International Journal of Veterinary Sciences and Animal Husbandry 2023; 8(4): 145-148

ISSN: 2456-2912
VET 2023; 8(4): 145-148
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www.veterinarypaper.com
Received: 02-03-2023
Accepted: 10-04-2023

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Gross anatomy of the skeleton of pectoral limb in Indian eagle owl (*Bubo bengalensis*)

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Abstract
The gross anatomy of bones of the wing was studied in Indian eagle owl. The shoulder girdle comprised of three bones i.e., scapula, coracoid and clavicle. Scapula was sword-like bone and its proximal extremity presented an acromion process and a coracoid process. The coracoid with its spatula-shaped distal end was the strongest bone of the shoulder girdle. The right and left clavicle fused distally to form a single 'V' shaped bony mass - the furcula. These three bones enclosed the foramen triosseum which allows the passage of tendon of flight muscles. Humerus was a strong cylindrical bone with a proximal extremity having head, lateral tubercle, and medial tubercle and distal extremity having ulnar and radial condyles, respectively. The radius was a long, rod-like bone with slightly curved shaft. Ulna was of almost equal length to radius. Its proximal extremity was expanded and presented the olecranon process and distal extremity presented a small condyle. The cylindrical shaft was fused with the radius thereby, enclosed a wide interosseous space between them. The carpus was comprised of two bones – radial and ulnar carpal bones. The carpometacarpal was formed by the fusion of the distal row of carpal bones and proximal extremity of the metacarpus. There were three carpometacarpals – major, minor and the alular carpometacarpus. Three digits (*Digiti manus*) were observed – digit-I (comprised of first phalanx only), digit-II (comprised of two phalanges), and digit- III (comprised of only one phalanx).

Keywords: Indian eagle owl, coracoid, clavicle, carpometacarpus, humerus, radius, scapula

1. Introduction
Owls are raptors, crepuscular and nocturnal birds known for their hunting ability and silent effortless flights. They occupy an important position in ecological niche particularly, in bio-controls as predators. The Indian eagle-owl, also known as rock eagle-owl is a sub-species of Eurasian eagle owl found across India classified as belonging to the order Strigiformes. It is a fairly large fowl with broad, rounded wings and prominent brown ear tufts. It usually hunts from a perch, but will also make low foraging flights to dive on prey. The skeleton of an owl is typical to that of birds in general i.e., lightweight and durable and thus, contributes to both aspects-walking and flight. The pectoral limb bones attribute to the efficient flight mechanism of this species as the wing bones are relatively long, and the associated wing surface area is large relative to the weight of the bird, resulting in a low wing loading and easy take-offs. The present study was undertaken to understand and document the normal gross anatomical features of the wing bones in Indian eagle-owl, assessing the structure-function paradigm. The results of this study will enrich the current anatomical knowledge, contribute to understand the functional aspects of musculoskeletal system and provide data base for better approach towards treatment in osteological affections.

2. Materials and Methods
The present study was conducted on one adult Indian eagle owl obtained dead around the campus of the college, PGIVER, Jaipur and was eaten by insects. The bird was preserved in 10% formalin for 48 hours and later processed to collect bones as per standard technique (Raghavan, 1964) and subsequently the various gross anatomical features were recorded.

3. Results and Discussion
Results showed bones of the pectoral limb/wing was composed of bones of the pectoral girdle (scapula, coracoid, clavicle), arm (humerus), forearm (radius, ulna), and manus (ossa carpi,

carpometacarpal and ossa digitorum manus). The shoulder girdle was composed of three separate bones - the scapula, coracoid and clavicle (Fig. 1). Similar observations were recorded in crested serpent eagle, brown wood owl, great Indian horned owl, pigeon, and crow (Keneisenuo *et al.*, 2019; Sridevi *et al.*, 2020) [9, 13]. Whereas, scapula and coracoid bones were partly fused to form a single bone scapulo-coracoid in emus (Kumar and Singh, 2014) [10].

3.1 Scapula

The scapula (Fig. 1) was a dorso-ventrally flattened, sword-like bone with broader base and narrower caudal end. It ran parallel to the vertebral column and presented two surfaces, two borders, a proximal extremity and a blade. Lateral surface was convex whereas, the medial surface was somewhat concave in emus (Kumar and Singh, 2014) [10]. Dorsal border bends downward posteriorly while, the ventral border was concave similar to the findings in great Indian horned owl and crow; however, the ventral border was straight in pigeon (Sridevi *et al.*, 2020) [13]. Its thickened proximal extremity presented two processes - an acromion process medially for articulation with the clavicle bone and a convex coracoid process for the coracoid bone. Single acromion process was observed in the present study which was in accordance with the findings made in domestic fowl, great Indian horned owl, pigeon, and owl (Nickel *et al.*, 1977; Sridevi *et al.*, 2020; John *et al.*, 2014) [11, 13, 8] whereas, an additional process i.e., the intermediate process separated from acromion process by a wide groove was observed in crow (John *et al.*, 2014; Sridevi *et al.*, 2020) [8, 13]. A facet was noticed on the lateral aspect of the coracoid process which articulated with the coracoid bone thereby, formed an articular socket in the shoulder joint which received the head of the humerus as also reported in fowl, pariah kite, crested serpent eagle, brown wood owl, great Indian horned owl, pigeon, and crow (Getty, 1975; Tomar *et al.*, 2010; Keneisenuo *et al.*, 2019; Sridevi *et al.*, 2020) [4, 14, 9, 13]. The caudal extremity/tip of the blade ran downwards and was tapered in the form of a pointed projection which aligns with the findings in pariah kite and barn owl (Tomar *et al.*, 2010; Usende *et al.*, 2017) [14, 15].

3.2 Coracoid

Coracoid was small but strongest among the three bones of the shoulder girdle (Fig. 1). It presented a cylindrical shaft and two cranio-caudally compressed extremities. Its wider distal extremity articulated with the sternum at sternocoracoid articulation. The proximal extremity exhibited two processes - procoracoid and acrocoracoid which articulated with the scapula and clavicles, respectively thereby, formed the foramen triosseum for the passage of the tendon of supracoracoideus muscle which was in agreement with the findings in domestic fowl, Ramphastidae, crested serpent eagle, brown wood owl, great Indian horned owl, pigeon (Nickel *et al.*, 1977; Hofling and Alvarenga, 2001; Keneisenuo *et al.*, 2019; Sridevi *et al.*, 2020) [11, 5, 9, 13]. The distal extremity was wide and presented an elongated articular facet for sternum, a medial angle and a lateral process which was also reported in crested serpent eagle, brown wood owl, pigeon hawk, and kite (Keneisenuo *et al.*, 2019; John *et al.*, 2017) [9, 7]. The medial angle was sharply concave as concluded by Sridevi *et al.* (2020) in great Indian horned owl followed by pigeon and crow [13]. The lateral process was not so sharp. In contrast, sharp and well-marked lateral processes were observed in peahen, green winged macaw, great Indian horned owl, and pigeon (Indu *et al.*, 2012; Sridevi *et al.*, 2020) [6, 13].

3.3 Clavicle

The findings of the present study regarding the ventral fusion of the right and left clavicles in an acute angle was consistent with previous researches in crested serpent eagle, brown wood owl, great Indian horned owl, pigeon, and crow (Keneisenuo *et al.*, 2019; Sridevi *et al.*, 2020) [9, 13]. Nickel *et al.* (1977) mentioned that clavicle in domestic birds unites into a single wish bone and presents a considerable inter-species variation in shape and strength in domestic birds [11]. In the present study, furcula was 'V' shaped (Fig. 1) which concurred with similar findings in owl, pigeon, great Indian horned owl, pariah kite, peahen (John *et al.*, 2014; Sridevi *et al.*, 2020; Tomar *et al.*, 2010; Indu *et al.*, 2012) [8, 13, 14, 6]. In contrast, the furcula was 'U' shaped as reported in goose, crow, crested serpent eagle, and brown wood owl (Getty, 1975; Sridevi *et al.*, 2020; Keneisenuo *et al.*, 2019) [4, 13, 9].

This bone presented two extremities, two surfaces, two borders and ramus as also recorded in pariah kite by Tomar *et al.* (2010), in great Indian horned owl, pigeon, and crow by Sridevi *et al.* (2020) [14, 13]. The proximal extremity was comparatively wider and thicker than the distal extremity. The dorsal border was curved, convex and ventral border was concave. However, Sridevi *et al.* (2020) recorded that both borders were almost straight in pigeon [13]. A facet was noticed on the lateral aspect of the proximal extremity for articulation with the acrocoracoid process of the coracoid bone. Another small facet close to the cranial border for articulation with the procoracoid process was present which was in agreement with the observations made by Sridevi *et al.* (2020) in great Indian horned owl [13]. Our results suggested that neither hypocleidium nor thoracic process was present at the junction of the two clavicles. However, previous records on crow and crested serpent eagle stated the presence of plate-like bony hypocleidium (Sridevi *et al.*, 2020; Keneisenuo *et al.*, 2019) [13, 9]. The hypocleidium was absent in pigeon, great Indian horned owl, owl, and brown wood owl (John *et al.*, 2014; Sridevi *et al.*, 2020; Keneisenuo *et al.*, 2019) [8, 13, 9]. In pigeon, the two clavicles fused ventrally and continued as a small thoracic process (Sridevi *et al.*, 2020) [13].

The bones of pectoral girdle formed a foramen triosseum, through which the tendon of supracoracoideus muscle passes to insert on the lateral tuberosity of humerus and thus, playing role in flight mechanism. Similar findings were reported in cattle egret, emu, and fowl (Rezk, 2015; Kumar and Singh, 2014; Dyce *et al.*, 2017) [12, 10, 3].

3.4 Humerus

Humerus was a strong, long, cylindrical bone (Fig. 1). It was longer than scapula but smaller than radius-ulna. In contrast, Dyce *et al.* (2017) mentioned it to be a stout bone [3]. A small pneumatic foramen noticed about the middle of the distal half of the shaft on the medial surface was variable in position which coincided with the observations in barn owl (Usende *et al.*, 2017) [15]. However, this foramen was observed on the caudal surface in emus (Kumar and Singh, 2014) [10]. The proximal extremity comprised of a head, lateral tubercle, and medial tubercle. The head was smooth and round as also recorded in emus (Kumar and Singh, 2014) and barn owl (Usende *et al.*, 2017) [10, 15]. The lateral tubercle was more prominent than the medial one and placed in proximity to the head. The tubercle continues as a laterally inclined ridge i.e.,

the lateral tubercular crest. However, Usende *et al.* (2017) mentioned that the dorsal tubercle was present close to the head which continued as a deltoid crest forming the lateral tubercular crest of humerus in barn owls [15] whereas, Kumar and Singh (2014) reported a ridge or scar-like tubercle, distal to pneumatic foramen in emus [10]. Ridge-like deltoid/delto-pectoralis crest was present on cranial edge of the dorsal surface. Similar findings were recorded by Nickel *et al.* (1977) in fowl [11]. The medial tubercle was located ventromedially and continued distally as medial tubercular crest. Similar findings were recorded by Nickel *et al.* (1977) in fowl [11]. Distal to the medial tubercle, pneumatic foramen was observed as also reported by Usende *et al.* (2017) in barn owls [15]. The distal extremity consisted of large ulnar and small radial condyles respectively, and was pointed caudolaterally. Ulnar condyle articulated with ulna, while the radial condyle articulated with both the ulna as well as radial bones. Both the condyles were separated by intercondyloid cleft as previously reported by Usende *et al.* (2017) in barn owls [15]. On the cranial surface, a sulcus was observed just above the condyles and on the caudal surface, a shallow olecranon fossa for articulation with the olecranon process of the ulna bone was noticed at its distal end.

3.5 Radius

The radius was a thin, long, rod-like bone (Fig. 1). The shaft was slightly curved with curvature more marked at the middle part. Similar findings were recorded by Usende *et al.* (2017) in barn owls [15]. It presented a head, namely caput radii with an articular facet at its proximal extremity which articulated with smaller radial condyle of humerus. This corroborates the works of Nickel *et al.* (1977) in domestic fowl and Kumar and Singh (2014) in emus [11, 10]. Both the extremities articulated with the extremities of ulna to enclose the inter-osseous space. On the distal extremity, it had a facet for articulation with the radial carpal which aligns with the previous findings in fowl, emus, and barn owls (Nickel *et al.*, 1977; Kumar and Singh, 2014; Usende *et al.*, 2017) [11, 10, 15].

3.6 Ulna

This bone was slightly curved and of almost equal length to radius (Fig. 1) which aligns with the works of Nickel *et al.* (1977) in domestic fowl and Rezk (2015) in cattle egret [11, 12]. The distinctly curved shaft was also observed in fowl, pigeon, emu, and barn owl (Nickel *et al.*, 1977; Kumar and Singh, 2014; Usende *et al.*, 2017) [11, 10, 15] whereas, less pronounced curvature was recorded in duck and goose by Nickel *et al.* (1977) [11]. It presented a proximal extremity, shaft and a distal extremity. The proximal extremity was expanded and had a large articular facet for the ulnar condyle on the distal extremity of humerus and, lateral to this, a sharp edged bony protrusion was there as observed in fowls, emus, and barn owls (Nickel *et al.*, 1977; Kumar and Singh, 2014; Usende *et al.*, 2017) [11, 10, 15]. This end presented the olecranon process and articular facets for articulation with the ulna. This corroborates with previous findings in fowls and cattle egret (Nickel *et al.*, 1977; Rezk, 2015) [11, 12]. The cylindrical shaft was fused with the radius thereby, enclosed a wide interosseous space between them. The distal extremity presented a small condyle which articulated with the ulnar and radial carpal bones similar to the findings in fowls by Nickel *et al.* (1977) [11].

3.7 Carpus

The carpus was comprised of two bones – radial and ulnar carpal bones. The radial carpal articulated with the radius and ulna while, the ulnar carpal bone articulated proximally with the ulna and distally with the carpometacarpus as also reported by Nickel *et al.* (1977) in fowls, Ali *et al.* (2016) in chicken, duck and pigeon, and Rezk (2015) in cattle egret [11, 1, 12]. Usende *et al.* (2017) mentioned that the os carpi ulnare was U-shaped and located at the caudal aspect of the carpal region whereas, the os carpi radiale was located at the cranial aspect in barn owls [15].

3.8 Carpometacarpal

The carpometacarpal was a composite product formed by the fusion of the distal row of carpal bones and proximal extremity of the metacarpus, the major part of this bone was derived from metacarpal II. Three carpometacarpals were observed in the present study. The major carpometacarpus was well-developed and the largest one was also reported in fowls and barn owls (Nickel *et al.*, 1977; Usende *et al.*, 2017) [11, 15]. The wider proximal extremity articulated with distal part of radial and ulnar carpals. The distal extremity articulated with first phalanx of digit-II. The minor carpometacarpus was the anlage of metacarpal III and was in the form of thin bone spindle, which enclosed a wide interosseous space as it fused with the major carpometacarpus at both the extremities. The alular carpometacarpus which represented the metacarpal I, sprang from the proximal radial end of the major carpometacarpus.

3.9 Digits

Three digits (*Digiti manus*) were observed that articulated with the carpometacarpus. The digit-I was short and comprised of first phalanx only. Digit-II was the longest among the three digits and made up of two phalanges. Digit-III had only one phalanx. These findings are similar to the reports of Rezk (2015) in cattle egret, Ali *et al.* (2016) in chicken, duck and pigeon, and Usende *et al.* (2017) in barn owls [12, 1, 15].

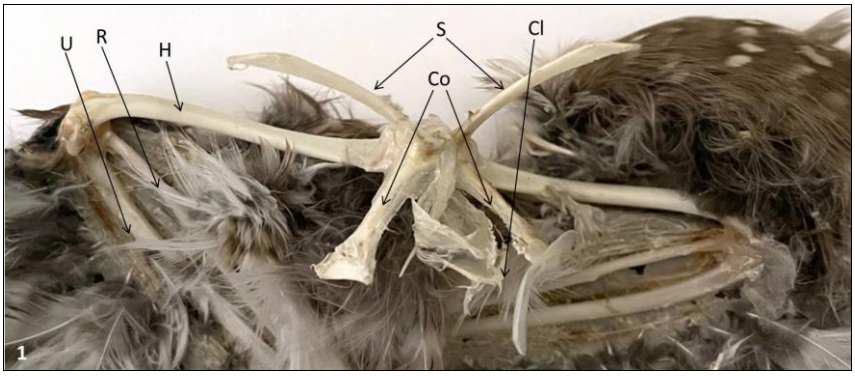

Fig 1: Pectoral limb of Indian eagle owl showing scapula (S), coracoid (Co), clavicle (Cl), humerus (H), radius (R) and ulna (U)

4. Conclusion

The morphology and shape of pectoral limb bones/wing bones in Indian Eagle owl attribute to the efficient flight mechanism of this species as these bones are relatively long, and the associated wing surface area is large relative to the weight of the bird, resulting in a low wing loading and easy take-offs. The three bones of the pectoral girdle enclosed the foramen triosseum which allows the passage of tendon of flight muscles. The furcula connects the shoulder joint to the axial skeleton. These features will be of helpful in understanding the adaptive features of this bird especially the famous so called, silent flight.

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