



# Gross Anatomical Studies on the Pelvic Limb of Indian Palm Squirrel (*Funambulus palmarum* (Linnaeus, 1766))

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## Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

## Article Information

DOI: <https://doi.org/10.56557/upjoz/2024/v45i184431>

## Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://prh.mbimph.com/review-history/3991>

Original Research Article

Received: 24/06/2024  
Accepted: 26/08/2024  
Published: 03/09/2024

## ABSTRACT

The aim of the study is to document the anatomical details of bones of pelvic limb of Indian palm squirrel (*Funambulus palmarum*). Samples for the present study were collected from six adult Indian palm squirrels (*Funambulus palmarum*) which died due to natural causes. The bones were collected by fresh water maceration technique. The gross anatomy of bones in pelvic limb was studied after fresh water maceration and cleaning. The bones of pelvic limb were found to be similar in structure and number to other rodents and carnivores that have been studied. Oscoxae, the bone of pelvic girdle showed a prominent caudal ventral iliac spine cranial to the acetabulum, tuber ischii was

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single, incomplete acetabular rim. Pelvic symphysis contained pubis and ischium. The obturator foramen was relatively large and oval. Fovea capitis was shallow in the femoral head; trochanter major, trochanter minor in proximal epiphysis. Trochanter tertius in the femur was connected distally to the mid-shaft region by a ridge. Tibia was the longest bone in body of Indian palm squirrel (*Funambulus palmarum*). Two sesamoid bones (febellae), embedded in the tendons of the origin of gastrocnemius muscle. Patella was a small wide square shaped bone that glides on trochlea of femur. Tibia and fibula were two long bones articulated at proximal and distal extremities with wide interosseous space. Tarsals were seven, arranged in three rows and articulate with the metatarsals distally. Five metatarsal bones, I-V were evident of which first one was short. Five digits were present, first one contained two phalanges and the remaining digits contained three phalanges each.

**Keywords:** Pelvic limb bones; gross anatomy; Indian palm squirrel (*Funambulus palmarum*).

## 1. INTRODUCTION

Squirrels are the mammals of the order Rodentia, occur indigenously in all continents except Australia and Antarctica. There are approximately 50 genera and 273 species recognized in the family Sciuridae [1]. In southern Asia, there are three tribes of squirrels, the Ratusini, including the giant tree squirrels of India and southeast Asia, Funambulini, including three and five striped squirrels and the Callosciurini, including all the non-striped smaller tree, ground, and pygmy squirrels of southeast Asia. The phylogenetic relationships of the subfamilies and tribes of squirrels are not well understood. Morphology and paleontology have not yet provided unambiguous evidence, probably because the divergence of these groups occurred early in the history of the Sciuridae [2]. The three striped squirrel or Indian palm squirrel (*Funambulus palmarum* *Linnaeus, 1766*) is a small common squirrel of peninsular India best seen in urban and rural areas of southern Madhya Pradesh, Bihar, Andhra Pradesh, Orissa, Karnataka, Tamil Nadu and Kerala. The Indian palm squirrel has three pale parallel lines on its back running on its back from head to tail. Greyish brown or olive brown under parts, Legs are short, bushy black and white peppered tail has a bold reddish brown mid-ventral line running through it. Indian palm squirrel is facing conservation treats due to habitat loss and poaching [3]. Hence, there is no information available on the anatomical features of the skeletal system of the Indian palm squirrel. Anatomical and morphological studies of the pelvic limb have always been of interest to the researchers in the field of anatomy, due to its high significance in various fields of Veterinary Medicine and Zoology. As the literature on the gross anatomical features about the pelvic limb in three striped squirrels is meagre, the present

study is conducted to contribute the dearth of information in Indian palm squirrel.

## 2. MATERIALS AND METHODS

The present study was conducted on pelvic limbs of six Indian palm squirrels which were died due to natural causes. The six dead squirrels were collected and macerated in fresh water at the College of Veterinary Science, Proddatur, Andhra Pradesh. After maceration, the bones of pelvic limb were cleaned, and the gross anatomical features of the pelvic limb bones were recorded.

## 3. RESULTS

### 3.1 Oscoxae

The pelvic girdle consisted of left and right os coxae. These two bones met at the pelvic symphysis ventrally. This bone articulated dorsally with the sacrum through ilium and runs linear to the vertebral column. The oscoxae built with three bones viz., ilium, ischium and pubis like other mammals (Fig. 1).

#### 3.1.1 Ilium

Ilium formed the cranio-dorsal part of the oscoxae. It was the largest of the three parts. It was a wide curvilinear bone. It was wide above with a wing dorsally and shaft ventrally. It was comprised of two surfaces, three borders and three angles.

**Surfaces:** This bone was comprised of two surfaces, lateral and medial. Lateral surface had a concave area called gluteal fossa. Anterior to the acetabular fossa, caudal ventral iliac spine was conspicuous and end in thick tubercle. The medial surface was strongly convex and divided

into a non-articular iliacus area cranially and a rough triangular shaped sacral articular area caudally. Ilio-pubic line extends from this surface to the anterior border of the pubis and carried a psoas tubercle at the middle.

**Borders:**The dorsal border was called as iliac crest which was thin. The cotyloid border was thick and concave towards the shaft. Greater ischiatic notch was shallow. Ischiatic border was convexo-concave, met the ischiatic spine and joined with the acetabulum.

**Angles:** The tuber sacrale was thick and rounded. Coxal tuber was pointed and the ischiatic angle met the concerned angles of the ischium and pubis at the acetabulum.

### 3.1.2 Ischium

Ischium had a twisted appearance, extended cranially from the acetabular fossa, connected to other half medially by symphysis and posteriorly by ischial tuberosity and ischial arch. It had two surfaces, four borders and four angles.

**Surfaces:** The dorsal or pelvic surface was concave and roughly triangular in shape. The ventral surface was divided by an elongated ischial spine into a lateral small area and wide area medially. The ischial spine was extended from the ischial tuberosity to the acetabular fossa. From the acetabular notch a narrow ischial groove extends on this surface.

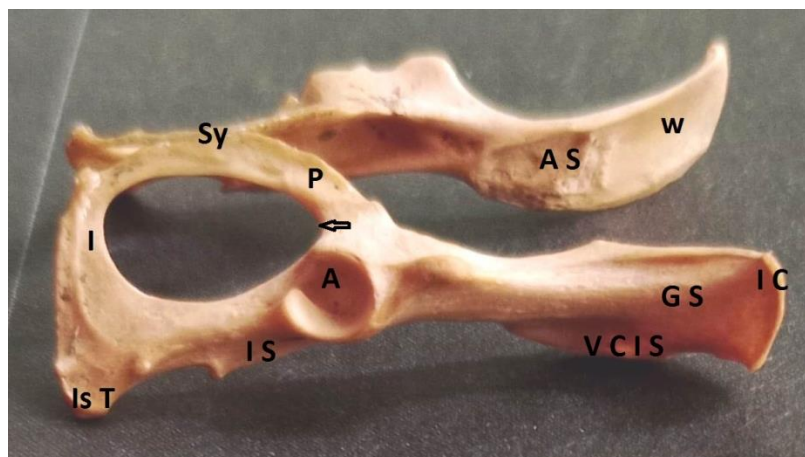
**Borders:** lateral border was concave and forms the lesser ischiatic notch and separated from the

ischiatric spine by a small pointed ridge. Medial border met with the similar border of the opposite half and forms the ischial symphysis. The anterior border was concave and formed the posterior half of the obturator foramen. The average saggital length and width of obturator foramen was 0.9 cm and 0.4 cm respectively. Posterior border was nearly straight extending from the ischial tuberosity to the ischial symphysis. It formed the ischial arch along with the similar border of the opposite half in a narrow "V" shaped structure.

**Angles:**Two lateral and two medial angles were present in this bone. The antero-lateral angle met the acetabular fossa and postero-lateral angle formed the rounded ischial tuberosity which was continued distally with the ischial spine. The medial angles met with the ischial symphysis.

### 3.1.3 Pubis

The body of pubis was a thin plate of bone with an acetabular branch cranially and caudal symphyseal branch. The dorsal or pelvic surface was slightly convex and the ventral surface was concave with rough lines. The anterior border was convex and thin which was continued anteriorly with the cotyloid border of the ilium. The caudal border was deeply concave and formed the anterior border of the obturator foramen. The medial border met the similar border of the other half forming the pelvic symphysis. The lateral angle joined with the similar angles of the ilium and ischium and formed the acetabular fossa.



**Fig. 1. Oscoxae- Lateral View IC- Iliac Crest, A S- Auricular surface for sacrum, W- Wing of ilium, G S- Gluteal Surface, V C I S- Ventral caudal Iliac Spine, A- Acetabulum, P- Pubis, Sy- Symphysis, Is T- Ischial Tuberosity, I- Ischium, I S-Ischial spine, Arrow showing obturator foramen**

Acetabulum was very deep cotyloid cavity which was formed by the contribution of the acetabular angles of the ilium, ischium and pubis. Acetabulum had an articular and deep non-articular area for the round ligament of the hip joint. The articular area was nearly circular for the head of the femur. A wide acetabular notch was present at the postero-medial aspect of the rim of the acetabular fossa.

### 3.2 Femur

The femur was a long slender bone of thigh region placed obliquely downward and forward with a shaft and two extremities. The shaft had four surfaces. The shaft was cylindrical. It had four surfaces and two borders. The surfaces were lateral, medial, anterior and posterior surfaces. The lateral, medial and anterior surfaces were smooth and continuous with each other. The lateral and posterior surfaces were flat and separated by a sharp ridge. The two borders were medial and lateral which were rounded and continuous with each other. The proximal epiphysis consisted of a femoral head, trochanter major, trochanter minor, trochanter tertius and trochanteric fossa. The femoral head was absolutely round in shape bent medially and distinctly separated from neck. It was in same level with the trochanter major unlike in domestic mammals. The fovea capitis appeared as a

distinct depression. The elongated neck was very strong and well developed which connects the epiphysis with head. The trochanter major was strongly bent medially, its lateral surface was rough and the medial surface bounded the trochanteric fossa (Fig. 2). The trochanter minor was a distinct elevation at lower part of the neck of femur. Trochanter tertius was connected to the trochanter major by a ridge dorsally and connected to the midshaft by another ridge distally. The trochanteric fossa was very deep. The proximal extremity was larger than the distal extremity.

The distal extremity carried a trochlea cranially and two condyles caudally. The trochlea articulated with patella. The patellar groove on trochlea was wide. The condyles were separated by a wide intercondyloid fossa. The trochlear groove was continuous with the intercondyloid fossa distally. The condyles showed an ellipsoidal articular area for articulation with the condyles of tibia. The epicondyles were less prominent. The medial and lateral epicondyles had roughened surfaces. Two sesamoid bones (febellae), embedded in the tendons of the origin of gastrocnemius muscle located on the dorsal surface of the lateral and medial condyles. The lateral and medial supracondyloid fossae were absent.



**Fig. 2. Caudal view and Cranial view of Femur showing H – Head, N- Neck, s-shaft, Tr M- Trochanter Major, Tr Mi- Trochanter Minor, Tr T –Trochanter tertius, Tr F- Trochanteric Fossa, M C- Medial Condyle, LC- Lateral Condyle, ICF- Intercondyloid Fossa, T- Trochlea**

### 3.3 Patella

Patella was a small square shaped bone. The cranial surface was smooth and nearly flat. The caudal surface had a flat articular area for the trochlea of femur.

### 3.4 Tibia and Fibula

These were the bones of the leg region which were separate but articulated at their extremities with a wide and elongated interosseous space between them with like facets.

#### 3.4.1 Tibia

Tibia was a long bone with a shaft and two extremities. The shaft was massive and three sided above and flattened below. The lateral surface was grooved and concave above and became gradually inclined towards the anterior face distally. The medial surface was flat proximally and became round distally. The lateral and medial surfaces were separated by a crest called the tibial crest. The posterior surface carried a groove proximally and the groove was limited laterally by a popliteal crest. The shaft

had three borders viz., lateral border was concave and applied against the fibula and formed the tibio-fibular groove (Fig. 3). The anterior border was prominent at the proximal third as the tibial crest, which joined the tibial tuberosity proximally and in the distal third it disappeared and joined with the anterior surface. The medial border was thick and blunt. The proximal extremity of tibia carried two condyles and a cranial tibial tuberosity. The condyles were medial and lateral which were slightly concave for articulation with the condyles of the femur. In between the condyles a small tibial spine was present that extended into the intercondyloid fossa of femur. The rough depressions were present in front and behind the tibial spine for the attachment of ligaments. The popliteal notch was present in between the condyles caudally. The lateral condyle bear an articular area for the head of fibula and the medial condyle bear a depression for the attachment of ligaments. The distal extremity was smaller than the proximal extremity. The medial border of the distal extremity was continuous with the medial malleolus. The lateral border articulated with the distal extremity of fibula. It showed articular areas for tibial tarsal distally.



**Fig. 3.** Cranial and caudal view of Tibia and Fibula showing Tt- Tibial tuberosity, s-shaft of tibia, Sf- shaft of fibula, MM- Medial Malleolus, LM- Lateral Malleolus, H- Head of Fibula, LC- Lateral condyle, MC- Medial Condyle, PN-Popliteal Notch

### 3.4.2 Fibula

The fibula was a slender rod like bone. It extended from proximal to the distal extremity of tibia on its lateral border. It had a shaft and two extremities. The shaft was thin and run parallel to the lateral border of the tibia and formed tibio-fibular arch. The proximal extremity was wide and its medial surface articulated with the lateral surface of the lateral condyle of the tibia. The distal extremity was also expanded and forms the lateral malleolus that articulated with the distal extremity of tibia on its lateral surface. The articular area for fibular tarsal was absent in this bone.

### 3.5 Tarsals

Tarsals were seven short bones arranged in three rows between the tibia proximally and metatarsals distally.

Proximal row consisted of two bones viz., fibular and tibial tarsal. The fibular tarsal was placed laterally and tibial tarsal was placed medially. The middle row had a single bone, the central

tarsal. The distal row consisted of four bones from medial to the lateral are 1, 2, 3 and 4 (Fig. 4).

#### 3.5.1 Fibular tarsal

The fibular tarsal was the largest among all the tarsal bones. The fibular tarsal had a body, a proximally projected tuber calcis and medially projected sustentaculum tali. The medial surface of the body articulated with the lateral surface of the tibial tarsal and distally articulated with the fourth tarsal. The sustentaculum tali articulated with the plantar surface of the tibial tarsal.

#### 3.5.2 Tibial tarsal

The tibial tarsal was located medially in the proximal row. It had a trochlea proximally and a rounded head distally. The trochlea articulated with the distal extremity of tibia whereas the plantar and lateral surface of the tibial tarsal articulated with the corresponding surface of body of fibular tarsal. The distal head was rounded and articulates with the proximal surface of the central tarsal.

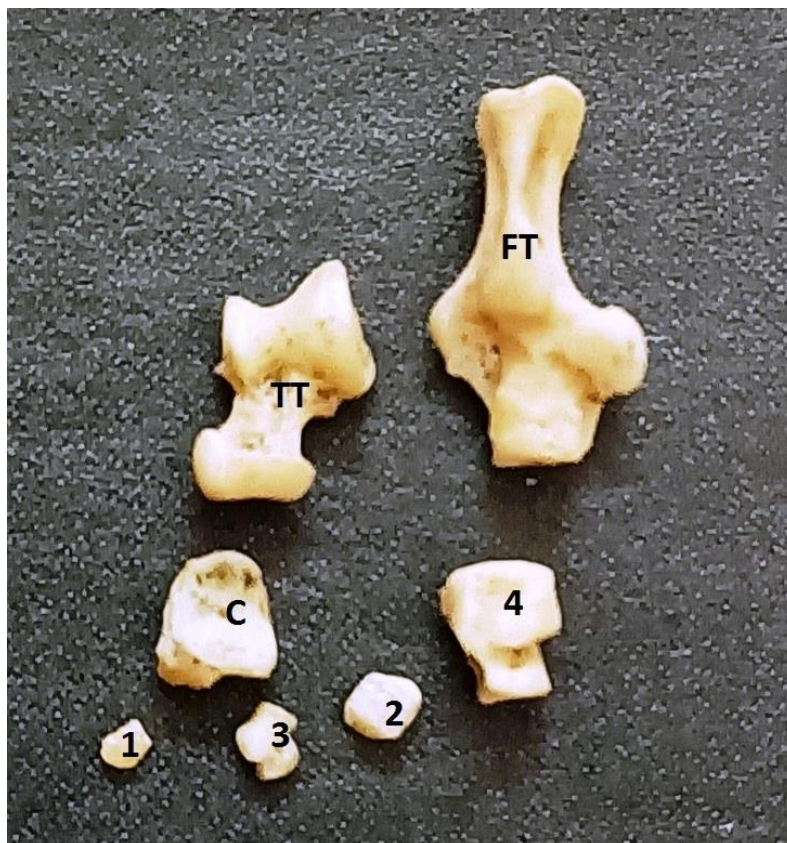


Fig. 4. Tarsals. TT- Tibial tarsal, FT- Fibular Tarsal, C- Central Tarsal,1,2,3,4 tarsals

### 3.5.3 Central tarsal

It was located in the central row. It had a deep concave articular surface on its dorsal surface for the head of tibial tarsal. It had a projection on its dorso-medial border of this surface. It articulated with the fibular and fourth tarsal bones partially. The distal surface articulated with the first, second and third tarsals from the medial to lateral aspect.

### 3.5.4 The tarsals of distal row

1, 2, 3 and 4 tarsals articulated with central and fibular tarsal dorsally that facilitated third, fourth, central and fibular tarsal articulation for the proximal heads of metatarsal bones distally. Each tarsal articulated with their corresponding metatarsals except that the fourth tarsal articulate with the fourth and fifth metatarsal bones. The fourth tarsal carries a distinct groove on lateral and plantar surface.

### 3.6 Metatarsals

The pedis comprised of metatarsal bones. Five metatarsal bones are present. The first one was short, third and fourth metatarsals were longer than first, second and fifth. First metatarsal carried two phalanges whereas second to fourth metatarsals carried three phalanges. Each metatarsal bone was a long bone and had a shaft and two extremities.

### 3.7 Digits

Five digits were present; each digit had three phalanges except the first digit that was comprised of two phalanges only.

#### 3.7.1 Phalanges

Each digit had three phalanges i.e., proximal, middle and distal phalanges. First digit consisted of only proximal and distal phalanges. Proximal phalanges were larger than the middle phalanges. These two phalanges were long bones with a shaft and two extremities. Shaft was flat and bent towards the palmar direction. Proximal extremity of first phalanx showed two condyles separated by a groove and the distal extremity contained a distinct trochlea. The proximal extremity of the middle phalanx contained two articular areas separated by a ridge and the distal extremity of it showed two condyles with a distinct groove between them. Distal phalanx or ungulate bone showed a

concave articular area for the middle phalanx, surrounded by prominent rim/crest. In front of this articular area extensor process was present dorsally and a flexor tubercle evident on palmar surface. Below the rim/crest an ungulate process was present, which was sharp and bent in palmar direction and also bear the claws.

Proximal sesamoids were 8 in number in each limb, which articulated at the ventro-palmar side of each metatarso-phalangeal joint. These bones were small and elongated. Distal sesamoids were five in number, which articulated at the distal phalangeal joints on the palmar side. These bones were small, round in shape.

## 4. DISCUSSION

The pelvic limb study of the Indian palm squirrel unveiled a lot of similarity and some differences in skeletal morphology with other species of rodents and carnivores as squirrels were kept under order rodentia. In the oscoxae of Indian squirrel, ilio-pubic line extended from medial surface of ilium to the anterior border of the pubis and carried a psoas tubercle at the middle. In contrary, the shaft of ilium presented an indistinct iliopubic eminence and psoas tubercle on ventral border in the oscoxae of Orange Rumped Agouti [4]. In the present study, dorsal border of ilium described as iliac crest which was thin but a thick and convex iliac crest and terminated in a hook like muscular projection was reported in Orange Rumped Agouti [4]. In present study, ilium carried a shallow greater ischiatic notch and the lesser sciatic notch was concave. Conversely in mole-rat, greater sciatic notch was wide and deep, lesser sciatic notch was deep and narrow [5]. In Indian palm squirrel anterior to the acetabular fossa, caudal ventral iliac spine was conspicuous and end in thick tubercle. Similar observations were noted in ground squirrels [6] and in the rabbit [7].

The antero-lateral angle of ischium met the acetabular fossa and postero-lateral angle forms the single rounded ischial tuberosity which was continued distally with the ischial spine in Indian palm squirrel. Similarly a prominent ischial tuber with two processes was observed in Orange Rumped Agouti [4]. Also, the ischial tuber was present caudo-laterally in the ischium of African giant pouched rat [8] and in ground squirrels [6]. The medial angles met with the ischial symphysis. In the present study, ischial arch was a narrow "V" shaped structure but rectilinear in ground squirrels [6]. The pubis

appeared as a curved bone in an antero-posterior position in Indian palm squirrel. In contrast pubis was L shaped bone in Orange Rumped Agouti [4]. The lateral angle of pubis was joined with the similar angles of the ilium and ischium and formed the acetabular fossa. The medial angles joined with the pelvic symphysis in Indian palm squirrel but the medial angle of pubis was slender in mole-rat [5]. A wide acetabular notch was present at the postero-medial aspect of the rim of the acetabular fossa in present study. In contrast, it was described that acetabular notch was absent in mole-rat instead a little foramen was present [5].

The femoral head was absolutely round in shape and distinctly separated from neck. It was at same level with the trochanter major unlike in domestic animals. In contrast, femoral head was higher in position than trochanter major in Orange Rumped Agouti [4]. The greater trochanter, lesser trochanter and trochanter tertius were prominent in Indian palm squirrel similar to mole-rat [5], African giant pouched rat [8] and hoary-bellied Himalayan squirrel [9] Orange Rumped Agouti [4]. Two sesamoid bones (febellae) of Indian palm squirrel, embedded in the tendons of the origin of gastrocnemius muscle were similar to canines [10] and in Orange Rumped Agouti [4] and ground squirrel [6]. Patella was a small square shaped bone in Indian palm squirrel similar to ground squirrel [6] but it was comma shaped in Orange Rumped Agouti [4].

Tibia and fibula were the bones of the leg region which articulated at their extremities with a wide and elongated interosseous space between them in present study was similar to Orange Rumped Agouti [4]. In contrast, the fusion between tibia and fibula in the distal 1/3 portion was reported in mole-rat [5] and in African giant pouched rat [8]. Tarsals were seven short bones arranged in three rows between the tibia proximally and metatarsals distally was similar to dog [11] and in hedgehog [12]. In contrast, 8 tarsal bones were reported in Orange Rumped Agouti [4], mole-rat [5] and in African giant pouched rat [8]. In our study, the pedis was complete with all five digits. Similarly five metatarsals and five digits were reported in other burrowing animals like Wistar rat [13], laboratory rat [14], Rabbit [15], Mink [16], Porcupine [17] and Mole rat [5]. In contrast, three metatarsals and three digits were reported in Orange rumped agouti [4] and in guinea pig [18], however, in some species of the Erinaceidae family the pedis consisted of four digits [19].

## 5. CONCLUSION

This study was an addition to the information regarding the hind limb skeleton of Indian palm squirrel. Well developed caudal ventral iliac spine and incomplete rim of acetabulum was noted in Indian palm squirrel. The proximal epiphysis in femur consisted of a femoral head, trochanter major, trochanter minor and trochanter tertius. Femoral head was at the same level with trochanter major unlike in domestic animals. Tibia and fibula were the long bones of the leg region which articulated at their extremities with a wide and elongated interosseous space between them. This anatomical feature was believed to be responsible for their capacity in digging the soil and to make holes. Tarsals were seven short bones arranged in three rows between the tibia proximally and metatarsals distally. The pedis was complete with all five digits. These anatomical features may be responsible for the ability of squirrels to stand merely on hind limbs.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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