Original article

Relative Density of The Bony Components of The Fetlock Joint in Thoroughbreds

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Abstract
The forelimb fetlock joint and its bony components are a common site of injury in racing horses. We hypothesized that the variations in relative density of these bones might correspond to their mechanical properties. This study aimed first to identify the relative density of third metacarpal bone (Mc3), proximal phalanx (P1) and proximal sesamoid bones (PSBs) of Thoroughbred race horses. Second, to determine whether there was any difference and/or similarity in the relative density between and within the bones. Bones from right and left forelimbs of 10 horses were collected and prepared by boiling and drying. Dry weight and volume for each bone were measured and the relative density was then calculated. Relative density of Mc3 was substantially greater than the other two bones with a mean of 1.7 ± 0.06. Relative density of P1 and PSBs showed a high similarity especially between P1 and the medial PSBs. Neither the comparisons between right and left sides nor between lateral and medial PSBs showed any significant differences. P1 had the most consistent relative density within right and left sides. Larger relative density in Mc3 and the similarity between P1 and PSBs presume a more important role of the bone mass on their properties than the volume

Keywords: Thoroughbreds; forelimb; fetlock bones; relative density; volume

Introduction

Early determination as to the value of an equine and quality of the legs especially in racing horses is very important. The fetlock joint is one of the most important regions in equines contributing to the assumed quality (Heat *et al.* 1985). It is located between the carpal and pastern joints. The joint is formed by the articulation between the distal extremity of the large metacarpal bone (Mc3), the proximal end of the first phalanx (P1) and the two proximal sesamoid bones (PSBs) palmarly (Sisson, 1975; Dyce *et al.* 2010) (Figure 1). The vertically positioned Mc3 and the dorso-distally oriented P1form a joint angle which ranges in the standing position from 135°to 168° based on a number of factors (Holmstrom *et al.* 1990; Weller et al.2006).
The importance of the fetlock joint in race horses may come from its high susceptibility to pathology and consequently the economic loss in the racing industry. Stress fracture of Mc3, for example, was reported to represent 70% of all fractures in Thoroughbred race horses (Martin *et al.* 1997). Fractures in P1 (Parkin *et al.* 2004) and PSBs (Palmer, 1982; Southwood *et al.* 1998; Southwood and McIlwraith, 2000; Hubert *et al.* 2001) also occurred with high percentages in race horses.
Many studies have been conducted to evaluate the properties of bones in the fetlock region in order to comprehend the causes of pathogenesis in the joint. The studies included the bones morphometries (Nunamaker *et al.* 1989; Alrtib *et al.* 2012), biomechanics (Davies, 2006; Hartog *et al.* 2009; Harrison *et al.* 2010; Merritt *et al.* 2010) and density (McClure *et al.* 2001; Carstanjen *et al.* 2003; Tóth *et al.* 2010). However, to the knowledge of the authors, there was no study that has reported the relative density of Mc3, P1 or PSBs of thoroughbreds.
Generally, the bone relative density is unlike the bone mineral density (BMD). The relative density corresponds to the whole bone composition including marrow spaces (Siemon and Moodie, 1974) while BMD represents the bone mineral content in a bone scanned area (Ammann and Rizzoli, 2003). Hence, identifying the relative density of a bone is principally dependant on the weight and the volume and its value should range between 1 and 2.4 (Frost, 1963). Bone volume is considered to be one of the important factors in bone strength (Ammann and Rizzoli, 2003). According to Bigley *et al.* (2008), increasing bone volume demonstrated a negative relationship with the bone strength. In respect to the bone weight or mass, on the other hand, a positive relationship has been established between bone mass and higher loading (Suominen, 1993; Courteix *et al.* 1998) in which increasing bone mass is an essential determinant of bone strength (Leonard and Bachrach 2012). Bones in the current study had different size, shape (Getty, 1975; Alrtib *et al.* 2012) and function (Davies, 2006; Hartog *et al.* 2009; Harrison *et al.* 2010; Merritt *et al.* 2010). Based on these studies, both Mc3 and P1 are long bones with marrow spaces whereas PSBs are sesamoid bones and without a marrow space. Mc3 is the largest bone in the fetlock region while PSBs are the smallest. Mc3 is the most loaded bone in the fetlock region. Whereas PSBs,

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which do not participate directly in bearing the body weight, and P1 are exposed to balanced forces (Merritt *et al.* 2010).

Since Mc3, P1 and PSBs are varied in size, shape and applied load, such differences would be expected to affect their relative densities. Therefore, in order to determine the influence of the correlation between volume and mass of a bone on its properties, the first aim of the study is to identify the relative density of Mc3, P1 and PSBs of Thoroughbreds. Secondly, to find whether there is any difference and/or similarity in the relative density between and within the bones. The current study hypothesized that the relative density of these bones would not be similar due to the diversity in the bone morphometries, density and biomechanical function.

Materials and Methods

Animals:

Both left and right manus regions from 10 adult Thoroughbreds (cadavers) were obtained. All distal forelimbs were collected from the department of Anatomy, The University of Melbourne, Victoria, Australia. The horses had died or were euthanized for non-orthopedic reasons that were not associated with this project. The limbs were collected by splitting them at the level of the carpal region. Any horses with obvious bone pathology visible on post mortem examination were excluded. Age and gender were recorded for each horse. Racing history and weights of the horses were not available. Their age varied from 2 to 25 years old with a mean of 7.3 ± 2.15 (SD) years.

Bone preparation:

Each distal forelimb was bagged and immersed in water at 95–99°C for 30 hours. The bones were then cleaned and air-dried at room temperature for 24 hours. Finally, they were dried at 49.5°C for 8 hours and the constant dry weight for each bone was recorded.

Bone volume:

The volume of each bone was determined by using dry weight and weight in water at a room temperature of 27°C. The bone was attached to a fine thread which was extended from a holder. A beaker with certain amount of water was fixed on a scale. Then the weight of the beaker with water was recorded. After that, the bone was entirely immersed in the beaker without any contact between the bone and the beaker. Then the weight of the beaker and the immersed bone was recorded. The difference between the two records was calculated and the result was considered as the weight of the bone in water. The volume of each bone was then calculated using the following formula:

Volume = weight in air - weight in water (Ott *et al.* 1997)

Relative density (specific gravity)**:**

Relative density of each bone was calculated using the dry weight of the bone and volume of the bone. The room temperature during measurement of the volume of the bones was 27°C.

According to Behnke *et al.* (1995), the relative density of each bone was measured using the following formula:

$$\text{Relative density} = \frac{\text{Dry weight in air}}{\text{Volume of bone}}$$

Comparisons between and within the bones:

Comparison between the bones: It included the comparison between the three groups of bones; Mc3, P1 and PSBs within each limb.

Comparison between the right and left sides: It was between the right and left Mc3, the right and left P1, and the right and left PSBs of the same horses.

Comparison between PSBs: This comparison was between the lateral and the medial PSBs of the same limb.

Statistical analysis included a two-way ANOVA test which was used to compare between the groups of bones, between and within the individual limb. P values < 0.05 were considered to be statistically significant.

Results and Discussion

In the comparisons between the three groups of bones, the relative density was dramatically greater in the large metacarpal bone than in the first phalanx and in the proximal sesamoid bones (Figure1& 2). The right Mc3 showed the highest relative density (1.71±0.06; mean ± SD) among bones. Whereas the lowest relative density was found in both the medial PSBs of the right forelimbs and the lateral PSBs of the left forelimbs with a mean of 1.41±0.13 for each bone. The most significant variation ($P<0.0001$) in the relative density was found between all Mc3s and all PSBs with the means of 1.70± 0.06 and 1.42±0.12 respectively (Table 1).

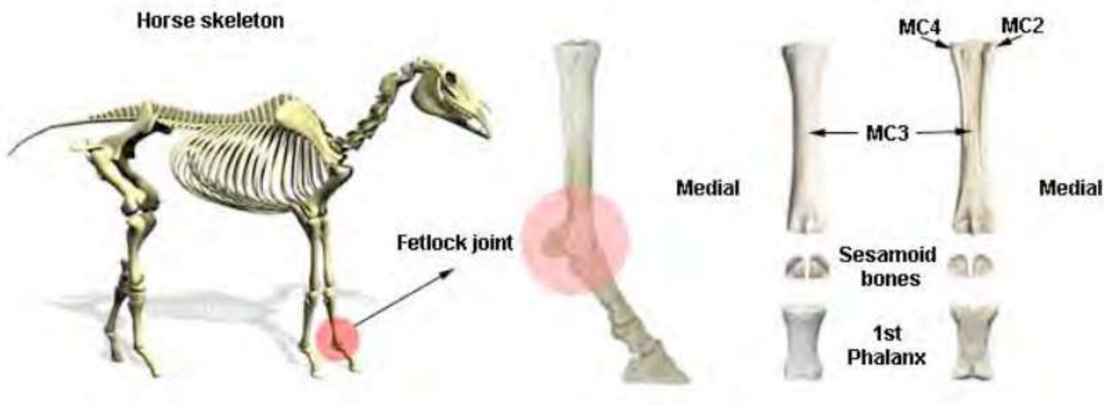

Figure 1: Horse skeleton showing the location of the MCPJ in relation to the body and the bony components (Alrtib, 2013)

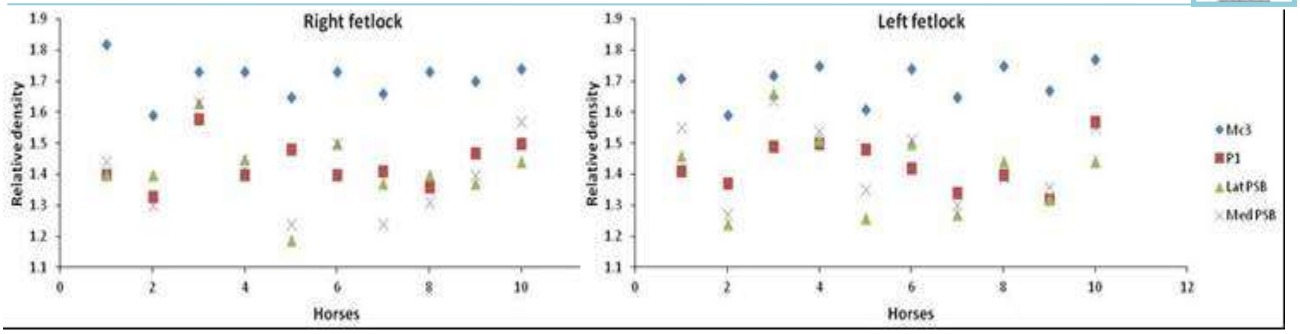

Figure 2: The chart shows the relative density of the right fetlock bones (left) and the left fetlock bones (right). Mc3: Third metacarpal bone, P1: First phalanx, Lat PBS: Lateral proximal sesamoid bone, Med PSB: Medial proximal sesamoid bone.

Table 1. The mean relative density (± SD) of the right and the left third metacarpal (Mc3), proximal phalanx (P1) and proximal sesamoid bones of 10 Thoroughbreds.

Property	Side	Mc3	P1	Proximal Sesamoid Bones		
				Lateral	Medial	Both (Lateral + Medial)
Relative Density	Right	1.71 ± 0.06	1.43 ± 0.07*	1.42 ± 0.11*	1.41 ± 0.13*	1.41 ± 0.12*
	Left	1.70 ± 0.06	1.43 ± 0.08*	1.41 ± 0.13*	1.45 ± 0.13*	1.43 ± 0.13*
	All (Right + Left)	1.70 ± 0.06	1.43 ± 0.07*	1.41 ± 0.12*	1.43 ± 0.13*	1.42 ± 0.12*

*: Show significance differences (P<0.0001) between Mc3 and P1; and Mc3 and PSB.
No significance differences were found between P1 and PSB

The relative density of the bones in the comparisons between the right and the left sides showed no significant differences in any of the three groups of bones. The relative density in both right and left P1 was almost the same with a mean of 1.43 ± 0.07 and 1.43 ± 0.08 respectively. Whereas the relative density of the medial PSBs showed the lowest similarity between the two sides with means of 1.41 ± 0.13 in the right bones and 1.45 ± 0.13 in the left bones.
The comparison between the medial and lateral PSBs within the individual limbs showed no significant differences in their relative density. Nevertheless, it could be noted that the lateral PSBs of the right limbs and the medial PSBs of the left limbs tended to show greater relative density (insignificant) than the opposite PSBs in the individual limbs.

Discussion

The current study revealed that despite the contribution of the third metacarpal, proximal phalanx and proximal sesamoid bones to the formation of the fetlock joint, their relative density showed some similarities and differences. Generally it can be seen that Mc3 had the highest relative density among the examined bones. This result indeed was expected because of its high absolute bone density. In a number of studies which estimated the bone mineral density of equine Mc3 and P1, they found that BMD of Mc3 was greater than BMD of P1 with means of 2.16g/cm^2 (Tóth *et al.* 2014) and 1.91g/cm^2 (Tóth *et al.* 2013) respectively. The high density of Mc3 was assumed because it is the only weight bearing bone in the metacarpal region (Sisson, 1975) and one of the most loaded bones in which loading can reach about 4.9 times of body weight during trotting (Piotrowski *et al.* 1983). Such high loading would motivate the bone to amend its internal properties by stimulating new bone formation (McCarthy and Jeffcott, 1992) to contain the load (Piotrowski *et al.* 1983). Regardless to what extent the new bone formation continues, the bone mass is consequently increased (Suominen, 1993; Courteix *et al.* 1998). Furthermore, in addition to a role of the bone weight in determining the relative density, the volume of an object is also a fundamental element. In the present study, although the volume of Mc3 was considerably the largest, its relative density was the highest. The potential effect of the bone volume was probably reduced by the high bone mass. Therefore, it could be suggested that the adaptation of the bone structures which leads to gain in the mass and density as a response to the loading appears to be the main reason for such greater relative density in Mc3.
The relative densities of P1s and PSBs were almost the same with the means of 1.43 ± 0.07 for the former and 1.42 ± 0.12 for the latter. The lack of significant differences between these two groups of bones which had considerably different actual sizes seems to support the suggestion that the bone volume has a smaller role in determining the bone relative density. Mechanically, it has been reported that both P1 and PSBs were likely to be exposed to balanced forces during locomotion (Merritt *et al.* 2010). The equivalent exerted loading might lead to a similar response of the bones and consequently resulted in an approximately equal relative density. If so, it might then be reasonable

to assume that the relative density of a bone is more related to the influence of the applied loading on its structures than the diversity of its proportionate volume.

In respect to the differences between the bones in the right and left sides, it could be important to highlight that the relative density showed no substantial variation between the two sides in any of the bones. The result was actually not corresponding to a number of geometrical studies which found some significant differences between the bones in both sides. Watson *et al.* (2003) and Davies and Watson (2005), for example reported that the right Mc3 was longer than the left Mc3 in Thoroughbred race horses. Anthenill *et al.* (2006) found a considerable difference between the right and the left PSBs. However, even if these dimensional variations are present in the used bones, they seem to be too small to induce any measureable change in the bone volume and then in the relative density. Hence, the lack of any significant variation in the relative density between the bones from the two sides might be more associated with the balanced loading which has been reported between the right and the left sides (Merkens *et al.* 1985; Dow *et al.* 1991; Back *et al.* 2007).

The comparison between the medial and lateral PSBs in the individual limbs showed no significant differences. However, it was notable that the relative density of the lateral PSBs of the right limbs and the medial PSBs of the left limbs tended to be greater than the opposite PSBs in the individual limbs. This pattern of variation (insignificant) does not concur with morphometrical studies even those which found significant differences between medial and lateral PSBs within the same limb (Anthenill *et al.* 2006; Alrtib *et al.* 2012). Mechanically, the track direction in Victoria, Australia is counter-clockwise. During racing, the greater loading was on the medial side of the right front limb and on lateral side of left forelimb (Schneider *et al.* 1988). This means that the current finding did not match the counter-clockwise loading distribution and might reveal a different pattern of the loading distribution applied on these sesamoid bones. The reason of such results could be similar to a previous study conducted on equine carpi in Victoria, Australia, which found that the relative density of the right accessory carpal bone tended to be larger (insignificant) than the left accessory carpal bone (Abdunnabi *et al.* 2012). Both PSBs and accessory carpal bone are considered as sesamoid bones (Sisson, 1975; Dyce *et al.* 2010), hence, they have the ability to change the direction of pull (Frandson *et al.* 2009). If this was the case in the examined PSBs, then perhaps the lateral PSB of right limb and the medial PSB of the left limb were subjected to higher forces due to shifting the tensile forces from the higher loaded region (medial of right limb and lateral of left limb) toward the lower loaded side of the individual limb. An ex-vivo study found that the partial transection of the medial branch of the suspensory ligament, which inserted on the medial PSB, caused an increase in strain on the lateral condyle of Mc3 during axial loading (Le Jeune *et al.* 2003). Therefore, altering the forces between PSBs might help to balance the great forces and provide a better stability in the region during counter-clockwise racing. However, further investigation is obviously required to examine the definite etiology of the current findings.

Limitations of the study were represented in a number of factors. The utilized bones were from horses of a wide range of ages, thus, the potential effect of the age on the relative density was not included. Secondly, the sample size of population included four males and six females. Hence, the results from these horses cannot be directly correlated to the gender. Finally, training as a factor was neglected because the horses were obtained from different places which presumably had a different exercise regime.

Greater relative density in Mc3 and similarity between P1 and PSBs is highlighting the influence of the variation in the bone mass and volume on its properties. The remarkable similarity between the bones in the right and left sides in the examined characters might demonstrate a consistency in their mechanical function during work. The insignificant variation between PSBs in the individual limb seems to be a sign of specific load configuration which needs more investigation. Finally, it can be concluded that identifying the bone relative density in the fetlock region may underlie a basic requirement for at least a minimal bone quality for Thoroughbred race horses.

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References:

Abdunnabi AH, Ahmed YA, Philip CJ and Davies HMS (2012). Morphometrical variations of the carpal bones in thoroughbreds and ponies. Anat Histol Embryol. 41:139–148.

Alrtib AM (2013). Radiographic bone morphometry of the equine metacarpophalangeal joint and relationships to the incidence of pathology in thoroughbred racehorses. PhD thesis. The University of Melbourne. Australia.

Alrtib A M, Philip CJ, Abdunnabi AH and Davies HM (2012). Morphometrical study of bony elements of the forelimb fetlock joints in horses. Anat Histol Embryol. 42: 9-20.

Ammann P and Rizzoli R (2003). Bone strength and its determinants. Osteoporos Int. 14 (suppl3): S13–S18.

Anthenill LA, Stover SM, Gardner IA, Hill AE, Lee CM, Anderson ML, Barr BC, Read DH, Johnson BJ, Woods LW, Daft BM, Kinde H, Moore JD, Farman CA, Odani JS, Pesavento PA, Uzal FA, Case JT and Ardans AA (2006). Association between findings on palmarodorsal radiographic images and detection of a fracture in the proximal sesamoid bones of forelimbs obtained from cadavers of racing Thoroughbreds. Am J Vet Res. 67: 858-868.

Back W, Macallister CG, Van Heel MCV, Pollmeier M and Hanson PD (2007). Vertical front limb ground reaction forces of sound and lame Warmbloods differ from those in Quarter Horses. J Equine Vet Sci. 27: 123–129.

Behnke AR, Feen, B.G. and Welham, W.C. (1995). The specific gravity of healthy men. Obes. res. 3: 295-300.

Bigley RF, Gibeling JC, Stover SM, Hazelwood SJ, Fyhrie DP and Martin RB (2008). Volume effects on yield strength of equine cortical bone. J. Mech. Behavior Biomed. Mater. 295-302.

Carstanjen B, Duboeuf F, Detilleux J and Lepage OM (2003). Equine Third Metacarpal Bone Assessment by Quantitative Ultrasound and Dual Energy X-Ray Absorptiometry: An Ex vivo Study. J Vet Med A. 50: 42–47.

Courteix D, Lespessailles E, Loiseau PS, Obert P,Germain P and Benhamou CL (1998). Effects of physical training on bone mineral density in prepubertal girls: a comparative study between impact-loading and non-impact-loading sports. Osteopor Int. 8: 152-158.

Davies HMS (2006). Estimating peak strains associated with fast exercise in Thoroughbred racehorses. Equine Vet J. 38(S36): 383-386.

Davies HM and Watson KM (2005). Third metacarpal bone laterality asymmetry and midshaft dimensions in Thoroughbred racehorses. Aust Vet J. 83: 224-6.

Dow SM, Leendertz JA, Silver IA and Goodship AE (1991). Identification of subclinical tendon injury from ground reaction force analysis. Equine Vet J.23: 266–272.

Dyce KM, Sack WO and Wensing CJG (2010). Textbook of veterinary anatomy, 4rd edn. Missouri, USA: W.B. Saunders Company.

Frandson RD, Wilke WL and Fails AD (2009). Anatomy and physiology of farm animals (7thedn). Ames, Wiley-Blackwell.

Frost HM (1963). Bone remodelling dynamics. Springfield, Illinois, U.S.A.: Charles C. Thomas.

Harrison SM, Whitton RC, Kawcak CE, Stover SM and Pandy MG (2010). Relationship between muscle forces, joint loading and utilization of elastic strain energy in equine locomotion. J Exp Biol.213: 3998-4009.

Hartog SM, Back W, Brommer H and Weeren PR (2009). In vitro evaluation of metacarpophalangeal joint loading during simulated walk. Equine Vet J. 41: 214-217.

Holmstrom M, Magnusson LE and Philipsson J (1990). Variation in conformation of Swedish warmblood horses and conformational characteristics of Èlite sport horses. Equine Vet J. 22: 186-193.

Le Jeune SS, Macdonald MH, Stover SM, Taylor KT and Gerdes M (2003). Biomechanical investigation of the association between suspensory ligament injury and lateral condylar fracture in thoroughbred racehorses. Vet Surg. 32: 585–597.

McClure SR, Glickman LT, Glickman NW and Weaver CM (2001). Evaluation of dual energy x-ray absorptiometry for in situ measurement of bone mineral density of equine metacarpi. Am J Vet Res. 62: 752-6.

Merkens HW, Schamhardt HC, Hartman W and Kersjes AW (1985). Ground reaction force patterns of Dutch Warmblood horses at normal walk. Equine Vet J. 18: 207–214.

Merritt JS, Pandy MG, Brown NA, Burvill CR, Kawcak CE, McIlwraith CW and Davies HM (2010). Mechanical loading of the distal end of the third metacarpal bone in horses during walking and trotting. Am J Vet Res. 71: 508-14.

Nunamaker DM, Butterweck DM and Provost MT (1989). Some geometric properties of the third metacarpal bone: a comparison between the thoroughbred and standardbred racehorse. J Biomech. 22: 129-134.

Ott SM, O'Hanlan M, Lipkin EW and Newell-Morris L (1997). Evaluation of vertebral volumetric vs. areal bone mineral density during growth. Bone 20: 553-6.

Palmer SE (1982). Radiography of the abaxial surface of the proximal sesamoid bones of the horse. J Am Vet Med Assoc.181: 264-265.

Piotrowski G, Sullivan M and Colahan PT (1983). Geometric properties of equine metacarpi. J Biomech.16: 129–139.

Schneider RK, Bramlage LR, Gabel AA, Barone LM and Kantrowitz BM (1988). Incidence, location and classification of 371 third carpal bone fractures in 313 horses. Equine Vet J Suppl.6: 33-42.

Siemon NJ and Moodie EW (1974). Reproducibility of specific gravity estimations on bone samples from different sites of cattle and sheep. Calc Tiss Res. 15: 181-188.

Sisson S (1975). Equine syndesmology. In Getty R (5theds) The anatomy of the domestic animals Vol. 1. Philadelphia, USA: W.B. Saunders Company:pp 355-358.

Leonard MB and Bachrach LK (2012). Non-invasive Techniques for Bone Mass Measurement. In Glorieux FH, Pettifor JM, Jüppner H (2ndeds) Pediatric Bone. Academic Press: pp 309-342.

Southwood LL, Trotter GW and McIlwraith CW (1998). Arthroscopic removal of abaxial fracture fragments of the proximal sesamoid bones in horses: 47 cases (1989-1997). J Am Vet Med Assoc. 213: 1016-1021.

Suominen H (1993). Bone mineral density and long term exercise. An overview of cross-sectional athlete studies. Sports Med. 16: 316-330.

Tóth P, Hinton G, Horváth C, Ferencz V, Tóth B, Szenci O and Bodó G (2014). Bone mineral density and computer tomographic measurements in correlation with failure strength of equine metacarpal bones. Acta Vet Brno. 83: 45-50.

Tóth P, Horváth C, Ferencz V, Nagy K, Gligor N, Szenci O and Bodó G (2010). Assessment of the mineral density and mineral content of the equine third metacarpal and first phalanx bone by dual energy x-ray absorptiometry. Acta Vet Hung. 58: 317-329.

Tóth P, Horváth C, Ferencz V, Tóth B, Váradi A, Szenci O and Bodó G (2013). Bone mineral density (BMD) and computer tomographic measurements of the equine proximal phalanx in correlation with breaking strength. Pol J Vet Sci. 16: 3-8.

Watson KM, Stitson DJ and Davies HMS (2003). Third metacarpal bone length and skeletal asymmetry in the Thoroughbred racehorse. Equine Vet J. 35: 712-714.

Weller R, Pfau T, May SA and Wilson AM (2006). Variation in conformation in a cohort of National Hunt racehorses. Equine Vet J. 38: 616-621