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ORIGINAL ARTICLE

MORPHOLOGICAL AND PHYSIOLOGICAL ASPECT OF IDENTIFICATION OF BONES RELATED TO FORELIMB IN CALF AND ADULT GREAT INDIAN ONE HORNED RHINOCEROS, *RHINOCEROS UNICORNIS*

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ABSTRACT : The present work was conducted to elucidate the comparative gross morphological characteristics of bones of forelimb of an adult and a calf Indian one horned Rhinoceros and corelated with its physiological adaptation. Scapula was the triangular flat bone situated at cranio-lateral aspect of the thorax. Lateral surface was divided into two unequal halves by scapular spine called supraspinous fossa and infraspinous fossa, spine was broad and bent backward found on lateral surface. The medial surface had a fossa known as subscapular fossa. The angles were three cranial, caudal and distal and three borders were found anterior, posterior and dorsal. Glenoid cavity and the tuber scapulae were found while the glenoid notch was rudimentary structure, tuber scapulae was rounded. Humerus was located obliquely downward and backward in direction forming shoulder joint above with the scapula and elbow joint below with radius and ulna. The proximal end was large presenting head, neck, tuberosities and grooves. The distal end was articular, expanded and basically a modified condyle. Radius and Ulna were fused with each other and the radius was situated in vertical direction. Proximal end articulated with the condyles of the humerus and therefore, possesses two articular surfaces separated by a groove. Ulna was a long bone fused with radius along its postero- lateral aspect. The proximal end was expanded and comprises of one large olecranon process and a semilunar notch while on distal end styloid process was present in both calf as well as adult specimens. Structure of carpus, metacarpus and digits were suggesting it as perisso-dactylar origin which had middle toe was larger than medial and lateral ones. The whole limbs were indicating physiological adaptation being odd toed ungulate.

Key words : Humerus, morphological, Manus, scapula, rhinoceros, radius and ulna.

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INTRODUCTION

There are five distinct species of Rhinoceros, within the group Perissodactyla (odd-toed ungulates), white (*Ceratotherium simum*), black (*Diceros bicornis*), Sumatran (*Dicerorhinus sumatrensis*), Javan (*Rhinoceros sondaicus*) and greater one-horned (*Rhinoceros unicornis*). All five species are listed on the International Union for the Conservation of Nature Red List of threatened species, at varying levels of vulnerability. Four of the five species are kept in captivity, where they are not only a popular zoo or safari park attraction but also fulfill important roles in education and conservation Rhino Resource Center (2011). The White Rhinoceros and Black Rhinoceros (*Diceros bicornis*) both live in sub-Saharan Africa, whereas the Indian Rhinoceros (*Rhinoceros unicornis*) the Javan Rhinoceros (*R. sondaicus*) and the Sumatran Rhinoceros (*Dicerorhinus sumatrensis*) survive in India and Nepal, Java and Sumatra, respectively (Dinerstein, 2011). The Indian Rhinoceros or great one- horned rhinoceros has a single horn 20-60 cm long. Studies has been done on various parameters of Rhinoceros i.e. by Laurie *et al* (1983), Pfistermuller *et al* (2011) and Panagiotopoulou *et al* (2019). Craniometrical study on one horned Rhinoceros done by Kalita *et al* (2003), Population census of Greater

Rhinoceros in Rajiv Gandhi Orange National Park, Assam done by Deba Kumar Dutta and Parikshit Kakati (2019) and study on Parathyroid, Thyroid and Recurrent Laryngeal nerve Anatomy in an Indian Rhinoceros by Udelsman *et al* (2017). But the information about the comparative study on bones of calf and adult Rhinoceros in relation to physiological effect on gait and bones is scanty. Hence, the present study was designed to evaluate the morphological features about bones of the forelimb of Rhinoceros in order to compare age determination of Rhinoceros and to compare the differentiating morphological features of the bones in relation to its physiology in calf and adult Indian Rhinoceros.

MATERIALS AND METHODS

The specimen was obtained from 8-month female calf and around 17 years old female great Indian Rhinoceros (*Rhinoceros unicornis*), brought from Wildlife Section ICAR-IVRI Izatnagar, after post-mortem examination. After that the specimens were biologically macerated, cleaned, dried and utilized for comparative and gross morphometrical studies in relation to its physiology at Section of Veterinary Anatomy, IVRI, Izatnagar, Bareilly (U.P.), India.

RESULTS AND DISCUSSION

Scapula was flat bone possesses two surface and two ends. Lateral surface of the scapula was divided into two unequal halves by a well-developed scapular spine as reported by Oliveira (2016), while Bordoloi *et al* (1993) stated that the well-developed spine divided the lateral surface into two equal deeper fossae. Scapula was the triangular flat bone with 46.25 cm in length and 23.75 cm in breadth (Fig. 1), while in calf 22.50 cm in length and 12.50 cm in breadth (Fig. 2), situated at cranio-lateral aspect of the thorax directed downward and forward (Bordoloi *et al*, 1993) stated similarly that scapula was the well-developed but less triangular flat bone however there were two surface, three angles and three borders as observed by Ghosh (2015). The spine was tuberous and triangular in shape. Posterior one was with breadth of 12.50 cm while in calf 7.50 cm called infraspinous fossa and the anterior one was 10.0 cm in breadth while in calf 5.0 cm called as supraspinous fossa, spine was broad and bent backward 33.47 cm in length with breadth of 13.75 cm over hanged the infraspinous fossa while in calf length was 16.25 and breadth was 6.25 cm (Figs. 1 and 2). Responsible for insertion of muscles (Fig. 19), Both the infraspinous fossa and supraspinous fossa were concave. Scapular spine diminished from the distal part (Figs. 1 and 2) as reported by Ghosh (2015). There were two nutrient foramen at distal end of the infraspinous

Fig. 1 : Photograph of scapula of adult Indian Rhinoceros (lateral view) showing semi-circular or half moon shaped supraspinous fossa (A), spine (S) and triangular infraspinous fossa (B).

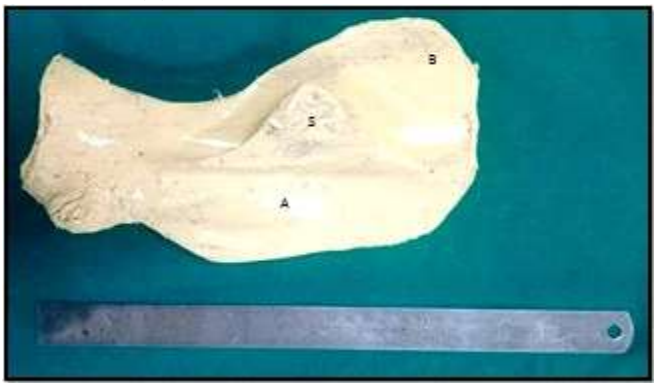

Fig. 2 : Photograph of scapula of calf Indian Rhinoceros (lateral view) showing semi-circular or half moon shaped supraspinous fossa (A), spine (S) and triangular infraspinous fossa (B).

Fig. 3 : Photograph of scapula of adult Indian Rhinoceros showing medial surface with subscapular fossa (Sf).

fossa. The medial surface had a shallow fossa at the middle known as subscapular fossa (Fig. 3), while Bordoloi *et al* (1993) stated that medial surface was divided into two equal halves by a serrated irregular horizontal line. Cranially the upper part of the surface was rough and caudally smooth. The angles were cranial, caudal and distal, the cranial angle was thin and formed by the anterior and dorsal border, anterior border was thin and convex while the dorsal border was rough, caudal angle was thick formed by posterior and small part of

Fig. 4 : Photograph of scapula of calf Indian Rhinoceros showing medial surface with subscapular fossa (Sf).

Fig. 5 : Photograph of scapula of adult Indian Rhinoceros showing Tuber scapulae (Ts) medially and oval glenoid cavity (G) distally.

Fig. 6 : Photograph of scapula of calf Indian Rhinoceros showing Tuber scapulae (Ts) medially and oval glenoid cavity (G) distally.

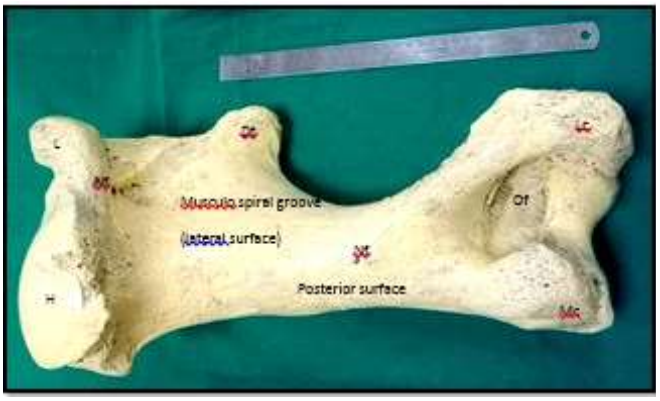

Fig. 7 : Photograph of humerus of adult Indian Rhinoceros lateral surface with musculo spiral groove, Deltoid Tuberosity (Dt) and proximal extremity having convexity of lateral tuberosity (L) and head (H), Nutrient foramen (Nf) and on posterior surface of distal end olecranon fossa (Of) and laterally Capitulum or lateral condyle (Lc) and medially trochlea or medial condyle (Mc).

dorsal border, one nutrient foramen was found on medial to the distal end of posterior border and another one found on lateral aspect between spine (Figs. 3 and 4) as reported in Rhinoceros by Laurie *et al* (1983). Distal angle comprises of the well-developed glenoid cavity and the tuber scapulae (Figs. 5 and 6) these findings were similar to Oliveira (2016). Glenoid cavity was shallow oval articular area had 10.0 cm in length and 8.75 cm in breadth with circumference 30.00 cm (Fig. 5) while in calf length was 6.25 cm and breadth was 4.25 cm and circumference was 18.75 cm (Fig. 6), it was shallow for the articulation with head of the humerus, tuber scapulae was rounded rough surfaced structure situated at the cranial aspect of the glenoid cavity as observed by Talukdar *et al* (2011) and Bordoloi *et al* (1993) and while in calf the tuber scapulae was comparatively small, coracoid process was absent on the tuber scapulae. The findings were in accordance with the observation of Bordoloi *et al* (1993) and Dinerstein (2011). To decelerating the animal's forward movement scapula and humerus was structured accordingly as studied.

Humerus was a long bone situated obliquely downward and backward forming shoulder joint above

with the scapula and elbow joint below with radius and ulna having length of 45.25 cm and width of proximal end was 25.0 cm and distal end was 16.25 cm while length of the calf was 23.75 cm and width of proximal end was 12.50 cm and of distal end was 11.25 cm similar finding were reported by Mallet *et al* (2019) and Von Houwald (2001) in Indian Rhinoceros. The cylindrical shaft of the bone twisted presenting four surfaces, lateral surface was spiral and smooth presents the Musculo-spiral groove (Fig. 7), while the medial surface was flat and rough surfaced having circumference at the middle was 25.50cm while in calf was 12.75 cm (Fig. 8) as observed by Pfistermuller *et al* (2011) in Indian Rhinoceros (*Rhinoceros unicornis*). At the middle of the anterolateral aspect a prominence was present known as deltoid tuberosity (Figs. 7 and 10). Posterior surface was rounded and smooth, nutrient foramen was situated at the middle of this surface similarly Panagiotopoulou *et al* (2019) find in white Rhinoceros. The proximal end was large and presents head, neck, tuberosities and grooves (Fig. 11) as observed by Von Houwald (2001) in Indian Rhinoceros. The head was circular, convex and articulates with glenoid cavity of scapula with circumference of 37.75 cm, while in calf was 22.50 cm. Neck was constricted part just below the head. The tuberosities were lateral and medial. These were separated by intertuberal groove. Lateral tuberosity was large and prominent and had two parts summit and a convexity (Fig. 11) as observed by Ghosh (2015). The summit was placed anteriorly and is curved over the bicipital groove as observed by Pfistermuller *et al* (2011). The distal end was articular, expanded and basically a modified condyle as reported by Von Houwald (2001) and Ghosh (2015) in Indian Rhinoceros. This end consisted of a trochlea in the form of medial condyle and the capitulum in the form of lateral condyle situated further distally and caudally with very small medial and lateral epicondyles, the olecranon fossa (Fig. 7) and the radial or coronoid fossa (Figs. 9 and 10). Similar observation was also reported by Panagiotopoulou *et al* (2019) in White Rhinoceroses (*Ceratotherium simum*). The trochlea was larger and was traversed by a groove. The groove extends cranially to the radial fossa and caudally to the olecranon fossa. The radial fossa accommodates articular surface of radius and olecranon fossa receives the anconeus process of ulna also reported in White Rhinoceroses (Panagiotopoulou *et al*, 2019) and Ghosh (2015). Medial and lateral epicondyles were small projections from the concerned condyles. Nutrient foramen was situated at distal third of the posterior surface as well as proximal end of the anterior and anterolateral

Fig. 8 : Photograph of humerus of calf Indian Rhinoceros lateral surface with musculo spiral groove, Deltoid Tuberosity (Dt) and proximal extremity having convexity of lateral tuberosity (Lt) and head (H) and on posterior surface of distal end, olecranon fossa (Of) and laterally Capitulum or lateral condyle (Lc) and medially trochlea or medial condyle (Mc).

Fig. 9 : Photograph of humerus of adult Indian Rhinoceros anterior surface with Deltoid Tuberosity (Dt) and proximal extremity having summit (S) of lateral tuberosity placed anteriorly and curved over the bicipital groove (Bg), Medial Tuberosity (Mt) and on anterior surface of distal end radial fossa (Rf) and laterally Capitulum or lateral condyle (Lc) and medially trochlea or medial condyle (Mc).

Fig. 10 : Photograph of humerus of calf Indian Rhinoceros anterior surface with Deltoid Tuberosity (Dt) and proximal extremity having summit (S) of lateral tuberosity placed anteriorly and curved over the bicipital groove (Bg), Medial Tuberosity (Mt) and on anterior surface of distal end, radial fossa (Rf) and laterally Capitulum or lateral condyle (Lc) and medially trochlea or medial condyle (Mc).

surface, while in calf the nutrient foramen was less in number (Fig. 7). It is also observed that more than 80% weight was beard by scapula providing attachment surface to scapular muscles to bear such huge weight as

reported by Hildebrand *et al* (1985) and Hutchinson (2021) (Fig. 19). Radius and ulna were fused with each other, Radius was situated in vertical direction, having length of 38.75 cm (Fig. 12) and while in case of calf length was 18.75cm (Fig. 13). It forms elbow joint with the humerus above and carpal joint with the carpal bones below as observed by Ghosh (2015) and Von Houwald (2001) in Indian Rhinoceros. The bone presents a shaft and two ends. The circumference of proximal end was 31.25 cm, mid of shaft was 16.25cm and of distal end was 33.75 cm while in case of calf circumference of proximal end was 20.0cm, mid of the shaft was 7.50 cm and of distal end was 20.0cm. The long shaft was flattened craniocaudally and curved longitudinally, presenting four surfaces in both the specimens. The posterior surface was concave throughout the whole length along the lateral part, it was attached to cranial surface of ulna proximally and distally. The radial surface of the space was smooth for the passage of interosseous vessels. Lateral surface was rounded and smooth, similar findings were reported by Pfistermuller *et al* (2011), but these finding are contrary to Laurie *et al* (1983). The medial surface was smooth and continuous with the anterior and posterior surface at its upper part bearing nutrient foramen in both the specimens. Proximal end articulated with the condyles of the humerus and therefore, possesses two articular surfaces separated by a groove (Fig. 14) similar finding were reported by Mallet *et al* (2019) and Pfistermuller *et al* (2011). The cranial rim of this surface presents a rough area and the medial and lateral tuberosities were placed at the corresponding aspect of this end just below the margin of the articular surface (Fig. 14). The cranial rim of the articular surface presents a projection called coronoid process (Fig. 14). The lateral tuberosity was well marked. These structures were similar in both the specimens. The distal end articulated with the proximal row of carpal bones and bear a styloid process at medial aspect and presents two articular surfaces, the facets at the articular surface at the distal end were straightly directed, also bearing number of nutrient foramens (Fig. 15), while number of foramina were not as so much in case of calf specimen (Fig. 13).

Ulna was a long bone fused with radius along its postero-lateral aspect with length of 47.5 cm (Fig. 12) while in case of calf it was 23.75cm (Fig. 13). The shaft was roughly prismatic and therefore, presenting three surface and three borders also reported by Dinerstein (2011) and Ghosh (2015). The anterior surface was fused with the posterior aspect of the radius excepting at the proximal and distal ends. At the upper part of this surface there were two articular facets for articulation with the

Fig. 11 : Photograph of humerus of adult Indian Rhinoceros showing proximal extremity with Deltoid tuberosity (Dt) and summit (S), curved over the bicipital groove (Bg) and convexity (C) of lateral tuberosity and Medial Tuberosity (Mt), Head (H) and Neck (N) of the bone.

Fig. 12 : Photograph of Radius and Ulna of adult Indian Rhinoceros showing Olecranon process (Op), Anconeus process (Ap) and Semilunar notch (Sn) at proximal extremity of Ulna and Interosseous space (Is) at mid of the shaft and styloid process (Sp) at the distal extremity while radius showing the proximal extremity with the border of articular surface (As), shaft (S) and at distal end presenting articular surface and at medial aspect styloid process (Sp).

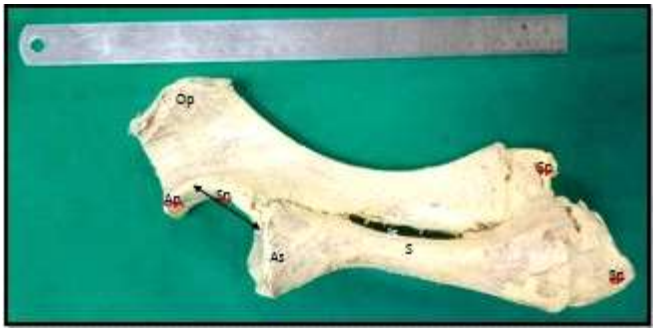

Fig. 13 : Photograph of Radius and Ulna of calf Indian Rhinoceros showing Olecranon process (Op), Anconeus process (Ap) and Semilunar notch (Sn) at proximal extremity of Ulna and Interosseous space (Is) at mid of the shaft and styloid process (Sp) at the distal extremity while radius showing the proximal extremity with the border of articular surface (As), shaft (S) and at distal end presenting articular surface and at medial aspect styloid process (Sp).

Fig. 14 : Photograph of Radius of adult Indian Rhinoceros showing the proximal extremity with the two articular surface (As) separated by a groove (G) and the cranial rim of this articular surface presents a projection- coronoid process (Cp) along with that medial (Mt) and lateral tuberosities (Lt) placed at corresponding aspect of this end.

Fig. 15 : Photograph of Radius of adult Indian Rhinoceros showing the distal extremity with the two articular surface (As), styloid process (Sp) and Nutient foramens (Nf).

corresponding facets of radius. The medial surface was smooth and concave. Lateral surface was smooth at the middle and rough surfaced at proximal and distal ends. Out of three borders medial was concave, lateral was convex and posterior one also concaves on its length responsible to bear more weight of the body (Fig. 19) similar finding observed by Talukdar *et al* (2011).

The proximal end was expanded and comprises of one large olecranon process and a semilunar notch (Figs. 12 and 13) also reported by Dinerstein (2011) and Ghosh

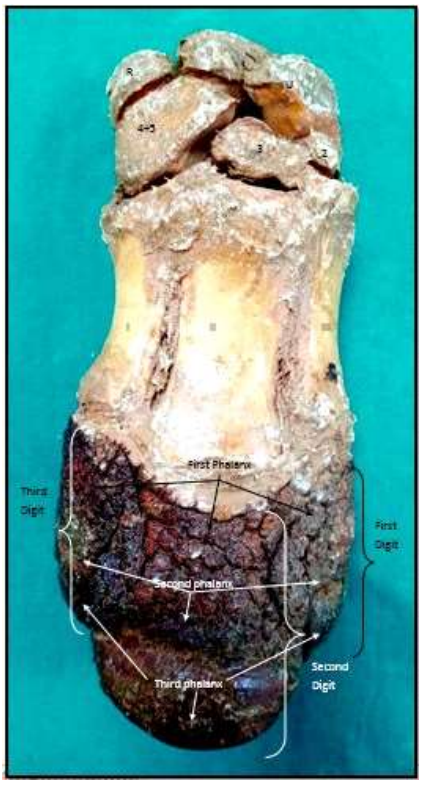

Fig. 16 : Photograph of carpals, metacarpals and digits of calf Indian Rhinoceros showing the radial (R), Intermediate (I), Ulnar (U), 2, 3, 4+5 carpal and I, II and III Metacarpal bone and first, second and third digit each with first, second and third phalanx.

(2015) having combined length of 16.25cm, while breadth was 12.50 cm, while in calf the combined length was 10.0 cm and breadth was 6.25cm (Figs. 12 and 13). The olecranon process had two surface and two borders. The lateral surface was convex and medial surface was highly concave. The anterior border was limited by semilunar notch and thereby formed a beak like projection called as anconeus process as reported by Von Houwald (2001). This process along with semilunar notch is inserted into the olecranon fossa of humerus during extension of the forelimb Ghosh (2015). The semilunar notch was smooth and broader distally. The distal end was projected downward and fused with the radius for the formation of the lateral facet having maximum circumference was 23.75cm while in case of calf specimen it was 15.0cm. This pointed projection was known as styloid process (Figs. 12 and 13). These findings were similar in both the specimens also observed by Talukdar *et al* (2011). Carpal bones were seven in number, four at the proximal row radial, intermediary, ulnar and accessory and three at the distal row second (2), third (3) and forth with fifth combined (4+5) (Fig. 16), radial carpal was placed at medial aspect of the proximal row, all the surface were irregular dorsally triangular in outline, ventral and posterior surface were concave and irregular in outline while other

were rough and irregular. Intermediate carpal was anteriorly roughly triangular in outline situated between radial and ulnar carpal bones, anterior surface was non-articular and broad, posterior surface was narrow, lateral and medial surface were articular, dorsal and ventral surface were roughly triangular in shape. Ulnar carpal was more irregular shaped bone and accessory carpal was small and roughly rounded articulated with ulnar carpal bone (Fig. 16), these finding were similar to the finding of Ghosh (2015). In the distal row second carpal which was smallest and compressed bone, third carpal was present in the middle roughly triangular in outline and while fused 4th and 5th carpal bone was larger of the two bones of this row, its dorsal surface was convex and divided into two unequal halves by a ridge, ventral surface articulated the metacarpal bone. There were three metacarpal bones representing II, III and IV (Figs. 16 and 17) as reported by Galateanu *et al* (2014) in Rhinoceros. The shaft of each metacarpal was cylindrical presenting two surface, the anterior surface was convex while posterior was concave. Proximal end and distal end were bearing nutrient foramens (Figs. 16 and 17). The proximal end of each metacarpal presents articular facets for carpal bones while distal ends of all three metacarpal bone in the form of condyle divided by a cleft at the middle (Figs. 17 and 18) and each metacarpal joined with corresponding digits, each digit representing (II, III and IV) were with three phalanges represented as first phalanx, second phalanx and distally third phalanx (Fig. 16) as reported by Rhinoceros Klaits (1973). First phalanx in each digit was short bone situated between the metacarpal and second phalanx in downward and forward direction. The anterior and lateral surface were continous, second phalanx was also short bone situated between first and third phalanx in downward and forward direction (Fig. 16). Third phalanx was proximally articulated with the distal end of the second phalanx and its solar surface was concave and flat. Middle digit was comparatively massive and strong (Fig. 16), these finding were similar to the finding of Ghosh (2015) and Galateanu *et al* (2014) in Rhinoceros. Rhinoceros forelimb biodynamics, focusing on the movement and forces exerted by the forelimbs, are playing crucial role for the locomotion and ability to support their massive body mass specially by the superficial pectorals and serratus ventralis muscles these observations were supported by Etinne *et al* (2021) and Hildebrand *et al* (1985) and Hutchinson (2021) (Fig. 19). It is also observed that more than 80% weight was beared by scapular muscles along with ribs and its related muscles, along with humerus however radius and ulna along with carpals and metacarpals bear only less than

Fig. 17 : Photograph of Metacarpals of adult Indian Rhinoceros showing I, II and III in series with shaft with anterior surface of the bone (S), articular facets (Af) at proximal end and condyle (C) at distal end.

Fig. 18 : Photograph of Metacarpals of adult Indian Rhinoceros showing I, II and III in series with shaft with posterior surface of the bone (S), articular facets (Af) at proximal end and condyle (C) at distal end.

20% weight as observed by Etinne *et al* (2021) and Hutchinson (2021). The forelimbs are particularly strong and play a major role in bodymass support due to their function in generating backward and medial impulses during movement. Large land vertebrates (i.e. above 1000 kg body mass) need strong muscles to stand and move, delivering intense forces to their limb bones, which are also subject to reaction forces at the articulations (Biewener, 1989; Biewener and Patek, 2018; Hildebrand *et al,* 1985; Hutchinson, 2021). This is particularly true for rhinoceroses, as they are the fourth heaviest species of land mammals on Earth today, with adult masses of 1350–3500 kg (average 2300 kg; Dinerstein, 2011); only smaller than the three species of elephants. *C. simum* is the heaviest mammal that is still capable of adopting a

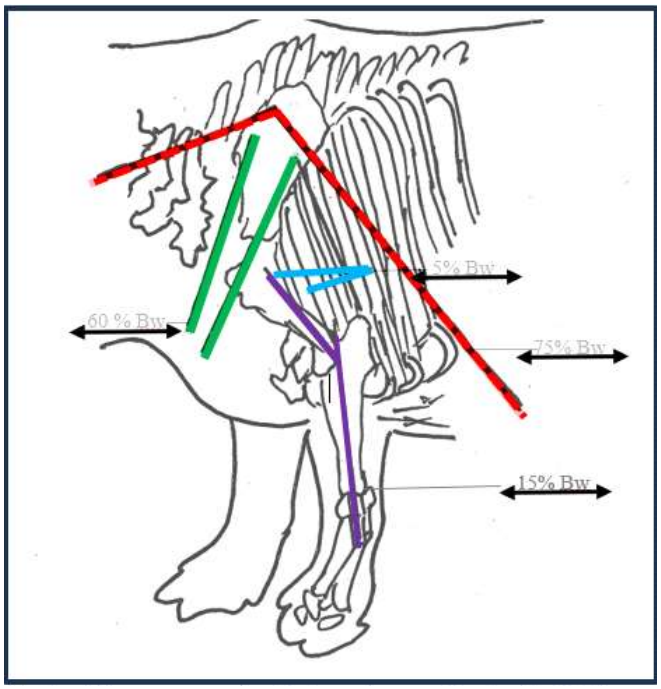

Fig. 19 a : Diagram representing the bones in respect to physiological forces working on the forelimb.

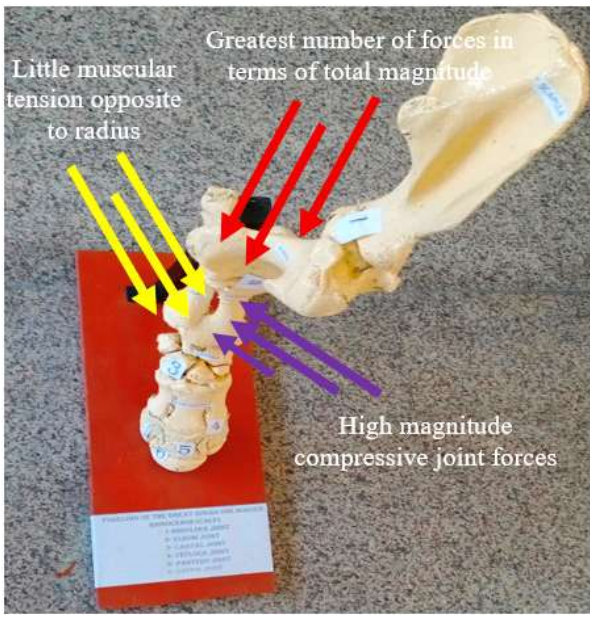

Fig. 19b : Photograph of Forelimb with articulated bones of Indian Rhinocerors Unicornis (Kept anatomy Museum, IVRI, Izzat-Nagar, Bareilly (UP). Courtsey by Dr. Rupam Sinha.

galloping gait, a 'four beat' asymmetrical footfall pattern in which all four limbs are off the ground at one point of the locomotion cycle (Alexander and Pond, 1992; Garland, 1983; Hildebrand, 1980, 1989). The pectoral girdle muscles, along with the serratus ventralis and other muscles, form a "thoracic sling" which supports the weight of the body between the forelimbs. However, their limb joints appear more flexed in Rhinoceros than other large mammals like in elephants, suggesting that relatively greater muscular forces should be necessary to keep the joints extended as observed by Biewener and Patek (2018). The functional morphology of their limb long bones has been studied in some detail and their musculature has recently been described, with quantification of maximal possible force outputs (Etienne *et al*, 2021; Mallet *et al*, 2019, 2020).

Rhinoceros incur large forces on their limb bones, due to the transmission of body weight and ground reaction forces, and the contractions of the various muscles of the limbs. Rhinoceros which is the heaviest extant animals capable of galloping. Overall, unsurprisingly, the most active muscles were antigravity muscles, which generate moments opposing body weight (thereby incurring the ground reaction force) and thus keep the joints extended, avoiding joint collapse via flexion. Some muscles like *ulnaris lateralis* and *superficial and deep digital flexor* have an antigravity action around several joints, and thus were found to be highly active and highly specialised in body weight support as reported by Cyril *et al* (2024). The humerus was subjected to the greatest amount of forces in terms of total magnitude; forces on the humerus furthermore came from a great variety of directions. The radius was mainly subject to high-magnitude compressive joint reaction forces, but to little muscular tension, whereas the opposite pattern was observed for the ulna (Fig. 19 a and b).

CONCLUSION

It was concluded from the present study that the bones of forelimb in calf and adult Rhinoceros showing almost similar morphological features but as per advancement of age their length and breadth increase accordingly and certain other features varies. Forelimbs of Rhinoceros have undergone significant physiological adaptations to support their large body mass and enable efficient locomotion. These adaptations include specialized muscle architecture, robust bone structure and thicker skin and padded feet for better support and protection. The large, thickly padded feet help cushion their steps and distribute their weight, minimizing stress on the limbs. While both forelimbs and hindlimbs are crucial for locomotion, the forelimbs bear a larger proportion of the body weight, particularly at rest. They are also more involved in decelerating the animal's forward movement. Rhinoceros forelimbs are characterized by thick, sturdy bones, particularly the humerus, radius, and ulna, which are designed to withstand the immense forces generated during weight bearing and locomotion.

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