Original Research

Gross Morphology and Morphometrical Studies on the Vertebral Column of Indian Giant Flying Squirrel (*Petaurista philippensis*)

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Abstract

The present study was conducted on the gross anatomical features of the vertebral column of Indian giant flying squirrel (Petaurista philippensis). It belongs to the order rodentia and Sciuridae family. The bones of vertebral column were collected during the post-mortem examination at Veterinary College, Shivamogga, Karnataka. The vertebral formula was found to be C_7, T_{12}, L_7, S_3 and Cy_{27}. The foramen transversarium was noticed in all the cervical vertebrae except in C_7. The width and length of the centrum progressively increased from L_1 to L_7. Haemal arch and haemal processes were observed in Cy_4 to Cy_9 and Cy_{10} to Cy_{19} respectively. The variations in neural spine, vertebral body length and transverse process were observed in all the vertebrae. So, these variations in the vertebral column may be attributed to the specialized movements such as gliding, lifting and balancing the body of Indian giant flying squirrel.

Key words: Gross Morphology, Indian Giant Flying Squirrel, Morphometry, Vertebral Column

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Introduction

The flying squirrel is a tribe of 50 species of squirrels in the family Sciuridae. The Indian giant flying squirrel also called the large brown flying squirrel or the common giant flying squirrel belongs to the order rodentia in the Sciuridae family. The species is native to China, India, Laos, Myanmar, Sri Lanka, Taiwan, Thailand, and Vietnam (Walston *et al.*, 2016). Flying squirrels are not capable of flying like the birds or bats but are able to glide from a tree to another with the aid of a patagium, a wooly, parachute-like

membrane that stretches from wrist to ankle. Their long tail provides stability in glide and the tail acts as an adjunct airfoil working as an air brake before landing on a tree trunk. The flying squirrels show lengthening of the lumbar vertebrae, which reveals their adaptation to minimize wing loading and to increase more maneuverability while gliding (Goldingay, 2000 and Asari *et al.*, 2007).

Skeletal structure in animals is largely dependent on evolution. As animal species adapt to different ecological niches, their physical structures often change over time as natural selection rewards with reproductive success those individuals with the most successful adaptations. Humans are adapted to a life of walking and running and so our bones have evolved to support our upright habits. Birds, however, are heavily adapted to a life of flight, which is reflected in the structure and composition of their skeletons. Tree squirrels react to disturbances by moving to the opposite side of their tree, whereas flying squirrels climb upwards and then glide to another tree. However, this behavior may increase susceptibility to attack from their most likely predator, owls (Scheibe and Robins, 1998; Paskins *et al.*, 2007).

The literature on the morphological and morphometrical studies on the Indian flying giant squirrels is very scanty. Hence, this study was undertaken with the aim to document morphological and morphometrical features on the vertebral column of the Indian flying giant squirrel which is also helpful to provide basic research data and also differentiate it from other gliding mammals.

Materials and Methods

The materials for the present study were collected from a female adult Indian giant flying squirrel carcass, brought for the post-mortem examination to the Department of Veterinary Pathology, Veterinary college, Shivamogga (Post-mortem No. 324/2018). The maceration of bones of vertebral column was carried out as per Mayakkannan *et al.* (2017). Briefly, the vertebral column region of the carcass was defleshed to the extent possible. After defleshing, the remaining carcass was buried two feet depth in the mud filled drum. The macerated bones were removed after about two months. The bones were cleaned, bleached properly and utilized for the present studies. The measurements of the different parts of the vertebrae were taken with help of Mitutoyo Digimatic Caliper and measuring scale.

Vertebral body length (VBL), height, width and length of the centrum (CH, CW and CL), height and width of the neural spine (NSH and NSW), length and width of the cranial and caudal articular process (CrAPL, CrAPW and CaAPL, CaAPW), length and width of the transverse process (TPL and TPW) and height and width of the neural canal were measured and the values were presented in the Tables 1 to 7. Photographs were taken by using Nikon coolpix p5100 digital camera.

Results and Discussion

The present study was undertaken to document the gross anatomical and morphometrical features of the vertebral column of Indian flying giant squirrel (*Petaurista philippensis*). The vertebral formula was

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Cervical (C_7), Thoracic (T_{12}), Lumbar (L_7), Sacrum (S_3) and Coccygeal (Cy_{27}) (Fig.1). The centrum of caudal extremity of axis (C_2) to Cy_7 was with a pit surrounded by bone. Peculiar findings found were centrally white colored similar to the table surface of incisor of horse. In Indian giant flying squirrel, the T_{11} and T_{12} were similar to lumbar vertebrae. This observation was similar to that of bat as reported by Gaurdioso *et al.* (2017).

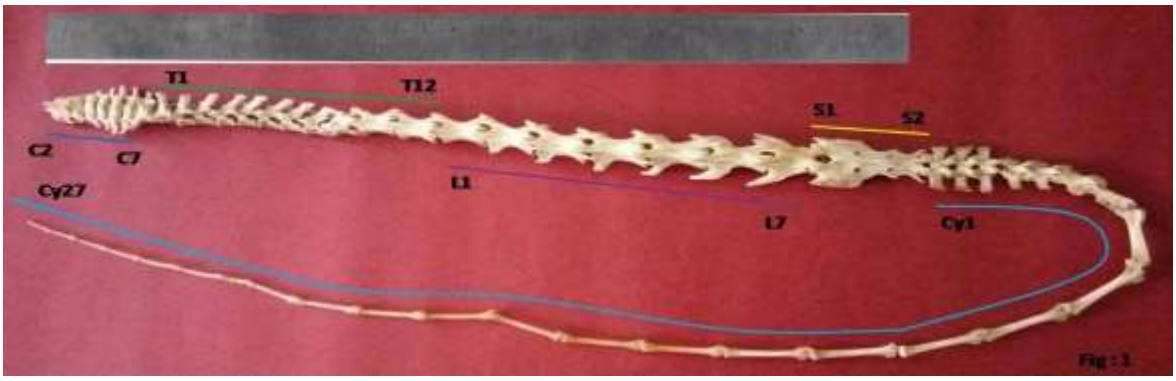

Fig.1: Panoramic view (dorsal) of vertebral column (C_2 to Cy_{27}) in Indian giant flying squirrel

Cervical Vertebrae

In the present study, the cervical vertebrae were seven in number (Fig. 2). Among the seven cervical vertebrae C_3, C_4 and C_5 were typical, whereas atlas (C_1), axis (C_2), C_6 and C_7 were atypical. This observation was similar with that of the ox, horse and dog as reported by Dyce *et al.* (2010). The width of the centrum and neural canal increased gradually from C_2 to C_7 whereas the height of neural canal declined from C_2 to C_7. The neural spinous process drastically decreased from C_3 to C_7 and was ridge like. The intertransverse foramen and canalis transversarium were present from C_2 to C_6. The width of the horizontal lamina decreased from C_2 to C_7.

Atlas (C_1) The atlas of the Indian flying giant squirrel was missing during the processing of the skeleton of vertebral column.

Axis (C_2)

In the axis, the centrum at its cranial extremity presented a well-developed dens or odontoid process (Fig. 2). It was very long, pointed and almost reached the occipital bone. The ventral border of the caudal extremity of axis showed a projection. The neural spinous process was large and extended from the cranial extremity to beyond the level of the caudal extremity, similar to the caudal extension in the neural spinous process of the axis reported in bats, which implies a greater lateral movement (Gaurdioso *et al.*, 2017). The caudal end of the neural spine was bifid. There were two nutrient foramina in the middle of the ventral spinous process.

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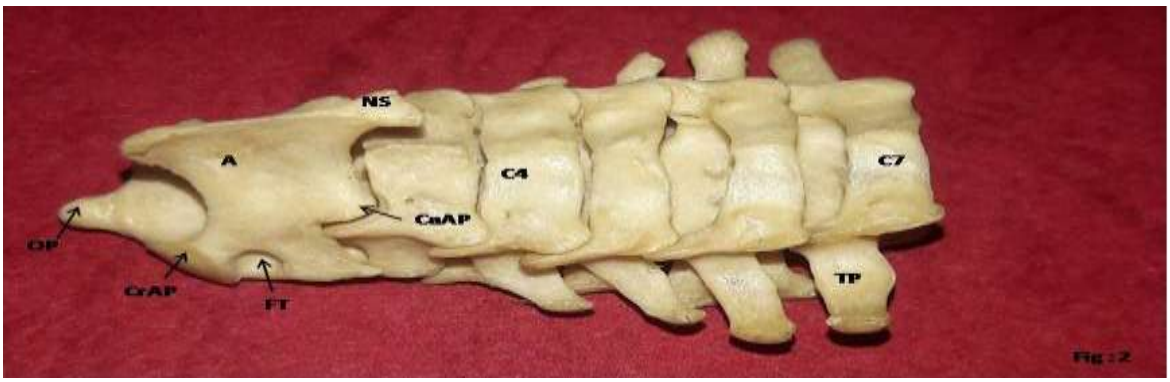

Fig. 2: Panoramic view (Dorsal) of C_2 to C_7 (OP-Odontoid Process; NS-Neural Spine; TP-Transverse process; CrAP-Cranial Articular Process; CaAP-Caudal Articular Process)

The cranial articular processes on either side of the dens were very large and oval shaped, whereas the caudal articular processes were smaller in size and facing downward. The cranial articular process of the axis was broader and better developed dorso ventrally, which implies a greater rotational movement of the head around the longitudinal axis (Gaurdioso *et al.*, 2017). The neural canal was made up of horizontal lamina and vertical pedicles. The height of the neural canal was 5.2 mm cranially and 4.5 mm caudally. The width of the neural canal at the cranial end was 6.8 mm and it was 6.6 mm at caudal end (Table 1). The transverse process was very small, thin, flat, undivided and projected backward. Its caudal orientation implies a greater mobility of the neck in a sagittal plane as explained by Gaurdioso *et al.* (2017). Foramen transversarium was passing through the base of the transverse process with cranial and caudal openings. A ridge like ventral spinous process was present on the ventral aspect of the centrum of axis. On either side of the ridge, two nutrient foramina were observed.

Cervical Vertebrae (C_3-C_7)

The centrums of these vertebrae were short and their lengths decreased gradually from C_3 to C_6 but increased in C_7 (Table 1). The cranial extremity of the centrum was flat and the caudal extremity was concave for articulation with the caudal and cranial extremities of adjacent vertebrae respectively. This observation was contrary to that in ox, horse and dog, where the cranial extremity was convex and the caudal extremity was concave (Dyce *et al.*, 2010). The peculiarity found here was that both the dorsal border of the cranial extremity and the ventral border of the caudal extremity showed a projection. The neural spinous processes of C_3 to C_7 were small and ridge like. There were four articular processes which were extensive, oval in outline, and slightly concave. The length and width of the cranial articular processes increased gradually up to C_6 while the caudal articular processes increased gradually up to C_5 (Table 1).

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Table 1: Morphometric details of cervical vertebrae (mm)

Parameters	Axis(C_2)	C_3	C_4	C_5	C_6	C_7
Centrum – Cranial Extremity						
Height	2.5	2.9	3.1	3.2	3.2	3.2
Width	2.5	7.3	7.5	7.6	7.9	7.3
Centrum – Caudal Extremity						
Height	3.2	3.3	3.5	3.5	3.5	3.6
Width	6.7	6.4	6	7.1	7.3	6
Centrum - Length						
Length	7.8	6	5.8	5.4	5.3	6.1
Neural Spine						
Height	4.2	-	-	-	-	-
Width	11.5	-	-	-	-	-
Cranial Articular Process						
Length	4.4	2.8	3	3.1	3.2	2.8
Width	4.7	1.7	2.5	2.5	2.5	2.2
Caudal Articular Process						
Length	2.8	2.8	2.8	2.9	2.6	2.8
Width	1.5	2.2	2.4	2.5	2.1	2.4
Neural Canal – Cranial						
Height	5.2	4.4	4.5	4.6	4.8	4.4
Width	6.2	6.8	7	7.4	7.5	7.8
Neural Canal – Caudal						
Height	4.5	4.1	4.3	4.4	4.4	4.7
Width	6.3	6.6	7.2	7.5	7.7	7.8
Vertebral Width						
Width	8.9	10.9	11.4	12.4	12.5	12.6

The cranial articular processes were directed dorso-medially, while the caudal ones were directed ventro-laterally as in lumbar vertebrae of horse (Budras *et al.*, 2018). The transverse processes of C_3 to C_5 vertebrae were rod like, whereas C_6 and C_7 were plate like. They were divided into dorsal and ventral parts. Each was raised by two spate roots, where ventral part was from the body and dorsal part from the arch, which were thickened and rough at the end for muscular attachment. The foramen transversarium was present between these roots, through which the vertebral vessels and nerves pass.

The C_6 and C_7 had some special features. The C_6 had a trifid transverse process similar to that in horse with dorsal and ventral parts (Konig and Liebich, 2014). The ventral part of the transverse process was divided into cranial and caudal parts whereas the dorsal part was undivided and curved laterally and dorsally. The transverse process of C_7 was laterally directed, like a lumbar transverse process as in cow and horse (Dyce *et al.*, 2010). The ventral surface of the transverse process showed a rough surface for muscular attachment. The costal facet for the 1st rib was present on either side of the caudal extremity of the centrum.

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Thoracic Vertebrae

The thoracic vertebrae were twelve in number in the flying squirrel (Fig. 3). All the twelve were typical. The total length of the thoracic column from cranial extremity of T_1 to caudal extremity of T_{12} was 108 mm whereas in rat, the total length of the thoracic column was 7.4 cm as reported by Olude *et al.* (2013).

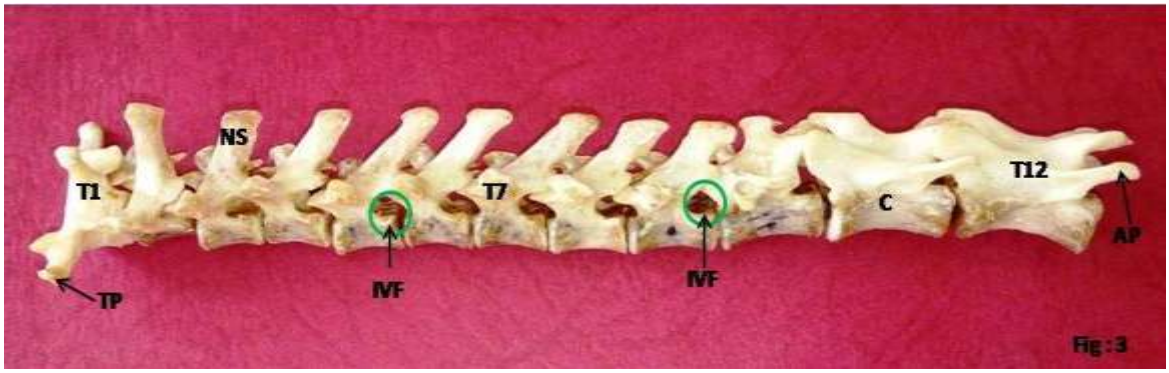

Fig. 3: Panoramic view (lateral) of T_1 to T_{12} (TP-Transverse process; IVF-Intervertebral Foramen; AP-Accessory Process)

The diameter of the vertebral canal from T_1 to T_{12} gradually increased and measured 4.1 mm and 4.8 mm respectively (Table 2). Each thoracic vertebra consisted of a large centrum, two vertical pedicles, two horizontal laminae and seven processes viz. four articular processes, two transverse processes and one neural spinous process up to T_7. From T_8 to T_{12} in addition to these seven processes, two mamillary and two accessory processes were also observed. The cranial extremity was flat while the caudal extremity was concave like platycoelous type of vertebrae as per the report of Girish Chandra (2011). The length of the centrum increased from T_1 and T_{12} and measured 6.6 mm and 13.3 mm respectively (Table 2). The costal facets for heads of the ribs were observed on either side of both the cranial and caudal extremities of centrum except in T_{12} where it was only on either side of the cranial extremity.

The neural spinous processes of the thoracic vertebrae were directed vertically in T_1 and T_2. Further, in T_{10} it was directed vertical, hence called anti-clinal vertebra. This observation was contrary to that in common squirrel, where T9 was observed as anticlinal vertebra (Atalar and Yilmaz, 2004). These processes from T_3 to T_9 were directed caudally, whereas in T_{11} and T_{12} they were inclined cranially. This observation was contrary to that in ox and horse, where it was inclined caudally as reported by Dyce *et al.* (2010). The summit of spinous process of T_1 was bifid in nature. The heights of the neural spinous processes decreased gradually from T_2 to T_{12} (Table 2). The length of the cranial and caudal articular processes increased gradually from T1 to T12 and the width decreased gradually from T_1 to T_4, while it increased gradually from T_5 to T_{12} (Table 2). The transverse processes of all the thoracic vertebrae were projected laterally. The

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length of the transverse processes gradually decreased from T_1 to T_{10} (Table 2) whereas in T_{11} and T_{12}, in the place of transverse process, there was a rough line.

Table 2: Morphometric details of thoracic vertebrae (mm)

Parameters	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Centrum – Length												
Length	6.6	7	7.2	7.3	7.6	7.8	8.4	8.6	9.9	11.5	12.8	13.3
Centrum – Cranial Extremity												
Height	3.3	3.5	3.6	3.6	3.7	3.8	3.9	4.1	4.3	4.8	4.9	5.2
Width	5.3	4.8	4.6	4.3	4.3	4.5	4.7	4.8	4.9	5.4	7.4	8.1
Centrum – Caudal Extremity												
Height	3.5	3.6	3.6	4.1	4	4	4.3	4.4	4.6	4.9	5.2	5.8
Width	6	5.6	5.5	5.3	5.4	4.9	6.4	7.2	8.2	8	8	8.4
Neural Spine												
Height	4.5	8.5	7.9	7.5	7.4	7.2	6.7	5.8	4.6	3.5	3.3	3.2
Width	1.5	4	3.8	3.7	3.6	3.6	3.6	3.5	3.5	3.5	1.3	1
Cranial Articular Process												
Length	2.5	2.6	2.6	2.7	2.7	2.7	2.8	2.8	2.8	2.9	3.1	3.6
Width	2.3	2.2	2.1	1.7	1.8	1.8	1.8	1.9	1.9	2	2.4	2.6
Caudal Articular Process												
Length	2.6	2.6	2.7	2.7	2.8	3	3.2	3.3	3.4	3.4	3.8	4.3
Width	2.2	2.2	2.1	1.7	1.9	1.9	1.9	2.1	2.1	2.3	2.3	2.4
Neural Canal – Cranial												
Height	4.1	4	4	4	4.2	4.2	4.3	4.3	4.4	4.4	4.5	4.8
Width	7.3	5.5	5.3	5.1	4.7	4.7	4.9	4.9	5	5.2	5.4	5.5
Neural Canal – Caudal												
Height	4.2	4.3	4.3	4.3	4.4	4.4	4.5	4.5	4.6	4.6	4.6	4.7
Width	6.6	6.1	5.4	5.2	5	5	4.8	4.8	5.4	5.4	5.6	5.7
Transverse Process												
Length	7.8	4.8	4.6	4.3	3.2	3	2.9	2.3	2.1	2	-	-
Width	2.8	2.9	3.4	4	3.6	3.6	3.2	2.3	2.2	1.6	-	-
Accessory Process												
Length	-	-	-	-	-	-	-	-	0.6	0.8	1.7	1.7
Width	-	-	-	-	-	-	-	-	1.8	4.3	5.6	8.1

The mamillary and accessory processes were observed from T_8 to T_{12}. From the T_8 to T_{10} the mamillary process was plate like projected cranially between the transverse process and cranial articular processes. The accessory processes also had a plate like structure projected caudally. The ventral spinous processes were absent in all the thoracic vertebrae. The height of the neural canal increased from T_1 to T_{12}, whereas width of the canal decreased from T_1 to T_8, then increased from T_9 to T_{12} (Table 2).

Lumbar Vertebrae

The lumbar vertebrae were seven in number (Fig. 4). The total length of the lumbar column from the cranial extremity of L_1 to the caudal extremity of L_7 was 132.7 mm.

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Fig. 4: Panoramic view (Dorsal) of L_1 to L_7 (NS-Neural Spine; TP-Transverse process; MP-Mamillary Process; AP- Accessory Process)

The length of centrum gradually increased from L_1 to L_6, followed by a sudden reduction in L_7 (Table 3). Both cranial and caudal extremities of the centrum showed a flat articular surface in all the lumbar vertebrae like Amphiplatyan type as explained by Girish Chandra (2011). The width of the cranial and caudal extremity of the centrum increased gradually from L_1 to L_7. It may be an important mechanism for gliding in flying squirrel. The entire lumbar vertebral column extremely increased in its length and width than the thoracic vertebral column (Table 3). This elongated lumbar vertebral column revealed the flying squirrels' adaptation to minimize wing loading and to increase maneuverability while gliding as reported by Thorington and Santana (2007) and Kawashima *et al.* (2017).

The neural spine, inclined cranially, was observed in all the lumbar vertebrae. The length and width of the neural spine increased gradually from L_1 to L_7 (Table 3). The cranial articular process faced medially, whereas the caudal articular surface faced laterally for articulation with the adjacent vertebrae as in the case of ox and horse. The length and width of cranial & caudal articular processes were increased gradually. The transverse processes were well developed and increased gradually in both length and width from L_1 to L_7 and in L_1 the transverse process was like a faint line. It was observed that the transverse process arose from the lateral surface of cranial $1/3^{rd}$ of centrum from L_1 to L_6 and in L_7 from the centre of the body. The transverse processes inclined craniolaterally. This observation was similar to that in dog, as reported by Kumar (2013). There were mamillary processes on all lumbar vertebrae between the cranial articular and transverse processes. The accessory processes were well developed, thin plate like and increased in both length and width from L_1 to L_6. They were located below the caudal articular process. They were absent in L_7. This observation was similar to that in dog, as reported by Kumar (2013). The ventral spine was absent and the ventral part of the centrum showed one or two foramina in all the lumbar vertebrae. The neural canal increased in its height and width from L_1 to L_6 whereas it decreased in L_7.

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Table 3: Morphometric details of lumbar vertebrae (mm)

Parameters	L_1	L_2	L_3	L_4	L_5	L_6	L_7
Centrum – Length							
Length	17	17.2	19.1	19.6	21.1	20.4	18.3
Centrum – Cranial Extremity							
Height	5.9	6	6.3	6.5	6.6	6.7	6.7
Width	8.3	10	10.4	11.8	11.1	10.6	10.4
Centrum – Caudal Extremity							
Height	6.2	6.4	6.4	6.5	6.6	6.6	6.6
Width	9	9.3	10.7	11.1	11.4	11.4	10.8
Neural Spine							
Height	3.6	4.3	5.6	6.1	7.5	8.2	9.3
Width	1.4	2	3.2	4.7	4.9	5.9	6
Cranial Articular Process							
Length	3.1	3.8	3.9	4.2	4.3	5	4.6
Width	3	3	3.1	3.8	4	4.1	3.9
Caudal Articular Process							
Length	4	4.1	4.2	4.3	4.4	4.3	4.2
Width	2.9	3	3.5	3.8	4.6	3.7	3.2
Neural Canal – Cranial							
Height	4.7	5.2	5.3	5.4	5.6	5.9	4.5
Width	5.2	5.5	5.6	6	6.3	6	5.8
Neural Canal – Caudal							
Height	4.6	5	5.5	5.9	5.7	5.2	3.9
Width	5.7	6	6.3	6.9	7.6	7.5	6.9
Transverse Process							
Length	-	3.2	6.5	7	10.1	13.8	15.5
Width	-	1	1.2	1.6	2.7	3.3	3.4
Accessory Process							
Length	8.2	10.6	12.4	13	11.6	7.3	-
Width	2.2	2.2	2.5	2.1	1.5	1.1	-

Sacrum

The sacral vertebrae were three in number and were fused to form an almost triangle shaped single piece (Fig. 5). This observation was similar to that in the common squirrel as reviewed by Atalar and Yilmaz, (2004). The centrum was very broad at the cranial end and narrow at the caudal end. The neural spine slightly inclined cranially at the S_1 and S_2 where in S_3; it was straight. The length and width of the neural spine decreased gradually from S_1 to S_3 (Olude *et al.*, 2013). The dorsal surface showed separate neural spinous processes like in common squirrel (Atalar and Yilmaz, 2004) and in horse (Budras *et al.*, 2018). The dorsal sacral grooves were present on either side of the spinous processes. The grooves showed two dorsal sacral foramina on either side indicating intervertebral foramen for the passage of dorsal sacral spinal nerves (Fig. 5).

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Fig. 5: Panoramic view (lateral) of S_1 to S_3 (CrAPL-Cranial Articular Process Length; CrAPW-Cranial articular process Width CaAP-Caudal Articular Process; DSF-Dorsal Sacral Foramina; NSW-Neural Spine Width; NSH-Neural Spine Height; AF-Articular Facet)

The ventral spinous process was absent fusion of S_1, S_2 and S_3 indicated two transverse ridges (Fig. 6). The ventral surface of the sacrum showed ventral longitudinal grooves on either side of the centrum. The grooves showed two ventral sacral foramina on either side for ventral spinal nerves. The caudal articular process was small compared to the cranial one, facing laterally to articulate with Cy_1.

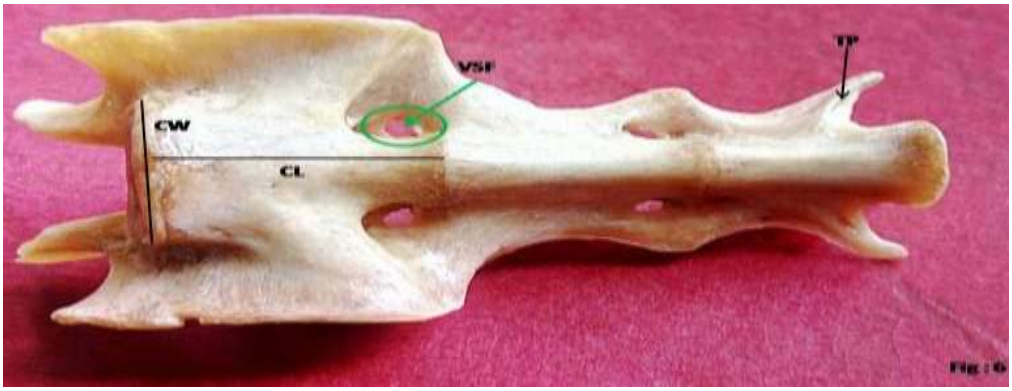

Fig. 6: Panoramic view (Ventral) of S_1 to S_3 (TP-Transverse process; VSF-Ventral Sacral Foramina; CW- Centrum Width; CL-Centrum Length)

The cranial articular process faced medially, extending beyond the cranial extremity for caudal articular process of L_7. The neural canal was triangular in outline and decreasing in its caliber from S_1 to S_3 (Table 4). The transverse processes of S_1 were converted into sacral wings and projected laterally, perpendicular to the centrum. The sacral wing had a rough articular surface on its lateral side for articulation with the ilium. This observation was contrary to that in horse (Budras *et al.*, 2018) where sacral wings were triangular, articulate with L_6 transverse process and also with Ilium. In rat, however, the transverse processes of S_1 and S_2 formed sacral wings and articulated with the ilium while the remaining two were never involved (Olude *et al.*, 2013). The transverse process of S_3 was projected caudolaterally and extended till the length of caudal extremity.

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Table 4: Morphometric details of sacral vertebrae (mm)

Parameters		S_1	S_2	S_3
Centrum – Length				
Length		14.5	12.6	11.73
Centrum -Cranial (Fused)	Height	6.6		
	Width	10.7		
Centrum – Caudal (Fused)	Height	3.4		
	Width	6.7		
Transverse Process				
Length		5.8	-	6.8
Width		18.3	-	1.3
Neural Spine				
Height		7.5	4	3.3
Width		6.2	6	4.4
Neural Canal -Cranial	Height	3		
	Width	5.1		
Neural Canal - Caudal	Height	1.3		
	Width	2.5		

Coccygeal Vertebrae

The coccygeal vertebrae were twenty seven in number, of which, the first seven were typical vertebrae and the remaining were atypical (Fig. 7).

Fig.7: Panoramic view (Dorsal) of Cy_1 to Cy_7 (HP- Haemal Process; Green Colour Arrow Indicating Foramen)

Typical Coccygeal Vertebrae (Cy_1 to Cy_7)

The centrum was cylindrical around which the other processes were constructed. The mean length of the typical vertebrae gradually increased from 7.89 mm to 14.3 mm in Cy_1 and Cy_7 respectively (Table 5 & 6). From Cy_1 to Cy_7, the cranial extremity was flat and the caudal extremity was concave.

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Table 5: Ranges of measured parameters (mm) along the vertebral column in Indian giant flying squirrel

Parameters	Cervical	Thoracic	Lumbar	Sacrum	Coccygeal
VBL	36.4 (except atlas)	108	132.7	38.8	501.3
CL	5.3 – 7.8	6.6 – 13.3	17 – 21.1	11.3 – 14.5	6.9 – 30.9
NSH	4.2	3.2 – 7.9	3.6 – 9.3	3.3 – 7.5	3.1
NSW	11.5	1.0 – 4.0	1.4 – 6.0	4.4 – 6.2	3.6
NCH-CrE	4.4 – 5.2	4 – 4.8	4.5 – 5.9	3	0.2 – 1.7
NCW-CrE	6.2 – 7.8	4.7 – 7.3	5.2 – 6.3	5.1	0.7 – 3.3
NCH-CaE	4.1 – 4.7	4.2 – 4.7	3.9 – 5.9	1.3	0.1 – 2.2
NCH-CaE	6.3 – 7.8	4.8 – 6.6	5.7 – 7.6	2.5	0.2 – 3.1
TPL	2.5 – 9.5	2 – 7.8	3.2 – 15.5	5.8 – 6.8	3.7 – 6.4
TPW	0.5 – 2.2	1.6 - 4	1.0 – 3.4	1.3 -18.3	1.4 – 2.7

The neural spine of the first coccygeal vertebrae was short, plate like and projected upward. In rest of the vertebrae, it was ridge-like. The transverse and vertical diameter of the vertebral canal decreased gradually (Table 6).

Table 6: Morphometric details of coccygeal vertebrae (typical vertebrae) (mm)

Parameters	Cy_1	Cy_2	Cy_3	Cy_4	Cy_5	Cy_6	Cy_7
Centrum – Cranial Extremity							
Height	4	3.9	3.8	4.1	4.2	4.3	4.4
Width	7.5	7.4	7.3	6.3	5.6	5.1	5
Centrum – Caudal Extremity							
Height	3.8	3.8	3.6	3.7	3.9	4	4.4
Width	6.7	6.9	6.8	5.3	5.1	5	5
Centrum - Length	9.5	8.5	7.8	6.9	7.7	10.3	14.3
Neural Spine							
Height	3.1	-	-	-	-	-	-
Width	3.6	-	-	-	-	-	-
Neural Canal – Cranial Extremity							
Height	1.7	1.6	1.5	1.4	1	0.5	0.2
Width	3.3	3.1	3	2.7	2.2	1.8	0.7
Neural Canal – Caudal Extremity							
Height	2.2	2	1.8	1	0.9	0.4	0.1
Width	3.1	2.6	2.5	2.1	1.3	0.9	0.2
Transverse Process							
Length	6.4	6.3	6.6	6.3	5.5	4.1	3.7
Width	5.5	5.4	4	3.5	3.5	4.2	7.7
Cranial Articular Process							
Length	3.4	3.1	3	3	2.7	2.4	1.6
Width	2.7	2.6	2.6	2.3	2	1.9	1.4
Caudal Articular Process							
Length	3.8	4.2	4.2	3.3	3	2.8	-
Width	2.7	2.6	2.3	2	1.5	1.3	-

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The cranial articular process were two in number, set wide apart facing medially on either side of the centrum and in front of the neural spine. The length and width of the cranial articular processes decreased gradually. The caudal articular processes faced laterally, articulated with the cranial articular processes of the preceding coccygeal as in ox and horse (Dyce *et al.*, 2010). The transverse processes were two in number for each vertebra and projected laterally perpendicular to the centrum. The C_7 showed a very broad thin plate like transverse process with foramina in its middle (arrow showing) (Fig. 7). The length and width of the transverse processes from Cy_1 to Cy_7 decreased gradually (Table 6). The cranial extremity of centrum from Cy_4 to Cy_7 also had a triangular bony plate like haemal arch as observed in rat (Olude *et al.*, 2013).

Atypical Coccygeal Vertebrae (Cy_8 to Cy_{27})

The centrum was a rod like structure observed in all the atypical vertebrae. The thickness of centrum and length decreased from Cy_{12} to Cy_{27} (Table 7). The neural canal was absent with only the centrum and some processes observed in rest of the vertebrae. The transverse and spinous processes were ridge-like and present from Cy_8 to Cy_{12}. In Cy_8 and Cy_9 as in atypical vertebrae, at the ventral aspect of the cranial extremity of centrum a haemal arch was observed, whereas from Cy_{10} to Cy_{19} haemal processes were observed and thereafter they disappeared. The caudal parts of the atypical coccygeal vertebral bones formed an hourglass shape, and their processes gradually became shorter and thinner progressively towards the tip of the tail as observed in rat (Olude *et al.*, 2013). This leads to lifting and balancing mechanism during gliding condition in Indian giant flying squirrel.

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Table 7: Morphometric details of coccygeal vertebrae (atypical vertebrae) (mm)

Parameters	Cy_8	Cy_9	Cy_{10}	Cy_{11}	Cy_{12}	Cy_{13}	Cy_{14}	Cy_{15}	Cy_{16}	Cy_{17}	Cy_{18}	Cy_{19}	Cy_{20}	Cy_{21}	Cy_{22}	Cy_{23}	Cy_{24}	Cy_{25}	Cy_{26}	Cy_{27}
Centrum																				
Length	23.5	28.09	29.74	29.99	30.09	29.51	28.72	28.03	25.71	24.7	23.61	21.63	19.47	18.63	16.91	14.71	13.61	11.9	10.4	8
Width	3.5	3.2	3	2.6	2.4	2.3	2.1	1.9	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	0.9	0.9	1

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Conclusion

The study helped in understating the gross anatomy and morphometrical features of vertebral column which is useful in understanding the axial rotation, gliding movement, lifting and balancing mechanism in Indian giant flying squirrel. Though the sample size was insufficient, the present basic data may be useful for future studies.

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