

ORIGINAL ARTICLE

**Morphological and morphometric characterization of forelimb bones in the Hanuman langur
(*Semnopithecus entellus*)**

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Abstract

Background: The Hanuman langur (*Semnopithecus entellus*) is a widely distributed non-human primate in South Asia; however, detailed anatomical and morphometric information on its appendicular skeleton remains limited. Baseline data on the forelimb osteology of this species are important for comparative anatomy, functional interpretation, radiology, and forensic investigations. The present study aimed to describe the gross morphology and morphometric characteristics of the forelimb bones of the Hanuman langur and to provide reference anatomical data with clinical and comparative relevance.

Methods: The forelimb bones (scapula, humerus, radius, and ulna) of an adult male Hanuman langur obtained from the Upazila Livestock Office and Veterinary Hospital, Barishal Sadar, Bangladesh, were examined. After standard gross anatomical processing in the Gross Anatomy Laboratory, the bones were prepared and cleaned for observation. Qualitative morphological features were documented photographically, and morphometric measurements were taken using standard anatomical landmarks and a calibrated measuring scale. Because the study involved a single specimen, the data were analyzed descriptively without inferential statistical testing.

Results: The scapula was quadrangular with a well-developed spine dividing the lateral surface into unequal supraspinous and infraspinous fossae, an oval glenoid cavity, and an acromion composed of hamate and suprahamate processes. The humerus was elongated with a spirally twisted cylindrical shaft, prominent greater tubercle, a small non-articulating tubercle beneath the head, distinct brachial groove, poorly developed deltoid tuberosity, tricipital line, caudally located nutrient foramen, and a medial supracondyloid foramen. The radius exhibited a well-defined head with a concave fovea capitis radii, prominent radial tuberosity, medial styloid process, and distal ulnar notch. The ulna was the longest forelimb bone, characterized by a triangular shaft, prominent olecranon tuberosity, large trochlear notch, coronoid processes, and a laterally placed styloid process.

Conclusions: The forelimb osteological features of the Hanuman langur reflect functional adaptations related to limb mobility and arboreal activity. These findings provide baseline anatomical reference data that may support comparative anatomical research, functional morphology, radiological interpretation, and forensic identification involving primates.

Key words: Comparative anatomy; Osteology; Primate locomotion; Skeletal morphology; Arboreal adaptation

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Introduction

The Hanuman langur (*Semnopithecus entellus*), also known as the common langur, is a member of the family Cercopithecidae and is one of the most widely distributed non-human primates in South Asia. The species is characterized by a grey to brownish-grey coat, darker pigmentation of the face, hands, feet, and ears, and a long tail that often exceeds body length, typically ending in a pale or white tip (Roonwal and Mohnot, 1977; Oppenheimer, 1977). Hanuman langurs are highly adaptable and inhabit a broad range of ecological zones, including tropical deciduous forests, monsoon forests, shrublands, rocky wastelands, and areas with xerophytic vegetation. Their geographic distribution extends from northern India and the Himalayan regions of Nepal, Bhutan, and Tibet to Sri Lanka, Pakistan, and Bangladesh (Khanal *et al.*, 2018; Sayers, 2022).

Despite being primarily forest-dwelling in much of their range, Hanuman langurs frequently occur in human-modified landscapes, particularly near settlements, temples, and agricultural areas, largely due to rapid habitat alteration and fragmentation (Chhangani, 2000). In Bangladesh, the species is mainly restricted to open wooded villages and forest margins rather than continuous forest habitats (Khan, 1981; Ahsan, 1984; Ahsan and Khan, 2006). Owing to this wide ecological tolerance and frequent human-animal interface, the species has gained importance not only in ecological and behavioral studies but also in comparative anatomical research. As one of the closest living relatives of humans, the Hanuman langur exhibits notable anatomical and functional similarities in its musculoskeletal system. In primates, variation in limb morphology is closely associated with locomotor behavior, postural adaptation, and habitat use. Differences in the structure of the scapula, humerus, radius, and ulna reflect evolutionary modifications related to climbing, quadrupedal locomotion, and manipulative abilities (Napier and Napier, 1967; Margulies *et al.*, 2001). Previous studies have emphasized that forelimb and hindlimb skeletal elements share conserved developmental patterns while adapting to specific functional demands (Shou *et al.*, 2005; Rolian *et al.*, 2010).

Detailed osteomorphometric descriptions of forelimb bones are essential for several applied disciplines, including comparative anatomy, radiology, orthopedic

interpretation, and forensic identification. However, published information on the gross morphology and morphometry of the forelimb bones of *S. entellus* remains limited, particularly from systematically prepared anatomical specimens. This lack of baseline data restricts meaningful comparison with other primate species and with humans.

Therefore, the present study was undertaken to document the gross morphological and morphometric characteristics of the forelimb bones (scapula, humerus, radius, and ulna) of the Hanuman langur. The specific objective was to provide a detailed anatomical description of these bones to establish reference data that may support future research in primate anatomy, functional morphology, radiological assessment, and forensic investigations.

Materials and methods

The forelimb bones (scapula, humerus, radius, and ulna) of an adult Hanuman langur (*Semnopithecus entellus*) were examined in the Anatomy Laboratory of Patuakhali Science and Technology University, Bangladesh. The specimen was obtained opportunistically after the animal sustained fatal injuries from an electric shock in Barishal city and was brought to the Upazila Livestock Office and Veterinary Hospital, Barishal Sadar. Based on postmortem examination, it was an adult male, weight 25-kilogram, age about 12 to 15 years. Following death, the carcass was collected for skeletal preparation. The body was buried in an isolated area near the laboratory under hygienic and aseptic conditions to allow natural decomposition. After several weeks, the bones were recovered, cleaned of adhering soil, and processed following standard osteological preparation techniques. The bones were simmered in water with hydrogen peroxide (H₂O₂) for approximately 30 minutes to remove residual soft tissues, then thoroughly washed with clean water and sun-dried for several days. Care was taken throughout the procedure to preserve all gross anatomical features.

Study design

This study was designed as a descriptive gross anatomical and morphometric investigation of the forelimb bones of a single adult specimen.

Ethical approval

The specimen was obtained from a naturally deceased animal, and no experimental procedures were performed

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on a live subject. The study protocol was reviewed and approved by the relevant institutional ethical authority of Patuakhali Science and Technology University. Formal ethical approval numbering was not applicable due to the opportunistic nature of the specimen.

Sample size calculation

Sample size calculation was not applicable, as the study was based on a single, opportunistically obtained specimen intended for descriptive anatomical documentation. Morphometric measurements and statistical analysis Gross anatomical features of the scapula, humerus, radius, and ulna were examined visually and documented photographically from multiple aspects. Morphometric parameters, including length, width, height, and circumference, were measured using a calibrated measuring scale and recorded in centimeters (cm). Data analysis was limited to descriptive assessment, and no inferential statistical tests were applied.

Comparative assessment

The morphometric observations were compared qualitatively with previously published anatomical descriptions of humans and other mammals, including canine and feline species, to support comparative anatomical interpretation.

Results and Discussion

Scapula

The scapula of the Hanuman langur was quadrangular in outline (Figures 1, 2), which is consistent with observations in the Indian wild cat (Palanisamy *et al.*, 2018) and civet cat (Sarma *et al.*, 2017). It comprised two surfaces, three borders, and three angles (Figures 1, 2), resembling the general scapular morphology described in domestic mammals such as the horse, cattle, sheep, and dog (Getty, 1975). The lateral surface was distinctly divided by a well-developed scapular spine into unequal supraspinous and infraspinous fossae (Figure 1), a feature also reported in the lion (Nzalak *et al.*, 2010). However, this contrasts with the nearly equal fossae described in dogs and Indian wild cats (Palanisamy *et al.*, 2018). The scapular spine gradually decreased in height toward the proximal extremity, similar to findings in the lion (Pandey *et al.*, 2004).



Figure 1. Lateral view of the left scapula of the Hanuman langur showing the cranial angle (1), caudal angle (2), cranial margin (3), caudal margin (4), supraspinous fossa (5), infraspinous fossa (6), scapular spine (7), tuberosity of the spine (8), suprahumeral process (9), hamate process (10), scapular notch (11), and coracoid process (12).

Figure 2. Medial view of the left scapula of the Hanuman langur showing the cranial angle (1), caudal angle (2), caudal ridge (3), cranial ridge (4), dorsal margin (5), cranial margin (6), caudal margin (7), scapular notch (8), glenoid cavity (9), and coracoid process (10).

The acromion process formed the distal continuation of the spine and consisted of both hamate and suprahumeral processes (Figure 3). The hamate process was triangular with wide, blunt margins and projected toward the glenoid cavity. Comparable morphology has been reported in the lion (Nzalak *et al.*, 2010), whereas in cattle, sheep, and goats the hamate process does not overhang the glenoid cavity (Getty, 1975). The pronounced development of the acromial components in the Hanuman langur may reflect functional adaptation to enhanced shoulder stability and mobility associated with arboreal locomotion (Napier and Napier, 1967; Preuschoft and Demes, 1984).

Morphometric analysis showed the dorsal border length to be 10.1 cm on the right and 10.0 cm on the left scapula (Table 1), markedly shorter than that reported in the Royal Bengal tiger (Uddin *et al.*, 2022). The cranial border was slightly convex, extending from the scapular notch to the cranial angle, with a smooth, circular outline comparable to that observed in the lion (Sohel *et al.*, 2021). Its length was 9.8 cm (right) and 9.5 cm (left), again substantially shorter than in the Royal Bengal tiger

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(Uddin *et al.*, 2022). The caudal border was straight, thick, and smooth, extending from the caudal angle to the glenoid cavity, a feature consistent with reports in the Indian lion (Nzalak *et al.*, 2010), leopard, and Indian

wild cat (Palanisamy *et al.*, 2018). The caudal border measured 10.4 cm on the right and 10.3 cm on the left scapula (Table 1), considerably smaller than in the Royal Bengal tiger (Uddin *et al.*, 2022).

Table 1. The morphometrical data of different parameters of the scapula

Parameter	Right (cm)	Left (cm)
Maximum length (Dorsal border to glenoid cavity)	10.8	10.8
Maximum width (Cranial border to caudal angle)	8.3	7.8
Length of cranial border	9.8	9.5
Length of caudal border	10.4	10.3
Length of dorsal border	10.1	10
Length of scapular spine	10.5	10.3
Height of scapular spine from supraspinous fossa	1.2	1.3
Height of scapular spine from infraspinous fossa	1.5	1.5
Maximum width of supraspinous fossa	2.4	2.2
Maximum width of infraspinous fossa	6.7	6.8
Length of glenoid cavity	2.1	2.2
Width of glenoid cavity	1.3	1.2
Distance between glenoid cavity and acromion process	1.9	2.0

The glenoid cavity was somewhat oval in shape (Figure 3), similar to that described in the Indian lion (Nzalak *et al.*, 2010) but differing from the elongated glenoid cavity reported in elephants (Ahasan *et al.*, 2016). The length of the glenoid cavity measured 2.1 cm (right) and 2.2 cm (left), while the width measured 1.3 cm (right) and 1.2 cm (left) (Table 1). These values were notably lower than those reported for the Royal Bengal tiger (Uddin *et al.*, 2022). The relatively smaller glenoid cavity dimensions may indicate a balance between joint stability and flexibility, favoring climbing and brachiation rather than high-impact terrestrial locomotion (Napier and Napier, 1967). The maximum scapular length (from dorsal border to glenoid cavity) was 10.8 cm on both sides, whereas a much larger dimension has been reported in the Royal Bengal tiger (Uddin *et al.*, 2022). Maximum width was greater on the right scapula (8.3 cm) than the left (7.8 cm), a pattern also noted in the tiger (Uddin *et al.*, 2022). The height of the scapular spine from the supraspinous fossa measured 1.2 cm (right) and 1.3 cm (left), which was considerably lower than values reported in the lion (Sohel *et al.*, 2021). Similarly, spine height from the infraspinous fossa measured 1.5 cm bilaterally, compared with 4 cm in the Royal Bengal tiger (Uddin *et al.*, 2022).

The maximum width of the supraspinous fossa was 2.4 cm (right) and 2.2 cm (left), whereas substantially larger measurements were reported in the tiger (Uddin *et al.*, 2022). In contrast, the width of the infraspinous fossa (6.7 cm right; 6.8 cm left) closely approximated values reported in the Royal Bengal tiger (Uddin *et al.*, 2022). This disproportion suggests a relatively greater development of the infraspinous musculature, potentially supporting sustained forelimb stabilization during arboreal postures (Preuschoft and Demes, 1984).

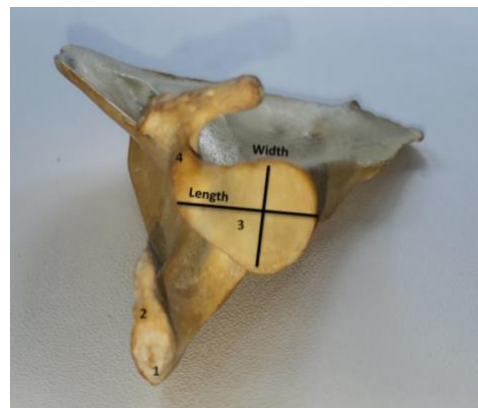


Figure 3. Ventral view of the left scapula of the Hanuman langur showing the hamate process (1), suprahamate process (2), glenoid cavity (3), and coracoid process (4).

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Humerus

The humerus of the Hanuman langur was a long bone forming the primary support of the forelimb. The shaft was spirally twisted and generally cylindrical. The proximal shaft was craniocaudally compressed, the midshaft was rounded to oval, and the distal shaft was mediolaterally compressed (Figures 4, 5), findings comparable to those described in the lion (Kirberger *et al.*, 2005). Two prominent extremities were identified. The proximal extremity displayed a rounded head articulating with the glenoid cavity to form the shoulder joint. A prominent greater tubercle was observed on the cranial and lateral aspects, while a smaller, non-articular medial tubercle was present just below the head (Figures 4, 5). Similar features have been described in the Asiatic cheetah (Nazem *et al.*, 2017), although elephants exhibit a more prominent major tubercle (Ahasan *et al.*, 2016). The distal extremity formed the elbow joint through articulation with the radius and ulna. Four surfaces, cranial, caudal, medial, and lateral, were identified, in contrast to reports of only medial and lateral surfaces in the Asiatic cheetah (Nazem *et al.*, 2017). A distinct brachial groove extended along the proximal half of the lateral surface (Figures 4, 5). The deltoid tuberosity was poorly developed, differing from the well-developed structure reported in dogs (Sarma *et al.*, 2017). The tricipital line (deltoid crest) was evident on the lateral surface and terminated at the deltoid tuberosity. A supracondyloid ridge was present above the lateral epicondyle and extended obliquely toward the caudal surface. A single nutrient foramen was observed on the caudal surface proximal to the midshaft, whereas in the lion it has been reported on the distal half of the shaft (Nzalak *et al.*, 2010), and in the Asiatic cheetah two nutrient foramina have been described (Nazem *et al.*, 2017). Two condyles, two epicondyles, radial and olecranon fossae, and a supracondyloid foramen were identified at the distal extremity. The supracondyloid foramen was located on the medial surface but did not connect the radial and olecranon fossae, unlike in dogs (Sarma *et al.*, 2017).

Morphometrically, the total humeral length measured 19.5 cm (right) and 19.2 cm (left) (Table 2), markedly shorter than in the Royal Bengal tiger (Uddin *et al.*, 2022). Shaft length was also substantially lower than values reported in the lion (Sohel *et al.*, 2021). The relatively reduced humeral dimensions are consistent with the smaller body size of the Hanuman langur and

its locomotor emphasis on controlled, multidirectional forelimb movements rather than powerful propulsion (Napier and Napier, 1967; Swindler, 2002).



Figure 4. Caudal view of the humerus of the Hanuman langur showing the head of the humerus (1), greater tubercle (2), lesser tubercle (3), neck of the humerus (4), deltoid tuberosity (5), supracondylar crest or ridge (6), supracondylar foramen (7), olecranon fossa (8), lateral epicondyle (9), and medial epicondyle (10).



Figure 5. Caudal view of the humerus of the Hanuman langur showing the lesser tubercle (1), head of the humerus (2), neck of the humerus (3), crest of the lesser tubercle (4), shaft of the humerus (5), and medial epicondyle (6).

Table 2. The morphometrical data of different parameters of the humerus

Parameter		Right (cm)	Left (cm)
Total length		19.5	19.2
Shaft	Length	15.2	15.3
	Circumference of upper part	5.9	5.8
	Circumference of middle part	5.5	5.3
	Circumference of lower part	5.7	5.6
Circumference of head		6.2	6.1
Proximal extremity	Circumference	9.0	8.9
	Width	2.5	2.4
Distal extremity	Circumference	9.7	9.5
	Width	2.3	2.2
Depth of olecranon fossa		1.3	1.4

Table 3. The morphometrical data of different parameters of radius

Parameter		Right (cm)	Left (cm)
Total length		20.4	20.2
Proximal extremity	Circumference	5.1	5.2
	Width	1.5	1.6
Distal extremity	Circumference	5.9	5.8
	Width	1.7	1.6
Midshaft	Circumference of upper part	3.6	3.7
	Circumference of middle part	3.9	3.8
	Circumference of lower part	4.6	4.5

Radius

The radius consisted of a long shaft and two extremities, with the distal extremity being larger and more expanded. The proximal extremity bore a well-defined head with a concave fovea capitis radii (Figure 6), consistent with previous descriptions (Nzalak *et al.*, 2010). The radial tuberosity was prominent and

roughened on the medial surface of the proximal extremity. The shaft was compressed craniocaudally and exhibited four distinct surfaces: lateral, medial, anterior, and posterior. The anterior surface was roughened for tendon attachment, while the posterior surface was slightly concave, as described in dogs and cats (Getty, 1975). The distal extremity displayed a

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well-developed medial styloid process and a distinct ulnar notch for articulation with the ulna.

The total length of the radius measured 20.4 cm (right) and 20.2 cm (left) (Table 3), considerably less than that reported for the Royal Bengal tiger (Uddin *et al.*, 2022). Circumferential and width measurements were likewise substantially lower than those recorded in lions (Sohel *et al.*, 2021). These reduced dimensions likely reflect adaptations for lighter forelimb loading and enhanced rotational capacity during climbing (Preuschoft and Demes, 1984).



Figure 6. Lateral view of the radius of the Hanuman langur showing the capitular fovea of the radius (1), radial tuberosity (2), shaft of the radius (3), and styloid process of the radius (4).

Ulna

The ulna was the longest bone of the forelimb in the Hanuman langur. The olecranon process extended proximally beyond the radius (Figure 7), consistent with observations in cattle (Budras and Habel, 2011) and sheep (Getty, 1975), but differing from the condition in horses (Getty, 1975). A distinct olecranon tuberosity was present, formed by a caudolateral projection of the olecranon process. Similar morphology has been described in dogs (Getty, 1975) and Asiatic cheetahs (Nazem *et al.*, 2017). A large trochlear (semilunar) notch articulated with the humeral trochlea and was bounded distally by medial and lateral coronoid processes, while proximally it projected into the

anconeal process. The shaft was triangular in cross-section and slightly convex cranially (Figure 7), consistent with observations in the Asiatic cheetah (Nazem *et al.*, 2017).

The distal extremity bore a laterally projecting styloid process articulating with the carpal bones, with a medial articular facet for the radius, in agreement with previous reports (Nzalak *et al.*, 2010). The total length of the ulna was 22.7 cm (right) and 22.1 cm (left) (Table 4), substantially shorter than in the Royal Bengal tiger (Uddin *et al.*, 2022). Circumference and width measurements followed a similar trend when compared with lion and tiger data (Sohel *et al.*, 2021; Uddin *et al.*, 2022). The elongated yet relatively slender ulna suggests a functional compromise between leverage for elbow extension and reduced distal limb mass, advantageous for arboreal locomotion (Swindler, 2002).



Figure 7. Lateral view of the ulna of the Hanuman langur showing the olecranon tuber (1), olecranon process (2), anconeal process (3), trochlear notch (4), and styloid process (5).

Table 4. The morphometrical data of different parameters of the ulna

		Parameter	Right (cm)	Left (cm)
Total length			22.7	22.1
Proximal extremity	Circumference		5.1	5.0
	Width		1.5	1.4
Distal extremity	Circumference		4.2	4.3
	Width		1.2	1.3
Midshaft	Circumference of upper part		5.9	5.8
	Circumference of middle part		3.4	3.5
	Circumference of lower part		3.1	3.0

Conclusions

The present study provides a detailed gross anatomical and morphometric description of the scapula, humerus, radius, and ulna of the Hanuman langur (*Semnopithecus entellus*), contributing original baseline data on the forelimb osteology of this primate species. The scapula was quadrangular in shape with a well-developed spine, distinct acromial processes, and an oval glenoid cavity, indicating a structural design that supports both joint stability and a wide range of shoulder movements. Comparative assessment revealed notable differences in scapular proportions when contrasted with large carnivores such as the lion and Royal Bengal tiger, reflecting species-specific functional demands rather than phylogenetic similarity alone. The humerus exhibited a spirally twisted shaft, relatively reduced deltoid tuberosity, and well-defined articular components at both extremities, suggesting an emphasis on controlled forelimb mobility rather than forceful propulsion. Similarly, the radius and ulna demonstrated elongated yet comparatively slender morphologies, with prominent articular features and muscle attachment sites that favor rotational capacity and precise positioning of the forelimb. The extended olecranon process of the ulna, together with the morphometry of the elbow joint, further supports efficient leverage during flexion and extension without excessive limb mass.

Overall, the morphometric patterns observed across the forelimb bones of the Hanuman langur appear to

represent functional adaptations to arboreal and semi-arboreal locomotion, including climbing, grasping, and sustained postural support. These adaptations contrast clearly with the robust and force-oriented limb architecture of large terrestrial carnivores, emphasizing the influence of locomotor behavior on skeletal design. The findings of this study enrich the comparative anatomical literature on non-human primates and provide reference data that may be valuable for taxonomy, functional morphology, evolutionary biology, and clinical or forensic investigations involving primates. Future studies incorporating larger sample sizes, bilateral asymmetry analysis, and advanced imaging or biomechanical modeling would further enhance understanding of forelimb functional specialization in the Hanuman langur.

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Author Contributions

MTH designed the experiments. MAJ, MTR, MYAS

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and MLH collected and analyzed the data and prepared the initial draft. MTH and MSR critically revised the manuscript.

Competing Interest

The authors declare that they have no conflicts of interest.

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