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Morphology and osteometry of femur of rhesus monkey (*Macaca mulatta*)

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Abstract
This study was conducted to elucidate the gross morphological and osteometrical features of the femur of rhesus monkey. The shaft was cylindrical and curved cranially. The caudal surface was concave and presented a rough area, facies aspera, which extended from the level of lesser trochanter to the nutrient foramen. The foramen index (FI) of left femur bone was 67.14 indicating its position at distal 3rd of the caudal surface of the shaft. Nutrient foramen was not seen on any of the surfaces of shaft of right femur bone. Supra-condyloid fossa was shallow. The medial supra-condyloid crest was more prominent than the lateral one. The left femur (21.00 cm) was longer than the right (19.00 cm) one. The proximal extremity was comprised of head, neck, greater trochanter, lesser trochanter, trochanteric ridge and deep trochanter fossa. Head was circular in outline with distinct deep fovea capitis which was elongated oval. The greater trochanter was undivided and above the level of the head. Lesser trochanter was in the form of a tuberosity. Trochanteric ridge was well developed. Trochanter fossa was deep and extensive. The distal extremity consisted of trochlea in front and condyles behind. Trochlea consisted of two unequal ridges, lateral and medial. Lateral ridge was more pronounced than the medial ridge. Caudally, medial and lateral condyles were separated by deep inter-condyloid fossa. Medial condyle was larger than the lateral one.

Keywords: Femur, osteometry, morphology, Rhesus monkey, supra-condyloid fossa

Introduction
Rhesus monkey belongs to order primates, family ceropithecidae, genus Macaca and species mulatta. Rhesus macaques are native to India, Bangladesh, Pakistan, Nepal, Myanmar, Thailand, Afghanistan, Vietnam, southern China, and some neighboring areas. It is one of the best-known species of old world monkey. They are brown or grey in color with pink face. They show better adaptability to human presence, and generally form larger troops in human-dominated landscapes than in forests [1]. They are diurnal animals and are both arboreal and terrestrial. Skeletal system is one of the body structures that has been used and still being used for the characterization of different species of animals including humans [2, 3] as most of the parameters such as shape, height, length and size are easily accessible in the skeleton.
Anatomical data on morphology of femur of different domestic animals have been reported [4]. Information on gross morphology and biometry of femur have been reported in leopard [5], Yankasa sheep and Red Sokoto goats [6], Indian Muntjac [7] and Royal Bengal tiger [8]. Schimming *et al.* [9] described osteology and radiographic anatomy of hind limbs in Marshdeer (*Blastocerus dichotomus*). Casteleyn *et al.* [10] also studied skeleton of common Marmoset (New World monkey) including femur bone. Zedda *et al.* [11] observed macroscopic and microscopic features to differentiate femur bone of sheep and goat. Osteometric analysis of long bones has been used to determine the difference between dog breeds [12], red fox and arctic fox [13], sheep and goat [6]. However, data on the morphology and biometry of femur of rhesus monkey is scant which makes identification of this bone difficult. Keeping these points in view, the present study was planned to generate some baseline data on gross morphological features and biometrical values of the femur bone of rhesus monkey.

Material and Methods
The present study was conducted on the right and left femur bones of one adult rhesus monkey. Bones were procured from Teaching Veterinary and Clinical Complex (TVCC), F.V.Sc & A.H., R.S Pura. The bones were processed in the Division of Veterinary Anatomy, F.V.Sc & A.H., R.S Pura as per standard technique [14] and subsequently studied to record

Gross morphological feature subsequently, biometry was carried out with the help of thread, meter scale and Vernier calipers. Following anatomical measurements were recorded on the femur of both the sides:

a. Weight (gm)
b. Maximum length (cm)
c. Length of shaft (cm)
d. Circumference of proximal and distal extremity (cm)
e. Circumference of shaft at upper, middle and distal parts (cm)
f. Antero-posterior and latero-medial diameter of shaft at upper, middle and distal parts (cm)
g. Height of greater trochanter (cm)
h. Depth of trochanteric fossa (cm)
i. Depth and width of inter-condyloid fossa (cm)
j. Width of trochlea (cm)
k. Antero-posterior and latero-medial width of proximal and distal extremity (cm)
l. Width of medial and lateral condyles (cm)
m. Circumference of head (cm)
n. Length, width and height of the caput (head) (cm)
o. Eccentricity of caput femoris was calculated as per Zedda *et al*. [11]. The width of the caput was considered as minor semiaxis of ellipse (b) and length was considered as major semiaxis of ellipse (a). The degree of eccentricity was calculated according to the following mathematical formula:

$$e = \sqrt{1 - b^2}/a^2$$

The value of eccentricity lies between 0 and 1 (0 < e < 1). When the eccentricity is 0, the figure is round and when the value of eccentricity is towards 1, the figure becomes more elongated.

p. Foramen index (FI) was calculated as per Hughes[15]:

FI = (D/L) x 100, where

D= Distance of foramen from the proximal end of the bone

L= Total length of the bone

As per Veeramuttu *et al*[16], the position of the foramen was divided into three types according to FI value.

Type I: FI below 33.33, the foramen was in the proximal 3rd of the bone

Type II: FI between 33.33 to 66.66, the foramen was in the middle 3rd of the bone

Type III: FI above 66.66, the foramen was in the distal3rd of the bone

Few morphometric index measurements were also taken as per Phatsara *et al*. [17]. These included:

a. Femoral robusticity index: The least circumference of femoral shaft divided by the maximum length from the proximal extremity to the distal ends of the bone.
b. Femoral intercondylar index: The width of the internal surface of the femoral condyles divided by the width from the external surface of femoral epicondyles.
c. Femoral platymeric index: The antero-posterior subtrochanteric diameter divided by the medio-lateral subtrochanteric diameter of femur.
d. Femoral epicondylar index: The width of the anterior part of the distal articular surface of femur divided by the epicondylar width of the bone.
e. Trochanteric index: The height of greater trochanter divided by the length from the head to proximal 3rd of the bone.

Result and Discussion

The femur was a strong, cylindrical bone directed downward and forward in an oblique direction. In this study, anatomical asymmetry was observed in the femur of rhesus monkey (Fig.1). Dhall and Singh [18] also suggested one-sided forelimb dominance in rhesus monkey. The left femur (45.20 g) was heavier than the right femur bone (28.20 g). Morphologically both the bones were similar. It presented for description a shaft and two extremities. The shaft was cylindrical and curved cranially (Fig. 2) as also reported in Sambar deer [19] and Indian Muntjac [7]. Mukungu *et al*. [20] reported straight femur in ring-tailed lemurs. It presented four surfaces. The lateral, medial and cranial surfaces were smooth as also seen in leopard [5] and Royal Bengal tiger[8]. The caudal surface was concave and presented a rough area, facies aspera (Fig. 3). Rajani *et al*. [7] also observed facies aspera in middle third of femur of Indian Muntjac bounded by the prominent lateral and very faint medial femoral lips. This rough area extended from the level of lesser trochanter to the nutrient foramen (Fig. 7). Schimming *et al*. [9] observed well developed muscle lines caudally in femur of Marshdeer. Tomar *et al*. [8] observed crest on the caudal surface of femur of leopard which originated from the trochanter minor, ran obliquely and terminated in to the lateral border. The foramen index (FI) of left femur bone was 67.14 (more than 66.66) indicating its position at distal 3rd of the caudal surface of the shaft (Fig. 4). Nutrient foramen was not seen on any of the surfaces of shaft of right femur bone. In leopard, nutrient foramen was seen in the middle of the shaft of femur towards lateral border [8]. In contrast, nutrient foramen was located in proximal third of cranial surface in femur of domestic cattle [21] and Indian Muntjac [7]. Just above lateral condyle, there was a shallow supra-condyloid fossa (Fig. 4). In contrast, supracondyloid fossa was well developed in Sambar deer [19] and Indian Muntjac [7]. On the other hand, Nickel *et al*. [22] recorded shallow supracondyloid fossa in large ruminants and supracondyloid tuberosity in small ruminants. Distal part of the medial border presented medial supra-condyloid crest. At the same level, towards the lateral border, lateral supra-condyloid crest was present. The medial supra-condyloid crest was more prominent than the lateral one.

The left femur (21.00 cm) was longer than the right (19.00 cm) one. In both the bones, distal extremity showed more circumference than the proximal extremity indicating broader distal extremity (Table. 1). Circumference of shaft was minimum at middle part in both right (3.8 cm) and left (4.3 cm) femur bone. The latero-medial diameter of shaft was more than the antero-posterior diameter at upper, middle and distal parts (Table. 1).

The proximal extremity was comprised of head, neck, greater trochanter, lesser trochanter, trochanteric ridge and deep trochanter fossa (Fig. 6). Head projected more medially. It was circular in outline with distinct deep fovea capitis which was elongated oval (Fig. 6). It was circular in sheep and oval in goats[11]. Zedda *et al*. [11] observed round caput in femur of goat and elliptical caput in sheep. Eccentricity was calculated as per Zedda *et al*. [11] which gave idea about the shape of the caput (head). In rhesus monkey, eccentricity was 0.32 and 0.26 for head of right and left femur, respectively, indicating more round head in left femur as compared to right one. In sheep, mean eccentricity was 0.63 whereas in goat, it was 0.39[11]. The round head or caput allowed for a wide range of motions in relation to the acetabulum [23].

The greater trochanter was undivided. The tip of greater trochanter was directed medially. In Marshdeer, the greater trochanter was divided in cranial and caudal portions [9]. It was above the level of the head. In leopard also, the position of greater trochanter was at higher position than the head [8]. In Sambar Deer, the head was in level with the greater trochanter [19]. Lesser trochanter was prominent and was in the form of a tuberosity (Fig. 6) as also observed by Tomar *et al*.

[8] in leopard. It was located on the caudo-medial aspect of the proximal 3rd of the shaft. Trochanteric ridge was well developed and connected greater and lesser trochanter obliquely. In ring-tailed lemur, the inter-trochanteric crest connected greater and third trochanter [20]. It was prominent proximally. Between neck and greater trochanter, there was a deep extensive trochanter fossa (Fig. 6) as also recorded by Sebastiani and Fishbeck [24] in domestic cat, Budras *et al*. [25] in dog and Tomar *et al*. [8] in leopard. Third trochanter was not seen unlike ring-tailed lemurs where well developed third trochanter was located caudo-laterally and was positioned more distally than the lesser trochanter [20]. The neck was very distinct. It was nearly horizontal as also seen in sheep whereas it was sloped in goat [11]. As a result, the top of caput/head was slightly lower than the greater trochanter.

The distal extremity consisted of trochlea in front and condyles behind. Trochlea consisted of two unequal ridges, lateral and medial (Fig. 5). Lateral ridge was more pronounced than the medial ridge. Similar observation was made by Makungu *et al*. [20] in ring-tailed lemur where lateral ridge was thicker and more elevated as compared to its counterpart. Trochlear groove was evident between the two ridges (Fig. 5). Medial ridge was more prominent in domestic cattle [21], Sambar Deer [19], Indian Muntjac [7] and Marshdeer [9]. In small ruminants, both the ridges were equal in size [22]. Caudally, medial and lateral condyles were present which were separated by deep inter-condyloid fossa (Fig. 4). Medial condyle was larger than the lateral one. In Indian Muntjac, lateral condyle was bigger than the medial [7]. Similar observation was made by Schimming *et al*. [9] in Marshdeer. Lateral aspect of both the condyles presented shallow depressions.

The biometrical data regarding femur of rhesus monkey has been depicted in Table 1. The morphometric index measurements of femur gives an idea about shape and size [17]. Femoral robusticity index gives idea about the size of the bone whereas femoral epicondylar index indicates the width ratio of the distal part of the bone. The trochanteric index indicated the height ratio of the greater trochanter of the bone. Phatsara *et al*. [17] measured these morphological indices in different species as humans, monkey, horses, cow, pig and dog. Kappelman [26] also measured the ratio of proximal antero-posterior and medio-lateral shaft dimensions at the distal base of lesser trochanter (Femoral platymeric index as per Phatsara *et al*. [17]). This ratio provides an estimate of various forces operating through the proximal femur. In monkey, latero-medial diameter was found to be larger than the antero-posterior diameter (ratio less than 1) in proximal femur. Kappelman [26] also observed larger latero-medial diameter than antero-posterior diameter in cursorial bovids from open habitats (ratio 0.962) than the bovids from closed habitats (1.061), which corroborated our present study.

Table 1: Biometrical parameters of femur of rhesus monkey

S. No.	Parameters	Right femur	Left femur
1.	Weight	28.20 g	45.20 g
2.	Maximum length	19.00 cm	21.00 cm
3.	Length of shaft	13.20 cm	13.60 cm
4.	Circumference of proximal extremity	09.20 cm	09.30 cm
5.	Circumference of distal extremity	09.70 cm	09.60 cm
6.	Circumference of shaft at upper part	03.90 cm	04.60 cm
7.	Circumference of shaft at middle part	03.80 cm	04.30 cm
8.	Circumference of shaft at distal part	03.80 cm	05.00 cm
9.	Antero-posterior diameter of shaft at upper part	01.01 cm	01.25 cm
10.	Latero-medial diameter of shaft at upper part	01.25 cm	01.32 cm
11.	Antero-posterior diameter of shaft at middle part	01.05 cm	01.25 cm
12.	Latero-medial diameter of shaft at middle part	01.18 cm	01.37 cm
13.	Antero-posterior diameter of shaft at distal part	01.05 cm	01.44 cm
14.	Latero-medial diameter of shaft at distal part	01.38 cm	01.74 cm
15.	Height of greater trochanter	02.30 cm	02.51 cm
16.	Depth of trochanteric fossa	00.85 cm	00.71 cm
17.	Depth of inter-condyloid fossa	01.28 cm	01.28 cm
18.	Width of inter-condyloid fossa	01.01 cm	01.01 cm
19.	Width of trochlea	01.25 cm	01.64 cm
20.	Antero-posterior width of proximal extremity	01.72 cm	01.75 cm
21.	Latero-medial width of proximal extremity	03.15 cm	03.61 cm
22.	Antero-posterior width of distal extremity	02.65 cm	02.55 cm
23.	Latero-medial width of distal extremity	03.14 cm	03.24 cm
24.	Width of medial condyle	01.14 cm	01.23 cm
25.	Width of lateral condyle	00.98 cm	01.01 cm
26.	Circumference of caput (head)	06.30 cm	05.90 cm
27.	Length of caput (head)	01.85 cm	01.81 cm
28.	Width of caput (head)	01.75 cm	01.75 cm
29.	Height of caput (head)	01.81 cm	01.72 cm
30.	Eccentricity (e)	00.32	00.26
31.	Foramen index (FI)	Nutrient foraman not found	67.14
Morphometric Index measurements			
1.	Femoral robusticity index	0.20	0.20
2.	Femoral intercondylar index	0.32	0.31
3.	Femoral platymeric index	0.81	0.93
4.	Femoral epicondylar index	0.40	0.51
5.	Trochanteric index	0.37	0.36

Fig 1: Photograph showing asymmetry in right and left femur bones of rhesus monkey

Fig 2: Photograph showing left femur bone of rhesus monkey (bent cranially)

Fig 3: Photograph showing proximal extremity of left femur bone of rhesus monkey (caudal view) showing head (H), greater trochanter (G), lesser trochanter (L), trochanteric ridge (R) and facies aspera (arrows)

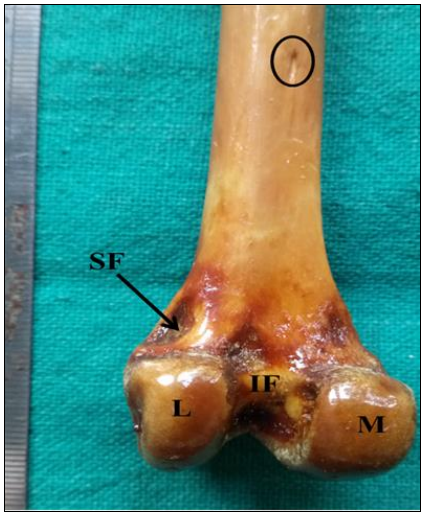

Fig 4: Photograph showing distal extremity of left femur bone of rhesus monkey (caudal view) showing nutrient foramen (encircled), medial condyle (M), lateral condyle (L), intercondyloid fossa (IF) and supra-condyloid fossa (SF)

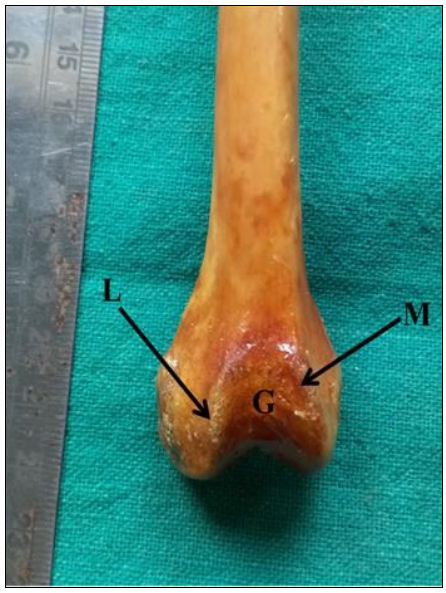

Fig 5: Photograph showing distal extremity of left femur bone of rhesus monkey (cranial view) showing medial trochlear ridge (M), lateral trochlear ridge (L) and trochlear groove (G)

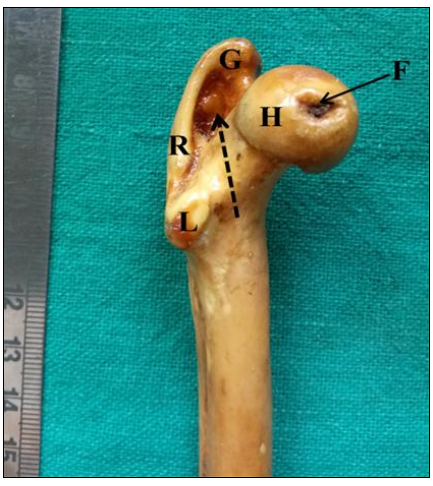

Fig 6: Photograph showing proximal extremity of left femur bone of rhesus monkey (medial view) showing head (H), greater trochanter (G), lesser trochanter (L), trochanteric ridge (R), fovea capitis (F) and trochanteric fossa (dotted arrow)

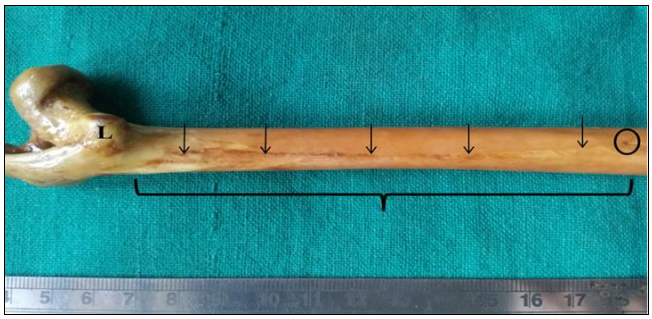

Fig 7: Photograph showing caudal aspect of shaft of left femur bone of rhesus monkey showing facies aspera (arrows) extending from base of lesser trochanter (L) to the level of nutrient foramen (encircled)

Conclusion

From this study, it was concluded that left femur bone was heavier and longer than the right one. Morphologically, bones of both the sides were similar. The information/data generated from this study will be useful to field veterinarians, zoo veterinarians and wildlife experts.

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