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Comparative morphological and morphometrical analysis of the humerus bone in bovines: A study of Ox (*Bos indicus*) and Nilgai (*Boselaphus tragocamelus*)

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Abstract
This research paper presents a comparative analysis of the humerus bone between two bovine species, Ox and Nilgai, focusing on the proximal extremity, head, distal extremity, and shaft. Biometrical measurements were conducted to gain insights into the anatomical differences and potential functional adaptations between the two species. The proximal extremity revealed significant variations in the humerus head shape, neck development, and lateral tuberosity between Ox and Nilgai. The head region displayed differences in transverse and vertical diameters, potentially influencing joint articulation and mobility. Moreover, circumference and bicipital groove analyses provided further distinctions in structural robustness and muscle attachment points. In the distal extremity, differences in condyles, epiphyses, and muscle attachment sites indicated adaptations related to locomotion behaviors. The shaft analysis revealed variations in length, circumference, and deltoid tuberosity position, reflecting potential functional differences. Overall, this study offers valuable insights into the anatomical adaptations and evolutionary history of Ox and Nilgai, contributing to our understanding of bovine species' functional morphology.

Keywords: Morphology, morphometry, humerus, Ox, Nilgai

1. Introduction

The Nilgai (*Boselaphus tragocamelus*) and Ox (*Bos taurus*) belong to the family Bovidae and share common characteristics as bovine species. Nilgai, also known as the blue bull, is the largest Asian antelope and is characterized by its robust build and distinctive blue-gray coat. They are primarily found in the Indian subcontinent, inhabiting grasslands, forests, and agricultural areas (Weblink) [10]. On the other hand, domestic Oxen, derived from the wild Aurochs, have been domesticated for thousands of years and are known for their utility in various agricultural tasks, such as plowing fields and transporting heavy loads. They come in various breeds, each adapted to specific environmental conditions and human needs (Ajmone-Marsan *et al.*, 2010) [1].

The humerus bone, present in the forelimbs of both Nilgai and Ox, plays a crucial role in supporting and facilitating movement. As mentioned earlier, this research delves into the intricate anatomical variations of the humerus bone in these two species. The humerus is a long bone that articulates with the scapula at the shoulder joint and the radius and ulna bones at the elbow joint. Its structure is essential for enabling a wide range of movements, such as flexion, extension, abduction, and adduction of the forelimbs.

By exploring the general characteristics of Nilgai and Ox, along with the unique anatomical features of their humerus bones, this research contributes to a comprehensive understanding of the adaptive strategies and evolutionary history of these bovine species. The insights gained from this study can enhance our knowledge of their functional morphology, providing valuable information for comparative anatomy, evolutionary biology, and animal biomechanics. Ultimately, this research adds to the growing body of knowledge concerning the diverse adaptations exhibited by different species in response to their respective environments and ecological niches.

2. Materials and Methods

The samples of humerus bones were collected from the local forest and nearby areas of the college, where different bones were scattered from naturally deceased Ox and Nilgai. Two samples of Nilgai and three Oxen bones were collected, regardless of their sex. To prepare the bones for analysis, the hot water maceration technique was employed following established methods. Subsequently, the macerated bones were left to sundry for six days before being used for further examinations. The morphometric analysis of the humerus bones was performed using vernier calipers (0-150mm) and involved routine statistical analysis using established methods (Snedecor and Cochran, 1994) [8]. Various measurements obtained during the analysis were subjected to statistical examination to gain insights into the anatomical characteristics and potential differences between the bones of Ox and Nilgai.

3. Results and Discussion

The humerus bone is a major long bone in the forelimb of large animals, such as bovines and equines. It provides structural support to the entire forelimb, enabling these animals to bear the weight of their bodies and carry out various locomotor activities (Meshram and Singh, 2019) [3]. The biometrical observations of the humerus bone for two different species, Ox and Nilgai were also measured. These measurements offer valuable insights into the anatomical differences between the two species. The humerus bone was situated obliquely downward and backward; forms shoulder joint above with the scapula and elbow joint below with the radius and ulna. It was composed of two extremity (Proximal and distal) and a shaft.

3.1 Proximal Extremity

The proximal extremity of the humerus plays a crucial role in the articulation and function of the shoulder joint in both Ox and Nilgai. In Nilgai, the humerus head exhibits an oval and highly convex shape, whereas in Ox, it appears circular. The neck of the humerus in Nilgai is more developed and constricted compared to the blunter neck observed in Ox (Fig. 1.1, 2.1). The lateral tuberosity, which forms the lateral boundary of the intertubercular or bicipital groove, differs between the two species. In Nilgai, the lateral tuberosity is larger and divided into anterior and posterior components, separated by a prominent groove. On the other hand, Ox has a single, more extensive lateral tuberosity (Fig.1.1, 2.1). The summit of the lateral tuberosity is positioned approximately 3 cm higher than the head in both species, providing essential points of attachment for muscles. The medial tuberosity in Nilgai is relatively smaller and lacks noticeable division seen in Ox, appearing quadrilateral in shape (Fig.1.2, 1.3, 2.2, 2.3). similar to the findings of (Raghavan, 1964) [6] in Ox and (Sarma *et al.*, 2008) [7] in Nilgai. These differences in the proximal extremity of the humerus bone may reflect adaptations to their distinct locomotor behaviors and ecological niches.

3.1.1 Head of Humerus

The comparative analysis of the humerus bone dimensions in Ox and Nilgai reveals intriguing differences in the head region. Ox exhibits a wider transverse diameter of the head (9.63 cm) compared to Nilgai (7.75 cm), suggesting a broader humerus head in Ox. Moreover, Ox also possesses a taller vertical diameter of the head (9.43 cm) compared to Nilgai (7.55 cm), indicating a relatively elongated head in Ox. However, when considering the circumference of the head, the difference between Ox (21.13 cm) and Nilgai (20.55 cm) is relatively minor. These variations in head dimensions may influence joint articulation and functional adaptations between the two bovine species, impacting their movement and mobility (Table-1).

3.1.2 Circumference and Bicipital Groove Analysis

The circumference at the proximal extremity differs significantly between Ox (30.93 cm) and Nilgai (27.35 cm), with Ox exhibiting a more robust structure. However, Nilgai displays a slightly wider proximal extremity (9.7 cm) compared to Ox (9.27 cm). The analysis of the bicipital groove width and summit height reveals distinctions between the two species. Nilgai has a slightly wider bicipital groove (2.45 cm) than Ox (2.27 cm), and Ox exhibits a taller summit over the bicipital groove (3.83 cm) compared to Nilgai (2.9 cm), indicating potential differences in shoulder joint mobility and muscle attachments. Additionally, the height of the summit over the convexity in Ox (1.87 cm) is higher than in Nilgai (1.05 cm), suggesting potential variations in functional adaptations in the shoulder region between the two species (Table-1). Overall, the proximal extremity and head region of the humerus bone exhibit notable differences between Ox and Nilgai, reflecting their distinct anatomical characteristics and potential adaptations related to locomotion and ecological preferences. Understanding these variations can offer valuable insights into the evolutionary history and functional morphology of these bovine species.

3.2 Distal Extremity

The distal extremity of the humerus in both Ox and Nilgai exhibits both similarities and significant anatomical differences. Both species possess condyles, pulleys, and epiphyses contributing to joint mobility, albeit varying in size and shape. Furthermore, distinct variations were observed in the alignment of muscle attachment sites, suggesting potential differences in biomechanical and functional adaptations between the two species.

In both Ox and Nilgai, the Radial fossa showed a similar depth, contrary to the findings of Sarma *et al*. (2008) [7] in Nilgai Additionally, the medial condyle was larger than the lateral condyle in both Ox (Raghavan, 1964) [6] and Nilgai (Sarma *et al.*, 2008) [7], featuring a sagittal groove (Fig.1.1, 1.2, 2.3). The Olecranon fossa, deeper in Nilgai than Ox (Sarma *et al.*, 2008) [7], allows better accommodation of the ulna's olecranon process in Nilgai (Fig.1.1, 1.2, 2.1, 2.2). Both species displayed a prominent lateral condylar crest, while the lateral epicondyle was longer than the medial epicondyle, which was wider in both cases. Moreover, the lateral margin of the lateral epicondyle exhibited a rough surface, in contrast to the smooth surface of the medial condyle (Fig.1.1, 1.2, 1.4, 2.3, 2.4). These differences in the distal part of the humerus between Ox and Nilgai are likely related to their distinct locomotion behaviors and evolutionary adaptations. The agile and swift movement of the Nilgai may have led to anatomical changes enhancing its running ability, while domesticated Ox, bred for strength and carrying purposes, may possess traits advantageous for those tasks. These findings underscore the role of natural selection in shaping the anatomical characteristics of bovine species.

In terms of circumference, Ox demonstrates a larger distal extremity (27.30 cm) compared to Nilgai (24.95 cm), indicating a more robust structure in this region. Additionally, Ox exhibits a wider distal extremity (7.83 cm) compared to

Nilgai (6.95 cm), implying potential variations in joint articulation and functional adaptations. The analysis of the capitulum in Ox and Nilgai reveals significant differences in length and width. Ox exhibits a longer capitulum (3.40 cm) compared to Nilgai (2.6 cm), indicating a more elongated structure in the distal end of the humerus bone. On the other hand, Nilgai shows a slightly wider capitulum (1.75 cm) compared to Ox (1.67 cm). The examination of the trochlea and radial fossa in Ox and Nilgai reveals notable differences in their dimensions. Ox exhibits a longer trochlea (4.47 cm) compared to Nilgai (3.55 cm), potentially affecting the articulation of the humerus with the ulna bone. While the length of the radial fossa shows only a slight difference between the two species, with Ox having an average length of 2.97 cm and Nilgai having 2.9 cm, Ox exhibits a deeper radial fossa (1.83 cm) compared to Nilgai (1.55 cm). These distinctions in the length and depth of the radial fossa may influence the movement and stability of the radius bone within the elbow joint. The examination of the olecranon fossa in Ox and Nilgai reveals distinct measurements that provide insights into their anatomical variations. Nilgai exhibits a slightly longer olecranon fossa (3.85 cm) compared to Ox (3.77 cm), suggesting potential differences in the interactions between the humerus and the ulna bone during elbow movement. On the other hand, Ox exhibits a wider olecranon fossa (2.77 cm) compared to Nilgai (2.6 cm), potentially impacting the accommodation and mobility of the olecranon process. Although the difference in the depth of the olecranon fossa between the two species is slight, with Ox having an average depth of 2.77 cm and Nilgai having 2.6 cm, these observations provide valuable insights into the unique anatomical adaptations of Ox and Nilgai (Table-1).

3.3 Shaft

The shaft of the Nilgai humerus is twisted and irregularly cylindrical, similar to the ox (Getty, 1975) [2]. However, it differs from other wild ruminants like Mithun, which have antero-posteriorly bent shafts (Talukdar *et al*., 2002) [9]. Both Ox and Nilgai humerus shafts have four surfaces. The cranial surface of the Nilgai's humerus is smooth and triangular, wider above than below (Fig.1.3, 2.3), similar to the Ox and Mithun (Getty, 1975; Talukdar *et al.*, 2002) [2, 9]. Unlike the ox, the front surface of Nilgai's humerus exhibits longitudinal muscular imprints on the proximal broad section and distal narrow part (Sarma *et al.*, 2008) [7].

The medial surface of both Nilgai and Ox humerus is nearly straight and rounded, but the teres tubercle is located just above the middle point in Nilgai, in contrast to cattle (Raghavan, 1964). The lateral surface of the Nilgai's humerus has a deep and well-developed musculospiral groove (Fig.1.2, 2.2), similar to cattle and Mithun (Nickel *et al.*, 1986; Talukdar *et al.*, 2002) [4, 9]. Between the anterior and lateral surfaces lies the crest of the humerus, including the deltoid tuberosity, which is profound and elongated in Nilgai, unlike the ox (Getty, 1975) [2]. The deltoid ridge in Nilgai is sharper and larger compared to the ox. Absence of the deltoid tuberosity was observed in the Western African giraffe (Onwuama, 2021) [5], while a well-developed deltoid tuberosity was noted in horses (Getty, 1975) [2]. The insertion nodule of the teres minor muscle is less developed in Nilgai than in the ox. Nutritional foramina are observed towards the lateral part of the posterior surface of the Nilgai's humerus (Fig.1.1, 1.4, 2.1, 2.4), similar to the ox (Nickel *et al.*, 1986) [4].

3.3.1 Morphometry of Shaft: The analysis of the humerus shaft in Ox and Nilgai provides valuable data on their anatomical differences and potential functional adaptations.

Shaft Length: Ox has a longer humerus shaft, measuring approximately 17.30 cm, compared to Nilgai's shaft length of around 16.35 cm (Table-1). This suggests Ox may have a longer lever arm for muscle attachments and joint movements, influencing its locomotion and movement patterns.

Deltoid Tuberosity Position: The deltoid tuberosity, serving as an insertion site for tendons of the triceps brachii and deltoid muscles, is positioned differently in Ox and Nilgai. In Ox, it is located around 13.30 cm from the proximal end, while in Nilgai, it is at approximately 11.4 cm (Table-1). This variation can impact the biomechanics of their upper limbs and muscle mechanical advantage during movement.

Shaft Circumference: Variations in circumference exist at different points in the humerus bone between Ox and Nilgai.

3.3.2 Proximal Shaft Circumference: Ox exhibits a larger circumference, around 23.20 cm, compared to Nilgai's 16.5 cm (Table-1). This suggests Ox's humerus has a more robust structural strength and support at the upper end. Middle Shaft Circumference: At the middle part, Ox measures approximately 14.87 cm in circumference, while Nilgai is around 12.35 cm (Table-1). This indicates potential differences in cross-sectional area and load-bearing capacity. Distal Shaft Circumference: The difference between Ox (approximately 12.53 cm) and Nilgai (approximately 12.2 cm) at the distal part is slight (Table-1), suggesting a similarity in this aspect of the humerus bone.

These morphometric data provide insights into the structural adaptations and functional characteristics of Ox and Nilgai. Their differences in shaft length and circumference may be associated with distinct locomotion behaviors and evolutionary adaptations. Ox's longer shaft and larger proximal circumference may be advantageous for strength and carrying capacity, while Nilgai's relatively shorter shaft and circumference may contribute to quick and agile movement. Moreover, the position of the deltoid tuberosity and the presence of longitudinal muscular imprints on the front surface of Nilgai's humerus indicate potential variations in muscle attachments and functional adaptations between the two species.

The humeral index, reflecting the ratio of maximum humeral length to circumference, indicates bone robustness. Ox shows an average humeral index of 55.48, while Nilgai's is 42.85 (Table-1). Ox has a higher humeral index, suggesting a more robust bone suited for carrying purposes, while Nilgai's slightly lower index aligns with its agility and swift movement. Understanding this index provides insights into their adaptations and evolutionary history.

The foraminal index, which relates shaft length to nutrient foramina count, is comparable in both species. Ox shows an average foraminal index of 47.76, while Nilgai's is 48.46 (Table-1). This similarity suggests a consistent pattern of nutrient foramina distribution along the shaft length in both species. The foraminal index serves as a valuable morphological marker in understanding bone vascularization and adaptations.

Fig 1.1: Lateral view (OX)

Fig 1.2: Medial view (OX)

Fig 1.3: Cranial view (OX)

Fig 1.4: Caudal view (OX)

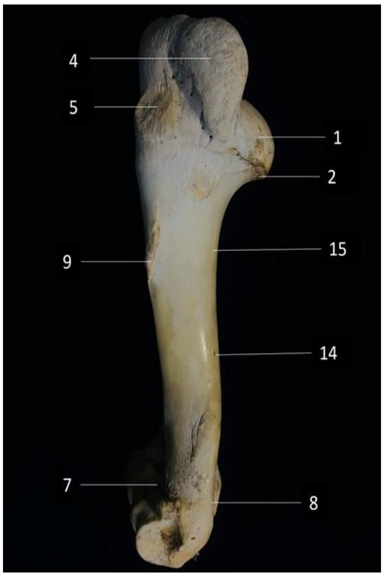

Fig 2.1: Lateral view (Nilgai)

Fig 2.2: Medial view (Nilgai)

Fig 2.3: Cranial view (Nilgai)

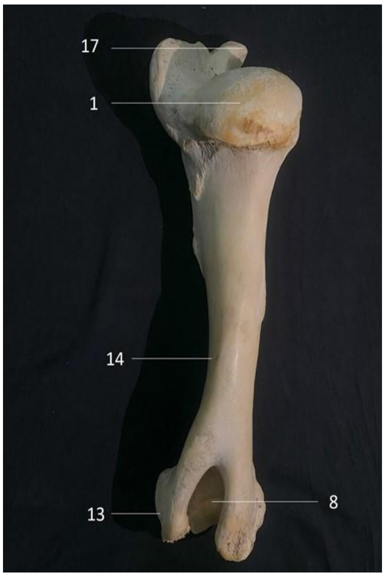

Fig 2.4: Caudal view (Nilgai)

Figures Showing-Legends: 1- Head, 2- Neck, 3- Medial tuberosity, 4- Lateral tuberosity, 5- Rough tubercle, 6- Teres tubercle, 7- Radial fossa, 8- Olecranon fossa, 9- Deltoid tuberosity, 10- Medial condyle, 11- Lateral condyle, 12- Medial epicondyle, 13- Lateral epicondyle, 14- Nutrient foramen, 15- Musculo-spiral groove, 16- Bicipital groove, 17- Summit of lateral tuberosity.

Table 1: Different Morphometrical observations of Humerus bone

		OX			Nilgai		OX	Nilgai
	Parameters	**S1**	**S2**	**S3**	**S1**	**S2**	**(AVG±SE)**	**(AVG±SE)**
	Maximum humeral length	27.7	27.3	27.6	26.1	26.5	27.53±0.12	26.3±0.2
Proximal Extremity (cm)	Transverse diameter of head	9.9	9.6	9.4	7.7	7.8	9.63±0.15	7.75±0.05
	Vertical diameter of head	9.4	9.4	9.5	7.5	7.6	9.43±0.03	7.55±0.05
	Circumference of head	22.7	20.8	19.9	20.3	20.8	21.13±0.83	20.55±0.25
	Circumference of proximal extremity	31.4	30.5	30.9	27.1	27.6	30.93±0.26	27.35±0.25
	Width of proximal extremity	9.3	9.3	9.2	9.7	9.7	9.27±0.03	9.7±0
	Bicipital groove width	2.2	2.2	2.4	2.5	2.4	2.27±0.07	2.45±0.05
	Height of summit over Bicipital groove	3.9	3.8	3.8	2.9	2.9	3.83±0.03	2.9±0
	Height of summit over convexity	1.9	1.8	1.9	1.0	1.1	1.87±0.03	1.05±0.05
Distal Extremity (cm)	Circumference distal extremity	27.2	27.5	27.2	24.8	25.1	27.30±0.10	24.95±0.15
	Width of distal extremity	7.7	8.0	7.8	6.9	7.0	7.83±0.09	6.95±0.05
	Length of capitulum	3.3	3.5	3.4	2.5	2.7	3.40±0.06	2.6±0.1
	Width of capitulum	1.7	1.6	1.7	1.7	1.8	1.67±0.03	1.75±0.05
	Length of trochlea	4.6	4.4	4.4	3.5	3.6	4.47±0.07	3.55±0.05
	Length of radial fossa	3.0	2.8	3.1	2.8	3.0	2.97±0.09	2.9±0.1
	Depth of radial fossa	2.1	1.6	1.8	1.6	1.5	1.83±0.15	1.55±0.05
	Length of olecranon fossa	3.8	3.8	3.7	3.9	3.8	3.77±0.03	3.85±0.05
	Width of olecranon fossa	2.8	2.7	2.8	2.6	2.6	2.77±0.03	2.6±0
	Depth of olecranon fossa	2.7	2.8	2.8	2.5	2.7	2.77±0.03	2.6±0.1
Shaft (cm)	Length of shaft	17.1	17.5	17.3	16.3	16.4	17.30±0.12	16.35±0.05
	No. of nutrient foramen	1	1	1	1	1	1.0±0.00	1±0
	Deltoid tuberosity from proximal end	13.1	13.4	13.4	11.3	11.5	13.30±0.10	11.4±0.1
	Circumference of shaft-proximal	23.7	22.8	23.1	16.2	16.8	23.20±0.26	16.5±0.3
	Middle	15.1	14.6	14.9	12.2	12.5	14.87±0.15	12.35±0.15
	Distal	12.6	12.4	12.6	12.1	12.3	12.53±0.07	12.2±0.1
Index	Humeral index	55.59	55.34	55.51	42.82	42.89	55.48±0.07	42.85±0.03
	Foraminal index	47.65	47.60	48.05	48.27	48.66	47.76±0.14	48.46±0.19

4. Conclusion

In this study, we conducted a comparative analysis of the humerus bone in two bovine species, Ox (*Bos indicus*) and Nilgai (*Boselaphus tragocamelus*), focusing on their morphological and morphometrical characteristics. The humerus bone is essential for providing structural support to the forelimb and enabling locomotor activities in large animals like bovines and equines.

The biometrical observations revealed significant differences in the proximal extremity of the humerus between Ox and Nilgai. The shape of the humerus head, neck development, and lateral tuberosity varied between the species, possibly indicating adaptations related to their distinct locomotion behaviors and ecological niches. The head region displayed intriguing variations in transverse and vertical diameters, potentially influencing joint articulation and functional adaptations. Additionally, the analysis of circumference and bicipital groove dimensions showed structural variations, which may play a role in mobility and support adaptations in Ox and Nilgai. In the distal extremity, distinct condyles, epiphyses, and muscle attachment sites were observed, suggesting adaptations related to their different locomotion behaviors. Nilgai's agile and swift movement may have led to anatomical changes enhancing its running ability, while Ox's domestication for strength and carrying purposes could explain its specific traits. The morphometric analysis of the humerus shaft provided insights into anatomical differences and potential functional adaptations. Shaft length and circumference variations may be associated with distinct locomotion behaviors, with Ox potentially having a longer lever arm for joint movements. The humeral index and foraminal index offered valuable information on bone robustness and vascularization adaptations. Ox's higher humeral index suggested a more robust bone suited for carrying, while Nilgai's lower index aligns with its agility. The consistent nutrient foramina distribution in both species indicated similarities in bone vascularization. Overall, our research contributes to understanding the anatomical adaptations and functional characteristics of Ox and Nilgai. The findings shed light on the role of natural selection in shaping the anatomical characteristics of bovine species and offer insights into their evolutionary history and ecological roles. This study lays the groundwork for further research in comparative anatomy and evolutionary biology, enriching our knowledge of vertebrate locomotor adaptations.

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