Original Article Buffalo Bulletin (March 2014) Vol.33 No.1

QUANTITATIVE EVALUATION OF WATER BUFFALO CANNON BONES

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ABSTRACT

The objective of this study was to evaluate different variables of the left and right metacarpal and metatarsal bones, especially with respect to the length of their lateral and medial parts. Measurements were done on forty cannon bones of 10 male water buffaloes by direct anatomical measurements. There were significant differences between the mean values of the greatest length of the lateral part (LL) and the greatest length of the medial part (ML) in the metacarpal bone and the metatarsal bone ($p < 0.001$). In the metatarsal bones, the LL and ML were longer than those of the metacarpal bones ($p < 0.001$). The metacarpal bones, the mean value of LL in 75% (15/20) was greater by 2.17 mm than the ML, in 10% (2/20) of specimens the LL and ML were the same, and in 15% (3/20), specimens the ML were longer. In all metatarsal bones, the mean value of LL was greater by 6.08 mm than the ML. In conclusion, the length asymmetry of water buffalo cannon bones might not affect on the development of digital and claw diseases, while this anatomical difference plays an important role in bovine lameness. This might be related to the natural habits of water buffalo and the type of environment. This study provides additional and important information as reference value in order to discriminate between complete or broken limb skeleton elements of water buffalo and other artiodactyla species in archaeozoological assemblages.

Keywords: water buffaloes, metacarpal bone, metatarsal bone, measurement

INTRODUCTION

Water buffaloes belong to the bovidae family. Archeological evidence suggests that water buffaloes were domesticated in Iran and migrated to southern Europe through this region (Naserian and Saremi, 2007). The Iranian buffalo is also very likely the biggest buffalo breed in the world (Moioli and Borghese, 2005). All ruminants have a cannon bone representing fused third and fourth metacarpal/ metatarsal bones. Within recent years, considerable attention has been focused on quantitative analysis of the large ruminants' metapodial bones not only for archaeozoological applications (Berteaux and Guintard, 1995; Paral *et al.*, 2004) but also for understanding the anatomy or biomechanical properties (Bani Ismail *et al.*, 2008; Muggli *et al.*, 2011) and for determination of the possible origins of the digital and claw diseases (Nacambo *et al.*, 2007). The last study reported that there was an anatomical difference in the length of the lateral and medial sides of the cannon bones in calves and cows by direct anatomical measurements. The

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differences were also recorded in ancient cattle bones (Paral *et al.,* 2004) and wild ruminants (Keller *et al.,* 2009). The lateral side was found to be few millimeters longer than the medial side. The longer lateral cannon bone is of advantage for a limb with a wider range of movements (Nacambo *et al.,* 2007) and is also predisposition factor for the development of claw diseases (Paral *et al.,* 2004).

Chronic foot injuries are encounterd in water buffaloes to much less than in cattle (FAO, 1977). In addition, the predisposition of the pelvic claws to water buffalo foot injuries has been reported (Lekharu *et al.,* 1991), but no clear cause could be found. Based on these studies, question arises whether such length differences of the cannon bone is present in water buffalo using direct anatomical measurements.

MATERIALS AND METHODS

Forty cannon bones of 10 male water buffalos *(Bubalus bubalis)* without any external abnormality or pathology were collected from a local slaughterhouse in Ahvaz, located in the southwest of Iran. The age of the dead animals, which was estimated from the chronology of the eruption of the permanent incisors (4), ranged from 2 to 3 years. The animals' live weight (316-383 kg) was computed based on carcass weight (190-230 kg).

All metacarpal and metatarsal bones were macerated according to the procedure Hildebrand (1986). Figure 1 shows only linear measurements of the left thoracic metacarpal bone, while the measurements correspond with the metatarsal bone. The following measurements for the metacarpal and metatarsal bones were taken: greatest length (GL), width of the proximal end (Bp), greatest depth of the proximal end (Dp), width of the distal end (Bd), smallest depth of the diaphysis (DD), smallest width of the diaphysis (SD), and greatest depth of the distal end (Dd) (Von den Driesch, 1976); greatest width of the metaphysis (Be) and greatest depth of the metaphysis (De), mid-shaft width of the diaphysis (d), mid-shaft depth of the diaphysis (e), antero-posterior diameter of the internal trochlea of the medial condyle (DIM), antero-posterior diameter of the external trochela of the medial condlye (DEM), antero-posterior diameter of the internal trochela of the lateral condlye (DIL), antero-posterior diameter of the external trochela of the lateral condlye (DEL), medio-lateral width of the medial condyle (WCM), and medio-lateral width of the lateral condyle (WCL) (Guintard and Lallemand, 2003). In addition to these variables, the distance between the distal points of two sagital ridges of the condyles (SRD), the greatest length of the medial part (ML), and greatest length of the lateral part (LL) were measured.

All parameters were measured three times. Then the mean values were documented. All measurements were taken using a measuring tape and a caliper (200 mm and 300 mm, Mitutoyo Vernier Caliper, Japan) to an accuracy of 0.05 mm. The mean values were established by use of SPSS 16.0. An independent student *t*-test was applied to analyze whether there was any difference between the mean values of the lateral and medial sides of the left or right cannon bones. Parametric values were shown as mean, standard deviation, minimum, and maximum of the right and left of the metacarpal and metatarsal bones. A p value of less than 0.05 was considered as significant.

RESULT

In preliminary examinations, it was observed that in many specimens, the length difference between the lateral and medial digits was clear with naked eye (Figure 2).

The mean parametric values of the right and left metacarpal and metatarsal bones are presented in Tables 1, 2, and 3.

There was no significant difference between left and right metacarpal and right and left metatarsal bones in any of the variables ($p > 0.05$).

Comparisons of the mean values of the greatest length (GL), greatest depth of the proximal end (Dp), mid-shaft depth of the diaphysis (e), smallest depth of the diaphysis (DD), and greatest depth of the metaphysis (De) between the metacarpal and metatarsal bone revealed significant differences ($p < 0.001$, Table 1). The mean values of those variables were greater in the metatarsal bone.

In all metatarsal bones, the mean value of GL was greater by a mean of 35.00 mm than that of the metacarpal bone. In the metatarsal bone, the mean value of Dp was greater by a mean of 8.35 mm in 95% (38/40) than that of the metacarpal bone. In the metatarsal bone, the mean value of e was greater by 3.95 mm in 97.57% (39/40) than that of the metacarpal bone. In all metatarsal bones, the mean value of DD was greater by 5.25 mm than that of the metacarpal bones.

There were significant differences between the mean values of width of the proximal end (Bp), mid-shaft width of the diaphysis (d), smallest width of the diaphysis (SD), width of the distal end (Bd), distance between the distal points of two sagital ridges (SRD), and greatest width of the metaphysis (Be) in the metacarpal and metatarsal bones ($p < 0.001$, Table 1). The mean values of those variables were greater in the metacarpal bone. In the metatarsal bone, the mean value of De was greater by 4.3 mm in 95% (38/40) than that of the metacarpal bone. In all metacarpal bones, the mean value of Bp was greater by 11.40 mm than that of the metatarsal bones. In all metacarpal bones, the mean value of d was greater by 7.12 mm than that of the metatarsal bones. In all metacarpal bones, the mean value of SD was greater by 8.35 mm than that of the metatarsal bone. In all the metacarpal bones, the mean value of Bd was greater than by a mean of 6.6 mm that of the metatarsal bones. In the metacarpal bone, the mean value of Be was greater than by 4.2 mm in 97.5% (39/40) that of the metatarsal bone. The mean value of SRD the metacarpal bone was greater by 3.26 mm in 91% (38/40) than that of the metatarsal bone.

There were significant differences between the mean values of the greatest length of lateral part (LL) and the greatest length of medial part (ML) in the metacarpal bone and the metatarsal bone ($p < 0.001$, Table 2). In the metatarsal bones, the LL and ML were longer than those of the metacarpal bones ($p < 0.001$). In the metacarpal bones, the mean value of LL in 75% (15/20) was greater by 2.17 mm than the ML, in 10% (2/20) of specimens the LL and ML were the same, and in 15% (3/20) of specimens the ML were longer. In all metatarsal bones, the mean value of LL was greater by 6.08 mm than the ML.

The mean values of antero-posterior diameter of the internal trochlea of the medial condyle (DIM), antero-posterior diameter of the external trochela of the medial condlye (DEM), antero-posterior diameter of the internal trochela of the lateral condlye (DIL), and antero-posterior diameter of the external trochela of the lateral condlye (DEL) were not different between the metacarpal and metatarsal bones (Table 3).

There were significant differences between the mean values of DEL/DEM in both metacarpal and metatarsal bones ($p < 0.001$, Table 3), while comparisons of the mean values of the DIM/DIL between the metacarpal and metatarsal bones demonstrated significant differences only in the metacarpal bone ($p < 0.05$, Table 3). In all metacarpal bones, the mean value of DEM was greater by 4.15 mm than the DEL. In all metatarsal bones, the mean value of DEM was greater by 4.25 mm than the DEL. Only in the metacarpal bone, the mean value of DIL was greater by 1.65 mm than the DIM in 85% (17/20).

There were significant differences between the mean values of medio-lateral width of the medial condyle (WCM) and medio-lateral width of the lateral condyle (WCL) in the metacarpal and metatarsal bones (Table 3).The mean value of WCM in the metacarpal bone was greater by 2.95 mm in 95% (38/40) than the WCM of the metatarsal bone ($p < 0.001$). In all metacarpal bones, the mean value of WCL was greater by 3.8 mm than the WCL in metatarsal bones ($p < 0.01$).

DISCUSSION

In the present study, the metatarsal bones were consistently longer and more slender than the metacarpal bones, which is in agreement with previous results of the studies in cattle (Nacambo *et al.,* 2007), juvenile one-humped camel (Bani Ismail *et al.,* 2008), and Amsterdam Island feral cattle (Berteaux and Guintard, 1995). In some Roman domestic cattle and recent breeds, the length of metacarpal bones are reported to have been longer (Berteaux and Guintard, 1995). Thus, mechanical effect of the shorter and broader metacarpal bones in the water buffalo might be related to the assumption that majority of the body weight rests on the thoracic limb. However, thoracic limbs suffer considerably less from disease than pelvic limbs in buffaloes (Lekharu *et al.,* 1991). The extrinsic musculo-tendinous structure of the thoracic girdle might act better than the bony pelvic girdle in response to traumatic overload.

The shape and size of the foot or leg of ruminants are closely adapted to the environment in which the animal lives and to the nature of its locomotory activities. The length of the foot is also largely determined by the length of the cannon bones (Gray, 1968). At this point, it would be logical to compare the mean values of the greatest length of the cannon bone in our study with other studies which have been made dealing with cannon bones from ancient cattle (Berteaux and Guintard, 1995) and present-day cattle (Nacambo *et al.,* 2007). We found that the mean values of our study were distinctively a few centimeters greater. This anatomical feature may be responsible for the bones' having more shock absorption capacity because longer and larger bones absorb more shock (impact energy) than shorter and more slender bones (Kardong, 1989; Muggli *et al.,* 2011; Muvdi and McNabb, 1980). Thus, the shock absorption ability in water buffaloes seems to be better than that of cattle. Moreover, this difference in length may play a role in better running ability of water buffaloes compared to common large domestic ruminants because the longer leg translates into the longer stride.

In all cases of the metatarsal bones, the mean value of LL was greater than ML. However, the difference was not consistent in the metacarpal bones. In some cases, the mean value of LL and ML of the metacarpal bone were equal or ML was longer. These results are in agreement with previous findings in cattle (Nacambo *et al.,* 2007).

Table 1. Mean parametric values (mm) of the cannon bones (n=40) of the water buffaloes (standard deviation, minimum, maximum).

	Metacarpal bone (n=20)		Metatarsal bone (n=20)	
	RIGHT	LEFT	RIGHT	LEFT
GL	210.50^{A} (6.34, 201.00, 217.00)	211.00^{A} (6.14, 202.00, 217.00)	248.60^{B} (13.71, 236.00, 280.00)	242.90^{B} (9.76, 229.00, 260.00)
BP	69.60^{A} (3.23, 66.00, 76.00)	68.80^{A} (3.45, 65.00, 75.00)	57.80^{B} (2.57, 55.00, 62.00)	57.80^{B} (2.57, 55.00, 62.00)
DP	37.40^{A} (1.71, 35.00, 40.00)	37.90^{A} (2.23, 35.00, 42.00)	45.60^{B} (4.22, 37.00, 50.00)	46.40^{B} (5.50, 35.00, 55.00)
d	41.14^{A} (2.87, 38.00, 46.00)	41.40^{A} (3.23, 37.00, 47.00)	33.90^{B} (2.42, 30.00, 37.00)	34.40^{B} (2.17, 31.00, 38.00)
e	26.50^{A} (2.01, 22.00, 29.00)	26.30^{A} (2.00, 22.00, 29.00)	30.70^{B} (1.82, 28.00, 33.00)	30.00^{B} (1.49, 29.00, 33.00)
SD	41.50^{A} (3.10, 38.00, 46,00)	41.30^{A} (3.49, 37.00, 46.00)	33.00^{B} (2.10, 30.00, 36.00)	33.10^{B} (2.42, 29.00, 36.00)
DD	25.70^{A} (2.26, 21.00, 29.00)	26.50^{A} (2.27, 22.00, 29.00)	31.90^{B} (2.37, 28.00, 37.00)	30.80^{B} (1.87, 27.00, 33.00)
Bd	$74.2\ 0^{A}$ (3.55, 69.00, 81.00)	74.30^{A} (3.59, 70.00, 82.00)	67.60^{B} (2.79, 63.00, 72.00)	67.70^{B} (2.66, 64.00, 72.00)
Dd	37.80^{A} (2.69, 33.00, 41.00)	37.80^{A} (2.82, 33.00, 41.00)	38.20^{A} (1.93, 36.00, 41.00)	38.10^{A} (1.91, 35.00, 41.00)
Be	69.90^{A} (4.35, 65.00, 79.00)	70.60^{A} (4.08, 66.00, 79.00)	66.20^{B} (3.04, 61.00, 72.00)	65.90^{B} (3.28, 61.00, 73.00)
De	33.80^{A} (3.88, 28.00, 40.00)	33.90^{A} (3.90, 28.00, 40.00)	38.50^{B} (3.68, 33.00, 44.00)	37.80^{B} (4.44, 30.00, 44.00)
SRD	39.87^{A} (2.23, 37.00,44.00)	39.75^{A} (2.43, 37.00, 44.00)	37.10^{B} (2.02, 35.00, 42.00)	36.60^{B} (2.17, 35.00, 42.00)

GL, greatest length; BP, width of the proximal end; DP, depth of the proximal end; d, mid-shaft width of the diaphysis; e, mid-shaft depth of the diaphysis; SD, smallest width of the diaphysis; DD, smallest depth of the diaphysis; Bd, width of the distal end; Dd, depth of the distal end; Be; greatest width of the metaphysis; De, greatest depth of the metaphysis; SRD, distance between two condyle of the sagital ridges.

Means in a row with different large superscript letters are statistically different between the right and left cannon bones ($p < 0.001$).

Table 2. Mean parametric values (mm) of the cannon bones (n=40) of the water buffaloes (standard deviation, minimum, maximum)

	Metacarpal bone (n=20)		Metatarsal bone (n=20)	
	RIGHT	LEFT	RIGHT	LEFT
LL	199.55^{Aa} (7.16, 189.00, 210.00)	201.40^{Aa} (11.46, 189.00, 229.00)	227.89^{Ba} (14.81, 206.00, 245.00)	231.71^{Ba} (8.49, 223.00, 245.00)
ML	197.36^{Ab} (5.46, 187.00, 206.00)	199.20^{Ab} (10.98, 187.00, 225.00)	222.44^{Bb} (14.50, 200.00, 240.00)	225.00^{Bb} (10.77, 201.00, 242.00)

LL, lateral length; ML, medial length.

Means in a row with different small superscript letters (a, b) are statistically different ($p < 0.001$).

Means in a column with different large superscript letters are statistically different between the right and left cannon bones ($p < 0.001$).

Table 3. Mean parametric values (mm) of the cannon bones (n=40) of the water buffaloes (standard deviation, minimum, maximum).

	Metacarpal bone (n = 20)		Metatarsal bone (n = 20)	
	Left	Right	Left	Right
DEL	25.50^{Aa} (1.50, 23.00, 27.00)	25.70^{Aa} (1.63, 23.00, 28.00)	24.60^{Aa} (1.83, 22.00, 28.00)	25.50^{Aa} (1.84, 22.00, 28.00)
DEM	29.90^{Ab} (1.52, 27.00, 32.00)	29.60^{Ab} (1.34, 27.00, 31.00)	29.00^{Ab} (1.49, 26.00, 31.00)	29.60^{Ab} (3.65, 26.00, 39.00)
DIL*	36.40^{Aa} (2.36, 34.00, 40.00)	36.70^{Aa} (2.54, 34.00, 40.00)	35.60^{Aa} (1.89, 33.00, 39.00)	35.90^{Aa} (1.85, 33.00, 39.00)
DIM	34.90^{Ab} (2.46, 33.00, 41.00)	34.90^{Ab} (2.51, 32.00, 40.00)	34.90^{Aa} (2.28, 32.00, 40.00)	35.30^{Aa} (2.21, 32.00, 40.00)
WCL**	32.70^{Aa} (1.94, 30.00, 36.00)	32.90^{Aa} (1.66, 31.00, 36.00)	30.10^{Ba} (1.19, 28.00, 32.00)	27.90^{Ba} (6.77,29.00, 32.00)
WCM	33.80^{Aa} (2.14, 30.00, 37.00)	33.90^{Aa} (1.91, 30.00, 37.00)	30.80^{Ba} (1.54, 28.00, 33.00)	31.00^{Ba} (2.49, 29.00, 37.00)

DEL, antero-posterior diameter of the external trochlea of the lateral condyle; DEM, antero-posterior diameter of the external trochlea of the medial condyle; DIL, antero-posterior diameter of the internal trochlea of the lateral condyle; DIM, antero-posterior diameter of the internal trochlea of the medial condyle; WCL, medio-lateral width of the lateral condyle; WCM, medio-lateral width of the medial condyle.

Means in a row with different large superscript letters (A, B) are statistically different ($p < 0.001$).

Means in a column with different small superscript letters (a, b) are statistically different between the right and left cannon bones ($p < 0.001$).

*($p<0.05$). ** ($p < 0.01$)

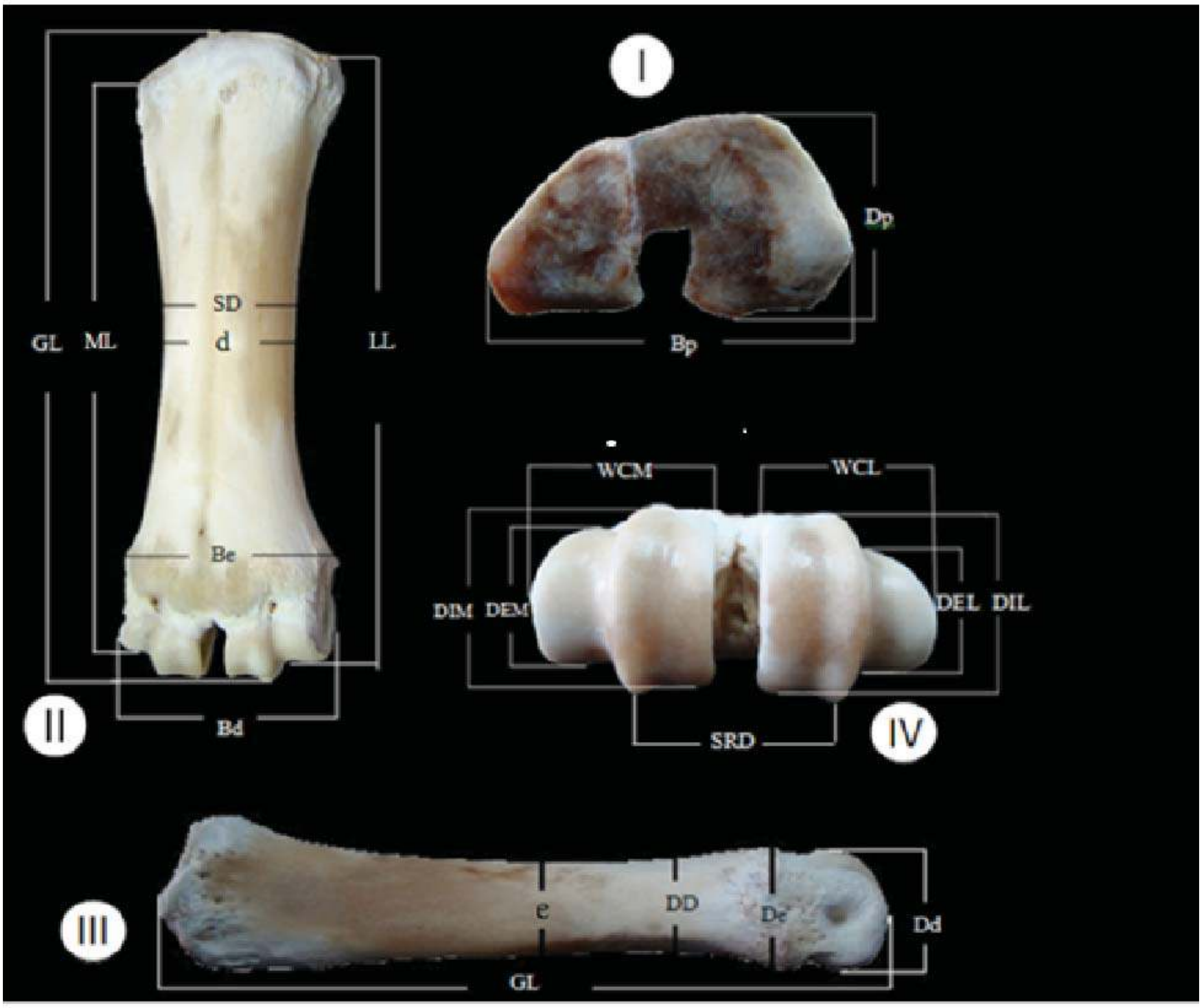

Figure 1. The proximal view (I), dorsal view (II), medial view (III), and distal view (IV) of the left metacarpal bone in water buffaloes showing where the parameters were measured. Dp, width of the proximal end; Bp, width of the proximal end (I). GL, greatest length; Bd, width of the distal end; LL, lateral length; ML, medial length; Be; greatest width of the metaphysis; SD, smallest width of the diaphysis; d, mid-shaft width of the diaphysis (II). GL, greatest length; Dd, depth of the distal end; DD, Smallest depth of the diaphysis; De, greatest depth of the metaphysis; e, mid-shaft depth of the diaphysis (III). DEL, antero-posterior diameter of the external trochlea of the lateral condyle; DEM, antero-posterior diameter of the external trochlea of the medial condyle; DIL, antero-posterior diameter of the internal trochlea of the lateral condyle; DIM, antero-posterior diameter of the internal trochlea of the medial condyle; WCL, medio-lateral width of the lateral condyle; WCM, medio-lateral width of the medial condyle; SRD, distance between two condyle of the sagital ridges (IV).

Figure 2. Dorsal view of the left pelvic hooves of water buffalo. It is clear that the cornet and hoof tip of the lateral digit extends distally than that of the medial digit.

This mean difference in the metatarsal bones was 6.08 mm and 2.19 mm in the metacarpal bone. This result prompts the question of whether such a small difference in cannon bone length can predispose water buffalo to claw disorders, particularly in the pelvic limbs. The majority of lesions causing lameness are found in the pelvic limb of buffalo (Lekharu *et al.,* 1991) and cattle (Nuss *et al.,* 2006; Tsuka *et al.,* 2012). The predisposition of the lateral claw of the buffalo pelvic limb to disease has not been discussed in the literature. Muggli *et al.* (12) have pointed out that only cattle with a larger difference in the length of paired digits including cannon bones, for example > 3 mm, are predisposed to overload and claw diseases under current housing systems, particularly in lateral pelvic limbs. It therefore seems reasonable to assume foot lesions causing lameness occur in water buffalo more than in cattle. However, chronic infections of foot were seen much less frequently in buffaloes than in cattle (FAO, 1977). In addition, the incidence of chronic laminitis, white line diseases, and sole ulcers in buffaloes was comparatively less in comparison with other foot disorders (Lekharu *et al.,* 1991). The most convincing explanation to answer these discussions is closely linked with the natural habits of the animal and the type of environment. Water buffaloes spend a majority of time wallowing in mud holes or in water. In other words, species' habitat of water buffalo might play a greater role in response to overload and foot diseases compared to the anatomical characteristic of cannon bone.

An asymmetry between the lateral and medial digital bones, including the metacarpal and metatarsal condyles in cattle (Muggli *et al.*, 2011) and in wild ruminants (Keller *et al.,* 1991) has been reported. The sum of cannon condyle and total length of three phalanges in the lateral digit were slightly longer than the corresponding structures in the medial digit mainly because of longer lateral cannon condyle. Nourinezhad and Mazaheri (16) found no significant difference between total lengths of three phalanges of the third and fourth digits in water buffaloes but did not measure the metacarpal/metatarsal bones. Thus, it seems that the origin of the length asymmetry of the water buffalo digits is positioned in length difference of the lateral and medial parts of the cannon bone. Perhaps the main conclusion to be drawn from this discussion is that longer lateral part of the metacarpal bone and particularly metatarsal bone may be responsible for the coronet and the hoof tip of the lateral claw reach further distally than the corresponding structures of the medial claw (Figure 2). The asymmetrical length of the lateral and medial parts of water buffalo cannon bone is perhaps a useful adaptation to enhance its lateral stability during movement and standing. In addition, this asymmetry is probably a result of an evolutionary selection process in bovidae.

Cannon bones of artiodactyla species well preserved in osteoarcheological excavations (Guintard and Lallemand, 2003) and examination of them in order to obtain knowledge regarding morphology of structure, animal size, and population might be useful for zooarchaeological studies (Alpak *et al.,* 2009). Hence, this study provides additional and important information as reference value in order to discriminate between complete or broken limb skeleton elements of water buffalo and other artiodactyls species in archaeozoological assemblages.

ACKNOWLEDGEMENTS

The authors wish to acknowledge Prof. Dr. M. S. M. Kumar for his valuable comments and editing of the manuscript. We would also like to thank Dr. M. Pourmahdi Borujeni for doing the statistical analysis. Funding for this research was provided by Shahid Chamran University.

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