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Anatomy of forelimb bones: Review

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Abstract

The forelimb skeleton in animals showed a significant structural diversity, reflecting adaptations to varied locomotor patterns, habitats, and functional demands. It comprises the scapula, humerus, radius, ulna, metacarpals, and phalanges, which collectively contribute to weight-bearing, stability, and movement. The forelimbs support a major proportion of body weight and play a crucial role in locomotor efficiency by minimizing energy expenditure. Comparative anatomical studies reveal notable interspecies variations in the morphology of these bones. In ruminants, fusion of the radius and ulna and the formation of a single cannon bone from metacarpals III and IV enhance stability for cursorial locomotion, whereas in carnivores and small mammals, separation of these bones permits rotational movements essential for manipulation. Species-specific differences are also evident in the shape and orientation of the scapula, structure of the humerus, and configuration of digits and phalanges, reflecting functional specialization. Morphometric and histological variations further emphasize adaptive modifications in domestic animals, wild species, and birds. Overall, the structural organization of the forelimb skeleton highlights its critical role in biomechanical efficiency and evolutionary adaptation among different animal species.

Keywords: Anatomical, animal, bone, forelimb, ruminant

1. Introduction

The forelimb skeleton of animals demonstrates considerable structural diversity, reflecting adaptations to varied modes of locomotion, habitats, and functional requirements. It is composed of the scapula, humerus, radius, ulna, metacarpals, and phalanges, all of which play essential roles in ensuring mobility, stability, and weight-bearing. The forelimbs support approximately 60% of the static body weight and function to receive and stabilize the body as it is propelled forward by the pelvic limbs. They contribute to efficient locomotion by reducing unnecessary vertical energy expenditure (Rohlan, 2017) [25].

The scapula, a principal component of the shoulder girdle, is a well-developed flat bone that provides attachment for muscles and facilitates limb movement (Kapadnis *et al.*, 2023) [15]. The humerus forms the proximal segment of the forelimb and is typically a strong, elongated, and slightly twisted bone in species such as blackbuck, ox, sheep, and goat, whereas in the camel it is comparatively straighter (Choudhary and Singh, 2016a) [7]. The radius, positioned cranio-medially to the ulna, is generally flattened in a craniocaudal direction. In ruminants, the radius and ulna are partially or completely fused, enhancing stability for weight-bearing; in contrast, in carnivores and certain small mammals, these bones remain separate, permitting rotational movements such as pronation and supination (Podhade *et al.*, 2015) [23].

In ruminants, the metacarpus typically consists of fused third and fourth metacarpal bones, forming a robust central structure that supports body weight (Choudhary and Singh, 2016b) [8]. Each forelimb usually bears two fully developed digits (III and IV), and each digit comprises three phalanges. The proximal phalanx is laterally compressed, the middle phalanx is approximately half its length, and the distal phalanx is an irregular prismatic bone characterized by a prominent extensor process on its dorsal aspect (Choudhary and Singh, 2016c) [9]. The number and morphology of phalanges, along with associated sesamoid bones,

are closely correlated with specific locomotor adaptations such as running, grasping, and digging, thereby highlighting the functional significance of the forelimb in animal biomechanics.

Anatomy of forelimb

The scapula exhibited a semi-lunar shape in the fishing cat, while it was triangular in the civet. In the leopard cat, the scapular spine showed less inclination toward the infraspinous fossa compared to both the fishing cat and civet. The glenoid cavity in the leopard cat was oval in outline, resembling that of the fishing cat. The tuber scapulae were more prominently developed in the civet than in the fishing cat. The acromion process was slightly directed toward the anterior border in the fishing cat and civet, whereas it remained straight in the leopard cat. Furthermore, the glenoid cavity diameter was found to be maximum in the small Indian civet and minimum in the leopard cat (Pathak *et al.*, 2020) ^[22].

Choudhary and Singh (2016a) ^[7] described the humerus of the Indian blackbuck as having a slightly twisted, cylindrical shaft. The caudal surface showed a nutrient foramen in the distal third, located toward the lateral side. A small teres tubercle was present in the proximal third, and the musculo-spiral groove was shallow. The deltoid tuberosity was identified as a minor, roughened convex prominence and was comparatively less distinct. The proximal extremity featured a roughly rounded head directed caudodorsally. The lateral tuberosity was well developed and extended over the intertubercular groove, consisting of a prominent cranial component and a smaller, poorly defined caudal part with a triangular outline. The intertubercular groove separated the two tubercles. The distal extremity comprised two condyles, two epicondyles, and two fossae.

The cortical bone thickness in sheep was recorded as 2.31 ± 0.29 mm in the left metacarpus and 2.09 ± 0.45 mm in the right metacarpus. The mean distance between Haversian canals measured 77.38 ± 26.63 μ m on the left side and 98.44 ± 14.85 μ m on the right side (Azizi *et al.*, 2025) ^[4].

Visto *et al.* (2018) ^[35] noted that the proximal extremities of the ulna and radius were thicker in commercial layer birds compared to desi birds. Similarly, the distal extremities of both bones were broader and more robust in commercial layers. A significant difference ($p < 0.05$) was observed in the length and width of the distal extremity of the ulna, while the circumference of its distal extremity showed a highly significant difference ($p < 0.01$). The length and circumference of the ulnar shaft were also highly significant ($p < 0.01$). In the radius, the length of the proximal extremity differed significantly ($p < 0.05$), whereas the circumference exhibited a highly significant difference ($p < 0.01$) between the two groups.

The scapula of the barn owl was a dorsoventrally flattened bone that curved caudolaterally along the vertebral column. The medial surface of the humerus exhibited a foramen located approximately at the midpoint of the distal half of the shaft. The distal extremity of the humerus consisted of two condyles, with the ulnar condyle being larger than the radial condyle. Furthermore, the caudal surface at the distal end bore a wide and shallow olecranon fossa, which articulated with the olecranon process of the ulna (Usende *et al.*, 2017) ^[34].

Choudhary and Singh (2016b) ^[8] conducted the metacarpus of the blackbuck comprised a large metacarpal formed by the fusion of the third and fourth metacarpals. The dorsal surface was smooth and semi-cylindrical, whereas the palmar surface was flat and exhibited a deep longitudinal groove containing

corresponding foramina. These foramina communicated with similar openings on the opposite surface through transverse canals. The proximal extremity showed two slightly concave articular facets separated by a median ridge anteriorly and a shallow groove posteriorly. The distal extremity was divided into two condyles by a dorsopalmar cleft. The smaller metacarpals were slender and cord-like, with metacarpal II located on the palmo-medial aspect and metacarpal V on the palmo-lateral aspect of the main metacarpal.

According to Girgiri *et al.* (2016) ^[11], adult hedgehogs exhibited well-developed acromion, metacromion (processus hamatus), and suprametacromion (processus suprahammatus) processes. The radius and ulna were distinct bones, connected only by a soft fibrous tissue at the midshaft.

The elephant scapula showed a prominent spine dividing the lateral surface into a smaller supraspinous and a larger infraspinous fossa, along with a well-developed hook-shaped suprahamate process. The glenoid cavity was elliptical and elongated craniocaudally (Kapadnis *et al.*, 2023) ^[15].

Gupta *et al.* (2020) ^[12] reported that the scapula of the ox, horse, and camel were flat and triangular in shape. The lateral surface in all three species was divided into supraspinous and infraspinous fossae by a prominent scapular spine. The acromion process showed species variation, being slightly proximal to the glenoid cavity in the ox, extending up to the glenoid cavity in the camel, and completely absent in the horse.

The scapula of the elephant exhibited a lateral surface divided into two unequal fossae by a prominent scapular spine. The cranial supraspinous fossa was smaller, whereas the caudal infraspinous fossa was more elongated. A well-developed, curved, hook-shaped flattened projection, termed the suprahamate process, was present at the mid-portion of the scapular spine. The glenoid cavity was well developed, oriented craniocaudally, and elliptical in shape (Kapadnis *et al.*, 2023) ^[15].

The blackbuck possessed two fully developed digits, each comprising three phalanges: proximal, middle, and distal. The proximal (first) phalanx was a long, laterally compressed bone with a broader proximal extremity compared to the distal end. The middle (second) phalanx was approximately half the length of the first and had an elongated shaft with three distinct surfaces. Its proximal extremity had an articular surface divided into two concave facets by a dorsopalmar ridge. The distal (third) phalanx was irregular and prismatic, bearing a prominent extensor process on its dorsal border. Two distal sesamoid bones, one for each digit, were located palmarly between the second and third phalanges, while the proximal sesamoid bones were small, short, and crescent-shaped (Choudhary and Singh, 2016c) ^[9].

Mahapatra *et al.* (2017) ^[18] described the scapula of the Indian tiger as a flat, quadrilateral bone. The scapular spine was inclined toward the infraspinous fossa and lacked a tuberosity enlargement at its middle portion. Near the distal end, just before the acromion process, the spine curved over the infraspinous fossa, forming the suprahamate process. The medial surface was divided into six regions by a series of progressively elevated ridges.

The glenoid cavity of the cattle scapula was roughly quadrilateral in shape, with a scapular index of 38.50 ± 2.34 (Chaurasia *et al.*, 2020) ^[6].

The scapula of wild deer was triangular in shape, with its outline influenced by a prominent tuber of the scapular spine, a pointed acromion, a broad infraspinous fossa, and a comparatively narrow supraspinous fossa. Partial ossification

of the scapular cartilage was observed in older deer. The tuber of the scapular spine was weakly developed, and the free margin of the spine appeared thickened (Kang *et al.*, 2023) [14].

Al Mahmud and Mussa (2016) [2] observed that the tuber scapula was blunt in the dog but slender in the Black Bengal goat, and the coracoid process was absent in the dog. The humerus in the dog was relatively longer, less twisted, and had a more rounded and convex head. A large supratrochlear foramen was present at the distal end of the humerus in the dog but absent in the Black Bengal goat. The radius and ulna were distinct and separate in the dog, whereas in the Black Bengal goat they were fused, with a narrow interosseous space extending along their length.

According to Rajashailesha *et al.* (2024) [24], the scapula of the wild boar was broad and triangular, characterized by two surfaces, three borders, and three angles. The glenoid cavity was rounded and measuring was 3.1 cm in the left limb and 2.9 cm in the right. The humerus was a typical long bone with a shaft and proximal and distal extremities; its proximal end included the head, neck, lateral and medial tuberosities, and the bicipital groove. The total length of the humerus, from the anterior summit of the lateral tuberosity to the lateral epicondyle, was 23.2 cm on the left and 23.0 cm on the right. The radius was rod-shaped with a slightly curved, thick shaft, measuring 17.0 cm in length on the left side and 16.9 cm on the right side (Rajashailesha *et al.*, 2024) [24].

Sarma *et al.* (2017a) [28] noted that the humerus in both pig and pygmy hog resembled the italic letter 'f' without the crossbar. The deltoid tuberosity was well developed in the pygmy hog. In both species, the humeral head was strongly curved, heart-shaped, and connected to the shaft by a short neck. A third eminence was observed distal to the caudal aspect of the tuberosity in both animals.

Sohel *et al.* (2021) [30] reported that the shaft of the humerus in the lion was craniocaudally compressed proximally, rounded to oval in the middle, and was mediolaterally compressed distally. A long, narrow supracondyloid foramen was present just above the medial epicondyle, without communication between the radial and olecranon fossae. The radius and ulna were paired bones, with the radius positioned craniolaterally to the ulna proximally and craniomedially distally. The ulna was the longest forelimb bone, and its olecranon tuberosity exhibited three prominences, two cranial and one larger, rounded caudal projection. Distally, both bones possessed projecting styloid processes.

The scapula of the civet cat was a flat, roughly quadrilateral bone. The medial surface had a subscapular fossa, while the lateral surface was divided into supraspinous and infraspinous fossae by the scapular spine. The spine measured 5.77 cm in length, with maximum height at the level of the proacromion, and terminated as the acromion process. A triangular, caudally directed metacromion process was present just dorsal to the acromion. The tuber of the spine was indistinct, and the glenoid cavity was elongated and elliptical. The ratio of the supraspinous to infraspinous fossae was 1:1.55, and the scapular index was 50.74 (Sarma *et al.*, 2017b) [29].

Palanisamy *et al.* (2018) [21] described the scapular spine of the Indian wild cat as well developed, with increasing height distally. The acromion process was divided into hamate and suprahamate processes, which were triangular and quadrilateral plate-like, respectively. The ratio of supraspinous to infraspinous fossae was approximately 1:1. The subscapular fossa displayed four ridges, and a nutrient foramen was located near the scapular neck. The coracoid

process was well developed and hook-shaped, while the glenoid cavity was shallow, oval, and exhibited a laterally positioned glenoid notch.

The humerus of the Asiatic cheetah was a long bone oriented obliquely downward and backward, forming the shoulder joint proximally with the scapula and the elbow joint distally with the radius and ulna. The radial and olecranon fossae were shallow, and the epicondylar crest was prominently developed at the distolateral aspect of the diaphysis. The radius appeared transversely oval in cross-section, with a shallow radial fovea capitis on the proximal head. The ulna had a triangular shaft in cross-section and, like the radius, exhibited slight cranial convexity (Nazem *et al.*, 2017) [20].

The scapula of the Indian blackbuck was a flat, triangular bone possessing two surfaces, three borders, and three angles. Its lateral surface was divided by a sharp, wavy scapular spine into a small, elongated supraspinous fossa and a larger, triangular infraspinous fossa. The acromion was pointed, the tuber spine was indistinct, and the subscapular fossa was deeply marked. Additionally, the tuber scapulae were small, the coracoid process was poorly developed, and the glenoid cavity was shallow and oval in shape (Choudhary and Singh, 2016d) [10].

Ahasan *et al.* (2016) [1] investigated the forelimb bones of an adult female Asian elephant and they found that the dorsal border of the scapula extended from the proximal extremity of the first rib to the midpoint of the sixth rib. The ventral angle of the scapula articulated with the humerus through an elongated glenoid cavity and the humeral head. The major tubercle of the humerus was positioned laterally to the head, with a smaller cranial part and a larger caudal part, extending cranially beyond the head. The crest of the minor tubercle appeared as a rough line on the medio-caudal surface of the humerus, terminating at a slightly elevated area known as the teres major tuberosity. The lateral supracondylar crest on the caudal aspect of the humeral shaft bounded the musculospiral groove. The radius and ulna formed paired bones of the forearm; proximally, the radius articulated craniomedially with the ulna, while distally, it spiraled laterally across the cranial surface of the ulna to articulate with its medial aspect.

Atabo *et al.* (2017) [3] reported that in Red Sokoto goats, the radius and ulna exhibited the lowest mean lengths of 58.23 ± 0.78 mm and 60.09 ± 0.21 mm, respectively, at the first week, increasing to 148.07 ± 0.35 mm and 149.72 ± 0.53 mm at the 144th week. Similarly, the minimum mean widths were 5.76 ± 0.06 mm (radius) and 1.96 ± 0.07 mm (ulna) at the first week, which increased to 12.04 ± 0.01 mm and 8.71 ± 0.07 mm, respectively, at the 144th week.

Sonfada *et al.* (2015) [31] studied the long bones of one-humped camel fetuses and observed that the radius and ulna appeared fused during the third trimester, whereas the tibia remained a single bone throughout all trimesters. Osteometric analysis revealed progressive growth, with mean bone length increasing from 1.06 ± 0.04 cm in the metatarsal during the first trimester to 27.18 ± 6.54 cm in the metacarpal during the third trimester. Bone weight also increased markedly, ranging from 0.04 ± 0.01 g in the metacarpal to 80.50 ± 0.82 g in the radio-ulna.

Botlagunta *et al.* (2025) [5] stated that the scapula of the Indian fox as a triangular bone characterized by two surfaces, three borders, and three angles. The cranial border was thin and convex with a forward-projecting process, while the caudal border was thick and straight, and the dorsal border was convex. The scapular spine was well developed, increasing in height distally and terminating in the acromion process. The

acromion comprised both hamate and supramate processes; the hamate process was quadrilateral with a blunt end overhanging the glenoid notch, whereas the supramate process was triangular and directed caudally. The supraspinous and infraspinous fossae were nearly equal in proportion (1:1). The subscapular fossa was located along the attached border of the spine on the costal surface, which also exhibited three ridges and a nutrient foramen near the scapular neck. The glenoid cavity was shallow and oval, with an average length and width of 1.28 cm and 0.80 cm, respectively. The maximum lengths of the right and left scapulae were 6.0 cm and 5.93 cm, respectively, while the average maximum width was 3.55 cm, and the scapular spine measured 5.8 cm in length.

In the blue bull, the radius was relatively shorter and broader than the ulna. It was fused with the ulna along most of its length, except at two distinct interosseous spaces, namely the proximal and distal interosseous spaces. The proximal extremity of the radius was irregularly oval with a mediolateral long axis, while the distal extremity is comparatively larger and thicker. The proximal end of the ulna consists of the olecranon process and the semilunar notch; the olecranon was directed dorsocaudally and bears a prominent summit known as the tuber olecrani (Rohlan *et al.*, 2022) [27].

Gupta *et al.* (2017) [12] reported that the scapula in ox, horse, and camel was flat and triangular, comprising two surfaces, three borders, and three angles. The lateral surface is divided by a prominent spine into supraspinous and infraspinous fossae. The acromion process was positioned slightly above the glenoid cavity in the ox, extends up to the glenoid cavity in the camel, and was absent in the horse.

Kawareti *et al.* (2017) [17] observed morphometric variations in horses of different age groups, recording mean values of 18.93 ± 0.17 cm and 18.94 ± 0.21 cm for left metacarpal circumference, and 20.63 ± 0.19 cm and 20.73 ± 0.23 cm for left metatarsal circumference in Group I and Group II, respectively.

Tomar *et al.* (2018) [33] described the scapula of the tiger as a broad plate with a well-developed scapular spine on its lateral surface, which increases in height distally. The acromion was divided into hamate and supramate processes; the hamate process overhangs the glenoid cavity, while the supramate process appears as a thin triangular plate directed caudally. The supraspinous fossa exhibits an undulating surface, whereas the infraspinous fossa was triangular and relatively flat. The subscapular fossa was shallow with two distinct ridges. The caudal angle terminates at the glenoid cavity, which varies from oval to quadrangular in shape. A prominent supraglenoid tubercle with a hook-shaped coracoid process was located cranial to the glenoid cavity.

Kapadnis *et al.* (2025) [16] noted that the humerus of the Indian elephant consists of a shaft with proximal and distal extremities. The shaft was cylindrical and presents four surfaces, with the musculospiral groove bounded posteriorly by the lateral epicondylar crest. The deltoid tuberosity was located in the proximal third of the shaft. The proximal extremity includes the head, neck, two tuberosities, and an intertubercular groove, while the distal extremity bears two unequal condyles separated by a ridge.

Islam *et al.* (2024) [13] described the scapula of the eland as a flat triangular bone with a prominent spine dividing the supraspinous and infraspinous fossae. The average weights of the scapula were 698 g (right) and 718 g (left). The humerus measured approximately 35.9 cm in length, with a

compressed cylindrical shaft and expanded ends, weighing 944 g (right) and 1016 g (left). The radius was slightly oblique and broader than the ulna, showing craniocaudal flattening, whereas the ulna was the longest forearm bone, averaging 41.6 cm in length.

In the leopard, the ulna was longer than the radius and mediolaterally flattened. The mean shaft circumference of the ulna was 7.77 ± 0.52 cm proximally, 5.15 ± 0.30 cm at midshaft, and 4.07 ± 0.28 cm distally. The olecranon process shows a rough and elevated lateral surface and a smooth, concave medial surface. The semilunar notch was a smooth, crescent-shaped concavity. The distal extremity has a mean circumference of 3.65 ± 0.06 cm, and the styloid process appears as a blunt projection with a circumference of 2.80 ± 0.10 cm (Podhade *et al.*, 2015) [23].

Rohlan *et al.* (2017) [26] observed that in the blue bull, each main metacarpal was associated with two palmar and one dorsal sesamoid bone, while the smaller metacarpal bears a single palmar sesamoid. The mean greatest length and breadth of abaxial proximal sesamoids were 1.93 ± 0.002 cm and 1.11 ± 0.002 cm, respectively, whereas axial proximal sesamoids measured 1.58 ± 0.07 cm in length and 0.75 ± 0.00 cm in breadth. The distal sesamoids measured 2.23 ± 0.002 cm in length and 1.51 ± 0.002 cm in breadth.

The humerus of the Sunda porcupine comprised of a well-defined head along with distinct lesser and greater tubercles. The upper arm forms a direct anatomical connection with the elbow joint. The forelimb terminates in five digits, with a comparatively shorter thumb (Suparmin *et al.*, 2018) [32].

Zagrai *et al.* (2020) [36] conducted a comparative study on reindeer and small ruminants and reported notable morphological differences between the species. The scapula was relatively longer in the reindeer than in the sheep, with an average height-to-width ratio of 2.14 in reindeer and 1.71 in sheep. The scapular spine in reindeer lacked prominent tubercles. The humerus of sheep exhibited a deeper intertubercular groove compared to that of reindeer. Differences were also evident at the proximal extremity of the ulna, where the olecranon was shorter in reindeer, with a ratio of 2.88 compared to 2.4 in sheep. Furthermore, the radio-ulnar arch was more elongated in *Rangifer tarandus*. At the distal extremity, the metacarpals in reindeer showed a wider intermetacarpal groove, attributed to the greater divergence of the axes of digits III and IV. The reindeer also lacked the lateral cusp of the ischiatic tubercle. In addition, the proximal tibia differed considerably, as sheep exhibited well-separated anterior and lateral tuberosities divided by a deep muscular groove, whereas this groove was only faintly developed in reindeer.

The forelimb of the common sloth consisted of the humerus as the single bone of the upper arm, while the forearm comprised two bones, namely the radius and the ulna. The humerus was divided into three parts: two epiphyses (proximal and distal) and a diaphysis. The humeral diaphysis was elongated and cylindrical in shape, with its distal portion being wider and flatter. The distal epiphysis was flattened in the craniocaudal direction and consisted of the condylus humeri, which was further divided into the medial trochlea and the lateral capitulum (Martins *et al.*, 2022) [19].

Conclusion

The present review highlights the remarkable diversity in the structure and morphology of the forelimb skeleton across a wide range of animal species. Variations in the scapula, humerus, radius, ulna, metacarpals, and phalanges clearly

reflect adaptations to different functional requirements, including weight-bearing, locomotion, manipulation, and habitat-specific activities. The fusion of bones in ruminants enhances stability for sustained locomotion, whereas the separation of these elements in carnivores and other species facilitates greater mobility and coordination. Comparative anatomical, morphometric, and histological observations further emphasize species-specific modifications influenced by evolutionary, ecological, and biomechanical factors. Differences in bone shape, size, orientation, and structural features such as processes, fossae, and foramina demonstrate the functional specialization of the forelimb in various taxonomy, including domestic animals, wild mammals, and birds. Overall, the forelimb skeleton serves as a vital component in maintaining biomechanical efficiency and adaptability, illustrating the close relationship between anatomical structure and functional performance. These findings contribute to a better understanding of comparative anatomy and provide a basic for further studies in functional morphology, veterinary science, and evolutionary biology.

Conflict of Interest

Not available

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