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MORPHOMETRIC STUDY ON DIGITAL BONES IN NATIVE KHUZESTAN WATER BUFFALOES *(BUBALUS BUBALIS)*

J. NOURINEZHAD[1], Y. MAZAHERI[1], M. POURMAHDI BORUJENI[2] & M. DANESHI[1]

[1]Division of Anatomy and Embryology, Department of Basic Sciences;
[2]Department of Food Sciences; Faculty of Veterinary Medicine, Shahid Chamran University of Ahvaz, Ahvaz, Iran

Summary

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The aim of this study was to compare the lateral and medial digital bones of the left and right thoracic and pelvic limbs of water buffaloes by direct anatomical measurements. This study was conducted on 240 digital bones of ten native Khuzestan buffalo bulls, aged 2 to 3 years. No significant differences were found between corresponding measurements of digital bones of the right and left limbs nor between the total lengths of the digital bones of the lateral and medial digits within the same limbs (P>0.05). The symmetric digital bones may have contributed to distribute an equal weight on the foot during standing or walking and might explain why biomechanical lesions of the feet in water buffaloes are much less frequent than in cattle. Moreover, data acquired in the present study might be useful for researchers working on osteoarchaeological excavations as reference values for evaluation and identification of digital bones of water buffaloes among artiodactyl species.

Key words: digital bones, length, measurement, water buffalo

INTRODUCTION

The digital bones of ruminants have been studied quite frequently because of various reasons: the examination of bones from ancient times and archaeological sites to compare recent and ancient cattle (Bartosiewicz, 1984, 1987; Bartosiewicz *et al.,* 1997; Paral *et al.,* 2004), studies of anatomy and embryology (Küpfer & Schinz, 1923), and the search for possible origins of digital and claw diseases. In archaeology, morphometric measurements were used to determine species and specific bones, including the determination of left- and right-sided osteologic remains (Paral *et al.,* 2004). In anatomy, each bone is described in detail according to its position and function which is characterised by length, breadth, shape, and the presence of tendon and ligament insertions. The digital bones of cattle have been studied previously by both direct and radiographic measurements (Ranft, 1936; Simon, 1963). These former studies demonstrated that the digital bones do not differ except for the pedal bones, which are longer in the medial digits, especially in the fore limbs. Recently, however, it has been found that the digital bones of cattle, including the metacarpal and metatarsal condyles, differ in length (Schwarzmann, 2004a; Nacambo *et al.,* 2007; Muggli *et al.,* 2011). The lateral digit was found to be a few millimeters longer than the medial digit, when comparing the sum of the bone lengths and various overall digit lengths. In addition, this difference in length has been found in other artiodactyls (Keller *et al.,* 2009). The latter authors discussed that a longer outer digit might be advantageous on soft ground to keep the centre of the body mass in good stability during the walk and also at faster speed. It was further speculated to be of advantage during fighting with rivals or making turns while trying to escape predators, because the grip would be better (Keller *et al.,* 2009).

The aim of this study was to compare the various digital bones of water buffaloes by direct anatomical measurements in order to check whether differences in the lengths of the single phalanx and total lengths of the three phalanges between the lateral and medial digits in the left and right thoracic and pelvic limbs are present also in this species.

MATERIALS AND METHODS

This study was conducted on 240 digital bones of ten young native Khuzestan buffalo bulls. The specimens, all without any external abnormality or pathology, were obtained from the slaughterhouse and im-

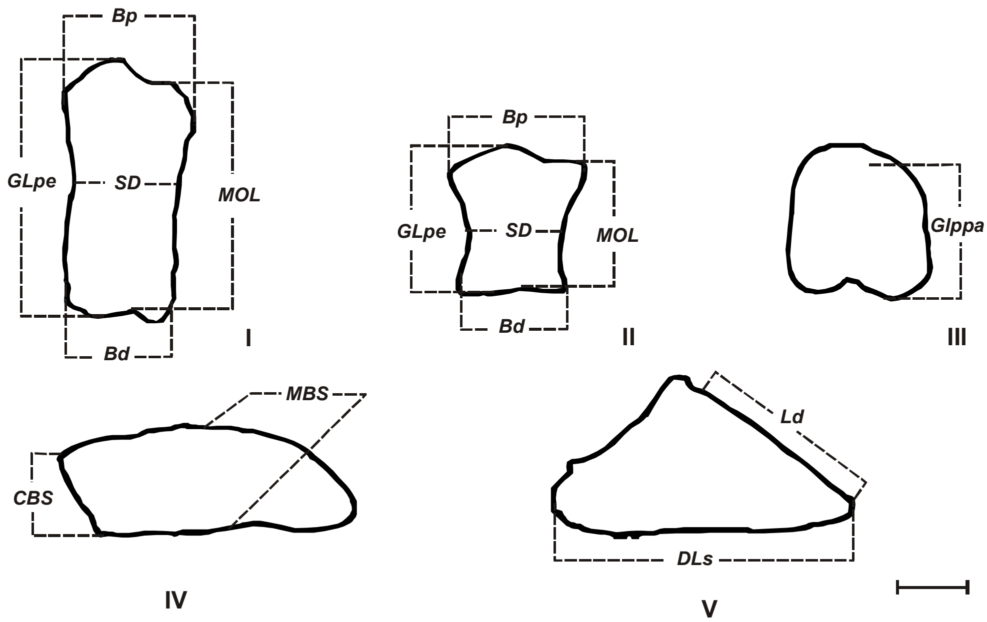

Fig. 1. Lateral proximal (I – dorsal view, III – proximal view), middle (II – dorsal view), and distal (IV – solar view, V – lateral view) phalanges of right thoracic limb of water buffalo showing where the measurements were taken. *GLpe*: greatest length of the peripheral (abaxial) half; *MOL*: middle overall length; *GLppa*: greatest length of the peripheral (abaxial) proximal articular surface; *SD*: smallest breadth of the diaphysis; *Bp*: breadth of the proximal end; *Bd*: breadth of the distal end; *Ld*: length of the dorsal surface; *DLS*: greatest diagonal length of the sole; *MBS*: middle breadth of the sole; *CBS*: caudal breadth of the sole. Bar = 0.5 cm.

mediately identified as part of the left and right thoracic or pelvic limbs. The age of animals was estimated from their teeth (FAO, 1977) and ranged between 2 to 3 years. Dew claw bones were not considered in this study. The live weight of the animals (317–383 kg) was determined based on carcass weight (190 to 230 kg).

The digital bones were macerated according to the procedure of Hildebrand (1968). Fig. 1 shows the position of the various linear measurements in the digital bones of the right thoracic limb. Similar measurements on the digital bones of the pelvic limb were performed on the corresponding sites.

According to the method of Von den Driesch (1976), the following parameters were determined for the proximal and middle phalanges: the greatest length of the peripheral (abaxial) half (*GLpe*), the smallest breadth of the diaphysis (*SD*), the breadth of the proximal end (*Bp*), the breadth of the distal end (*Bd*). In the distal phalanx, the length of the dorsal surface (*Ld*), the greatest diagonal length of the sole (*DLS*), and the middle breadth of the sole (*MBS*) in the distal phalanx were measured. In addition to these variables, the greatest length of the peripheral (abaxial) proximal articular surface (*GLppa*) of the proximal phalanges, middle overall length (*MOL*) of the proximal and middle phalanges, and the caudal breadth of the sole (*CBS*) in the distal phalanx were considered. All the parameters were measured three times. The total length of the three phalanges of the lateral and medial digits for the thoracic and the pelvic limbs was measured by adding the middle overall length (*MOL*) for the proximal and middle phalanges and the length of the dorsal surface (Ld) for the distal phalanx of the relevant digits. Then the mean values were calculated. The measurements were done by a measuring tape and a caliper (200 mm: Mitutoyo Vernier Caliper, Japan) to an accuracy of 0.05 mm.

SPSS 16.0 for Windows statistical software was used to compute the means and standard error values of all parameters. The paired sample *t*-test was applied to compute means of the medial and lateral digital bones of the right and left thoracic and pelvic limbs. In addition, a general linear model was applied for repeated measurements with the animal. The significance level was set at 0.05.

RESULTS

Means of the measured parameters of the proximal, middle, and distal phalanges are presented in Tables 1, 2, and 3.

There were no significant differences between corresponding measurements of digital bones of the right and left limbs (P>0.05).

In the proximal phalanx, the mean values of the medial and lateral digits in the same limb differed significantly in the middle overall length (*MOL*) of the thoracic limb and in the greatest length of the peripheral (abaxial) proximal articular surface (*GLppa*) of both limbs (P<0.05, Table 1). The mean values of the breadth of the proximal end (*Bp*), smallest breadth of the diaphysis (*SD*), breadth of the distal end (*Bd*), middle overall length (*MOL*), and greatest length of the peripheral (abaxial) proximal articular surface (*GLppa*) for the proximal phalanx were significantly different between the thoracic and pelvic limbs (P<0.05, Table 1). The *Bp* of the proximal phalanx in 80 % (32/40) of the thoracic limb was larger (P<0.01) than that in pelvic limb. The *MOL* of the proximal phalanx in 65 % (26/40) of the pelvic limb was larger (P<0.01) than that in the thoracic limb. The *Bd* of proximal phalanx

Table 1. Mean values of parameters (mm) of the proximal phalanx (n=80) of the eight digits in water buffaloes. *Bp*: breadth of the proximal end; *SD*: smallest breadth of the diaphysis; *Bd*: breadth of the distal end; *MOL*: middle overall length; *Glpe*: greatest length of the peripheral (abaxial) half; *Glppa*: greatest length of the peripheral (abaxial) proximal articular surface

	Pelvic limbs (n=20)		Thoracic limbs (n=20)		Pelvic limbs	Thoracic limbs
	Lateral (n=20)	Medial (n=20)	Lateral (n=20)	Medial (n=20)		
Bp	35.25 ± 2.49^{b}	37.71 ± 2.74^{a}	35.35 ± 0.61^{A}	35.15 ± 0.50^{A}	37.84 ± 0.62^{A}	37.58 ± 0.65^{A}
SD	29.65 ± 1.67^{b}	31.85 ± 2.49^{a}	29.65 ± 0.37^{A}	29.65 ± 0.37^{A}	32.00 ± 0.57^{A}	31.70 ± 0.55^{A}
Bd	32.82 ± 1.62^{b}	34.97 ± 2.25^{a}	32.80 ± 0.39^{A}	32.85 ± 0.33^{A}	35.00 ± 0.53^{A}	34.95 ± 0.48^{A}
MOL	64.32 ± 3.44^{b}	62.77 ± 3.27^{a}	64.65 ± 0.81^{A}	64.00 ± 0.73^{A}	63.20 ± 0.73^{A}	62.35 ± 0.73^{B}
GLpe	70.60 ± 4.04^{a}	69.67 ± 4.99^{a}	70.30 ± 0.82^{A}	70.90 ± 0.98^{A}	69.95 ± 0.99^{A}	70.00 ± 1.25^{A}
GLppa	34.82 ± 3.70^{b}	32.57 ± 3.19^{a}	33.55 ± 0.82^{B}	36.10 ± 0.73^{A}	31.60 ± 0.74^{B}	33.55 ± 0.62^{A}

Means marked by different large superscripts A and B in a row differ significantly between the medial and the lateral digits in the same limbs ($p<0.05$). Means marked by different small superscripts (a and b) in a row indicate significant differences between thoracic and pelvic limbs regardless of lateral or medial ($p<0.05$).

Table 2. Mean values of parameters (mm) of the middle phalanx (n=80) of the eight digits in water buffaloes. *Bp*: breadth of the proximal end; *SD*: smallest breadth of the diaphysis; *Bd*: breadth of the distal end; *MOL*: middle overall length, *GLpe*: greatest length of the peripheral (abaxial) half

	Pelvic limbs (n=20)		Thoracic limbs (n=20)		Pelvic limbs	Thoracic limbs
	Lateral (n=20)	Medial (n=20)	Lateral (n=20)	Medial (n=20)		
Bp	34.67 ± 2.20^{a}	36.80 ± 2.29^{a}	34.45 ± 0.46^{A}	34.90 ± 0.52^{A}	36.85 ± 0.50^{A}	36.75 ± 0.50^{A}
SD	27.10 ± 2.60^{b}	27.97 ± 1.99^{a}	27.45 ± 0.67^{A}	26.75 ± 0.47^{A}	27.95 ± 0.46^{A}	28.00 ± 0.44^{A}
Bd	28.50 ± 1.56^{b}	30.30 ± 2.15^{a}	28.55 ± 0.40^{A}	28.45 ± 0.24^{A}	30.05 ± 0.49^{B}	30.55 ± 0.47^{A}
MOL	45.90 ± 2.01^{b}	43.15 ± 2.80^{a}	46.30 ± 0.44^{B}	45.50 ± 0.44^{A}	42.95 ± 0.65^{A}	43.35 ± 0.61^{A}
GLpe	50.72 ± 4.42^{b}	48.20 ± 4.66^{a}	50.85 ± 1.04^{A}	50.60 ± 0.95^{A}	47.85 ± 0.96^{A}	48.55 ± 1.03^{A}

Means marked by different large superscripts A and B in a row differ significantly between the medial and the lateral digits in the same limbs ($p<0.05$). Means marked by different small superscripts (a and b) in a row indicate significant differences between thoracic and pelvic limbs regardless of lateral or medial ($p<0.05$).

Table 3. Mean values of parameters (mm) of the distal phalanx (n=80) of the eight digits in water buffaloes. *Ld*: length of the dorsal surface; *MBS*: middle breadth of the sole; *DLS*: greatest diagonal length of the sole; *CBS*: caudal breadth of the sole

	Pelvic limbs (n=20)		Thoracic limbs (n=20)		Pelvic limbs	Thoracic limbs
	Lateral (n=20)	Medial (n=20)	Lateral (n=20)	Medial (n=20)		
Ld	$59.40±1.01^{B}$	$61.30±0.90^{A}$	$59.25±0.77^{B}$	$60.60±1.06^{A}$	$60.35±4.32^{a}$	$59.92±4.16^{a}$
MBS	$25.05±0.38^{A}$	$25.20±0.40^{A}$	$27.05±0.38^{A}$	$26.70±0.48^{A}$	$25.12±5.48^{b}$	$26.87±6.38^{a}$
DLS	$73.15±0.97^{B}$	$75.35±1.10^{A}$	$77.75±1.09^{A}$	$79.65±1.21^{A}$	$74.25±1.72^{b}$	$78.70±1.93^{a}$
CBS	$33.45±0.43^{A}$	$33.95±0.40^{A}$	$35.30±0.41^{B}$	$36.25±0.46^{A}$	$33.70±4.73^{b}$	$35.77±5.19^{a}$

Means marked by different large superscripts A and B in a row differ significantly between the medial and the lateral digits in the same limbs ($p<0.05$). Means marked by different small superscripts (a and b) in a row indicate significant differences between thoracic and pelvic limbs regardless of lateral or medial ($p<0.05$).

Table 4. Comparison of the mean lengths of the each phalanx and total lengths of the three phalanges of present study with two other studies in Holstein bulls (Ocal *et al.,* 2004) and heifers and steers (Muggli *et al.,* 2011)

		Water buffaloes average live weight 317–383 kg		Holstein bulls average live weight 400 kg		Heifers and steers average live weight 396 kg	
		Pelvic limb	Thoracic limb	Pelvic limb	Thoracic limb	Pelvic limb	Thoracic limb
Proximal phalanx (*MOL*)	Medial	52.10±3.40	53.10±3.70	53.18±0.78	52.04±0.81	64.00±0.73	62.35±0.73
	Lateral	53.60±3.40	51.20±3.50	53.79±0.78	52.21±0.81	64.65±0.81	63.20±0.73
Middle phalanx (*MOL*)	Medial	37.70±2.30	35.40±2.20	38.15±0.52	36.42±0.52	45.50±0.44	43.35±0.61
	Lateral	38.30±2.20	36.20±2.00	38.10±0.52	36.68±0.74	46.30±0.44	42.95±0.65
Distal phalanx (*Ld*)	Medial	40.70±3.80	42.30±3.90	47.19±0.40	48.63±0.45	61.30±0.90	60.60±1.06
	Lateral	40.10±3.80	41.00±4.10	46.11±0.31	47.29±0.71	59.40±1.01	59.25±0.77
Total length	Medial	130.50	130.80	138.52	137.90	170.8±1.66	166.3±1.61
	Lateral	132.00	128.40	138.00	136.18	170.35±1.80	165.4 ±1.60

MOL: middle overall length; *Ld*: length of dorsal surface in 80% (32/40) of the thoracic limb was larger (P<0.05) than that in the pelvic limb. The *SD* of the proximal phalanx in 82.5% (33/40) of the thoracic limb was larger (P<0.05) than that in the pelvic limb. The *GLppa* of the proximal phalanx in 70% (28/40) of the pelvic limb was greater (P<0.05) than that in the thoracic.

In the middle phalanx, the mean values of the medial and lateral digits in the same limb differed significantly in breadth of the distal end (*Bd*) of the thoracic limb and in middle overall length (*MOL*) of the pelvic limb (P<0.05, Table 2). The mean values of *MOL*, *SD*, *Bp*, *Bd*, and the greatest length of the peripheral (abaxial) half (*GLpe*) of the middle phalanx differed significantly between the thoracic and pelvic limbs (P<0.05). The *MOL* of the middle phalanx in 87.5% (35/40) of the thoracic limb was shorter (P<0.05) than that in the pelvic limb. The *SD* of the middle phalanx in 77.5% (31/40) of the thoracic limbs was greater (P<0.05) than that in pelvic limb. The *Bp* of the middle phalanx in 75% (30/40) of the thoracic limbs was larger (P<0.05) than that in the pelvic limb. The *Bd* in 70% (28/40) of the thoracic limbs was larger (P<0.05) than that in the pelvic limb. The *GLpe* of the middle phalanx in 72.5% (29/40) of pelvic limbs was larger (P<0.05) than respective thoracic limb measurements.

In the distal phalanx, the mean values of the medial and lateral digits in the same limb differed significantly in length of the dorsal surface (*Ld*) of the both limbs, greatest diagonal length (*DLS*) of the pelvic limb and in caudal breadth of the sole (*CBS*) of the thoracic limb (P<0.05, Table 3). The mean values of *DLS*, *CBS*, and middle breadth of the sole (*MBS*) of the distal phalanx were significantly different between the thoracic and pelvic limbs (P<0.05). The *DLS* of the distal phalanx in 97.5 (39/40) of the thoracic limbs was greater (P<0.05) than in the pelvic limbs. The *CBS* of distal phalanx in 87.5% (35/40) of thoracic limb was longer (P<0.05) than that in the pelvic limb. The *MBS* of the distal phalanx in 80% (32/40) of the thoracic limb was larger (P<0.05) than that in the pelvic limb.

No significant differences were found between the total lengths of the three phalanges of the medial (mean 166.3±1.61 mm) and the lateral digits (mean 165.4±1.6 mm) of the thoracic limb as well as in the medial (mean 170.8±1.66 mm) and lateral digits (mean 170.35±1.8 mm) of the pelvic limb (Table 4).

DISCUSSION

In the present study, no asymmetry between the lengths of the lateral and medial distal phalanges and the total lengths of the three phalanges within the left and right thoracic and pelvic limbs was found. Nevertheless, Muggli *et al.* (2011) pointed out that the lengths of lateral and medial individual digital bones, the metacarpal/ metatarsal condyles, and total lengths of the three phalanges, including the metacarpal/ metatarsal condyles of 40 cattle of different ages were significantly different. In addition, Ocal *et al.* (2004) measured four variables of all digital bones of eight Holstein bulls and found no significant differences between the lengths of the lateral and medial proximal and middle phalanges but did not measure the total lengths of the digital bones or the metacarpal/metatarsal condyles.

Based on findings of studies (Nacombo *et al.,* 2007; Keller *et al.,* 2009; Muggli *et al.,* 2011) the length asymmetry of medial and lateral cannon condyles are responsible for the difference in the length of the paired digits. It can be hypothesised that such a length asymmetry of cannon bones exists in the water buffalo. This hypothesis is supported by a recent described small difference in size (toe length) of paired hooves in water buffalo through naked eye (Nourinezhad & Mazaheri, 2012). However, it is unclear whether the difference in length of the cannon bone condyles does account for an overall length difference of the digits.

Our methods and results were similar to the measurements of Ranft (1936) and Von den Driesch (1976) but differed from the radiographic measurements of other authors. Direct measurements have the advantage of direct visibility and better determination of measuring points, whereas in radiographic measurements, projection errors and poorer visibility of the surface of the bones may account for mistakes. On the other hand, reference points have to be determined very thoroughly in direct measurements of bones.

It is obvious that form and function are closely correlated; appropriate structures enable an animal to perform specific tasks. In accordance with anatomical observations in cattle (Bartosiewicz *et al.,* 1997; Schwarzmann, 2004b), we found that breadth parameters of the medial digits were greater than those of the lateral digits in thoracic limb. This finding indicates a difference in function, or weight bearing, between the lateral and medial digit. Furthermore, the advantages of symmetric digital bones may contribute to distributing equal weight on a foot during standing or walking and might explain why biomechanical lesions of the feet in water buffaloes are much less frequent than in cattle (FAO, 1977). Another possible reason is that water buffaloes spend much of their day submerged in the muddy waters of tropical and subtropical forests (FAO, 1977), where the hooves sink equally into the ground and a difference in length might not be necessary.

Table 4 shows a comparison of the mean values of the lengths of the single bones and the total lengths of the three phalanges between the lateral and medial digits in the thoracic and the pelvic limbs. When we compared our results with other studies in Holstein bulls weighing 400 kg (Ocal *et al.,* 2004); and heifers and steers weighing 396 kg (Muggli *et al.,* 2011), the mean values in our study were distinctively greater than the values of the bovine studies. This difference in length of the foot or legs among ruminants may influence locomotor habits. This structural adaptation may be responsible for having more capacity of shock absorption because longer and larger bones absorb more shock (impact energy) than short and slender bones (Muvdi & McNabb, 1980). Thus, the ability of shock absorption in water buffaloes seems to be better than that of the large domestic ruminants. Moreover, this difference in length may play a role in better running ability of water buffaloes compared to the large domestic ruminants because the longer the leg, the longer the stride.

Complete or broken limb skeleton elements of animals occur very frequently in archaeological deposits (Von den Driesch, 1976). Therefore, data acquired in the present study might be useful as reference values for the evaluation and identification of water buffalo digits for researchers working on osteoarchaeological excavations.

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Correspondence:

J. Nourinezhad
Faculty of Veterinary Medicine,
Shahid Chamran University of Ahvaz,
P. O. Box 145, 61355 Ahvaz, Iran
e-mail: j.nourinezhad@scu.ac.ir