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The relationship between morphometric measurements and radiographic changes associated with distal interphalangeal joint flexural deformity in donkeys

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Abstract

Background Flexural deformity of the distal interphalangeal (DIP) joint is a common condition in both working and non-working donkeys, arising from congenital or acquired causes, or as a secondary consequence of trauma or chronic lameness. The deformity results in abnormal weight distribution on

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the hoof. Although radiography is essential for identifying osseous and articular abnormalities, few studies have documented the morphometric and radiographic changes associated with DIP joint flexural deformity in donkeys. The objective of this study was to investigate the relationship between morphometric parameters and radiographic findings in donkeys with DIP joint flexural deformity. Twenty-three forefeet with DIP joint flexural deformity were collected from Egyptian donkeys. Lateral photographic evaluation was used to assess morphometric parameters, including toe length (TL), toe angle (TA), heel length (HL), heel angle (HA), coronet length (CL), coronary band angle (CBA), dorsal coronary band height (DCBH), palmar coronary band height (PCBH), hoof base of support (HBS), foot base of support (FBS), hoof pastern axis (HPA), base of support difference (FBS–HBS), and toe–heel angle difference (TA–HA). The following ratios were also determined: toe – to – heel length ratio (TL:HL), height index (HI), dorsal coronary band height to hoof base of support ratio (DCBH:HBS), and toe length to hoof base of support ratio (TL:HBS). Lateromedial (LM) and dorsopalmar (DP) radiographic views were obtained to identify radiographic abnormalities.

Results Radiographic changes included osteolytic lesions affecting the solar and dorsal aspects of the third phalanx (P3), with additional abnormalities observed in the second phalanx (P2), the navicular bone, the collateral ligaments of the DIP joint, degenerative joint disease (DJD) of the DIP joint, and exostosis of P3. Regarding morphometric parameters, TA,

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HA, and PCBH were increased, whereas most linear and angular parameters – including TL, HL, coronary band measures, HBS, HPA, and HI – were decreased.

Conclusions The results reveal correlations between morphometric parameters and radiographic findings in hoof capsule structures, which should be considered during the management of DIP joint flexural deformity in donkeys.

Keywords Donkey, Flexural deformity, Hoof, Radiology, Morphometric parameters, Correlations.

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Background

DIP joint flexural deformity is a conformational defect characterized by the development of a clubfoot [1, 2, 3, 4]. It is a common condition in both working and non-working donkeys, arising from congenital or acquired causes, or as a secondary consequence of trauma or chronic lameness [3, 5, 6].

The hoof capsule of a donkey exhibits asymmetry characterized by increased heel height and length. The central sulcus is deep and narrow, with degeneration of the sole, frog, and digital cushion horn, whereas loaded heels roll under and unloaded heels flare [2]. The changes in hoof capsule shape are related to variations in hoof growth rates at different sites that are associated with DIP joint flexural deformity, as the heels grow

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faster than the toe [4, 7]; additional contributing factors include the viscoelastic properties of the hoof capsule [4] and plastic compression [8].

In DIP joint flexural deformity, the mechanical imbalance caused by functional shortening of the flexor muscle-tendon unit results in persistent excessive tension in the deep digital flexor tendon (DDFT), maintaining the DIP joint in relative flexion. This chronic alteration associated with loading leads to a concave dorsal hoof wall and compression of the solar corium, particularly at the apex of the P3 [9].

Equine radiographic studies of the foot are used to assess digit conformation, shape, and angles, as well as to evaluate hoof injuries and balance [10, 11]. The donkey's foot radiography is important for diagnosing the changes and the internal relationships of the osseous structures of the foot and P3 [12]. Several studies support the notion that radiographic evaluation of DIP joint flexural deformity in horses reveals an increase in dorsal surface concavity and/or bone demineralization of the P3, resulting from abnormal pressure distribution at the level of the P3 apex [1, 13]. Meanwhile, in donkeys with flexural deformity of the DIP joint, the P3 exhibits osteophytic and osteolytic changes, soft tissue thickening with a radio-opaque mass, and calcification of the palmar structures [2].

Nevertheless, to the best of our knowledge, there is no data on the relationship between morphometric measurements and radiographic abnormalities within the hoof capsule in donkeys with DIP joint flexural

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deformity. Therefore, this study aimed to (1) describe the radiographic abnormalities within the hoof capsule in relation to morphometric parameters, (2) analyze correlations between toe and heel measurements—including TA, TL, HL, and HA—and hoof capsule parameters, and (3) determine the relationship between hoof measurements and radiographic features in donkeys with DIP joint flexural deformity.

Methods

Data collection

This study was carried out on 23 forefeet (13 right and 10 left) collected from 18 Egyptian donkey cadavers (11 males and 7 females) with DIP joint flexural deformity. Thirteen donkeys were unilaterally affected (8 right and 5 left), and five donkeys were bilaterally affected. The donkeys selected for the study had a mean age of 7.42 ± 2.54 years. Each distal limb was disarticulated from the carpal joint. All hooves included in this study had toe angles of 60 degrees or greater, consistent with previous findings [6]. The distal limbs were collected via convenience sampling from donkey cadavers following euthanasia for reasons other than hoof lameness at the Veterinary Teaching Hospital, Cairo University, based on case availability. All donkeys were owned by Veterinary Teaching Hospital, Cairo University. This study received approval from the Institutional Animal Care and Use Committee at Cairo University (CU/II/F/ASTC/5/25).

Morphometric assessments

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The hooves were thoroughly brushed and cleaned of mud and debris. Visual assessment and evaluation of the hooves were performed. Hooves were then imaged from the lateral aspect using a digital camera (KODAK, 8.2-megapixel camera, China) according to El-Marakby et al. [14, 15]. A standardized distance (50 cm) was used between the camera and each hoof. The solar surface of the hoof was parallel to the ground and in contact with it. At the same time, the metacarpus was perpendicular to the ground during digital photography in a simulated weight-bearing position by the same operator (AIE).

Eleven morphometric hoof capsule parameters were obtained from each digital photograph (Table 1 and Fig. 1). Intra-rater repeatability was determined by measuring ten donkey hooves five times (three days between each time) by the same individual (A.I. El-Marakby) then using intraclass Correlation Coefficient. The measured parameters were determined using AutoCAD 2019 software after prior training and using a standardized protocol.

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Radiological Assessments

LM and DP radiographic projections were obtained using an indirect portable X-ray machine (Fischer). The exposure factors were 50-55 kV, 10 mAs, and a focal film distance of 90 cm. According to El-Marakby et al. [15], two metallic wires were placed on the dorsal hoof wall and lateral heel during LM projection. In contrast, they were placed on the medial and

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lateral hoof walls during DP projection, and a small metallic ball was placed just dorsal to the apex of the frog. The distal limb was held in a simulated weight-bearing position on a wooden block by the same operator: the solar aspect was in close contact with the block, and the metacarpus was perpendicular to it. The X-ray was focused 1 cm distal to the coronet, perpendicular to the cassette and parallel to the ground in both LM and DP projections [16]. Radiographic assessment was interpreted by the same radiologist (A. I. Abdelgalil).

Statistical Analysis

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Descriptive statistics (mean ± standard deviation [SD], minimum and maximum values) for morphometric hoof capsule parameters were calculated. Cronbach's alpha (α) was calculated to determine the reliability of morphometric hoof capsule parameters and the incidence of radiographic changes. The Kolmogorov–Smirnov test was used to assess data normality. Spearman's correlation coefficient (r_s) was calculated for TA. Pearson's correlation coefficient (r) was calculated for TL, HA, and HL, whereas TA and CBA were assessed using Spearman's correlation coefficient (r_s). Spearman's correlation coefficient (r_s) was also used to assess correlations among the different radiographic changes and morphometric hoof capsule parameters. The dependent t-test between left and right limbs of bilaterally affected donkeys was performed. Statistical significance was set at P ˂ 0.05.

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SPSS (IBM SPSS version 25 × 64-bit edition) was used to conduct all statistical analyses.

Results

The incidence of radiographic changes associated with DIP joint flexural deformity in donkeys in the current study is presented in Fig. 2. Radiographic findings included an osteolytic reaction at the solar aspect of P3 (23 feet, 100%) and at the P3 apex (21 out of feet, 91.3%). Osteolytic and osteophyte reactions were detected on the P2 (8 out of feet, 34.78%). The navicular bone showed an osteophyte reaction at the palmar aspect and an osteolytic reaction in the body and palmar cortex (6 out of feet, 26.09%). Mineralization of the DIP joint collateral ligaments was observed in 4 out of feet (17.39%). The DIP joint exhibited DJD (4 out of feet, 17.39%), and bony exostosis was observed at the P3 apex (2 out of feet, 8.5%) (Figs. 3 and 4).

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Descriptive statistics for morphometric hoof capsule parameters, differences, and ratios are presented in Table 2. The morphometric parameters showed an increase in TA, HA, and PCBH, and decreases in TL, HL, CL, CBA, DCBH, HBS, FBS, HPA, FBS–HBS, TA–HA, and HI. The morphometric parameters and radiographic changes incidence demonstrated acceptable reliability (Cronbach's $\alpha = 0.701$).

Correlation coefficients between TA, TL, HA, and HL and the measured parameters are shown in Table 2. Moderate negative correlations were observed for TL with both TA and HA , and for HL with HA, whereas

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moderate positive correlations were observed for both TL with HL and TA with HA. The TA–HA difference showed a strong negative correlation with HA (r = - 0.677, *P-value* ≤ 0.0001, 95% CI = - 0.85: - 0.37), whereas the TL:HL ratio showed a strong negative correlation with HL and a moderate negative correlation with TA. A strong positive correlation was observed between CL and TL , and a strong negative correlation was observed between CBA and HA ; moderate positive correlations were also observed between CL and HL and between CBA and TL , and moderate negative correlations were observed between CL and HA and between CBA and TA. The correlation between DCBH and TL was strong and positive (r = + 0.919, *P-value* ≤ 0.0001, 95% CI = + 0.82: + 0.97), whereas the correlation between PCBH and HL was strong and negative (r = - 0.622, *P-value* = 0.002, 95% CI = - 0.82: - 0.28); additionally, DCBH showed a moderate positive correlation with HL and a moderate negative correlation with HA. The HI showed a strong negative correlation with HA and a moderate positive correlation with TL. TL showed a strong positive correlation with both HBS and FBS (r = + 0.677, *P-value* ≤ 0.0001, 95% CI = + 0.37: + 0.85; r = + 0.767, *P-value* ≤ 0.0001, 95% CI = + 0.52: + 0.9, respectively), whereas HA showed a strong negative correlation with FBS (r = - 0.622, *P-value* = 0.002, 95% CI = - 0.82: - 0.28) ; additionally, a moderate positive correlation was observed between FBS and HL , and a moderate negative correlation was observed between HBS and TA. The FBS–HBS difference showed a strong positive correlation with HL, a strong negative correlation

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with HA and a moderate positive correlation with TL. The HPA showed a moderate negative correlation with TA. The DCBH:HBS and TL:HBS ratios showed no significant correlation.

Significant increases in TA and HA and significant decreases in TL, DCBH, and HPA were associated with DIP joint flexion, a broken-forward HPA, and a shift of body weight to the dorsal hoof. The increase in PCBH and decrease in CBA were attributed to elevation of the heels resulting from a broken-forward HPA rather than an increase in heel length, as HL in this study was decreased. The significant decreases in HL, CL, HBS, FBS, FBS–HBS, TA–HA, HI, and the TL:HL ratio were attributed to hoof capsule contraction, dorsopalmar imbalance, and changes in hoof capsule shape and size.

Correlation coefficients between radiographic changes and morphometric parameters are presented in Table 3. Osteolysis of the dorsal aspect of P3 showed a significant moderate positive correlation only with HBS. Affections of P2 showed a significant, strong negative correlation with CL, FBS, and HI; a moderate negative correlation with HBS, FBS–HBS, and TA–HA; and a moderate positive correlation with HA and the TL:HBS ratio. Navicular disease showed a significant, moderate negative correlation with CBA, FBS–HBS, and HI, and a moderate positive correlation with HA and PCBH. Mineralization of the DIP joint collateral ligaments showed a significant moderate negative correlation with HL, CL, FBS–HBS, and TA–

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HA , and a moderate positive correlation with HA and the TL:HL ratio. Both DIP joint DJD and bony exostosis of the dorsal aspect of P3 showed non-significant correlations with the morphometric hoof capsule parameters.

The dependent t test showed non-significant differences between right and left limbs in bilaterally affected donkeys (Table 4). Intraclass Correlation Coefficient revealed excellent repeatability (Table 5).

Discussion

The radiographic findings in the present study included an osteolytic reaction at the apex and solar aspect of P3, as well as bony exostosis at the P3 apex. The P2 exhibited osteolytic and osteophyte reactions. The navicular bone showed an osteophyte reaction at the palmar surface and an osteolytic reaction in the body and palmar cortex. The DIP joint exhibited DJD with collateral ligament mineralization. In this respect, radiographic images of DIP joint flexural deformity in horses have revealed DIP joint remodelling, lipping, or bone demineralization resulting from abnormal pressure distribution at the P3 apex [1, 13].

Mostafa et al. [2], Ernst et al. [3], O'Grady [4], Butler et al. [16], and Caldwell [17] reported that DIP joint flexural deformity is characterized by a high hoof angle and the development of clubfoot, which is associated with greater forces placed on the toe. In addition, changes in the HPA lead to excessive strain on the long or common digital extensor tendon,

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contributing to periostitis and enthesophyte formation along the dorsal joint surface [6].

Previous studies have shown that an increase in TA contributes to flexion of the DIP joint and to changes in internal tissue strain and force distribution within the hoof, which is associated with a reduction in the compressive force on the navicular bone via the DDFT [4, 18–21]. Consequently, the radiographic findings in donkeys with DIP joint flexural deformity are consistent with previous findings in horses [2, 3, 16, 17].

Previous studies have reported that the TA in normal donkey hooves is 58.25º and 59.5º, whereas the TL is 67.3 mm and 70 mm, respectively [15, 22]. In the present study, DIP joint flexural deformity was associated with a higher TA and a lower TL. The decrease in toe length in the present study can be attributed to increased weight bearing on the dorsal aspect of the hoof capsule, which leads to wear and tearing of the toe region [1].

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Moreover, a high hoof angle has been associated with strain on the navicular bone and the suspensory ligaments [1, 4]. Accordingly, the observed radiographic findings in the navicular bone and collateral ligament mineralization, as well as the osteolytic and bony exostosis reactions at the dorsal and solar aspects of P3, can be attributed to the high toe angle. The moderate negative correlation between high TA and low TL, and the radiographic findings in the present study, are consistent with the findings of O’Grady & Dryden [1], Ernst et al. [3], and O’Grady [4].

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El-Marakby et al. [15] reported that the HA in normal donkey hooves is 43.33º. However, donkeys with DIP joint flexural deformity in the present study exhibited higher HA levels. The HA showed a moderate positive correlation with TA and a moderate negative correlation with TL and HL. Consequently, heel conformation has been associated with forces within the foot and with radiographic abnormalities [23, 24]. In addition, previous studies have demonstrated that foot pain in lame horses is associated with increased HA [18, 25].

The increase in P2 affections, navicular disease, and DIP joint collateral ligament mineralization in the present study has been attributed to the positive correlation of HA and the negative correlation of HL with the radiographic changes. Consequently, high toe and heel angles contribute to DIP joint flexion, a toe-first landing, and an increase in the pressure on the dorsal portion of the foot and in the strain on the suspensory ligament of the navicular bone [4].

Despite the finding of a non-significant correlation between HL and TA in the present study, which may be attributed to the evaluation of HL from only the lateral aspect of the hoof, this finding is consistent with previous findings in horses with DIP joint flexural deformity, as an increase in TA at an early stage does not affect the heel length. The heel begins to lengthen only in long-standing, untreated cases [26].

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A previous study reported that mineralization of the collateral ligaments results from repeated trauma and desmitis [27, 28]. Consequently, the correlations between morphometric parameters and radiographic findings demonstrate the changes observed in donkeys with DIP joint flexural deformity.

The present study has shown that the P3 exhibited exostosis and lysis at the dorsal aspect. Butler et al. [16] mentioned that, in more advanced cases, new bone growth and lysis may occur on the dorsal surface of the P3 as a result of an increase in the pressure at the toe region in DIP joint flexural deformity and laminitis.

Furthermore, Redden [9] reported that DIP joint flexural deformity causes mechanical imbalance, excessive tension in the DDFT, and clubfoot development. This persistent alteration in conformation and load is reflected in the hoof capsule as compression of the solar corium at the P3 apex.

In the present study, the TA–HA difference was 12.74º and decreased with increasing HA. Butler et al. [16] recommended using ratios and differences rather than single measurements because horses vary in size and magnification. Moreover, dorsopalmar balance is better evaluated using TA–HA [29, 30], whereas hoof capsule shape and size are determined using the TL:HL ratio [18].

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Kane et al. [29] demonstrated that catastrophic musculoskeletal injuries in Thoroughbred horses are associated with an increase in TA–HA. However, in donkeys with DIP joint flexural deformity, TA–HA was decreased, and this was associated with collateral ligament mineralization and P2 osteolytic and osteophyte reactions. Additionally, the strong, significant negative correlation between decreases in TA–HA and increases in HA reveals a relationship between morphometric parameters and radiographic abnormalities in the present study.

The TL:HL ratio was 1.27 and increased with decreasing HL in the present study. Dyson et al. [18] found that an increase in the TL:HL ratio is associated with an increase in DIP joint collateral ligament injuries. Similar findings were observed in the present study.

The CBA in donkeys with DIP joint flexural deformity was 16.26° in the present study, whereas in normal donkeys it was 22.83° [15]. Dyson et al. [18] reported that CBA decreases as the degree of lameness increases in horses with foot pain. Therefore, these findings are consistent with the current study.

CL in donkeys with DIP joint flexural deformity in the present study showed a strong positive correlation with TL and a moderate positive correlation with HL. Therefore, as TL and HL decreased, CL decreased as well. Baxter & Stashak [6] and Dyson et al. [18] mentioned that DIP joint flexural deformity develops as a result of disuse of the foot in chronic lameness, with

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weight-bearing shifted to the dorsal aspect of the hoof. The impact force transferred to the bony structures directly without affecting the palmar hoof soft tissue structures, leading to heel contraction. The contracted heel may have contributed to the decrease in CL observed in the present study, which showed a negative correlation with P2 pathology and collateral ligament mineralization of the DIP joint.

Donkeys with DIP joint flexural deformity showed that the DCBH, PCBH, and HI were 56.01 mm, 37.42 mm, and 1.52, respectively. Meanwhile, in normal donkeys, these parameters were 68.47 mm, 31.7 mm, and 2.21, respectively [15]. The DCBH and HI were lower, whereas the PCBH was higher than normal.

In horses with foot pathologies, the group with navicular bone lesions had the lowest DCBH. In contrast, the group with combined lesions in P2 and P3, as well as in the distal and proximal interphalangeal joints, had the highest PCBH. This group was followed by the group with combined lesions in the DDFT, navicular bone, and the collateral ligaments of the DIP joint [25]. Donkeys with DIP joint flexural deformity in the current study exhibited similar results. Contrary to the present findings, HI was significantly increased in horses with foot pain [18]. Therefore, the correlations between HI, PCBH, and radiographic changes confirm the link between morphometric alterations and pathological findings in donkeys with DIP joint flexural deformity.

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HBS was 55.38 mm in donkeys with DIP joint flexural deformity in the present study. It was higher (68.73 mm) in normal donkeys [15]. Davies et al. [31] mentioned that the normal hoof capsule deforms and expands, especially at the heels, to withstand the impact force of the horse's body weight during the stance phase of the stride. O'Grady [4], Baxter & Stashak [6], Ovnicek [32], and Hunt [33] reported that, in DIP joint flexural deformity, the hoof becomes contracted and smaller, particularly at the heels, losing its ability to expand and impairing the normal biomechanical function of the hoof capsule.

The correlations of HBS, FBS, and FBS–HBS in the present study with TL, TA, HL, and HA showed a reduction in these parameters with an increase in TA and HA and a decrease in TL and HL, which contributed to hoof capsule contraction and loss of normal biomechanical function. Consequently, these reductions were negatively correlated with P2 osteolysis and osteophyte reactions, navicular disease, and DIP joint collateral ligament mineralization, indicating an increase in these radiographic changes in donkeys with DIP joint flexural deformity. In contrast, these parameters were elevated in Thoroughbred racehorses with catastrophic musculoskeletal injuries [29].

A broken-forward HPA is a key feature of DIP joint flexural deformity [4]. In donkeys with DIP joint flexural deformity, HPA was lower (176.78º) than in normal donkeys (182.5º) [15], confirming the presence of a broken-forward

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HPA. In the present study, HPA showed a moderate negative correlation with TA, indicating that an increase in TA was associated with a decrease in HPA, despite the absence of the effect of body weight on the foot. Parks [34] reported that a broken-forward HPA increases the weight-bearing on the dorsal hoof wall, leading to pedal osteitis. This finding supports the higher incidence of osteolytic reaction of the solar aspect of the P3 observed in the present study.

Morphological evaluation of the hoof capsule has clinical relevance for identifying areas of excessive hoof wall stress; however, such evaluation must be combined with knowledge of the abnormal distribution of forces that causes hoof capsule deformation, enabling the clinician to apply appropriate farriery to modify these stresses [4]. Donkeys with DIP joint flexural deformity in the present study exhibited an increase in TA and HA and a decrease in TL, HL, HPA, and supportive hoof parameters; moreover, the navicular bone and P3 were subjected to abnormal loading, excessive strain, and subsequent remodelling, osteolysis, and degenerative joint changes. These findings should be considered during the management of donkeys with DIP joint flexural deformity.

The main limitations of the present study were the lack of data on body weight and body condition score, the lack of dorsopalmar photographic evaluation, and the measurement of the heel length from the lateral side. Further studies are needed to evaluate mediolateral balance in donkeys

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with DIP joint flexural deformity. The absence of these parameters may affect the loading on digital structures and their function [9].

Conclusions

In donkeys with DIP joint flexural deformity, radiographic evaluation revealed a high incidence of osteolytic changes, particularly in the solar and apical regions of the P3, as well as frequent involvement of the P2 and the navicular bone. DIP joint degeneration, collateral ligament mineralization, and occasional bony exostoses were also noted.

Morphometric analysis showed increased TA and HA, accompanied by reductions in TL, HL, the HPA, and supportive hoof parameters. These changes contributed to abnormal loading, excessive strain on the navicular bone and P3, and subsequent remodelling, osteolysis, and degenerative joint changes.

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The contraction of the hoof capsule, reflected in reduced support parameters (HBS, FBS, and FBS–HBS), further disrupted normal biomechanics. Overall, the strong and moderate correlations between morphometric and radiographic findings highlight the close association between altered hoof conformation and pathological changes in donkeys with DIP joint flexural deformity.

Declarations

Abbreviations

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DIP, distal interphalangeal; TL, toe length; TA, toe angle; HL, heel length; HA, heel angle; CL, coronet length; CBA, coronary band angle; DCBH, dorsal coronary band height; PCBH, palmar coronary band height; HBS, hoof base of support; FBS, foot base of support; HPA, hoof pastern axis; FBS–HBS, base of support difference; TA–HA, toe–heel angle difference; TL:HL, toe – to – heel length ratio; HI, height index; DCBH:HBS, dorsal coronary band height to hoof base of support ratio; TL:HBS, toe length to hoof base of support ratio; LM, lateromedial; DP, dorsopalmar; P3, third phalanx; P2, second phalanx; DJD, degenerative joint disease; DDFT, deep digital flexor tendon; SD, standard deviation; Min, minimum value; Max, Maximum value; CI, confidence interval

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Ethics approval and consent to participate

All donkeys were owned by Veterinary Teaching Hospital, Cairo University. This study was approved by the Institutional Animal Care and Use Committee at Cairo University (CU/II/F/ASTC/5/25).

Consent for publication

Not applicable

Availability of data and materials

All analyzed/raw data are available on request from the corresponding author.

Competing interests

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The authors declare that they have no competing interests.

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Authors' contributions

AIA contributed to writing, review, editing, visualization and methodology. AIE contributed to conceptualization, methodology and software. MBM contributed to writing, original draft and data curation. ASS contributed to supervision and investigation. All authors read and approved the final manuscript.

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Figures and Figure legends:

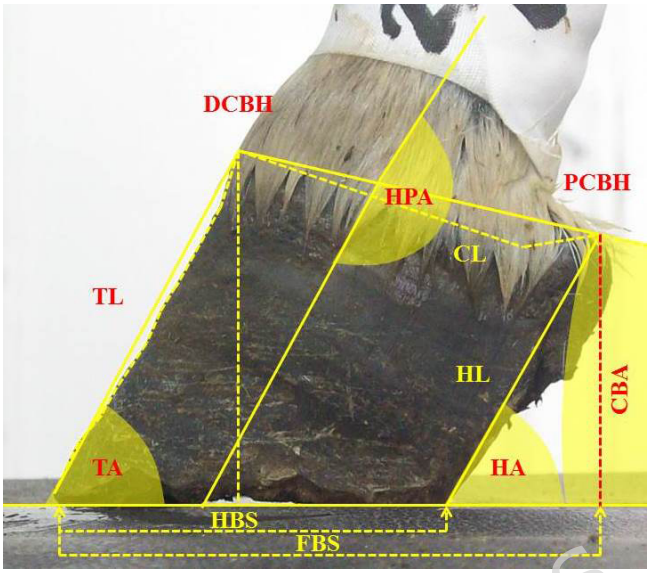


Fig. 1 Lateral morphometric parameters

Toe angle (TA), toe length (TL), heel angle (HA), heel length (HL), coronary band angle (CBA), coronet length (CL), dorsal coronary band height (DCBH), palmar coronary band height (PCBH), hoof base of support (HBS), foot base of support (FBS), and hoof pastern axis (HPA).

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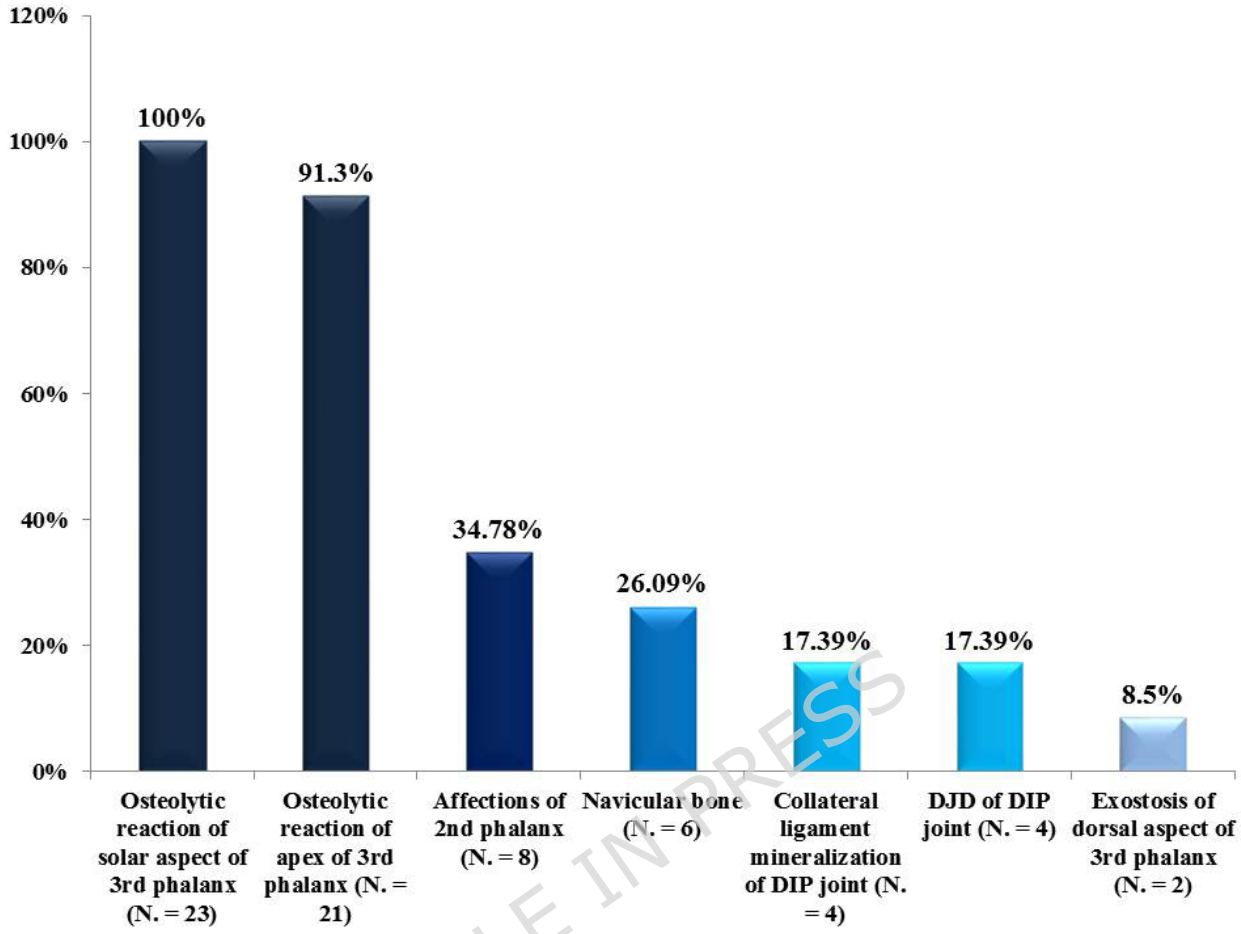
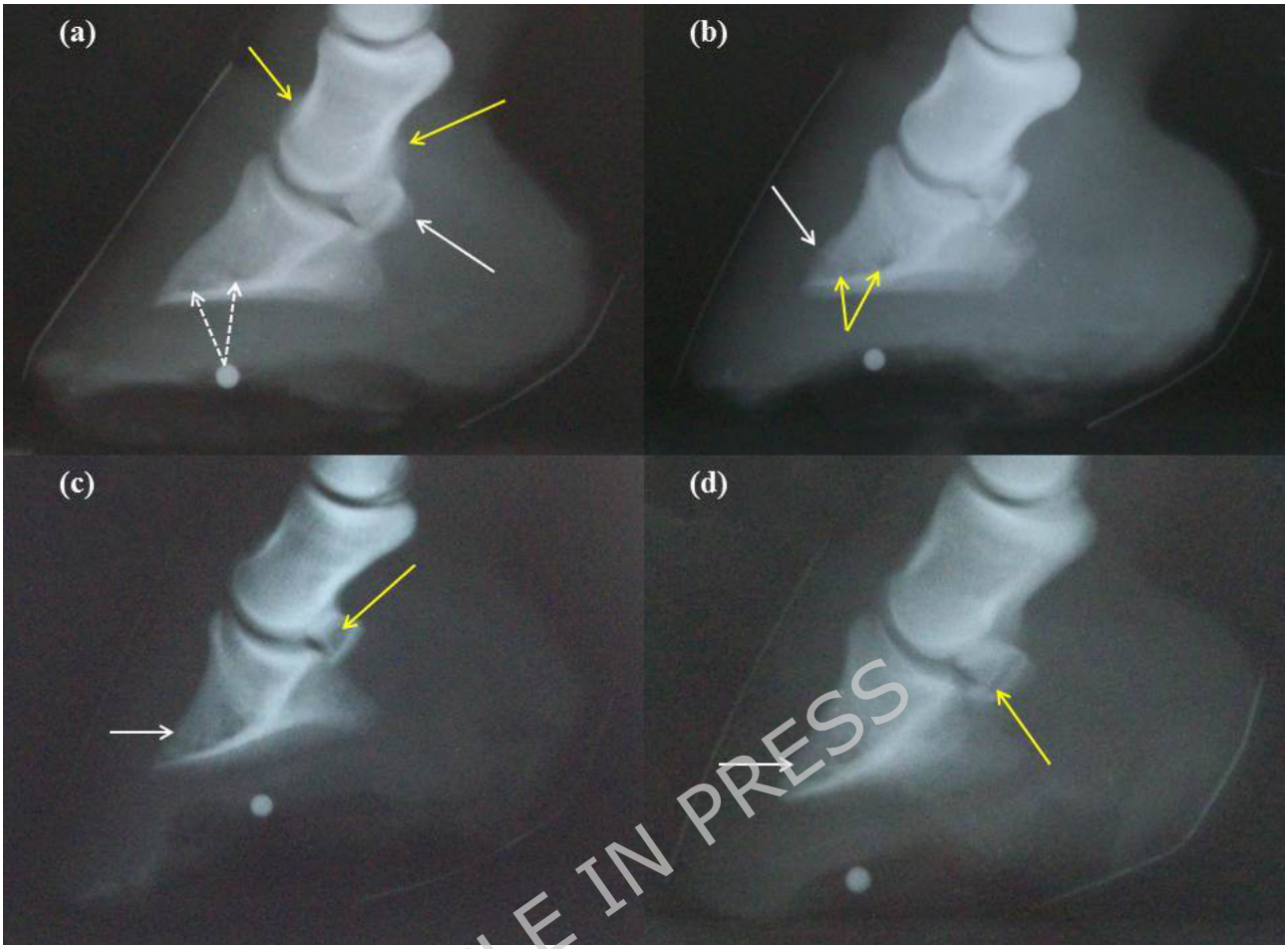


Fig. 2 The incidence of radiographic changes associated with DIP joint flexural deformity in donkeys

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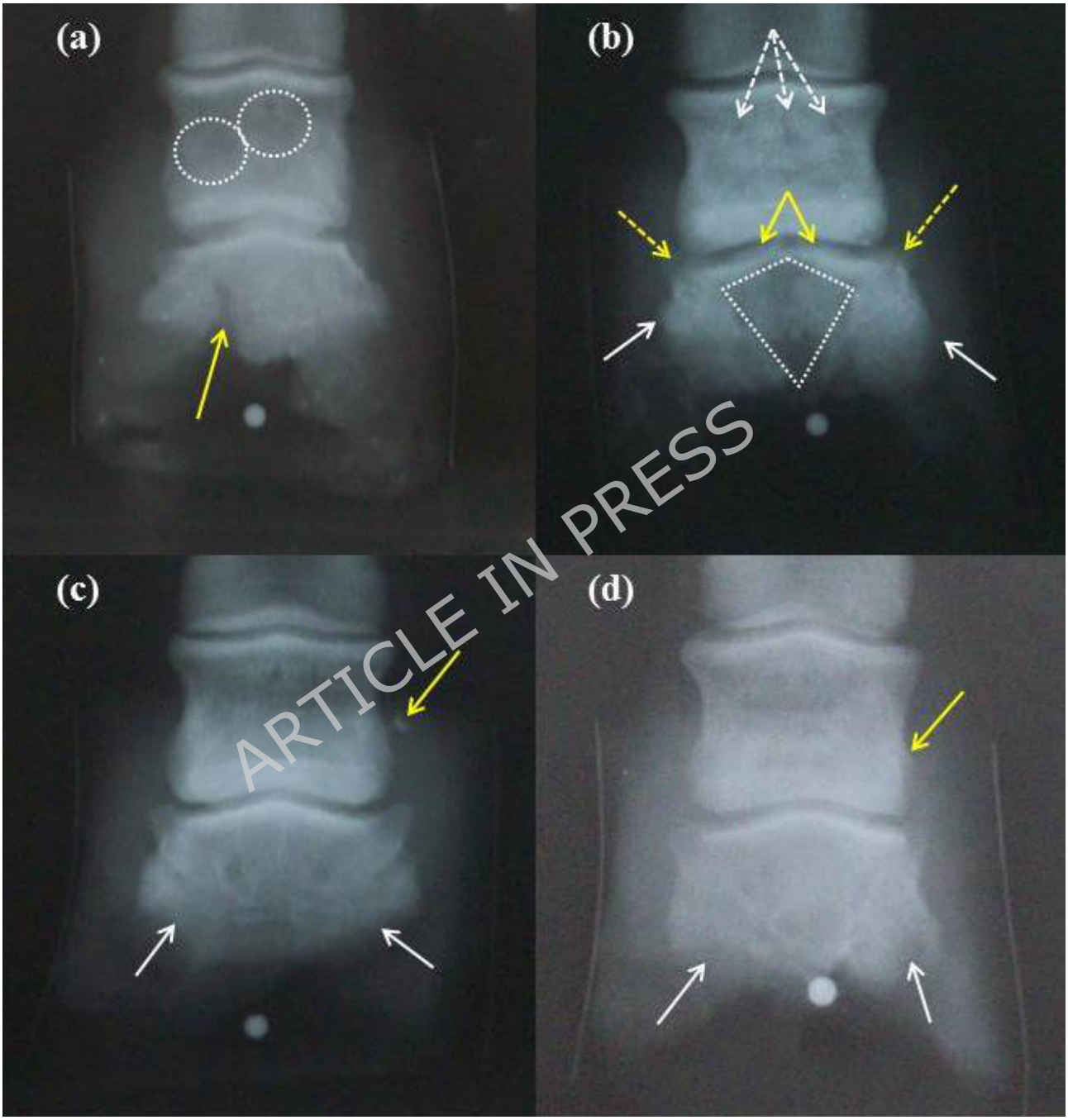
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Fig. 3 Lateromedial radiographic views for donkeys with DIP joint flexural deformity

3**a**: DIP joint osteoarthritis with osteophyte formation at the dorsal and palmar distal aspects of P2 (yellow arrows), involvement of the navicular bone (white arrow), and osteolysis at the P3 apex (dashed white arrows). 3**b**: Dorsal distal exostosis of P3 (white arrow) with concurrent solar margin osteolysis (yellow arrows). 3**c**: Osteolysis of the navicular bone body (yellow arrow) with concurrent involvement of the P3 apex (white arrow). 3**d**:

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Osteolysis affecting the palmar cortex of the navicular bone (yellow arrow) and the P3 apex (white arrow).



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Fig. 4 Dorsopalmar radiographic views for donkeys with DIP joint flexural deformity: “the medial aspect was to the left”

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4**a**: Severe osteolysis extending to the medial vascular channel of the solar margin of P3 (yellow arrow), with marked osteolysis of the body of P2 (dashed white circles). 4**b**: Advanced degenerative changes of the DIP joint, including periarticular osteophyte formation (dashed yellow arrows), enthesophyte development at collateral ligament insertions (white arrows), marked osteolysis of P3 (dashed white shape), joint space narrowing (yellow arrows), and concurrent osteolysis of P2 (dashed white arrows). 4**c**: Mineralization of the lateral collateral ligament of the DIP joint (yellow arrow) with associated osteolysis of P3 (white arrows). 4**d**: Osteophyte formation at the lateral aspect of P2 (yellow arrow) with concurrent osteolysis of P3 (white arrows).

Tables:

Table 1 Morphometric hoof capsule parameters.

Parameters	Abbreviation	Definition	Clinical Significance
Toe length “mm”	TL	Distance from the most proximal point to the most distal point at the dorsal aspect of the hoof wall.	Define the shape and size of the hoof and indicate the hoof balance and forces acting on DDFT [18, 21, 29, 35].
Toe angle	TA	Palmar angle which is made by the dorsal hoof wall and the ground surface.	Determine the inclination angle and dorsopalmar balance of the hoof capsule [18, 29]. It affects the strain and stress forces inside the hoof capsule, distal phalanx rotation, and body weight distribution between toe and heel [19–21, 23].
Heel length “mm”	HL	Distance from the most proximal point to the most distal point at the palmar aspect of the hoof wall from lateral aspect of the hoof.	Has an impact on hoof balance [35].

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Heel angle	HA	Palmar angle which is made by the palmar hoof wall and the ground surface.	Define dorsopalmar balance of the hoof [18, 29].
Coronet length “mm”	CL	Distance from the most dorsal point to the most palmar point of the coronary band.	Assess the hoof and foot balance [35].
Coronary band angle	CBA	Angle which is made between the coronary band and the ground surface.	Determine the degree of capsular truncation, which is influenced by hoof capsule wearing [36]. It estimates the distal phalanx position inside the hoof capsule [37]. It determines the viability of hoof capsule horn material in resisting the forces acting on the hoof capsule [23].
Dorsal coronary band height “mm”	DCBH	Perpendicular distance from the most dorsal point of the coronary band to the weight-bearing surface.	Determine the hoof balance and force distribution within the foot [15, 18, 23, 25, 38].
Palmar coronary band height “mm”	PCBH	Perpendicular distance from the most palmar point of the coronary band to the weight-bearing surface.	Determine the hoof balance and force distribution within the foot [15, 18, 23, 25, 38].
Hoof base of support “mm”	HBS	Distance from the most dorsal point at toe to the most palmar point at the heel along the ground surface of the hoof.	Define the dorsopalmar balance of the hoof [29].
Foot base of support “mm”	FBS	Distance from the most dorsal point at the toe to the palmar point that intersects with the vertical line from the heel bulb at the ground surface of the hoof.	Define the dorsopalmar balance of the hoof [29].
Hoof pastern axis	HPA	Palmar angle between the axis of the pastern and hoof.	A standardized landmark in evaluating hoof balance [4].
Base of support difference “mm”	FBS–HBS	Foot base of support to hoof base of support difference.	Define the dorsopalmar balance of the hoof [29].

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Toe–Heel angle difference	TA–HA	Toe angle to heel angle difference.	More important in assessment of dorsopalmar balance of the hoof than using TA or HA alone [29, 30].
Toe to heel length ratio	TL:HL	Ratio between the toe length and heel length.	Determine the difference in the size and shape of the hoof capsule. It is important in determining the viability of hoof capsule horn material in resisting the forces at the dorsal and palmar aspects [18].
Height index	HI (DCBH:PCBH)	Ratio between dorsal coronary band height and palmar coronary band height.	Determine the difference in the size and shape of the hoof capsule [18]. It is important in determining the viability of hoof capsule horn material in resisting the forces acting on the hoof capsule [18, 23, 25].
Dorsal coronary band height to hoof base of support ratio	DCBH:HBS	Ratio between the dorsal coronary band height and the hoof base of support.	Determine the difference in the size and shape of the hoof capsule. It is important in determining the viability of hoof capsule horn material in resisting the forces acting at the midline of the capsule [18].
Toe length to hoof base of support ratio	TL:HBS	Ratio between the toe length and the hoof base of support.	Determine the difference in the size and shape of the hoof capsule. It is important in determining the viability of hoof capsule horn material in resisting the forces acting at the midline of the capsule [18].

Abbreviations: DDFT, deep digital flexor tendon.

Table 2 Descriptive statistics for morphometric parameters and correlation coefficients for TA, TL, HA, and HL.

Parameters	**Mean ± SD**	**Min.**	**Max.**	**Correlation Coefficient**											
				TA			**TL**			**HA**			**HL**		
				r_s	***P Value***	***95% CI***	r	***P Value***	***95% CI***	r	***P Value***	***95% CI***	r	***P Value***	***95% CI***
TL (mm)	59.79 ± 5.76	51	71.27	**-0.509***	**0.013**	**-0.76:-0.12**	1.000	----	------	**-0.478***	**0.021**	**-0.74:-0.08**	**+0.490***	**0.018**	**+0.1:+0.75**
TA	65.65 ± 5.05	60	80	1.000	----	------	**-0.509***	**0.013**	**+0.76:-0.12**	**+0.481***	**0.020**	**+0.08:+0.75**	-0.035	0.872	-0.44:+0.38
HL	47	3	62	-	0.	-	**+**	**0.**	**+0.1**	**-**	**0.**	**-**	1.0	----	------

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(mm)	.43 ± 5.59	6.54	.35	0.035	872	0.44:+0.38	**0.490***	**018**	**:+0.75**	**0.423***	**044**	**0.71:-0.01**	00	--	
HA	52.91 ± 6.4	38	62	**+0.481***	**0.0200**	**+0.08:+0.75**	**-0.478***	**0.021**	**-0.74:-0.08**	1.000	------	------	**-0.423***	**0.044**	**-0.71:-0.01**
CL (mm)	66.57 ± 11.99	50.26	98.51	-0.052	0.814	-0.46:+0.37	**+0.611****	**0.002**	**+0.27:+0.82**	**-0.555****	**0.006**	**-0.79:-0.18**	**+0.436***	**0.037**	**+0.03:+0.72**
CBA	16.26 ± 4.27	9	26	**-0.428***	**0.041**	**-0.71:-0.02**	**+0.437***	**0.037**	**+0.03:+0.72**	**-0.578****	**0.004**	**-0.8:-0.22**	-0.279	0.197	-0.62:+0.15
DCBH (mm)	5601 ± 4.95	44.36	65.48	-0.294	0.173	-0.63:+0.14	**+0.919****	**≤0.0001**	**+0.82:+0.97**	**-0.505***	**0.014**	**-0.76:-0.12**	**+0.470***	**0.024**	**+0.07:+0.74**
PCBH (mm)	37.42 ± 4.03	27.16	43.7	+0.155	0.431	-0.28:+0.53	-0.235	0.280	-0.59:+0.2	-0.290	0.180	-0.63:+0.14	**-0.622****	**0.002**	**-0.82:-0.28**
HBS (mm)	55.38 ± 10.38	41.7	82.55	**-0.409**	**0.053**	**-0.7:+0.005**	**+0.677****	**≤0.0001**	**+0.37:+0.85**	-0.223	0.307	-0.58:+0.21	+0.130	0.554	-0.3:+0.52
FBS (mm)	87.94 ± 14.42	66.13	128.68	-0.390	0.066	-0.69:+0.03	**+0.767****	**≤0.0001**	**+0.52:+0.9**	**-0.622****	**0.002**	**-0.82:-0.28**	**+0.495***	**0.016**	**+0.1:+0.75**
HPA	176.78 ± 6.	163	190	**-0.445***	**0.033**	**-0.72:-0.04**	+0.051	0.818	-0.4:+0.45	-0.080	0.718	-0.48:+0.34	+0.079	0.721	-0.35:+0.48

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FBS-HBS (mm)	9 32.5 5 ± 7.89	20.71	52.42	-0.362	0.089	-0.67:+0.06	**+0.510***	**0.013**	**+0.12:+0.76**	**-0.843****	**≤ 0.0001**	**-0.93:-0.66**	**+0.732****	**≤ 0.0001**	**+0.46:+0.88**
TA-HA	12.74 ± 6.15	1	29	+0.360	0.092	-0.06:+0.67	+0.100	0.651	-0.33:+0.49	**-0.677****	**≤ 0.0001**	**-0.85:-0.37**	+0.365	0.087	-0.06:+0.68
TL:HL	1.27 ± 0.14	0.98	1.55	**-0.468***	**0.024**	**-0.74:-0.07**	+0.356	0.095	-0.07:+0.67	-0.069	0.7555	-0.47:+0.35	**-0.622****	**0.002**	**-0.82:-0.28**
HI	1.52 ± 0.22	1.2	2.13	-0.399	0.059	-0.7:+0.02	**+0.453***	**0.030**	**+0.05:+0.73**	**-0.647****	**0.001**	**-0.84:-0.32**	-0.255	0.241	-0.6:+0.18
DCBH:HBS	1.03 ± 0.13	0.78	1.21	+0.382	0.072	-0.04:+0.69	-0.307	0.155	-0.64:+0.12	-0.017	0.938	-0.43:+0.4	+0.183	0.404	-0.25:+0.55
TL:HBS	1.1 ± 0.14	0.84	1.32	+0.214	0.327	-0.22:+0.58	-0.193	0.379	-0.56:+0.24	-0.027	0.904	-0.43:+0.39	+0.217	0.321	-0.21:+0.58

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). SD, standard deviation; Min, minimum value; Max, maximum value; CI, confidence interval

Table 3 Spearman's correlation coefficient (r_s) between different radiographic changes and morphometric hoof capsule parameters.

	Correlation Coefficient						
Parameters	**Osteolysis of solar aspect of 3rd**	**Osteolysis of dorsal aspect (apex) of 3rd phalanx**	**2nd phalanx affections**	**Navicular disease**	**DIP joint CL mineralization**	**DIP joint DJD**	**Bony exostosis at dorsal aspect of 3rd phalanx**

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	phalanx																			
	r_s	*P Value*	r_s	*P Value*	*95% CI*	r_s	*P Value*	*95% CI*	r_s	*P Value*	*95% CI*	r_s	*P Value*	*95% CI*	r_s	*P Value*	*95% CI*	r_s	*P Value*	*95% CI*
TL (mm)	--	--	+0.303	0.1600	-0.13:+0.64	-0.262	0.228	-0.61:+0.17	-0.239	0.272	-0.59:+0.19	-0.087	0.695	-0.48:+0.34	-0.035	0.875	-0.44:+0.38	-0.140	0.525	-0.52:+0.29
TA	--	--	+0.094	0.6699	-0.33:+0.49	+0.167	0.446	-0.26:+0.54	+0.294	0.173	-0.14:+0.63	-0.070	0.751	-0.47:+0.35	+0.009	0.968	-0.41:+0.42	-0.024	0.915	-0.43:+0.39
HL (mm)	--	--	+0.256	0.239	-0.18:+0.61	+0.069	0.755	-0.35:+0.47	+0.015	0.946	-0.4:+0.43	**-0.432***	**0.039**	**-0.72:-0.02**	+0.173	0.430	-0.26:+0.55	-0.186	0.395	-0.56:+0.25
HA	--	--	+0.047	0.832	-0.37:+0.45	**+0.526****	**0.010**	**+0.14:+0.77**	**+0.549****	**0.007**	**+0.18:+0.78**	**+0.453***	**0.030**	**+0.05:+0.73**	+0.287	0.184	-0.14:+0.63	+0.059	0.791	-0.36:+0.46
CL (mm)	--	--	+0.396	0.062	-0.02:+0.7	**-0.6661****	**0.001**	**-0.84:-0.34**	-0.343	0.109	-0.66:+0.08	**-0.450***	**0.031**	**-0.73:-0.05**	-0.381	0.073	-0.69:+0.04	-0.279	0.197	-0.62:+0.15
CBA	--	--	-0.236	0.278	-0.59:+0.2	-0.308	0.153	-0.64:+0.12	**-0.4700***	**0.024**	**-0.74:-0.07**	+0.044	0.842	-0.38:+0.45	-0.272	0.209	-0.62:+0.16	+0.059	0.789	-0.36:+0.46
DCBH (mm)	--	--	+0.349	0.103	-0.07:+0.67	-0.385	0.069	-0.69:+0.03	-0.224	0.304	-0.58:+0.21	-0.190	0.385	-0.56:+0.24	-0.156	0.478	-0.53:+0.27	-0.209	0.338	-0.57:+0.22
PCB	--	--	+0	0.	-0.0	+0.	0.	-0.1	**+0.**	**0.**	**+0.00**	+0.	0.	-0.3	+	0.	-0.	-0	0.	-0.

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H (mm)	-0.396	--	.062	2:+0.7	289	181	4:+0.63	**418***	**047**	**5:+0.71**	026	906	9:+0.43	0.363	088	06:+0.67	.023	916	43:+0.39
HBS (mm)	-0.419*	--	**+0.047**	**+0.0006:+0.71**	**-0.5233***	**0.010**	**-0.77:-0.14**	-0.134	0.541	-0.52:+0.29	0	1.000	-0.41:+0.41	-0.208	0.342	-0.57:+0.22	-0.209	0.338	-0.57:+0.22
FBS (mm)	-0.372	--	+0.080	-0.05:+0.68	**-0.6199****	**0.002**	**-0.82:-0.28**	-0.3733	0.079	-0.68:+0.05	-0.3329	0.126	-0.65:+0.1	-0.329	0.126	-0.65:+0.1	-0.256	0.239	-0.61:+0.18
HPA	-0.152	--	0.490	-0.53:+0.28	0	1.000	-0.41:+0.41	+0.210	0.337	-0.22:+0.57	+0.199	0.362	-0.23:+0.57	+0.121	0.581	-0.31:+0.51	+0.303	0.159	-0.13:+0.64
FBS-HBS (mm)	-0.023	--	0.916	-0.43:+0.39	**-0.4133**	**0.050**	**-0.71:+0.00004**	**-0.493***	**0.017**	**-0.75:-0.1**	**-0.5536****	**0.008**	**-0.78:-0.16**	-0.138	0.529	-0.52:+0.29	0	1.000	-0.41:+0.41
TA-HA	-0.140	--	0.525	-0.52:+0.29	**-0.420***	**0.046**	**-0.71:-0.008**	-0.306	0.155	-0.64:+0.12	**-0.5466****	**0.007**	-0.78:-0.17	-0.294	0.173	-0.63:+0.14	+0.035	0.874	-0.38:+0.44
TL:HL	-0.035	--	0.874	-0.38:+0.44	-0.255	0.240	-0.6:+0.18	-0.120	0.587	-0.51:+0.31	**+0.4166***	**0.049**	**+0.004:+0.71**	-0.182	0.406	-0.55:+0.25	+0.035	0.874	-0.38:+0.44
HI	-0.058	--	0.792	-0.46:+0.36	**-0.6006****	**0.002**	**-0.82:-0.26**	**-0.456***	**0.029**	**-0.73:-0.05**	-0.156	0.478	-0.53:+0.27	-0.389	0.066	-0.69:+0.03	-0.023	0.916	-0.43:+0.39
DCB H:H	-0.3	--	0.12	-0.65:+0.1	+0.39	0.05	-0.02:+0.7	-0.00	0.97	-0.42:+0.4	-0.10	0.63	-0.5:+0.32	+0.	0.55	-0.3:+0	+0.	0.39	-0.25:+

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BS	-		26	9		9	9		7	3	1	4	7		130+	5	.52	186+	5	0.56
TL:HBS	--	--	-0.349	0.103	-0.67:+0.07	**+0.475***	**0.022**	**+0.08:+0.74**	+0.037	0.866	-0.38:+0.44	+0.009	0.969	-0.41:+0.42	0.182	0.407	-0.25:+0.55	0.209	0.338	-0.22:+0.57

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed). CL, collateral ligament; DJD, degenerative joint disease; CI, confidence interval

Table 4 dependent t-test between left and right limbs of bilaterally affected donkeys.

Parameters	Mean ± SD		*t-value*	*P-value*	*r-value*
	Left limb	Right limb			
TL (mm)	61.48 ± 6.41	58.3 ± 4.65	+ 1.050	0.353	0.465
TA	66.6 ± 3.98	67.2 ± 3.42	- 0.226	0.832	0.112
HL (mm)	47.29 ± 3.38	48.11 ± 5.09	- 0.381	0.723	0.187
HA	56 ± 4.42	54.4 ± 3.21	+ 0.560	0.605	0.27
CL (mm)	63.95 ± 9.73	65.85 ± 12.31	- 1.187	0.301	0.51
CBA	16.6 ± 5.64	14.8 ± 1.92	+ 0.609	0.576	0.291
DCBH (mm)	57.03 ± 4.86	55.55 ± 4.66	+ 0.652	0.550	0.31
PCBH (mm)	38.92 ± 1.84	38.94 ± 3.55	- 0.013	0.990	0.007
HBS (mm)	56.77 ± 12.47	53.15 ± 10.44	+ 1.031	0.361	0.458
FBS (mm)	85.2 ± 10.47	85.91 ± 13.38	- 0.191	0.858	0.095
HPA	176.2 ± 9.31	178.6 ± 3.72	- 0.715	0.514	0.337
FBS-HBS (mm)	28.43 ± 3.72	32.76 ± 5.01	- 1.294	0.265	0.543
TA-HA	10.6 ± 2.88	12.8 ± 2.78	- 0.952	0.395	0.43
TL:HL	1.3 ± 0.13	1.2 ± 0.09	+ 1.303	0.263	0.546
HI	1.47 ± 0.15	1.43 ± 0.13	+ 0.406	0.705	0.199
DCBH:HBS	1.03 ± 0.16	1.06 ± 0.14	- 0.544	0.615	0.262
TL:HBS	1.12 ± 0.2	1.12 ± 0.16	- 0.038	0.971	0.019

Table 5 Intraclass Correlation Coefficient to assess the intra-rater repeatability.

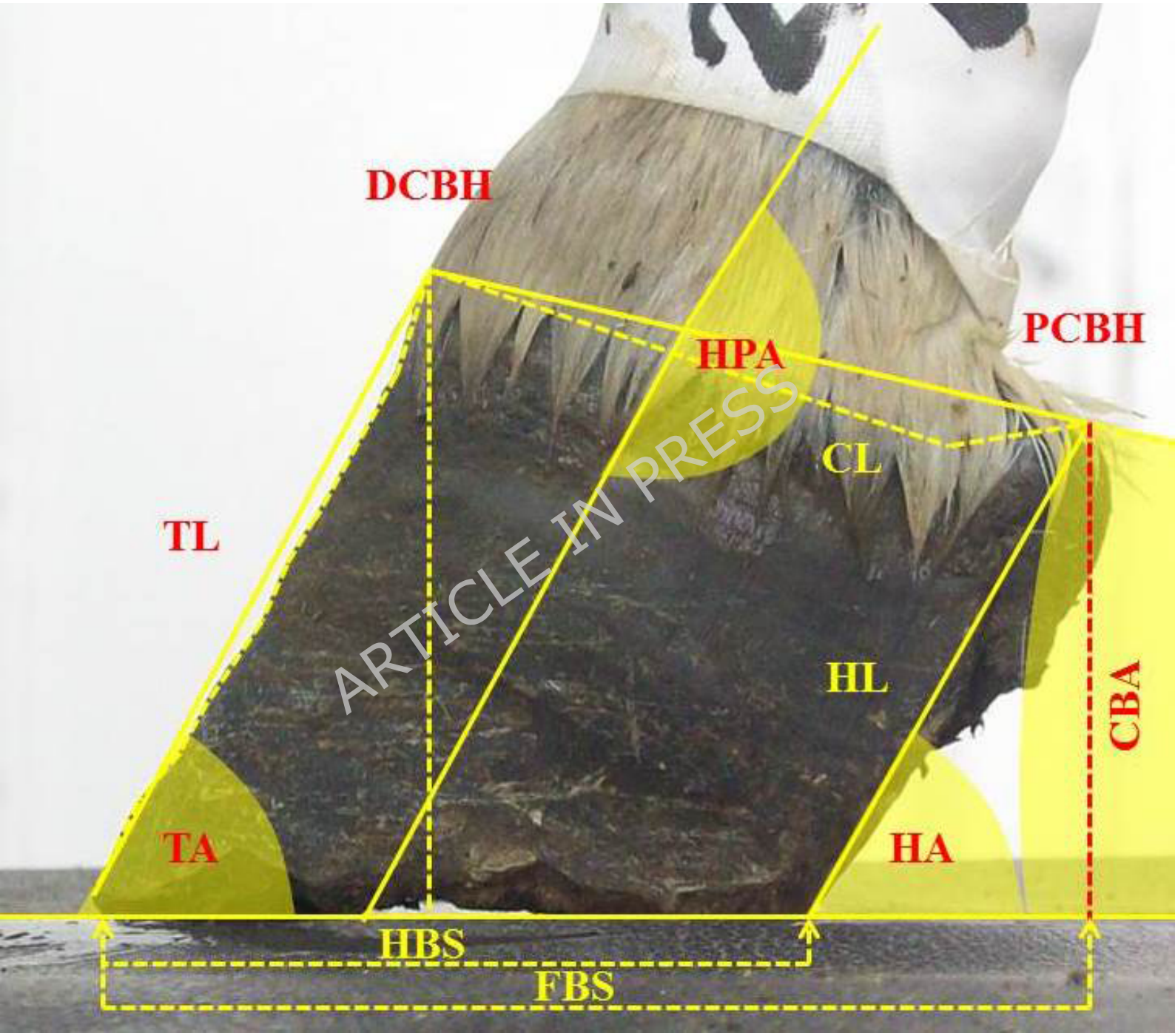
Parameters	Intraclass Correlation	95% Confidence Interval
TL (mm)	0.998	0.995:0.999
TA	0.995	0.987:0.999
HL (mm)	0.997	0.993:0.999
HA	0.995	0.987:0.998
CL (mm)	0.999	0.998:1.000
CBA	0.990	0.974:0.997
DCBH (mm)	0.994	0.986:0.998
PCBH (mm)	0.997	0.992:0.999
HBS (mm)	0.999	0.998:1.000
FBS (mm)	1.000	0.999:1.000

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HPA	0.992	0.981:0.998
FBS–HBS (mm)	0.997	0.992:0.999
TA–HA	0.980	0.951:0.994
TL:HL	0.992	0.980:0.998
HI	0.996	0.990:0.999
DCBH:HBS	0.997	0.992:0.999
TL:HBS	0.998	0.995:0.999

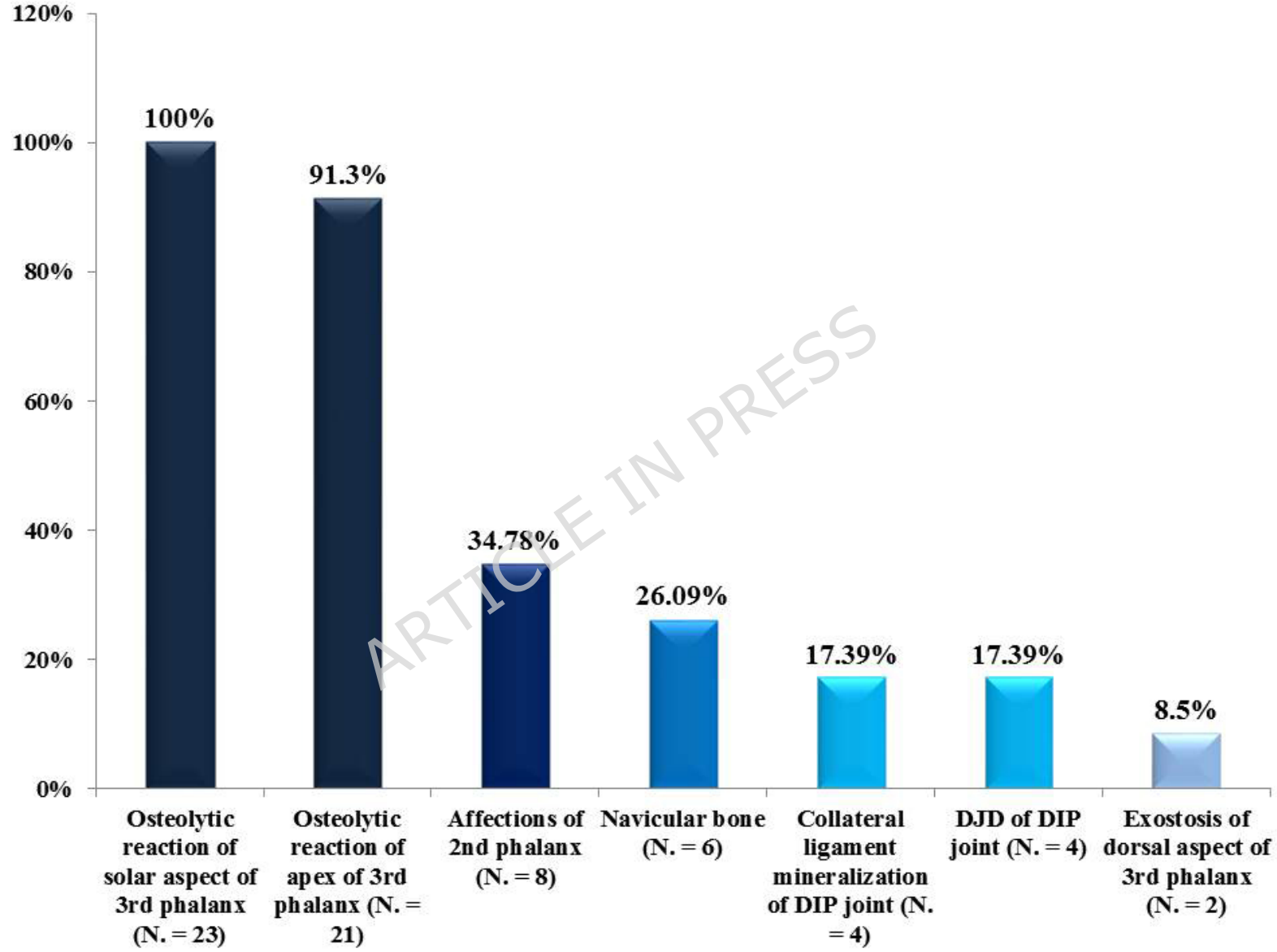
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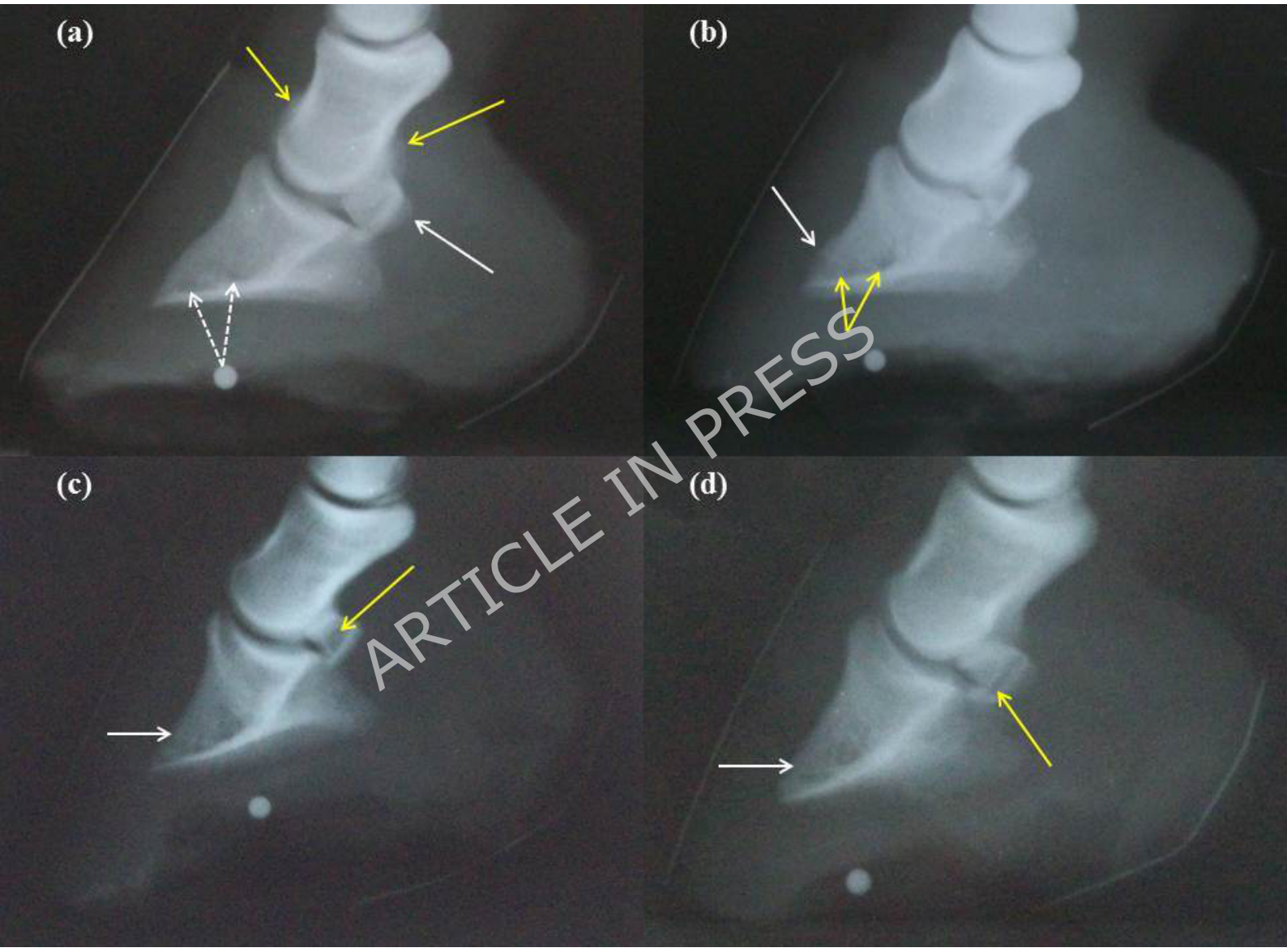
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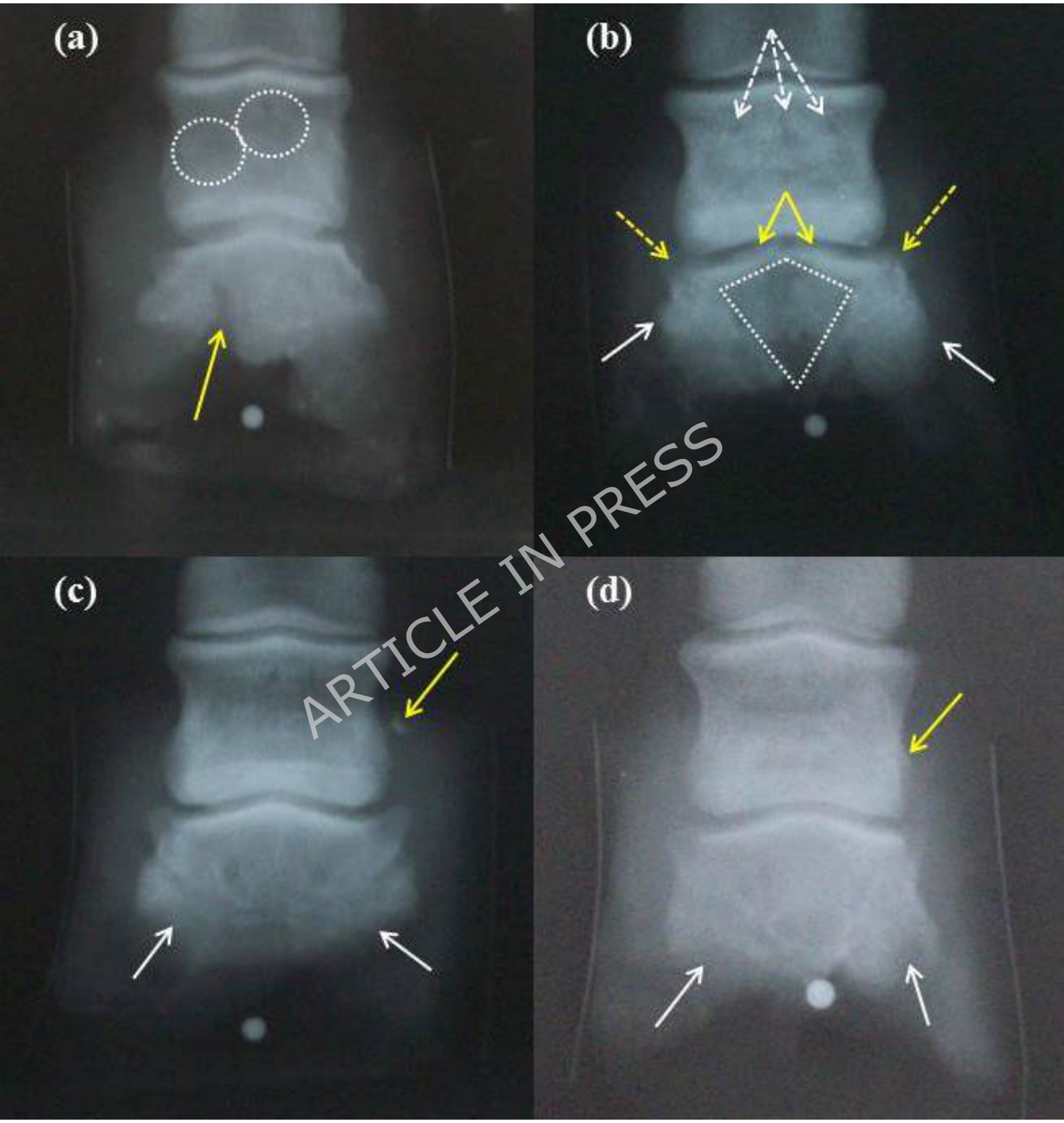
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Table 1 Morphometric hoof capsule parameters.

Parameters	Abbreviation	Definition	Clinical Significance
Toe length "mm"	TL	Distance from the most proximal point to the most distal point at the dorsal aspect of the hoof wall.	Define the shape and size of the hoof and indicate the hoof balance and forces acting on DDFT [18, 21, 29, 35].
Toe angle	TA	Palmar angle which is made by the dorsal hoof wall and the ground surface.	Determine the inclination angle and dorsopalmar balance of the hoof capsule [18, 29]. It affects the strain and stress forces inside the hoof capsule, distal phalanx rotation, and body weight distribution between toe and heel [19–21, 23].
Heel length "mm"	HL	Distance from the most proximal point to the most distal point at the palmar aspect of the hoof wall from lateral aspect of the hoof.	Has an impact on hoof balance [35].
Heel angle	HA	Palmar angle which is made by the palmar hoof wall and the ground surface.	Define dorsopalmar balance of the hoof [18, 29].
Coronet length "mm"	CL	Distance from the most dorsal point to the most palmar point of the coronary band.	Assess the hoof and foot balance [35].
Coronary band angle	CBA	Angle which is made between the coronary band and the ground surface.	Determine the degree of capsular truncation, which is influenced by hoof capsule wearing [36]. It estimates the distal phalanx position inside the hoof capsule [37]. It determines the viability of hoof capsule horn material in resisting the forces acting on the hoof capsule [23].
Dorsal coronary band height "mm"	DCBH	Perpendicular distance from the most dorsal point of the coronary band to the weight-bearing surface.	Determine the hoof balance and force distribution within the foot [15, 18, 23, 25, 38].
Palmar coronary band height "mm"	PCBH	Perpendicular distance from the most palmar point of the coronary band to the weight-bearing surface.	Determine the hoof balance and force distribution within the foot [15, 18, 23, 25, 38].

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Hoof base of support "mm"	HBS	Distance from the most dorsal point at toe to the most palmar point at the heel along the ground surface of the hoof.	Define the dorsopalmar balance of the hoof [29].
Foot base of support "mm"	FBS	Distance from the most dorsal point at the toe to the palmar point that intersects with the vertical line from the heel bulb at the ground surface of the hoof.	Define the dorsopalmar balance of the hoof [29].
Hoof pastern axis	HPA	Palmar angle between the axis of the pastern and hoof.	A standardized landmark in evaluating hoof balance [4].
Base of support difference "mm"	FBS–HBS	Foot base of support to hoof base of support difference.	Define the dorsopalmar balance of the hoof [29].
Toe–Heel angle difference	TA–HA	Toe angle to heel angle difference.	More important in assessment of dorsopalmar balance of the hoof than using TA or HA alone [29, 30].
Toe to heel length ratio	TL:HL	Ratio between the toe length and heel length.	Determine the difference in the size and shape of the hoof capsule. It is important in determining the viability of hoof capsule horn material in resisting the forces at the dorsal and palmar aspects [18].
Height index	HI (DCBH:PCBH)	Ratio between dorsal coronary band height and palmar coronary band height.	Determine the difference in the size and shape of the hoof capsule [18]. It is important in determining the viability of hoof capsule horn material in resisting the forces acting on the hoof capsule [18, 23, 25].
Dorsal coronary band height to hoof base of support ratio	DCBH:HBS	Ratio between the dorsal coronary band height and the hoof base of support.	Determine the difference in the size and shape of the hoof capsule. It is important in determining the viability of hoof capsule horn material in resisting the forces acting at the midline of the capsule [18].
Toe length to hoof base of support ratio	TL:HBS	Ratio between the toe length and the hoof base of support.	Determine the difference in the size and shape of the hoof capsule. It is important in determining the viability of hoof capsule horn material in resisting the forces acting at the midline of the capsule [18].

Abbreviations: DDFT, deep digital flexor tendon.

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Table 2 Descriptive statistics for morphometric parameters and correlation coefficients for TA, TL, HA, and HL.

Parameters	Mean ± SD	Min.	Max.	Correlation Coefficient											
				TA			TL			HA			HL		
				r_s	*P Value*	*95% CI*	r	P_V *alue*	*95% CI*	r	P_V *alue*	*95% CI*	r	P_V *alue*	*95% CI*
TL (mm)	59.79 ± 5.76	51	71.27	**-0.509***	**0.013**	**-0.76:-0.12**	1.000	----	------	**-0.478***	**0.021**	**-0.74:-0.08**	**+0.490***	**0.018**	**+0.1:+0.75**
TA	65.65 ± 5.05	60	80	1.000	----	------	**-0.509***	**0.013**	**+0.76:-0.12**	**+0.481***	**0.020**	**+0.08:+0.75**	-0.035	0.872	-0.44:+0.38
HL (mm)	47.43 ± 5.59	36.54	62.35	-0.035	0.872	-0.44:+0.38	**+0.490***	**0.018**	**+0.1:+0.75**	**-0.423***	**0.044**	**-0.71:-0.01**	1.000	----	------
HA	52.91 ± 6.4	38	62	**+0.481***	**0.020**	**+0.08:+0.75**	**-0.478***	**0.021**	**-0.74:-0.08**	1.000	----	------	**-0.423***	**0.044**	**-0.71:-0.01**
CL (mm)	66.57 ± 11.99	50.26	98.51	-0.052	0.814	-0.46:+0.37	**+0.611****	**0.002**	**+0.27:+0.82**	**-0.555****	**0.006**	**-0.79:-0.18**	**+0.436***	**0.037**	**+0.03:+0.72**
CBA	16.26 ± 4.27	9	26	**-0.428***	**0.041**	**-0.71:-0.02**	**+0.437***	**0.037**	**+0.03:+0.72**	**-0.578****	**0.004**	**-0.8:-0.22**	-0.279	0.197	-0.62:+0.15
DCBH (mm)	56.01 ± 4.95	44.36	65.48	-0.294	0.173	-0.63:+0.14	**+0.919****	**≤ 0.00001**	**+0.82:+0.97**	**-0.505***	**0.014**	**-0.76:-0.12**	**+0.470***	**0.024**	**+0.07:+0.74**
PCBH	37.42	27.	43.7	+0.	0.4	-0.28:	-0.	0.280	-0.59:+0.2	-0.	0.180	-0.63:	**-0.**	**0.002**	**-0.82**

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(mm)	± 4.03	16		155	81	+0.53	235			290		+0.14	**622****		**:-0.28**
HBS (mm)	55.38 ± 10.38	41.7	82.55	**-0.409**	**0.0053**	**-0.7:+0.005**	**+0.677****	**≤ 0.00001**	**+0.37:+0.85**	-0.223	0.307	-0.58:+0.21	+0.130	0.554	-0.3:+0.52
FBS (mm)	87.94 ± 14.42	66.13	128.68	-0.390	0.066	-0.69:+0.03	**+0.767****	**≤ 0.00001**	**+0.52:+0.9**	**-0.622****	**0.002**	**-0.82:-0.28**	**+0.495***	**0.0166**	**+0.1:+0.75**
HPA	176.78 ± 6.9	163	190	**-0.445***	**0.033**	**-0.72:-0.04**	+0.051	0.818	-0.4:+0.45	-0.080	0.718	-0.48:+0.34	+0.079	0.721	-0.35:+0.48
FBS-HBS (mm)	32.55 ± 7.89	20.71	52.42	-0.362	0.089	-0.67:+0.06	**+0.510***	**0.013**	**+0.12:+0.76**	**-0.843****	**≤ 0.00001**	**-0.93:-0.66**	**+0.732****	**≤ 0.00001**	**+0.46:+0.88**
TA-HA	12.74 ± 6.15	1	29	+0.360	0.092	-0.06:+0.67	+0.100	0.651	-0.33:+0.49	**-0.677****	**≤ 0.00001**	**-0.85:-0.37**	+0.365	0.087	-0.06:+0.68
TL:HL	1.27 ± 0.14	0.98	1.55	**-0.468***	**0.0244**	**-0.74:-0.07**	+0.356	0.095	-0.07:+0.67	-0.069	0.755	-0.47:+0.35	**-0.622****	**0.002**	**-0.82:-0.28**
HI	1.52 ± 0.22	1.2	2.13	-0.399	0.059	-0.7:+0.02	**+0.453***	**0.030**	**+0.05:+0.73**	**-0.647****	**0.001**	**-0.84:-0.32**	-0.255	0.241	-0.6:+0.18
DCBH:HBS	1.03 ± 0.13	0.78	1.21	+0.382	0.072	-0.04:+0.69	-0.307	0.155	-0.64:+0.12	-0.017	0.938	-0.43:+0.4	+0.183	0.404	-0.25:+0.55
TL:HBS	1.1 ± 0.14	0.84	1.32	+0.214	0.3277	-0.22:+0.58	-0.193	0.379	-0.56:+0.24	-0.027	0.904	-0.43:+0.39	+0.217	0.321	-0.21:+0.58

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* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). SD, standard deviation; Min, minimum value; Max, maximum value; CI, confidence interval

Table 3 Spearman's correlation coefficient (r_s) between different radiographic changes and morphometric hoof capsule parameters.

	Correlation Coefficient																			
Parameters	**Osteolysis of solar aspect of 3rd phalanx**		**Osteolysis of dorsal aspect (apex) of 3rd phalanx**			**2nd phalanx affections**			**Navicular disease**			**DIP joint CL mineralization**			**DIP joint DJD**			**Bony exostosis at dorsal aspect of 3rd phalanx**		
	rs	***P Value***	***rs***	***P Value***	***95% CI***	***rs***	***P Value***	***95% CI***	***rs***	***P Value***	***95% CI***	***rs***	***P Value***	***95% CI***	***rs***	***P Value***	***95% CI***	***rs***	***P Value***	***95% CI***
TL (mm)	-.---	---	+0.303	0.160	-0.13:+0.64	-0.2662	0.228	-0.61:+0.17	-0.239	0.272	-0.59:+0.19	-0.087	0.695	-0.48:+0.34	-0.035	0.875	-0.44:+0.38	-0.140	0.525	-0.52:+0.29
TA	-.---	---	+0.094	0.669	-0.33:+0.49	+0.1667	0.446	-0.26:+0.54	+0.294	0.173	-0.14:+0.63	-0.0700	0.751	-0.47:+0.35	+0.009	0.968	-0.41:+0.42	-0.024	0.915	-0.43:+0.39
HL (mm)	-.---	---	+0.256	0.239	-0.18:+0.61	+0.0669	0.755	-0.35:+0.47	+0.015	0.946	-0.4:+0.43	**-0.432***	**0.039**	**-0.72:-0.02**	+0.173	0.430	-0.26:+0.55	-0.186	0.395	-0.56:+0.25
HA	-.---	---	+0.047	0.832	-0.37:+0.45	**+0.526****	**0.010**	**+0.14:+0.77**	**+0.549****	**0.007**	**+0.18:+0.78**	**+0.453***	**0.030**	**+0.05:+0.73**	+0.287	0.184	-0.14:+0.63	+0.059	0.791	-0.36:+0.46

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CL (mm)	----	----	+0.396	0.062	-0.02:+0.7	**-0.661****	**0.01**	**-0.84:-0.34**	-0.343	0.109	-0.66:+0.08	**-0.4550***	**0.031**	**-0.73:-0.05**	-0.381	0.073	-0.69:+0.04	-0.279	0.197	-0.62:+0.15
CBA	----	----	-0.236	0.278	-0.59:+0.2	-0.308	0.153	-0.64:+0.12	**-0.4700***	**0.024**	**-0.74:-0.07**	+0.044	0.842	-0.38:+0.45	-0.272	0.209	-0.62:+0.16	+0.059	0.789	-0.36:+0.46
DCBH (mm)	----	----	+0.349	0.103	-0.07:+0.67	-0.385	0.069	-0.69:+0.03	-0.224	0.304	-0.58:+0.21	-0.190	0.385	-0.56:+0.24	-0.156	0.478	-0.53:+0.27	-0.209	0.338	-0.57:+0.22
PCBH (mm)	----	----	+0.396	0.062	-0.02:+0.7	+0.289	0.181	-0.14:+0.63	**+0.418***	**0.047**	**+0.005:+0.71**	+0.026	0.906	-0.39:+0.43	+0.363	0.088	-0.06:+0.67	-0.023	0.916	-0.43:+0.39
HBS (mm)	----	----	**+0.419***	**0.047**	**+0.006:+0.71**	**-0.523****	**0.010**	**-0.7:-0.14**	-0.134	0.541	-0.52:+0.29	0	1.000	-0.41:+0.41	-0.208	0.342	-0.57:+0.22	-0.209	0.338	-0.57:+0.22
FBS (mm)	----	----	+0.372	0.080	-0.05:+0.68	**-0.619****	**0.002**	**-0.82:-0.28**	-0.373	0.079	-0.68:+0.05	-0.329	0.126	-0.65:+0.1	-0.329	0.126	-0.65:+0.1	-0.256	0.239	-0.61:+0.18
HPA	----	----	-0.152	0.490	-0.53:+0.28	0	1.000	-0.41:+0.41	+0.210	0.337	-0.22:+0.57	+0.199	0.362	-0.23:+0.57	+0.121	0.581	-0.31:+0.51	+0.303	0.159	-0.13:+0.64
FBS-HBS (mm)	----	----	-0.023	0.916	-0.43:+0.39	**-0.413**	**0.050**	**-0.71:+0.00004**	**-0.4933***	**0.017**	**-0.75:-0.1**	**-0.536****	**0.008**	**-0.78:-0.16**	-0.138	0.529	-0.52:+0.29	0	1.000	-0.41:+0.41

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TA-HA	-.--.--		-0.140	0.525	-0.52:+0.29	**-0.420***	**0.046**	**-0.71:-0.008**	-0.306	0.155	-0.64:+0.12	**-0.546****	**0.007**	-0.78:-0.17	-0.294	0.173	-0.63:+0.14	+0.035	0.874	-0.38:+0.44
TL:HL	-.--.--		+0.035	0.874	-0.38:+0.44	-0.255	0.240	-0.6:+0.18	-0.120	0.587	-0.51:+0.31	**+0.416***	**0.049**	**+0.004:+0.71**	-0.182	0.406	-0.55:+0.25	+0.035	0.874	-0.38:+0.44
HI	-.--.--		-0.058	0.792	-0.46:+0.36	**-0.6062****	**0.002**	**-0.82:-0.26**	**-0.456***	**0.029**	**-0.73:-0.05**	-0.156	0.478	-0.53:+0.27	-0.389	0.066	-0.69:+0.03	-0.023	0.916	-0.43:+0.39
DCBH:HBS	-.--.--		-0.326	0.129	-0.65:+0.1	+0.3999	0.059	-0.02:+0.7	-0.007	0.973	-0.42:+0.41	-0.104	0.637	-0.5:+0.32	+0.130	0.555	-0.3:+0.52	+0.186	0.395	-0.25:+0.56
TL:HBS	-.--.--		-0.349	0.103	-0.67:+0.07	**+0.475***	**0.022**	**+0.08:+0.74**	+0.037	0.866	-0.38:+0.44	+0.009	0.969	-0.41:+0.42	+0.182	0.407	-0.25:+0.55	+0.209	0.338	-0.22:+0.57

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed). CL, collateral ligament; DJD, degenerative joint disease; CI, confidence interval

Table 4 dependent t-test between left and right limbs of bilaterally affected donkeys.

Parameters	Mean ± SD		*t-value*	*P-value*	*r-value*
	Left limb	Right limb			
TL (mm)	61.48 ± 6.41	58.3 ± 4.65	+ 1.050	0.353	0.465
TA	66.6 ± 3.98	67.2 ± 3.42	- 0.226	0.832	0.112
HL (mm)	47.29 ± 3.38	48.11 ± 5.09	- 0.381	0.723	0.187
HA	56 ± 4.42	54.4 ± 3.21	+ 0.560	0.605	0.27
CL (mm)	63.95 ± 9.73	65.85 ± 12.31	- 1.187	0.301	0.51
CBA	16.6 ± 5.64	14.8 ± 1.92	+ 0.609	0.576	0.291
DCBH (mm)	57.03 ± 4.86	55.55 ± 4.66	+ 0.652	0.550	0.31
PCBH (mm)	38.92 ± 1.84	38.94 ± 3.55	- 0.013	0.990	0.007
HBS (mm)	56.77 ± 12.47	53.15 ± 10.44	+ 1.031	0.361	0.458
FBS (mm)	85.2 ± 10.47	85.91 ± 13.38	- 0.191	0.858	0.095

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HPA	176.2 ± 9.31	178.6 ± 3.72	- 0.715	0.514	0.337
FBS–HBS (mm)	28.43 ± 3.72	32.76 ± 5.01	- 1.294	0.265	0.543
TA–HA	10.6 ± 2.88	12.8 ± 2.78	- 0.952	0.395	0.43
TL:HL	1.3 ± 0.13	1.2 ± 0.09	+ 1.303	0.263	0.546
HI	1.47 ± 0.15	1.43 ± 0.13	+ 0.406	0.705	0.199
DCBH:HBS	1.03 ± 0.16	1.06 ± 0.14	- 0.544	0.615	0.262
TL:HBS	1.12 ± 0.2	1.12 ± 0.16	- 0.038	0.971	0.019

Table 5 Intraclass Correlation Coefficient to assess the intra-rater repeatability.

Parameters	Intraclass Correlation	95% Confidence Interval
TL (mm)	0.998	0.995:0.999
TA	0.995	0.987:0.999
HL (mm)	0.997	0.993:0.999
HA	0.995	0.987:0.998
CL (mm)	0.999	0.998:1.000
CBA	0.990	0.974:0.997
DCBH (mm)	0.994	0.986:0.998
PCBH (mm)	0.997	0.992:0.999
HBS (mm)	0.999	0.998:1.000
FBS (mm)	1.000	0.999:1.000
HPA	0.992	0.981:0.998
FBS–HBS (mm)	0.997	0.992:0.999
TA–HA	0.980	0.951:0.994
TL:HL	0.992	0.980:0.998
HI	0.996	0.990:0.999
DCBH:HBS	0.997	0.992:0.999
TL:HBS	0.998	0.995:0.999

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