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Morphological and Morphometrical studies on the phalanges and sesamoid bones of blue bull (*Boselephus tragocamelus*)

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Abstract
The present study was conducted on the phalanges and sesamoid bones of Blue bull (*Boselephus tragocamelus*). Two fully developed digits (III) and IV) were observed in each limb. Each digit comprised of three phalanges. The first or proximal phalanx was laterally compressed. The second phalanx was nearly half the length of the first phalanx. The third phalanx was irregularly prismatic bone; a prominent extensor process was present on the dorsal border. In the present study, four proximal sesamoid bones, two for each digit were present. These bones were placed palmar to the metatarsophalangeal and metatarso-phalangeal joint (fetlock joint). Two distal sesamoid bones were present one for each digit, placed palmarly in between the second and third phalanx (coffin joint).

Keywords: Phalanges, Sesamoid bones, Fetlock, Coffin, Blue bull

1. Introduction
The Blue bull (*Boselephus tragocamelus*) is sometimes also known as nilga**i**. Blue bull is found in the day open forests of northern and central part of India and is one of the largest antelopes in the Asian continent. These animals are protected under International Union for Conservation of Nature and Natural Resources (IUCN) since 2003 by (Mallon 2008) [8] and also protected under Schedule III of the Indian Wildlife Protection Act, 1972 (Bagchi *et al*. 2004) [1]. The purpose of this work is to investigate phalanges and sesamoid bones of blue bull, thereby creating a contribution in filling the gap of knowledge in this area. As per knowledge, in many vetero-legal cases, one fails to identify the bones of this animal and blur them with those of some other large ruminants and wild animals. This investigation will be helpful to the field veterinarians as well as zoo veterinarians.

2. Materials and Methods
The present study was conducted on the phalanx and sesamoid bones of six adult blue bull of either sex. The permission for the specimen collection was sought from the Principal Chief Conservator of Forest (PCCF), Government of Rajasthan. The skeletons were collected from the Jodhpur zoo after official approvals from the Principal Chief Conservator of Forest vide letter no. F, 3 (04) Tech-II/CCF/2013/2326 dated 12.01.2015 and from The Deputy Conservator of Forest wildlife, Jodhpur s.n./sam/388-90 dated 22.01.2015.The skeletons were dug out from the graveyards located in the premises of Jodhpur zoo and processed as per standard technique (Raghavan, 1964) [11]. Subsequently, these osteological specimens were studied to record their morphometrical features. Different parameters of phalanges and sesamoid bones of blue bull were measured and subjected to routine statistical analysis (Snedecor and Cochran, 2004) [14].

2.1. Following parameters were taken for digits of adult blue bull of either sex
A. Measurements for the first and second phalanx:
a) greatest length (Lg)

b) Maximum breadth of proximal extremity (Bp)
c) Maximum breadth of distal extremity (Bd)
d) Maximum breadth of shaft (Bs)

B. Measurements for the third phalanx:
a) Greatest length (Lg)
b) Maximum breadth of articular surface (Ba)
c) Maximum height including extensor process (He)

C. Measurements for the proximal and distal sesamoid bones:
a) Greatest length (Lg)
b) Maximum breadth (Bm)

3. Results and Discussion
In the present study, two fully developed digits possessed three phalanges per digit, namely, proximal, middle and distal phalanx in blue bull (Fig.1 to 5) as described by Raghavan (1964) [11] in ox, Budras and Robert (2003) in bovine, Siddiqui *et al.* (2008) in Black Bengal goat, Choudhary *et al.* (2014) [5] in chital and Choudhary *et al.* (2015) [3] in blackbuck. However, five digits were present in dog (Miller *et al.*, 1964; Konig and Liebich, 2006) [10], where each digit consists of three phalanges, except for the first digit, which had only two phalanges, in the African elephant (Smuts and Bezuidenhout, 1993) where second to fourth digits consist of three phalanges each, fifth digit has two phalanges, while the first digit has a single phalanx; four digits were present in pig (Konig and Liebich, 2006; Akers and Denbow, 2008 and Frandson *et al.*, 2009) [6] where each digit consisted of three phalanges each. Only one digit consisting of three phalanges was present in horse (Getty, 1975) [7]

3.1 First or Proximal Phalanx (phalangia proximalis vel os compedele)
The first phalanx was a long bone and presented a shaft and two extremities (Fig. 1 to 2). The shaft or body was elongated and laterally compressed as reported by (Raghavan, 1964) [11] in ox and Choudhary *et al.* (2015) [3] in blackbuck; but in contrast it was dorso-palmarly compressed in horse (Getty, 1964). The dorsal and abaxial surfaces were continuous as described in ox (Raghavan, 1964) [11]. The axial surface was flat as reported by Raghavan (1964) [11] in ox, Siddiqui *et al.* (2008) in Black Bengal goatmand Choudhary *et al.* (2015) [3] in blackbuck, while it was somewhat elevated in horse (Getty, 1975) [7]. It had a nutrient foramen just below the half way marker. The caudal or palmar surface bore a nodular elevation at its distal aspect on both sides as revealed in ox (Raghavan, 1964) [11] and Choudhary *et al.* (2015) [3] in blackbuck.
The proximal extremity was broader as compared with distal one as reported in horse (Getty, 1975) [3], in ox (Raghavan, 1964) [11] and Choudhary *et al.* (2015) [3] in blackbuck. It bore a concave articular surface, which was divided into two by a deep sagittal groove. The abaxial articular facet was larger and higher than the axial one as distinguished in ox (Raghavan, 1964) [11], in Back Bengal goat (Siddiqui *et al.* 2008), Choudhary *et al.* (2015) [3] in blackbuck and dissimilar to horse (Getty, 1975) [7], in which, the axial one was larger. Caudally two articular facets were present, an axial, and relatively larger and higher abaxial facet for articulation with the proximal sesamoids as mentioned in ox (Raghavan, 1964) [11] and Choudhary *et al.* (2015) [3] in blackbuck.
On the distal extremity the articular surface was divided by a dorso-palmar groove into two condyles, of which, the abaxial one was larger as reported in ox (Raghavan, 1964) [11], in Black Bengal goat (Siddiqui *et al.* 2008) and in Blackbuck (Choudhary *et al.* 2015) [3]; however, the medial condyle was larger in horse (Getty, 1975) [7]. The distal extremity presented a depression on both sides as distinguished in horse (Getty, 1975) [7] and in dromedary (Smuts and Bezuidenhout, 1987).
The average greatest length of the first phalanx of blue bull was 7.64±0.01 cm. The average maximum breadth of proximal extremity, shaft and distal extremity was 2.55±0.01cm, 2.25±0.01and 2.35±0.01cm, respectively.
The maximum length of first phalanx was 2.88±0.08 cm in adult Black Bengal goat (Siddiqui *et al.*, 2008). However, the average greatest length of the first phalanx of was 4.61±0.008 cm. The average maximum breadth of proximal extremity, shaft and distal extremity was 1.03±0.002 cm, 0.85±0.003 and 0.89±0.005 cm, in Blackbuck (Choudhary *et al.* 2015) [3]; respectively,

3.2 Second or Middle Phalanx (phalangia mediae vel os coronale)
The second phalanx (Fig.3 & 4) was nearly more than the half the length of the first phalanx as described in dromedary (Smuts and Bezuidenhout, 1987) and in chital (Choudhary *et al.*, 2013) and nearly half of the length of the first phalanx as described by in Blackbuck (Choudhary *et al.* 2015) [3]; whereas in ox (Raghavan, 1964) [11], it was two third of the first phalanx.
The shaft was elongated and presented three surfaces as described by Raghavan (1964) [11] in ox, Siddiqui *et al.* (2008) in black Bengal goat and Choudhary *et al.* (2015) [3] in Blackbuck; while the shaft was four sided and flattened dorso-palmarly in horse (Getty, 1975) [7]. The axial surface was rough and slightly depressed distally. It bore a small tubercular elevation a little above the middle. The palmar surface was slightly concave, while in dromedary, it was flat (Smuts and Bezuidenhout, 1987). These findings completely agree the observations of Raghavan (1964) [11] in ox, Choudhary *et al.* (2014) [11] in chital and Choudhary *et al.* (2015) [3]; in blackbuck.
The proximal extremity presented an articular surface which was divided into two concave facets by a dorso-palmar ridge. The abaxial facet was larger than the axial one as elucidated in ox (Raghavan, 1964) [11], in Black Bengal goat (Siddiqui *et al.* 2008) and in Blackbuck (Choudhary *et al.* 2015) [3].
The distal extremity was smaller than the proximal one as reported by Raghavan (1964) [11] in ox, Siddiqui *et al.* (2008) in Black Bengal goat and in Blackbuck (Choudhary *et al.* 2015) [3].
The distal extremity was divided by a dorso-palmar groove into two condyles, the axial of which was comparatively larger than axial one as narrated by Raghavan (1964) [11] in ox, Smuts and Bezuidenhout (1987) in dromedary, Choudhary *et al.* (2014) in chital and in Blackbuck (Choudhary *et al.* 2015) [3]. The articular surface encroached considerably on the anterior and posterior aspects as reported in ox (Raghavan, 1964) [11].
The average greatest length of the second phalanx of blue bull was 4.31±0.01 cm. The average maximum breadth of proximal extremity, shaft and distal extremity was 2.23±0.00 cm, 1.89±0.01cm and 2.05±0.01 cm, respectively. However, (Choudhary *et al.* 2015) [3] epitomized in blackbuck it was 2.31±0.01 cm, 0.93±0.005 cm, 0.67±0.005 cm and 0.84±0.005 cm, respectively.
The total length of middle phalanx was 1.88±0.03 cm in adult Black Bengal goat (Siddiqui *et al.*, 2008).

Fig 1: Cranial view of the medial first phalanx showing shaft (a); abaxial and axial articular surface (b,c).

Fig 2: Axial view of the medial first phalanx showing proximal extremity (a); shaft (b); axial depression (c); distal extremity (d).

Fig 3: Cranial view of the medial second phalanx showing proximal extremity (a); shaft (b); axial articular facet (c); abaxial articular facet (d).

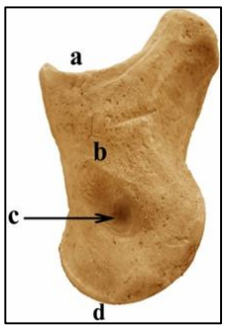

Fig 4: Axial view of the medial second phalanx showing proximal extremity (a); shaft (b); axial depression (c); distal extremity (d).

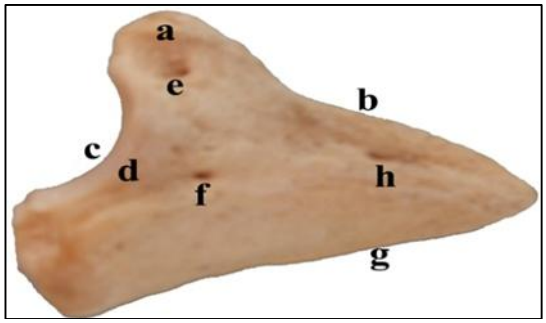

Fig 5: Axial view of the medial third phalanx showing extensor process (a); dorsal border (b); axial articular facet (c); abaxial articular facet (d); cranial foramen (e); distal foramen (f); ventral border (g); caudal foramen (h).

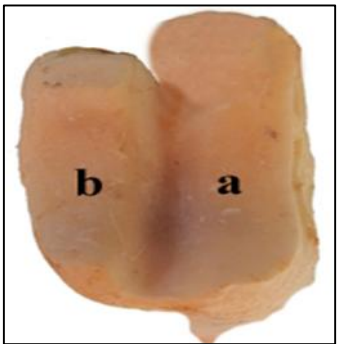

Fig. 6: Dorsal view of the proximal sesamoids showing abaxial sesamoid (a); axial sesamoids (b).

3.3 Third or Distal Phalanx (phalangia distalis vel os ungulare)

The third phalanx (Fig.5) was irregularly prismatic bone, which presented four surfaces and six borders in blue bull as distinguished by Raghavan (1964) [11] in ox, Siddiqui *et al.* (2008) in black Bengal goat and (Choudhary *et al.* 2015) [3] in blackbuck, and dissimilar to the observations of Getty (1975) [7] in horse, where it presented three surfaces, three borders and two angles. The abaxial surface was almost convex, rough and traversed by a cranio-caudal ridge. The area below the ridge was rough, raised and presented three foramina; of which caudal-most foramen was the largest. In contrast the area above the ridge was rough and perforated by a number of foramina in ox (Raghavan, 1964) [11] and in blackbuck (Choudhary *et al.* 2015) [3]. The axial surface bore a groove, which possessed a foramen of considerable size; while there were a number of foramina in ox (Raghavan, 1964) [11]. The ventral or sole surface was nearly flat to slightly concave as described in ox (Raghavan, 1964) [11] and in blackbuck (Choudhary *et al.* 2015) [3].

The dorsal or articular surface was concave cranio-caudally, and sloped downwards and backwards facing posteriorly and dorsally as mentioned by Raghavan (1964) [11] in ox, Siddiqui *et al.* (2008) in Black Bengal goat and in blackbuck (Choudhary *et al.* 2015) [3]. It was divided by a cranio-caudal sharp oblique ridge into two areas; of which the abaxial one was smaller and higher in level than the axial one. In contrast the ridge was faint and abaxial area was comparatively larger as reported in ox (Raghavan, 1964) [11] and in blackbuck (Choudhary *et al.* 2015) [3]. This surface presented posteriorly a small transverse concave facet posteriorly for articulation with the distal sesamoid.

In the present study four surfaces were separated by six borders in blue bull as notified in blackbuck (Choudhary *et al.* 2015) [3]. The dorsal border was straight and sharp, and presented a prominent extensor process posteriorly as elucidated in ox (Raghavan, 1964) and in blackbuck (Choudhary *et al.* 2015) [3]. Below to this process, axial and abaxial foramina were present; of which axial one was significantly larger. The anterior tip of this border, the apex was sharp as described in ox (Raghavan, 1964) [11] and in blackbuck (Choudhary *et al.* 2015) [3].

The average greatest length of the third phalanx in blue bull was 5.79±0.01 cm. The average maximum breadth of articular surface was 1.83±0.01 cm and the average maximum height including extensor process was 3.89±0.01 cm. However, (Choudhary *et al.* 2015) [3] elucidated in blackbuck 2.77±0.007 cm, 0.82±0.006 cm and 1.87±0.01 cm respectively.

3.4. Sesamoid Bones (ossa sesamoidea)

In the present study, four proximal sesamoid bones (ossa sesamoidea proximalia) (Fig. 6), two for each digit were present. These bones were placed palmar to the metacarpo-phalangeal joint (fetlock joint) as described by Raghavan (1964) [11] in ox, Miller *et al.* (1964) [10] in dog, Smuts and Bezuidenhout (1993) in African elephant (*Loxodonta african)* and (Choudhary *et al.* 2015) [3] in blackbuck.

There were two distal sesamoid bones present one for each digit, placed palmarly in between the second and third phalanx (Coffin joint) as elucidated by Raghavan (1964) [11] in ox, Getty (1975) [7] in sheep, Budras and Robert (2003) in bovine, Siddiqui *et al.* (2008) in Black Bengal goat, Frandson *et al.* (2009) [6] in most of the domestic animals and (Choudhary *et al.* 2015) [3] in blackbuck.

However, two palmar and one dorsal sesamoid bone were present for each main metacarpal and one palmar sesamoid for small metacarpal in the proximal row in dog (Miller *et al.*, 1964) [10], while two proximal and one distal sesamoid bone were present in horse (Getty, 1975) [7]. The distal row of sesamoids was missing in dog (Miller *et al.*, 1964) [10] and in dromedary (Smuts and Bezuidenhout, 1987).

The proximal sesamoid bones of blue bull were small, oval in outline as reported by (Raghavan, 1964) [11] in ox, while in horse, these were three sided pyramid shaped (Getty, 1975) [7] and in dromedary, these were wedge-shaped with the apex pointing proximally (Smuts and Bezuidenhout, 1987) and where crescent shaped, short bones, (Choudhary *et al.* 2015) [3] in blackbuck. These were arranged in pairs as medial and lateral of the two bones of each pair, the abaxial one was wider and less elongated than the axial one as described in ox (Raghavan, 1964) [11], dromedary (Smuts and Bezuidenhout, 1987) and in blackbuck (Choudhary *et al.* 2015). The articular surface of each sesamoid was concave and was divided into two unequal areas by a faint vertical ridge, of which axial one was larger as reported by Raghavan (1964) [11] in ox, Smuts and Bezuidenhout (1987) in dromedary and (Choudhary *et al.* 2015) [3] in blackbuck. The palmar surface was rough and convex. The anterior part of the base was drawn forwards and downwards and presents a facet for articulation with the first phalanx. The apex was pointed dorsally as reported by (Choudhary *et al.* 2015) [3] in blackbuck.

The greatest length and maximum breadth of abaxial sesamoid bone in blue bull was 2.48±0.01 cm and 1.22±0.01 cm, respectively, while the greatest length and the maximum breadth of axial sesamoid bone were 2.42±0.01 cm and 1.26±0.01 cm, respectively. However, the greatest length and maximum breadth of abaxial sesamoid bone was 1.13±0.006 cm and 0.55±0.004 cm, respectively, while the greatest length and the maximum breadth of axial sesamoid bone were 0.95±0.004 cm and 0.45±0.003 cm, respectively (Choudhary *et al.* 2015) [3] in blackbuck.

The distal sesamoid was short bone, which was rounded in outline in blue bull unlike in Indian One-horned Rhinoceros where it was quadrilateral in outline (Baishya *et al.*, 2001) [2], in horse, where it was shuttle-shaped (Getty, 1975) [7]. The distal sesamoid offered two surfaces and two borders in blue bull as described by Raghavan (1964) [11] in ox and (Choudhary *et al.* 2015) [3] in blackbuck; while in disagreement with Baishya *et al.* (2001) [2], who examined it to be presenting three surfaces, three borders and two extremities in Indian One-horned Rhinoceros and Getty (1975) [7], who reported it to have two surfaces, two borders and two extremities in horse. The articular surface was divided by an oblique ridge into two concave areas, the axial of which was larger than the abaxial one as describe in ox (Raghavan, 1964) [11] and in blackbuck (Choudhary *et al.* 2015) [3]. The palmar surface was rounded, smooth and convex.

The greatest length and maximum breadth of distal sesamoid bone in blue bull was 2.06±0.00 cm and 1.62±0.02 cm, respectively. However, same was 0.88±0.005 cm and 0.63±0.007 cm, respectively in blackbuck (Choudhary *et al.* 2015) [3]

4. Conclusion

The results of the present study on gross morphological and morphometrical parameters were very useful for forensic investigation of poaching wild animals. In the present study, two fully developed digits (III) and IV) were observed in each forelimb of blue bull. Each digit had three phalanges. The first or proximal phalanx was laterally compressed. The second phalanx was nearly half the length of the first phalanx. The third phalanx was irregularly prismatic bone; a prominent extensor process was present on the dorsal border. These findings were similar to ox, sheep and goat; however, five digits were present in dog, where each digit consists of three phalanges, except for the first digit, which had only two phalanges. Only one digit consisting of three phalanges was present in horse. Two small, crescent shaped proximal and one rounded distal sesamoid bones were present in each digit similar to ox, sheep and goat; However, two palmar and one dorsal sesamoid bone were present for each main metacarpal and one palmar sesamoid for small metacarpal in the proximal row in dog, while two proximal and one distal sesamoid bone were present in horse The distal row of sesamoid is missing in dog and camel.

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