value was significantly different at  $p < 0.05$

**Table 2f: Comparison of disto-dorsal slope angle of the third carpal bone (C3DDSA) measured at ZDP with each of the other 24 rotational variations and postural positions.**

		Descriptive statistics	Paired t-test
--	--	------------------------	---------------

Parameter (Dependable variable)	Rotational Positions (°)	N	Mean±SD (°)	SEM (°)	Paired Samples Correlations Coeff.	Paired Mean Difference (ZDP - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) p < 0.05
Disto-dorsal slope angle of the third carpal bone (C3DDSA)	ZDP	16	8.11±1.37	0.34				
	VBR-20	15	7.85±1.23	0.30	0.502	0.26±1.30	0.32	0.429
	VBR-15	16	7.76±1.04	0.26	0.505	0.36±1.23	0.31	0.262
	VBR-10	16	7.89±1.16	0.29	0.508	0.22±1.27	0.32	0.492
	VBR-5	16	8.00±0.97	0.24	0.583	0.11±1.12	0.28	0.696
	VBR+5	16	8.30±1.25	0.31	0.623	-0.18±1.14	0.29	0.532
	VBR+10	16	8.44±1.39	0.35	-0.031	-0.33±1.98	0.50	0.515
	VBR+15	15	8.28±1.48	0.38	0.014	-0.08±2.00	0.52	0.876
	VBR+20	12	8.25±2.00	0.58	0.307	0.11±1.99	0.57	0.846
	HBR-10	16	7.81±0.97	0.24	0.811	0.30±0.81	0.20	0.156
	HBR-5	16	7.86±1.12	0.28	0.804	0.26±0.81	0.20	0.229
	HBR+5	16	7.95±0.92	0.23	0.669	0.16±1.02	0.25	0.534
	HBR+10	16	7.77±1.05	0.26	0.466	0.34±1.28	0.32	0.304
	CVR-10	16	7.87±0.97	0.24	0.672	0.24±1.02	0.25	0.350
	CVR-5	16	7.58±0.99	0.25	0.561	0.54±1.16	0.29	0.082
	CVR+5	16	7.60±1.03	0.26	0.707	0.51±0.97	0.24	0.052
	CVR+10	16	7.80±1.00	0.25	0.740	0.32±0.92	0.23	0.186
	FLT5	16	7.63±1.15	0.29	0.505	0.49±1.27	0.32	0.143
	FLT10	16	7.83±1.05	0.26	0.383	0.29±1.37	0.34	0.412
	BLT5	16	7.69±0.80	0.20	0.430	0.42±1.25	0.31	0.198
BLT10	15	7.65±0.69	0.18	0.387	0.42±1.30	0.34	0.233	
MLT5	16	7.85±0.90	0.23	0.484	0.26±1.22	0.31	0.408	
MLT10	16	7.73±0.90	0.23	0.349	0.38±1.35	0.34	0.273	

	LLT5	16	8.00±1.04	0.26	0.693	0.12±0.99	0.25	0.648
	LLT10	16	7.90±0.70	0.18	0.521	0.21±1.17	0.29	0.483

SD = Standard deviation; SEM = Standard error of (measurement) mean; ZDP = zero dorsopalmar; Sig = Significance at level  $p < 0.05$

**Table 2g: Comparison of disto-dorsal wedge angle of the fourth carpal bone (C4DDWA) measured at ZDP with each of the other 24 rotational variations and postural positions.**

Parameter (Dependable variable)	Rotational Positions (°)	Descriptive statistics			Paired t-test			
		N	Mean±SD (°)	SEM (°)	Paired Samples Correlations Coeff.	Paired Mean Difference (ZDP - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) $p < 0.05$
Disto-dorsal wedge angle of the fourth carpal bone (C4DDWA)	ZDP	16	132.52±7.99	1.99				
	VBR-20	14	137.08±7.67	2.05	0.147	-3.50±8.91	2.38	0.166
	VBR-15	15	136.75±10.24	2.65	0.720	-4.67±7.14	1.84	0.024*
	VBR-10	16	134.43±9.13	2.28	0.631	-1.91±7.42	1.85	0.320
	VBR-5	16	134.73±9.07	2.27	0.731	-2.21±6.34	1.58	0.183
	VBR+5	16	135.15±7.63	1.91	0.750	-2.63±5.53	1.38	0.077
	VBR+10	15	133.69±8.13	2.10	0.705	-1.61±6.22	1.61	0.332
	*VBR+15	8	126.10±11.66	4.12	0.818	5.95±6.71	2.37	0.041*
	<sup>†</sup> VBR+20	4	129.36±11.55	5.78	0.992	4.28±5.07	2.53	0.189
HBR-10	16	134.75±7.84	1.96	0.777	-2.23±5.29	1.32	0.113	

HBR-5	16	135.05±7.79	1.95	0.861	-2.53±4.17	1.04	0.029*
HBR+5	16	135.82±8.78	2.20	0.745	-3.30±6.04	1.51	0.045*
HBR+10	16	135.69±8.27	2.07	0.802	-3.17±5.13	1.28	0.026*
CVR-10	16	135.01±7.68	1.92	0.828	-2.49±4.60	1.15	0.047*
CVR-5	16	134.43±7.64	1.91	0.841	-1.92±4.42	1.10	0.103
CVR+5	16	134.82±7.70	1.92	0.796	-2.30±5.02	1.26	0.087
CVR+10	16	134.98±7.51	1.88	0.786	-2.46±5.08	1.27	0.072
FLT5	16	135.14±7.98	2.00	0.821	-2.62±4.79	1.20	0.045*
FLT10	16	134.54±7.65	1.91	0.841	-2.02±4.42	1.11	0.088
BLT5	16	134.76±7.77	1.94	0.786	-2.24±5.16	1.29	0.103
BLT10	16	133.90±7.38	1.84	0.761	-1.38±5.35	1.34	0.318
MLT5	16	134.02±7.40	1.85	0.781	-1.50±5.12	1.28	0.260
MLT10	16	134.87±7.72	1.93	0.803	-2.36±4.94	1.24	0.076
LLT5	16	133.92±7.55	1.89	0.799	-1.40±4.95	1.24	0.275
LLT10	16	134.18±7.88	1.97	0.758	-1.66±5.52	1.38	0.247

SD = Standard deviation; SEM = Standard error of (measurement) mean; ZDP = zero dorsopalmar; Sig = Significance at level  $p < 0.05$ ; \*Value was significantly different at  $p < 0.05$

**Table 2h: Comparison of disto-palmar wedge angle of the fourth carpal bone (C4DPWA) measured at ZDP with each of the other 24 rotational variations and postural positions.**

		Descriptive statistics	Paired t-test
--	--	------------------------	---------------

Parameter (Dependable variable)	Rotational Positions (°)	N	Mean±SD (°)	SEM (°)	Paired Samples Correlations Coeff.	Paired Mean Difference (ZDP - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) p < 0.05
Disto-palmar wedge angle of the fourth carpal bone (C4DPWA)	ZDP	16	116.07±7.68	1.92				
	VBR-20	14	117.96±8.60	2.30	0.725	-1.97±6.14	1.64	0.251
	VBR-15	15	119.81±7.10	1.83	-0.039	-3.35±10.73	2.77	0.246
	VBR-10	16	121.92±7.77	1.94	0.452	-5.86±8.09	2.02	0.011*
	VBR-5	16	119.39±5.94	1.48	0.447	-3.33±7.31	1.83	0.089
	VBR+5	16	119.64±7.01	1.75	0.332	-3.58±8.50	2.13	0.113
	VBR+10	16	118.40±11.64	2.91	0.453	-2.34±10.65	2.66	0.393
	VBR+15	8	118.41±8.05	2.85	0.687	-.043±6.00	2.12	0.985
	VBR+20	5	114.53±5.67	2.54	0.093	2.46±6.80	3.04	0.465
	HBR-10	16	117.94±7.47	1.87	0.942	-1.88±2.58	0.65	0.011*
	HBR-5	16	117.14±7.36	1.84	0.929	-1.08±2.86	0.71	0.152
	HBR+5	16	117.92±7.52	1.88	0.861	-1.86±4.00	1.00	0.083
	HBR+10	16	118.00±6.62	1.66	0.922	-1.94±3.00	0.75	0.021*
	CVR-10	16	117.11±6.24	1.56	0.879	-1.05±3.70	0.93	0.275
	CVR-5	16	117.66±5.98	1.50	0.853	-1.59±4.05	1.01	0.136
	CVR+5	16	117.68±6.53	1.63	0.872	-1.62±3.76	0.94	0.106
	CVR+10	16	117.38±6.19	1.55	0.840	-1.31±4.18	1.04	0.227
	FLT5	16	118.10±7.41	1.85	0.668	-2.03±6.15	1.54	0.206
	FLT10	16	118.97±7.56	1.89	0.903	-2.90±3.36	0.84	0.004*
	BLT5	16	118.40±6.74	1.69	0.856	-2.33±3.97	0.99	0.033
BLT10	16	117.11±7.80	1.95	0.716	-1.05±5.84	1.46	0.485	
MLT5	16	118.16±5.11	1.28	0.780	-2.09±4.88	1.22	0.107	
MLT10	16	118.21±4.75	1.19	0.839	-2.14±4.51	1.13	0.077	

	LLT5	16	118.08±6.01	1.50	0.887	-2.01±3.63	0.91	0.042*
	LLT10	16	118.28±5.80	1.45	0.817	-2.22±4.45	1.11	0.065

SD = Standard deviation; SEM = Standard error of (measurement) mean; ZDP = zero dorsopalmar; Sig = Significance at level  $p < 0.05$ ; \*Value was significantly different at  $p < 0.05$

**Table 2i: Comparison of disto-dorsal slope angle of the radial carpal bone (CrDDSA) measured at ZDP with each of the other 24 rotational variations and postural positions.**

Parameter (Dependable variable)	Rotational Positions (°)	Descriptive statistics			Paired t-test			
		N	Mean±SD (°)	SEM (°)	Paired Samples Correlations Coeff.	Paired Mean Difference (ZDP - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) $p < 0.05$
Disto-dorsal slope angle of the radial carpal bone (CrDDSA)	ZDP	16	9.41±3.11	0.78				
	VBR-20	16	8.73±3.73	0.93	0.850	0.69±1.97	0.49	0.183
	VBR-15	16	8.52±3.59	0.90	0.831	0.90±2.00	0.50	0.093
	VBR-10	16	8.70±2.52	0.63	0.644	0.72±2.43	0.61	0.258
	VBR-5	16	9.08±3.09	0.77	0.902	0.34±1.38	0.34	0.340
	VBR+5	16	9.21±2.99	0.75	0.850	0.20±1.67	0.42	0.638
	VBR+10	16	9.68±2.64	0.66	0.707	-0.26±2.24	0.56	0.646
	VBR+15	16	9.55±3.34	0.83	0.805	-0.14±2.02	0.51	0.790
	VBR+20	10	9.57±3.33	1.05	0.572	0.23±2.76	0.87	0.803
HBR-10	16	9.51±3.03	0.76	0.755	-0.10±2.15	0.54	0.858	

	HBR-5	16	9.70±3.00	0.75	0.815	-0.29±1.86	0.46	0.542
	HBR+5	16	9.99±3.00	0.75	0.854	-0.57±1.66	0.41	0.187
	HBR+10	16	9.72±3.07	0.77	0.734	-0.30±2.25	0.56	0.598
	CVR-10	16	10.07±3.27	0.82	0.851	-0.65±1.75	0.44	0.156
	CVR-5	16	9.74±3.02	0.75	0.802	-0.33±1.93	0.48	0.507
	CVR+5	16	9.71±2.71	0.68	0.815	-0.30±1.81	0.45	0.523
	CVR+10	16	9.82±3.04	0.76	0.828	-0.41±1.82	0.45	0.381
	FLT5	16	9.71±3.07	0.77	0.860	-0.30±1.64	0.41	0.482
	FLT10	16	9.19±2.56	0.64	0.690	0.23±2.29	0.57	0.695
	BLT5	16	9.22±3.00	0.75	0.705	0.19±2.35	0.59	0.751
	BLT10	16	9.35±2.91	0.73	0.765	0.06±2.07	0.52	0.907
	MLT5	16	9.59±2.88	0.72	0.757	-0.18±2.10	0.53	0.743
	MLT10	16	9.47±2.69	0.67	0.895	-0.06±1.39	0.35	0.867
	LLT5	16	10.19±3.20	0.80	0.685	-0.78±2.51	0.63	0.235
	LLT10	16	9.72±2.79	0.70	0.753	-0.31±2.09	0.52	0.563

SD = Standard deviation; SEM = Standard error of (measurement) mean; ZDP = zero dorsopalmar; Sig = Significance at level  $p < 0.05$

**Table 2j: Comparison of proximo-dorsal slope angle of the radial carpal bone (CrPDSA) measured at ZDP with each of the other 24 rotational variations and postural positions.**

		Descriptive statistics	Paired t-test
--	--	------------------------	---------------

Parameter (Dependable variable)	Rotational Positions (°)	N	Mean±SD (°)	SEM (°)	Paired Samples Correlations Coeff.	Paired Mean Difference (ZDP - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) p < 0.05
Proximo- dorsal slope angle of the radial carpal bone (CrPDSA)	ZDP	16	15.25±2.57	0.64				
	VBR-20	16	12.99±2.71	0.68	0.819	2.25±1.60	0.40	0.000*
	VBR-15	16	13.43±2.47	0.62	0.752	1.82±1.78	0.44	0.001*
	VBR-10	16	14.10±2.52	0.63	0.914	1.15±1.06	0.26	0.001*
	VBR-5	16	15.26±2.64	0.66	0.945	-0.01±0.87	0.22	0.968
	VBR+5	16	14.70±2.82	0.70	0.925	0.55±1.07	0.27	0.057
	VBR+10	16	13.52±2.72	0.68	0.824	1.73±1.57	0.39	0.001*
	VBR+15	16	12.83±2.80	0.70	0.734	2.42±1.97	0.49	0.000*
	VBR+20	14	13.17±2.38	0.64	0.547	2.60±2.23	0.60	0.001*
	HBR-10	16	14.62±2.22	0.55	0.796	0.63±1.56	0.39	0.128
	HBR-5	16	14.85±2.63	0.66	0.924	0.40±1.02	0.25	0.135
	HBR+5	16	15.18±2.77	0.69	0.949	0.07±0.87	0.22	0.746
	HBR+10	16	14.74±2.72	0.68	0.939	0.51±0.94	0.23	0.045
	CVR-10	16	15.21±2.46	0.62	0.861	0.04±1.33	0.33	0.910
	CVR-5	16	14.50±2.34	0.59	0.923	0.75±0.99	0.25	0.008*
	CVR+5	16	14.32±2.26	0.57	0.840	0.93±1.40	0.35	0.018*
	CVR+10	16	14.76±2.17	0.54	0.817	0.49±1.48	0.37	0.207
	FLT5	16	14.76±2.13	0.53	0.857	0.49±1.32	0.33	0.157
FLT10	16	14.64±1.74	0.44	0.387	0.61±2.48	0.62	0.340	
BLT5	16	14.20±2.86	0.72	0.835	1.05±1.58	0.40	0.018*	
BLT10	16	14.69±3.29	0.82	0.838	0.56±1.81	0.45	0.232	
MLT5	16	14.55±2.25	0.56	0.839	0.70±1.40	0.35	0.065	
MLT10	16	14.69±2.27	0.57	0.792	0.56±1.58	0.40	0.177	

	LLT5	16	14.65±2.41	0.60	0.902	0.60±1.11	0.28	0.046
	LLT10	16	15.05±2.47	0.62	0.885	0.20±1.21	0.30	0.518

SD = Standard deviation; SEM = Standard error of (measurement) mean; ZDP = zero dorsopalmar; Sig = Significance at level  $p < 0.05$ ; \*Value was significantly different at  $p < 0.05$

**Table 2k: Comparison of disto-dorsal wedge angle of the intermediate carpal bone (CiDDWA) measured at ZDP with each of the other 24 rotational variations and postural positions.**

Parameter (Dependable variable)	Rotational Positions	Descriptive statistics			Paired t-test			
		N	Mean±SD	SEM	Paired Samples Correlations Coeff.	Paired Mean Difference (ZDP - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) $p < 0.05$
Disto-dorsal wedge angle of the intermediate carpal bone (CiDDWA)	ZDP	16	155.34±3.67	0.92				
	VBR-20	16	149.59±4.01	1.00	0.380	5.75±4.29	1.07	0.000*
	VBR-15	16	151.32±4.41	1.10	0.424	4.02±4.39	1.10	0.002*
	VBR-10	16	153.75±3.83	0.96	0.572	1.59±3.47	0.87	0.088
	VBR-5	16	154.12±4.09	1.02	0.729	1.22±2.88	0.72	0.111
	VBR+5	16	155.73±4.91	1.23	0.545	-0.39±4.24	1.06	0.719
	VBR+10	16	157.42±5.69	1.42	0.285	-2.09±5.82	1.46	0.172
	VBR+15	14	157.93±5.68	1.52	0.362	-2.73±5.60	1.50	0.092
	VBR+20	8	160.78±5.46	1.93	0.574	-5.67±4.64	1.64	0.011*
HBR-10	16	154.10±3.78	0.94	0.651	1.24±3.12	0.78	0.132	

HBR-5	16	154.06±3.89	0.97	0.799	1.28±2.41	0.60	0.050
HBR+5	16	154.57±4.30	1.07	0.811	0.77±2.52	0.63	0.242
HBR+10	16	156.28±4.70	1.18	0.776	-0.94±2.97	0.74	0.225
CVR-10	16	154.62±4.05	1.01	0.663	0.72±3.18	0.80	0.379
CVR-5	16	153.98±4.09	1.02	0.595	1.36±3.51	0.88	0.142
CVR+5	16	153.50±4.02	1.00	0.656	1.84±3.20	0.80	0.037*
CVR+10	16	153.78±4.64	1.16	0.758	1.56±3.03	0.76	0.057
FLT5	16	154.89±4.91	1.23	0.676	0.45±3.64	0.91	0.624
FLT10	16	154.23±3.96	0.99	0.611	1.12±3.37	0.84	0.203
BLT5	16	153.93±4.29	1.07	0.745	1.41±2.90	0.73	0.070
BLT10	16	153.98±3.78	0.94	0.758	1.36±2.59	0.65	0.053
MLT5	16	154.59±4.26	1.06	0.616	0.75±3.51	0.88	0.406
MLT10	16	153.29±4.22	1.05	0.624	2.05±3.45	0.86	0.031*
LLT5	16	156.60±9.01	2.25	0.362	-1.26±8.41	2.10	0.559
LLT10	16	154.76±4.25	1.06	0.686	0.58±3.19	0.80	0.480

SD = Standard deviation; SEM = Standard error of (measurement) mean; ZDP = zero dorsopalmar; Sig = Significance at level  $p < 0.05$ ; \*Value was significantly different at  $p < 0.05$

**Table 21: Comparison of distal slope angle of the ulnar carpal bone (CuDSA) measured at ZDP with each of the other 24 rotational variations and postural positions.**

		Descriptive statistics	Paired t-test
--	--	------------------------	---------------

Parameter (Dependable variable)	Rotational Positions	N	Mean±SD	SEM	Paired Samples Correlations Coeff.	Paired Mean Difference (ZDP - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) p < 0.05
Distal slope angle of the ulnar carpal bone (CuDSA)	ZDP	16	30.90±3.67	0.92				
	VBR-20	16	28.08±4.05	1.01	0.889	2.82±1.85	0.46	0.000*
	VBR-15	16	29.19±3.34	0.84	0.943	1.72±1.23	0.31	0.000*
	VBR-10	16	28.93±3.01	0.75	0.858	1.97±1.89	0.47	0.001*
	VBR-5	16	29.71±2.41	0.60	0.778	1.19±2.35	0.59	0.061
	VBR+5	16	31.50±2.96	0.74	0.925	-0.60±1.46	0.37	0.123
	VBR+10	16	30.70±3.74	0.94	0.192	0.20±4.71	1.18	0.867
	VBR+15	16	31.66±3.73	0.93	-0.226	-0.76±5.79	1.45	0.608
	VBR+20	16	29.44±4.56	1.14	-0.269	1.46±6.58	1.64	0.388
	HBR-10	16	30.60±3.67	0.92	0.826	0.30±2.17	0.54	0.585
	HBR-5	16	30.38±3.09	0.77	0.932	0.53±1.37	0.34	0.144
	HBR+5	16	30.98±3.01	0.75	0.950	-0.08±1.24	0.31	0.796
	HBR+10	16	30.44±2.63	0.66	0.817	0.47±2.15	0.54	0.401
	CVR-10	16	29.73±4.19	1.05	0.660	1.18±3.27	0.82	0.172
	CVR-5	16	30.41±2.81	0.70	0.846	0.49±1.98	0.49	0.336
	CVR+5	16	30.38±3.15	0.79	0.701	0.52±2.68	0.67	0.452
	CVR+10	16	30.83±3.47	0.87	0.807	0.08±2.23	0.56	0.895
	FLT5	16	29.81±2.78	0.69	0.681	1.09±2.70	0.68	0.126
FLT10	16	29.75±2.18	0.54	0.650	1.15±2.80	0.70	0.121	
BLT5	16	30.28±2.89	0.72	0.602	0.63±3.01	0.75	0.419	
BLT10	16	30.76±3.13	0.78	0.735	0.14±2.53	0.63	0.827	
MLT5	16	30.53±2.35	0.59	0.663	0.38±2.75	0.69	0.592	
MLT10	16	30.65±2.74	0.68	0.824	0.25±2.10	0.53	0.643	

	LLT5	16	30.07±2.95	0.74	0.831	0.83±2.04	0.51	0.125
	LLT10	16	30.11±3.24	0.81	0.763	0.79±2.41	0.60	0.210

SD = Standard deviation; SEM = Standard error of (measurement) mean; ZDP = zero dorsopalmar; Sig = Significance at level  $p < 0.05$ ; \*Value was significantly different at  $p < 0.05$

**Table 2m: Comparison of width ratio of distal radius to proximal metacarpus (WDR:WPM) measured at ZDP with each of the other 24 rotational variations and postural positions.**

Parameter (Dependable variable)	Rotational Positions	Descriptive statistics			Paired t-test			
		N	Mean±SD	SEM	Paired Samples Correlations Coeff.	Paired Mean Difference (ZDP - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) $p < 0.05$
Width ratio of Distal radius to Proximal metacarpus (WDR:WPM)	ZDP	16	1.10±0.02	0.01				
	VBR-20	16	1.11±0.03	0.01	0.317	-0.013±0.03	0.008	0.119
	VBR-15	16	1.10±0.03	0.01	0.423	0.005±0.03	0.007	0.501
	VBR-10	16	1.09±0.02	0.01	0.620	0.015±0.02	0.005	0.013*
	VBR-5	16	1.10±0.03	0.01	0.783	0.002±0.02	0.005	0.723
	VBR+5	16	1.09±0.03	0.01	0.794	0.012±0.02	0.004	0.010*
	VBR+10	16	1.09±0.02	0.01	0.744	0.014±0.02	0.004	0.008*
	VBR+15	16	1.09±0.03	0.01	0.746	0.013±0.02	0.005	0.028*
	VBR+20	16	1.09±0.03	0.01	0.712	0.013±0.02	0.006	0.058
HBR-10	16	1.10±0.03	0.01	0.274	0.004±0.03	0.008	0.650	

HBR-5	16	1.09±0.02	0.01	0.393	0.012±0.03	0.007	0.098
HBR+5	16	1.09±0.03	0.01	0.341	0.008±0.03	0.008	0.380
HBR+10	16	1.10±0.03	0.01	0.002	0.003±0.04	0.010	0.747
CVR-10	16	1.09±0.01	0.00	-0.100	0.012±0.03	0.007	0.125
CVR-5	16	1.09±0.02	0.00	-0.006	0.006±0.03	0.008	0.432
CVR+5	16	1.09±0.02	0.01	-0.422	0.008±0.04	0.010	0.464
CVR+10	16	1.10±0.02	0.00	0.003	0.003±0.03	0.008	0.757
FLT5	16	1.09±0.02	0.01	0.540	0.010±0.02	0.006	0.092
FLT10	16	1.10±0.03	0.01	-0.181	0.003±0.04	0.010	0.803
BLT5	16	1.09±0.03	0.01	0.058	0.010±0.04	0.009	0.284
BLT10	16	1.10±0.03	0.01	0.455	0.002±0.03	0.007	0.784
MLT5	16	1.10±0.02	0.00	0.589	0.006±0.02	0.005	0.286
MLT10	16	1.10±0.03	0.01	0.331	0.014±0.03	0.008	0.079
LLT5	16	1.09±0.02	0.00	0.117	0.007±0.03	0.007	0.353
LLT10	16	1.08±0.02	0.01	-0.120	0.016±0.04	0.009	0.092

SD = Standard deviation; SEM = Standard error of (measurement) mean; ZDP = zero dorsopalmar; Sig = Significance at level  $p < 0.05$ ; \*Value was significantly different at  $p < 0.05$

**Table 2n: Comparison of width ratio of distal radius' medial articular condyle to lateral articular condyle (DRW.MAC:LAC) measured at ZDP with each of the other 24 rotational variations and postural positions.**

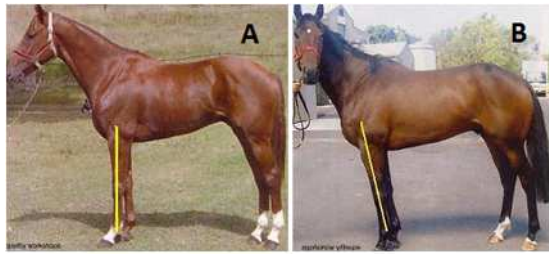
		Descriptive statistics	Paired t-test
--	--	------------------------	---------------

Parameter (Dependable variable)	Rotational Positions	N	Mean±SD	SEM	Paired Samples Correlations Coeff.	Paired Mean Difference (ZDP - others) ±SD	Std. Error of Mean Diff	Sig. (2-tailed) p < 0.05
Width ratio of distal radius' medial articular condyle to lateral articular condyle (DRW.MAC:LAC)	ZDP	16	0.79±0.07	0.02				
	VBR-20	16	0.62±0.07	0.02	0.610	0.171±0.06	0.015	0.000*
	VBR-15	16	0.67±0.07	0.02	0.380	0.122±0.08	0.020	0.000*
	VBR-10	16	0.71±0.06	0.01	0.799	0.084±0.04	0.010	0.000*
	VBR-5	16	0.75±0.06	0.01	0.829	0.046±0.04	0.010	0.000*
	VBR+5	16	0.84±0.08	0.02	0.824	-0.046±0.05	0.011	0.001*
	VBR+10	16	0.91±0.09	0.02	0.499	-0.114±0.08	0.021	0.000*
	VBR+15	16	0.97±0.10	0.02	0.249	-0.175±0.10	0.026	0.000*
	VBR+20	16	1.05±0.14	0.04	0.687	-0.256±0.11	0.027	0.000*
	HBR-10	16	0.78±0.05	0.01	0.574	0.012±0.06	0.014	0.422
	HBR-5	16	0.78±0.06	0.01	0.545	0.009±0.06	0.015	0.573
	HBR+5	16	0.79±0.05	0.01	0.461	-0.001±0.06	0.016	0.970
	HBR+10	16	0.79±0.05	0.01	0.443	-0.004±0.06	0.016	0.819
	CVR-10	16	0.78±0.05	0.01	0.203	0.011±0.08	0.019	0.583
	CVR-5	16	0.79±0.05	0.01	0.296	0.004±0.07	0.018	0.808
	CVR+5	16	0.76±0.06	0.01	0.209	0.026±0.08	0.020	0.204
	CVR+10	16	0.77±0.05	0.01	0.393	0.025±0.07	0.017	0.164
	FLT5	16	0.78±0.06	0.01	0.578	0.012±0.06	0.015	0.432
	FLT10	16	0.79±0.06	0.02	0.421	0.000±0.07	0.018	1.000
	BLT5	16	0.78±0.06	0.02	0.594	0.008±0.06	0.015	0.620
BLT10	16	0.77±0.05	0.01	0.364	0.022±0.07	0.017	0.227	
MLT5	16	0.77±0.06	0.02	0.709	0.016±0.05	0.013	0.215	
MLT10	16	0.79±0.06	0.02	0.335	0.001±0.08	0.019	0.949	

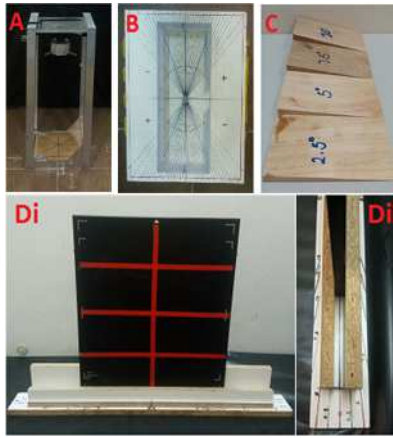
	LLT5	16	0.80±0.06	0.01	0.268	-0.012±0.08	0.019	0.542
	LLT10	16	0.79±0.05	0.01	0.460	0.006±0.06	0.016	0.731

SD = Standard deviation; SEM = Standard error of (measurement) mean; ZDP = zero dorsopalmar; Sig = Significance at level  $p < 0.05$ ; \*Value was significantly different at  $p < 0.05$

Author Manuscript



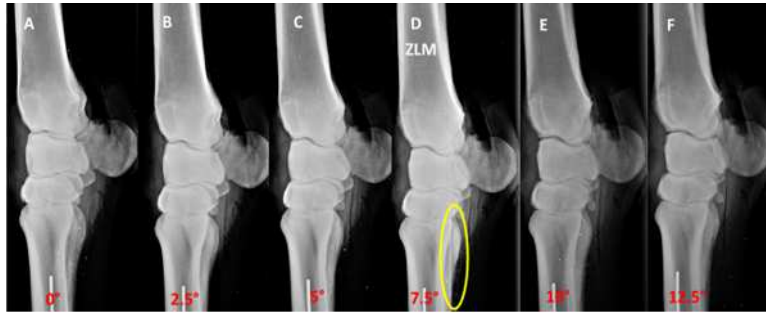
ahc\_12651\_f1.tif



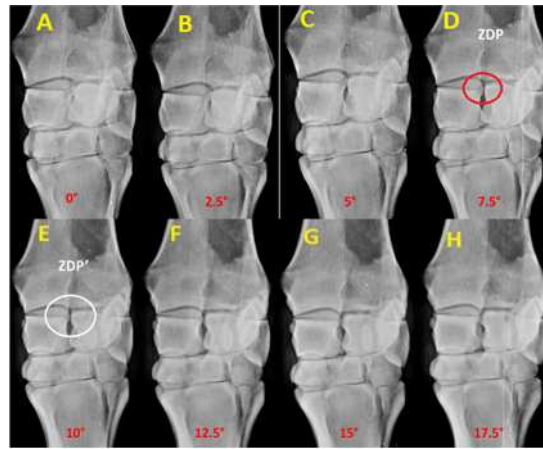
ahe\_12651\_f2.tif



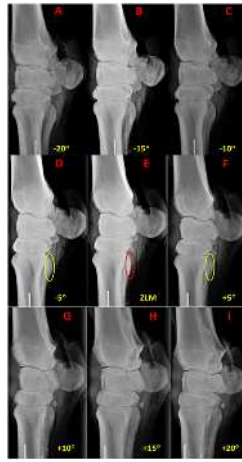
ahe\_12651\_f3.tif



ahe\_12651\_f4.tif



ahe\_12651\_f5.tif



ahe\_12651\_f6.tif



ahe\_12651\_f7.tif