Kafkas Universitesi Veteriner Fakultesi Dergisi
Journal Home-Page: http://vetdergikafkas.org
ISSN: 1309-2251

Kafkas Univ Vet Fak Derg
28 (5): 653-661, 2022
DOI: 10.9775/kvfd.2022.27964

RESEARCH ARTICLE

Morphometrical Analysis of the Egyptian Mongoose *(Herpestes ichneumon)* Hind Limb Bones (Pelvis, Femur and Crus) Using Three-Dimensional Reconstructed Images

Sema ÖZKADİF [1,a (*)] Ayşe HALIGÜR [1,b]

[1] Cukurova University, Faculty of Ceyhan Veterinary Medicine, Anatomy Department, TR-01930 Ceyhan/Adana - TÜRKİYE
ORCIDs: [a] 0000-0002-5398-9874; [b] 0000-0002-3668-4286

Article ID: KVFD-2022-27964 Received: 16.06.2022 Accepted: 28.09.2022 Published Online: 29.09.2022

Abstract: The Egyptian mongoose *(Herpestes ichneumon)* is on the International Union for Conservation of Nature's Red List of Threatened Species, and very little information is available on its morphometric characteristics. This study aimed to create the three-dimensional (3D) reconstruction of the pelvis, femur and crus bones in the hind limb of the Egyptian mongoose using two-dimensional (2D) multidetector computed tomography (MDCT) images, perform morphometric measurements on these models, and compare these measurements to other Carnivora members described in the literature. For this purpose, MDCT was performed on the hind limb bones of two adult mongooses (one male, one female) who died as a result of traffic accidents at different times and were brought to the anatomy laboratory, and the data were stored in the DICOM format. These images were transferred to a computer with 3D reconstruction software Mimics 14.1 loaded, and the reconstruction of the hind limb bones was undertaken. Some morphometric measurements were performed from the 3D models of the pelvis, femur and crus bones. Also, cortical thickness, endosteal and periosteal diameter values of the femur and tibia were measured using MDCT images. According to the results, the measurements of the male mongoose were larger than those of the female mongoose, except for the angle of arcus ischiadicus. The Egyptian mongoose was found to have a minor form among the members of the order Carnivora. It is expected that the morphometric measurements revealed as a result of this study will contribute to the knowledge concerning wild animals and guide future clinical studies.

Keywords: *Carnivora, Mongoose, Morphometry, Three-dimensional reconstruction, Wild animal*

Kuyruk Süren *(Herpestes ichneumon)* Arka Bacak Kemiklerinin (Pelvis, Femur ve Crus) Üç Boyutlu Rekonstrüksiyon Görüntüleri Kullanılarak Morfometrik Analizi

Öz: Kuyruk süren *(Herpestes ichneumon),* Uluslararası Doğayı Koruma Birliği Tehdit Altındaki Türlerin Kırmızı Listesi'nde yer almaktadır ve morfometrik özellikleri hakkında çok az bilgi mevcuttur. Bu çalışmanın amacı; arka ekstremite'nin yapısında bulunan pelvis, femur ve crus kemiklerinin iki-boyutlu (2B) multidedektor bilgisayarlı tomografi (MDBT) görüntülerini kullanarak, üç-boyutlu (3B) rekonstrüksiyonlarını oluşturmak ve bu modeller üzerinden alınan morfometrik ölçümleri ortaya koyarak, literatürde bulunan Carnivor ile karşılaştırmaktır. Bu amaçla farklı zamanlarda trafik kazası sonucu ölen ve Anatomi laboratuvarına getirilen erişkin 2 adet (1 erkek, 1 dişi) kuyruk süren'in arka ekstremite kemiklerinin MDBT görüntüleri alındıktan sonra, veriler DICOM formatında stoklandı. Bu görüntüler 3B rekonstrüksiyon programı olan Mimics 14.1'in yüklü olduğu bir bilgisayara aktarılarak, arka ekstremite kemiklerinin rekonstrüksiyonları gerçekleştirildi. Pelvis, femur ve crus kemiklerinin 3B modellerinden bazı morfometrik ölçümler alındı. Ayrıca femur ve tibia'nın kortikal kalınlığı, endosteal ve periosteal çap değerleri MDBT görüntüleri kullanılarak ölçüldü. Ölçüm sonuçlarına göre, erkeğe ait değerlerin arcus ischiadicus açısı dışında dişiye ait olanlardan daha büyüktü. Kuyruk süren'in Carnivora takımının üyeleri arasında küçük bir yapıya sahip olduğu tespit edildi. Bu çalışma sonucunda ortaya konulan morfometrik ölçüm değerlerinin yaban hayvanlarının bilgi birikimine katkı sağlaması ve klinik uygulamalarda yardımcı olması beklenmektedir.

Anahtar sözcükler: *Karnivor, Kuyruk süren, Morfometri, Üç-boyutlu rekonstrüksiyon, Yabani hayvan*

INTRODUCTION

The Egyptian mongoose *(Herpestes ichneumon)* is a member of the family *Viverridae* from the order Carnivora [1]. It is found across the African continent, from the Sinai Peninsula in the Levant to the south of Turkey, as well as in the southwest of the Iberian Peninsula in Europe [2]. In Turkey, it has a limited habitat in Hatay, Mersin, Adana,

How to cite this article?
Özkadif S, Haligür A: Morphometrical analysis of the Egyptian mongoose *(Herpestes ichneumon)* hind limb bones (pelvis, femur and crus) using three-dimensional reconstructed images. *Kafkas Univ Vet Fak Derg,* 28 (5): 653-661, 2022.
DOI: 10.9775/kvfd.2022.27964

(*) Corresponding Author
Tel: +90 322 613 3507
E-mail: semaerten80@gmail.com (S. Özkadif)

and Aydın [3,4]. It generally lives in villages and rural areas, and does not hesitate to approach residential areas in search of food. Therefore, some mongooses can be found dead on roadsides as a result of traffic accidents [4]. Since the mongoose legs are short, their movement is like crawling on the ground [1]. While it has the ability to dig into the ground to change its nest, it lacks climbing skills [5].

Among the members of the Carnivora, the hind limbs only carry the animal forward [6]. This has a stronger effect on the shaping of the movement than the front extremities [7]. The morphology of these bones is very important, since the hind limb bones provide most of the driving force [8]. Animal bone morphometry studies provide important data for many scientific fields [9].

Three-dimensional (3D) models are created by the 3D reconstruction of data obtained from two-dimensional (2D) imaging modalities, such as computed tomography (CT), magnetic resonance imaging (MRI), and X-ray [10]. Since measurements performed on 3D models are very sensitive, they are used for measurement and assessment. In addition, models can be customized to cut, flip, and rotate images [11]. 3D models are also very useful in planning surgery and creating prostheses [12].

A review of the literature on the mongoose shows that there are studies performed on their body morphology and metric measurements [3], investigating their karyological and some morphological features [4], and examining their skull morphology [13], as well as comparing the craniometric measurements of mongooses living in Asia and Africa [14]. In addition, research has been undertaken on the extremities of many members of the order Carnivora, including morphometric studies on the pelvis of the retriever and German shepherd dog breeds, and the red fox [15-17], microanatomic investigation of the hind bones of the lynx *(Lynx lynx)* [18], comparison of the long bones of the modern red fox *(Vulpes vulpes)* and arctic fox *(Alopex lagopus)* [19], measurements of the canine fore and hind bones [20], 3D reconstruction and morphometric analysis of the long bones of the hind limb and hip bones (ossa coxae) of the Van cat [21,22], and 3D model measurements performed from the ossa cruris of the brown bear *(Ursus arctos)* [23].

This study was conducted to create the 3D reconstruction of the pelvis, femur and crus bones in the hind limb using 2D MCDT, perform morphometric measurements using these models, and compare these measurements to other Carnivora members described in the literature.

Material and Methods

Ethical Approval

This study was performed with permission from the Turkish Ministry of Forestry and Water Management (permission number: 92554751-445.04-148699). Ethical approval was obtained from the Research Ethics Committee of Cukurova University on December 7, 2021 (decision number: 14/05).

Animals

In this study, two adult mongooses *(Herpestes ichneumon)* [(one male (4.5 kg), one female (4.2 kg)] were used. Both mongooses died at different times by hitting their heads in traffic accidents and were brought to the anatomy laboratory. The cadavers were in good condition with intact hind limb bones.

Study Design

The animals were placed in the prone position to obtain MDCT images. The parameters of the MDCT instrument (Somatom Sensation 64; Siemens Medical Solutions, Germany) were adjusted as follows: physical detector collimation, 32 x 0.6 mm; final section collimation, 64 x 0.6 mm; section thickness, 1 mm; gantry rotation time; 330 msec; kVp; 120; mA, 300; resolution, 512 x 512 pixel; and resolution range, 0.92 x 0.92. The dosage parameters and scans were in agreement with standard protocols described in the literature [24,25]. Radiometric resolution (MONOCHROME2; 16 bits) was obtained at the lowest radiation level with optimum image quality. The images were stored in the DICOM format and transferred to a personal computer containing the 3D modelling software Mimics 14.1. (Materialise Group, Belgium). The boundaries of the pelvic bones (os coxae, sacrum), femur, and crus bones (tibia, fibula) were determined using the same software. The demarcated images were overlapped, and reconstruction was performed with this translator program. Mimics 14.1 program was used for measurements on 3D models.

Measurements

In this study, the measurements of the pelvic cavity and os coxae (1. dorsal transverse diameter, 2. intermediary transverse diameter, 3. ventral transverse diameter, 4. right sacrocotyloid diameter, 5. left sacrocotyloid diameter, 6. angle of arcus ischiadicus, 7. length of ischium, 8. total length of the symphysis pelvis, 9. mid-pubis width 10. cranial transverse diameter, 11. medial transverse diameter, 12. caudal transverse diameter, 13. total length of pelvis, 14. length of ilium, 15. length of pubis, 16. greatest length of the foramen obturatorium, 17. greatest width of the foramen obturatorium, 18. conjugata vera, 19. conjugata diagonalis, 20. vertical diameter, and 21. inclinatio pelvis), the femur (1. total length of femur, 2. distal width of femur, 3. femoral head diameter, 4. narrowest neck width, 5. proximal width, 6. angle between center of head of femur and center point of fossa trochanterica), the fibula and tibia (1. total length of the fibula, 2. width of fibula at mid-shaft, 3. mid-shaft transverse diameter of the corpus tibia, 4. greatest breadth of the proximal end of the tibia, 5. greatest breadth of the distal end of the tibia, 6. total length of the tibia, 7. angle between medial and lateral malleolus) were performed using the 3D computer model of each bone according to the literature [8,16,19,21,26,27] *(Fig. 1, Fig. 2, Fig. 3, Fig. 4, Fig. 5)*. The cortical thickness (medial and lateral aspects) of the femur and tibia in the proximal, mid-shaft and distal were measured using tomography sections [28] *(Fig. 6)*. Also endosteal diameter and periosteal

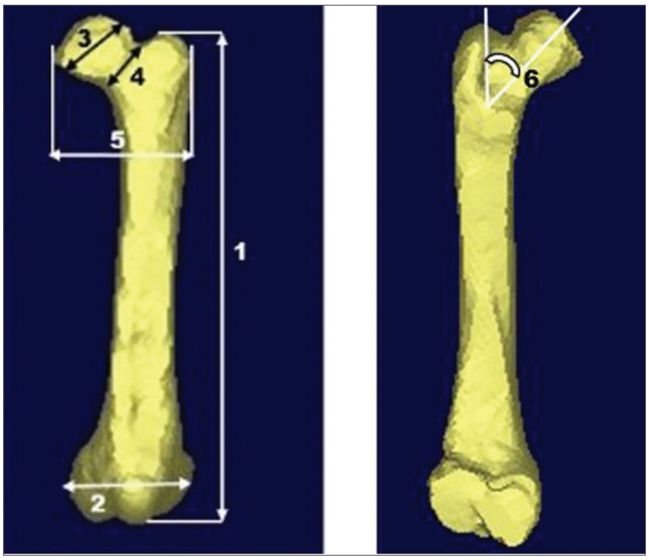

Fig 1. Cranial and caudal view of the femur: 1. total length of the femur, 2. distal width of the femur, 3. femoral head diameter, 4. narrowest neck width, 5. proximal width of the femur, 6. angle between center of head of femur and center point of fossa trochanterica

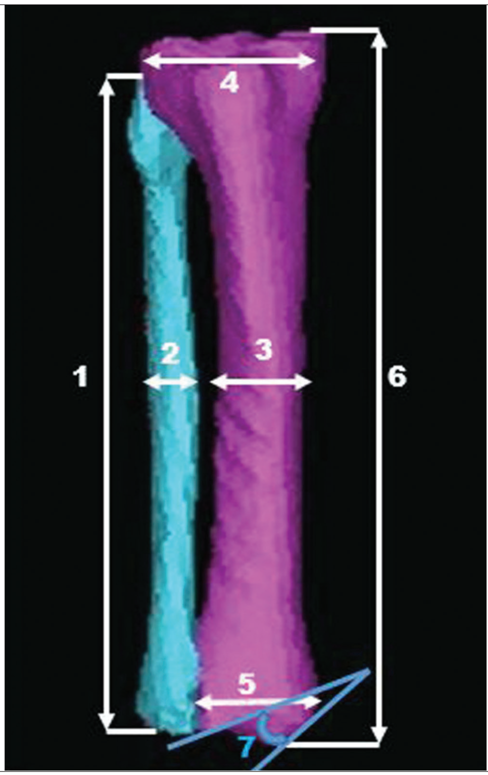

Fig 2. Cranial view of the fibula and tibia: 1. total length of the fibula, 2. width of the fibula at mid-shaft, 3. mid-shaft transverse diameter of the corpus tibia, 4. proximal width of the tibia, 5. distal width of the tibia, 6. total length of the tibia, 7. angle between medial and lateral malleolus

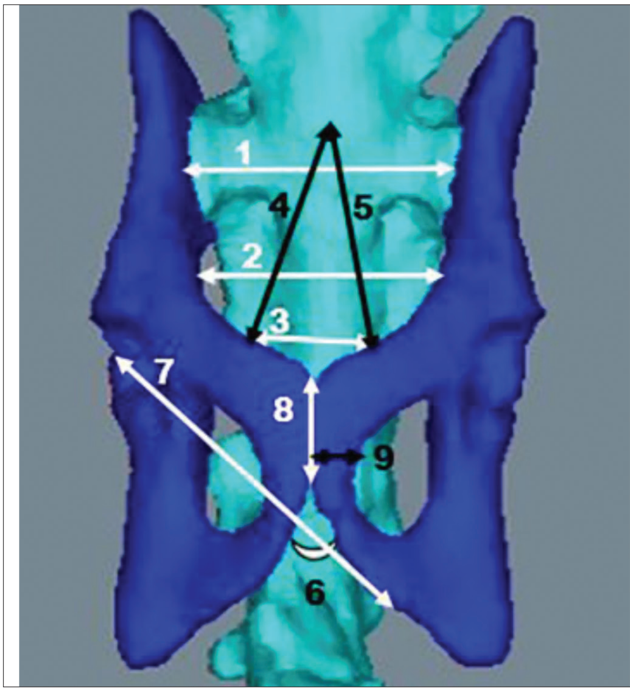

Fig 3. Ventral view of the pelvic cavity: 1. dorsal transverse diameter, 2. Intermediary transverse diameter, 3. ventral transverse diameter, 4. right sacrocotyloid diameter, 5. left sacrocotyloid diameter, 6. angle of arcus ischiadicus, 7. length of ischium, 8. total length of the symphysis pelvis, 9. mid-pubis width

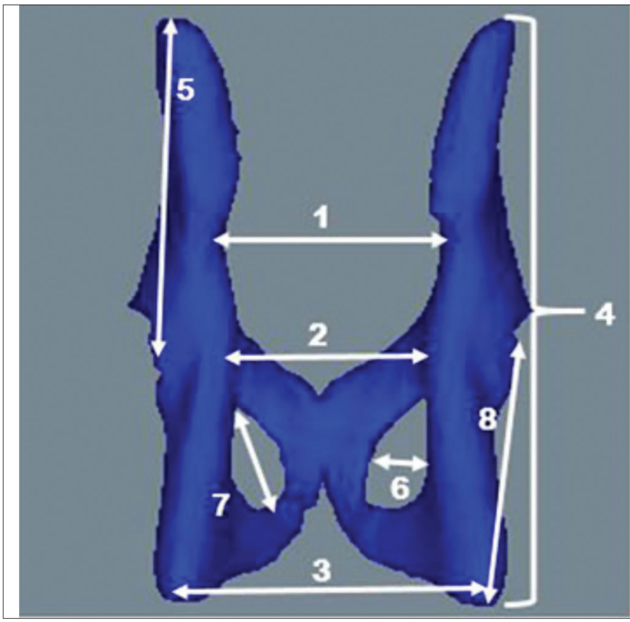

Fig 4. Dorsal view of the pelvic cavity: 1. cranial transverse diameter, 2. medial transverse diameter, 3. caudal transverse diameter, 4. total length of pelvis, 5. length of ilium, 6. greatest width of the foramen obturatorium, 7. greatest length of the foramen obturatorium, 8. length of pubis

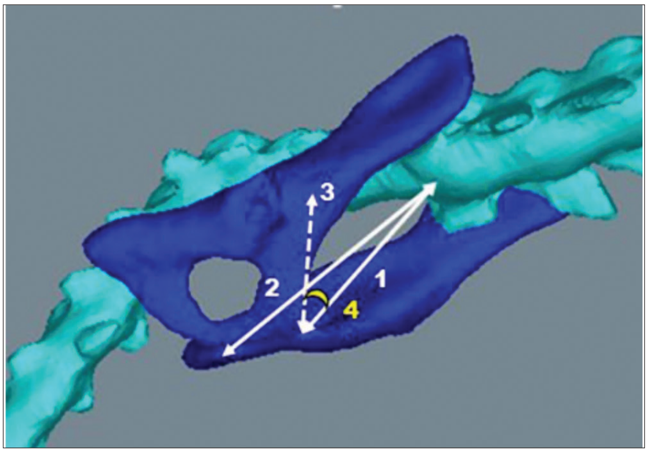

Fig 5. Lateral view of the pelvic cavity: 1. conjugata vera, 2. conjugata diagonalis, 3. vertical diameter, 4. inclinatio pelvis

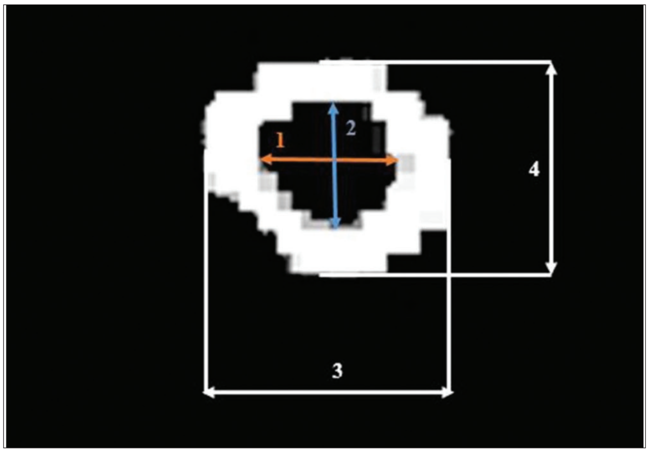

Fig 7. Measurement of endosteal and periosteal diameters at the mid-shaft of the long bone on MDCT: 1. endosteal diameter in X-axis direction, 2. endosteal diameter in Y-axis direction, 3. periosteal diameter in X -axis direction, 4. periosteal diameter in Y-axis direction

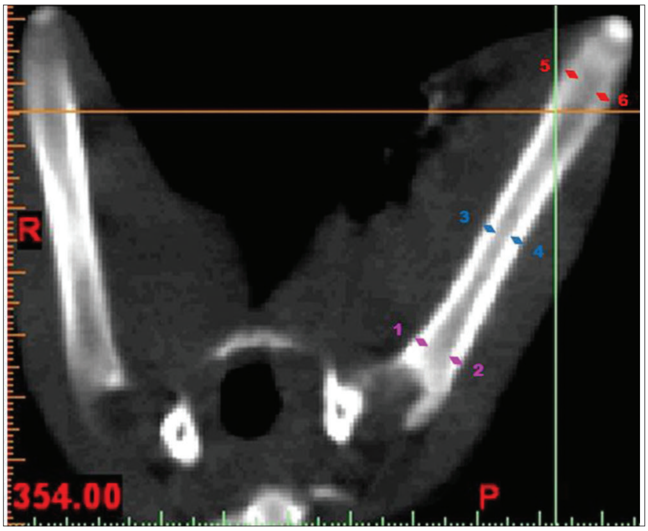

Fig 6. Measurements taken at the proximal, mid-shaft and distal level on MDCT images: 1. medial cortical thickness at proximal, 2. lateral cortical thickness at proximal, 3. medial cortical thickness at mid-shaft, 4. lateral cortical thickness at mid-shaft, 5. medial cortical thickness at distal, 6. lateral cortical thickness at distal

diameter in X-axis and Y-axis direction of the femur and tibia were taken from MDCT images [28] *(Fig. 7)*.

Results

The first of the bone forming the os coxae, the os ilium, was in sagittal position; the second bone, os pubis, was in cranio-caudal position and the third bone, os ishcii, was in horizontal position. The shape of the pelvis was narrow and small. Aperture pelvis cranialis was highly oblique *(Fig. 3, Fig. 4. Fig. 5)*.

The data of the morphometric values obtained from the 3D model of the mongoose are showed in *Table 1* and *Table 2*. All the measurements, except the angle of arcus ischiadicus, which is one of the measurement values of the pelvis, indicated greater values in the male mongoose than in the female mongoose. It was determined that the dorsal transverse diameter of the cranial opening of pelvis was larger than the other transverse diameters, but close to intermediary transverse diameter. Among the transverse diameters of the cavum pelvis, the caudal transverse diameter had the greatest value. Aperture pelvis caudalis were wide. The sacrocotyloid diameter was similar on both sides *(Table 1)*.

Table 1. *Results of the morphometric measurements of the pelvic cavity obtained from 3D reconstruction*

Measurements	Female	Male
Dorsal transverse diameter (mm)	24.26	25.24
Intermediary transverse diameter (mm)	23.07	24.94
Ventral transverse diameter (mm)	15.64	16.93
Right sacrocotyloid diameter (mm)	26.14	31.72
Left sacrocotyloid diameter (mm)	26.03	31.72
Angle of arcus ischiadicus (°)	50.43	45.30
Length of ischium (mm)	35.78	40.77
Total length of the symphysis pelvis (mm)	9.98	14.72
Mid-pubis width (mm)	1.87	2.89
Cranial transverse diameter (mm)	23.40	27.98
Medial transverse diameter (mm)	22.72	26.69
Caudal transverse diameter (mm)	28.04	35.16
Total length of pelvis (mm)	66.55	71.04
Length of ilium (mm)	37.54	40.53
Length of pubis(mm)	25.06	33.39
Greatest length of the foramen obturatorium (mm)	16.21	17.93
Greatest width of the foramen obturatorium (mm)	12.79	14.64
Conjugata vera (mm)	32.67	37.05
Conjugata diagonalis (mm)	40.81	49.25
Vertical diameter (mm)	23.28	31.11
Inclinatio pelvis (°)	26.54	27.22

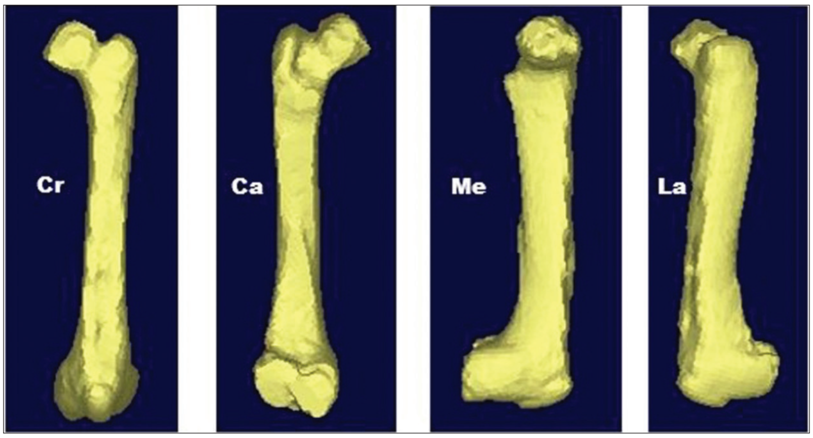

Fig 8. 3D model of the femur obtained from MDCT images. Cr. cranial view, Ca. caudal view, Me. medial view, La. lateral view

Fig 9. 3D model of crus bones obtained from MDCT images. Cr. cranial view, Ca. caudal view, Me. medial view, La. lateral view

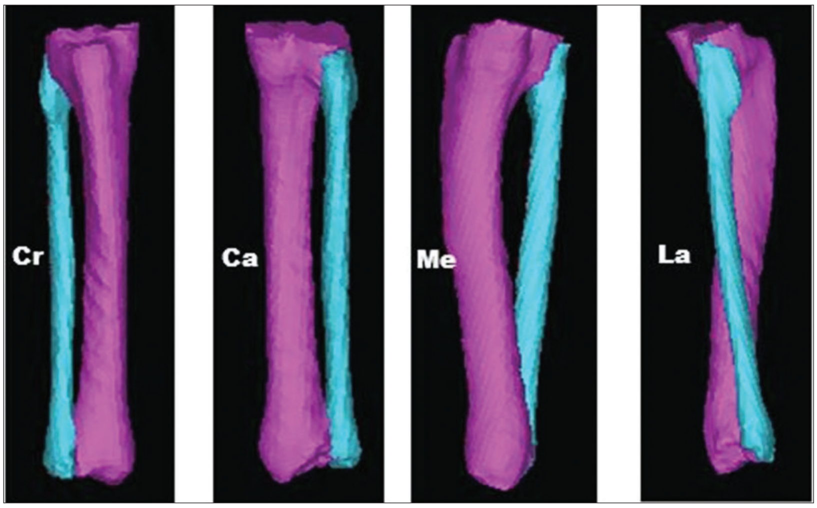

Table 2. *Results of the morphometric measurements of the femur, tibia and fibula obtained from 3D reconstruction*

Measurements	**Female**		**Male**	
	Right	**Left**	**Right**	**Left**
Total length of the femur (mm)	75.53	74.84	78.11	78. 56
Distal width of the femur (mm)	15.43	15.12	16.22	16.38
Femoral head diameter (mm)	8.92	8.67	9.43	9.78
Narrowest neck width (mm)	6.72	6.72	7.00	7.12
Proximal width of the femur (mm)	16.27	16.73	19.26	19.43
Angle between center of head of femur and center point of fossa trochanterica (°)	30.73	30.73	31.30	31.28
Total length of the fibula (mm)	61.16	61.50	63.87	63.39
Width of fibula at mid-shaft (mm)	3.68	3.98	4.25	4.36
Total length of the tibia (mm)	68.14	67.32	69.25	69.74
Mid-shaft transverse diameter of the corpus tibia (mm)	6.94	6.83	7.38	7.21
Proximal width of the tibia (mm)	15.46	15.95	18.38	18.23
Distal width of the tibia (mm)	11.26	11.35	12.58	12.36
Angle between medial and lateral malleolus (°)	41.27	41.35	41.54	41.60

The femur was proximally inclined towards its long axis in the cranio-ventral direction. The fibula extended to the distal end of the tibia. A wide interosseous space was formed between tibia and fibula *(Fig. 1, Fig. 2, Fig. 8, Fig. 9)*.

The measurement values of the femur, tibia and fibula of the female mongoose were smaller than those of the male mongoose *(Table 2)*. In addition, the data on the right and left sides were very similar to each other in both

***Table 3**. Results of the morphometric measurements of the femur and tibia obtained from MDCT images*

Measurements		**Female**		**Male**	
		Right	**Left**	**Right**	**Left**
Femur	Medial cortical thickness at proximal (mm)	1.87	1.92	2.03	2.10
	Lateral cortical thickness at proximal (mm)	2.11	2.06	2.19	2.21
	Medial cortical thickness at mid-shaft (mm)	1.85	1.79	1.91	1.96
	Lateral cortical thickness at mid-shaft (mm)	2.65	2.27	2.86	2.75
	Medial cortical thickness at distal (mm)	2.95	2.85	3.07	3.10
	Lateral cortical thickness at distal (mm)	3.70	3.58	3.85	3.82
	Endosteal diameter in X-axis direction at mid-shaft (mm)	3.63	3.52	3.73	3.67
	Endosteal diameter in Y-axis direction at mid-shaft (mm)	3.12	3.17	3.22	3.19
	Periosteal diameter in X-axis direction at mid-shaft (mm)	6.82	6.89	7.08	7.01
	Periosteal diameter in Y-axis direction at mid-shaft (mm)	6.21	6.15	6.28	6.39
Tibia	Medial cortical thickness at proximal (mm)	1.21	1.55	1.36	1.48
	Lateral cortical thickness at proximal (mm)	1.55	1.74	1.62	1.69
	Medial cortical thickness at mid-shaft (mm)	1.74	1.80	1.90	1.93
	Lateral cortical thickness at mid-shaft (mm)	1.48	1.51	1.59	1.62
	Medial cortical thickness at distal (mm)	1.56	1.64	1.68	1.74
	Lateral cortical thickness at distal (mm)	1.42	1.48	1.56	1.59
	Endosteal diameter in X-axis direction at mid-shaft (mm)	1.73	1.73	2.64	2.52
	Endosteal diameter in Y-axis direction at mid-shaft (mm)	2.25	2.08	2.52	2.39
	Periosteal diameter in X-axis direction at mid-shaft (mm)	4.66	4.83	5.53	4.91
	Periosteal diameter in Y-axis direction at mid-shaft (mm)	5.88	5.54	6.42	6.17

sexes. Among the long bones, the femur had the greatest values, followed by the tibia and fibula in that order. In addition, the femur had a thicker structure than the tibia. The proximal ends of both the femur and tibia had larger values than their distal ends. Among the long bones in the hind limb, the fibula had the least values.

According to the medial and lateral cortical thickness measurements obtained from the tomography images of the femur, it was seen that lateral cortical thickness had higher values than medial cortical thickness at proximal, mid-shaft and distal. Medial and lateral cortical thickness was measured the most in the distal part of the femur. It was observed that the lateral cortical thickness was greater than the medial cortical thickness in the proximal, and on the contrary, the medial cortical thickness was greater than the lateral cortical thickness in the mid-shaft and distal part of the tibia. It was found that medial cortical thickness was the most in the mid-shaft and lateral cortical thickness was the most at proximal part of tibia. Endosteal and periosteal diameter values in the femur were greater on the X-axis direction than on the Y-axis direction. In the tibia, on the contrary, endosteal and periosteal diameter values on the Y-axis direction were higher than on the X-axis direction *(Table 3)*.

Discussion

It has been reported that the pelvis of the retriever dog and red fox statistically significantly differed according to sex [16,17], while there is no sexual dimorphism in the German shepherd dog [15]. Except for the angle of arcus ischiadicus, all the measurement values have been reported to be greater in the male retriever, German shepherd and red fox compared to their female counterparts [15-17]. In the current study, the measurement values of the pelvis were smaller in the female mongoose, except for the angle of arcus ischiadicus, similar to the previous studies on dogs and red foxes.

It has been stated that the size of the pelvis and the thickness of the leg bones determine the differences that distinguish dog breeds from each other. Dogs with a large pelvis have thin limb bones and dogs with a small pelvis have thicker limb bones. For example, greyhounds have relatively thinner legs than pit bulls. Fast running dogs have a wider pelvis and thinner leg bones [29]. In this study, it was observed that the mongoose had a small and narrow pelvis, thick and short leg bones. This anatomical structure caused the mongoose not run fast and move in a crawling manner on the ground [1].

In the red fox, it was reported that the aperture pelvis cranialis was widest in the middle and caudal transverse diameter had greatest value of the cavum pelvis [17]. In this study, unlike the fox, the dorsal transverse diameter of the aperture pelvis cranialis was the largest, but the values were close to the intermediary transverse diameter. The caudal transverse diameter of the mongoose was also the largest transverse diameter of the pelvic cavity, just like in the fox.

For *Metailurus parvulus* belonging to the family *Felidae* of the order Carnivora, the total length of the femur was reported as 216.0 mm, transverse diameter at the midshaft of the femur as 19.7 mm, greatest anteroposterior diameter of the distal end of the femur as 40.7 mm, anteroposterior diameter of the caput femoris as 20.7 mm, greatest antero-posterior diameter of the proximal end of the femur as 44.1 mm, total length of the tibia as 207.8 mm, transverse diameter at the mid-shaft of the tibia as 15.2 mm, greatest anteroposterior diameter of the proximal end of the tibia as 42.2 mm, greatest anteroposterior diameter of the distal end of the tibia as 19.2 mm, and total length of the fibula as 186.0 mm [30]. In the current study, the measurement values of the femur, tibia and fibula of the mongoose were approximately one-third of those reported for the same bones in *Metailurus parvulus.* This finding is consistent with the representatives of the family *Herpestidae* being characterized by a relatively small-to-medium body size [31]. Body size is the main factor determining limb bone morphology in Carnivora [5]. Among the hind limb bones of the mongoose, the femur was the largest, and the measurement between the distal end of the femur and the proximal ends of the tibia, which are involved in the formation of the articularis genus, were close to each other, which is also in agreement with the anatomy of *Metailurus parvulus.* In our study, it was observed that the distal end of the femur was narrower in the female than in the male, as described for humans [32].

As a result of the measurements performed on the long bones of the modern red fox *(Vulpes vulpes)* and arctic fox *(Alopex lagopus),* it was reported that the male animals had statistically significantly larger measurements than their female counterparts. The total length of the femur in the red fox was determined as 122.2 mm in the female and 130.4 mm in the male, the proximal breadth of the femur was 23.2 mm and 25.2 mm, respectively, and the distal breadth of the femur was 19.1 mm and 20.8 mm, respectively [19]. In the mongoose, the total length of the femur on the right side was measured as 75.53 mm in the female and 78.11 mm in the male, the proximal breadth of the femur was 16.27 mm in the female and 19.26 mm in the male, and the distal breadth of the femur was 15.43 mm in female and 16.22 mm in male. This shows that the measurement values of the male mongoose were larger than those of the female, and the proximal end of the femur was wider than the distal end, similar to the red fox. It has also been reported that there is a difference between the male and female femurs in humans, with the former being larger than the latter [32].

The total length of the tibia in the red fox was reported to be 137.5 mm in the female and 147.3 mm in the male, the proximal breadth of the tibia was 20.9 mm in the female and 22.0 mm in the male, and the distal breadth of the tibia was 14.2 mm in the female and 14.8 mm in the male [19]. In the current study, the total length of the tibia on the right side was 68.14 mm in the female mongoose and 69.25 mm in the male mongoose, the proximal breadth of the tibia was 15.46 mm and 18.38 mm, respectively, and the distal breadth of the tibia was 11.26 mm and 12.58 mm, respectively. Thus, as reported for the red fox, the male mongoose also presented with larger measurements than the female mongoose. In a human study, it was also reported that the tibia was statistically significantly larger in men than in women [32].

From the canine remains, which were found during excavations in Van-Yoncatepe, the femoral length was determined as 181.6 mm and the tibial length as 180.2 mm [20]. In another study, the mean femoral length of the Makah and Coast Salish dog was reported as 164.4 mm, and the mean tibial length as 158.5 mm [33]. While the femur of the mongoose was observed to be longer compared to the length of the tibia, as in dogs [20,33], the tibia was reported to be larger than the femur in the red fox [19].

In the literature, it is stated that the mean length of the fibula in the Makah and Coast Salish dog is 148.2 mm [33], while the total length of the fibula in the red fox is 130.2 mm in the female and 138.1 mm in the male [19]. In our study, the total length of the fibula on the right side was measured as 61.16 mm in the female mongoose and 63.87 mm in the male. Thus, the shortest bone among the hind limb bones of the mongoose was determined to be the fibula, which is similar to the reports on the red fox and dog.

For the Nigerian local dog *(Canis lupus familiaris),* no statistically significant difference was reported between the right and left sides according to the biometric measurement values of the hind limb bones [34]. Similarly, in the current study, the measurement values of the femur, tibia, and fibula were similar for the right and left sides in both the male and female mongooses.

It has been reported that the medial cortical thickness of the femur in dogs gradually decreases from proximal to distal. It was stated that the lateral cortical thickness remained more or less the same in the proximal and mid-shaft, and decreased in the distal. It has been reported that the medial cortical thickness in the tibia increases from proximal to distal, and the lateral cortical thickness decreases from proximal to distal [35]. In our study, the mongoose unlike the dog [35], it was observed that the medial and lateral cortical thickness was the most in the distal of the femur. It was seen that medial cortical thickness was the most in the mid-shaft and lateral cortical thickness was the most at proximal part of tibia unlike the dog. In the literature [28], it was reported that the endosteal and periosteal diameter measurement values on the X-axis direction of the rabbit femur were higher than those on the Y-axis direction. In our study, it was determined that the values of endosteal and periosteal diameter measurements on the X-axis direction were greater than those on the Y-axis direction in the mongoose femur as in the rabbit femur [28].

According to the data obtained from the hind limb of the mongoose, the measurement values of the male were greater than those of the female. This is consistent with the previous knowledge that male mongooses are larger than females [14]. The male mongoose has been reported to be 20% heavier on average than the female [36]. According to the results of the morphometric study performed on the long bones of the hind limb of the Van cat, it was stated that there was sexual dimorphism, with the male having greater values than the female [21]. The measurements of the coxae, femur and tibia of the hind limb are also reported to differ according to sex in *Felis catus* [9].

The Egyptian mongoose *(Herpestes ichneumon)* is on the International Union for Conservation of Nature's Red List of Threatened Species [37] and lives in a limited area in Turkey; therefore, the number of animals in our study was limited. Due to the few number of animal used in the study, statistical results could not be expressed by performing a statistical analysis. In future studies, it is recommended to study with more animals, if possible.

In conclusion, when the hind limb bones of the Egyptian mongoose were compared between sexes, all the measurement values were higher in the male mongoose than in the female. In addition, the right and left side measurements were very close to each other in both sexes. The 3D reconstruction of the entire bone from 2D computed tomography images is very useful for morphometric studies and clinical applications. It is expected that the morphometric data presented in this paper will contribute to the knowledge of the anatomy of wild animals and guide future clinical studies.

Ethical Approval

This study was performed with permission from the Turkish Ministry of Forestry and Water Management (permission number: 92554751-445.04-148699). Ethical approval was obtained from the Research Ethics Committee of Cukurova University on December 7, 2021 (decision number: 14/05).

Availability of Data and Materials

Data sets analyzed during the current study are available from the corresponding author (S. Özkadif) on reasonable request.

Competing Interests

There was no conflict of interest in regards to authors reporting their findings.

Author Contributions

The conception of the investigation was performed by SÖ and AH. Collection of materials and obtaining MDCT images were done by two of the authors. Reconstruction of bones, taking morphometric measurements and writing of the article were done by SÖ. Revision of manuscript and preparation of the figures were performed by AH.

References

1. Demirsoy A: Yaşamın Temel Kuralları. Omurgalılar/Amniyota (Sürüngenler, Kuşlar ve Memeliler) Cilt-III/Kısım-II. 5. Baskı, 766, Meteksan, Ankara, 2003.

2. Detry C, Bicho N, Fernandes H, Fernandes C: The Emirate of Cordoba (756-929 AD) and the introduction of the Egyptian mongoose (*Herpestes ichneumon*) in Iberia: The remains from Muge, Portugal. *J Archaeol Sci*, 38, 3518-3523, 2011. DOI: 10.1016/j.jas.2011.08.014

3. Atay E, Yeşiloglu M: The Egyptian mongoose, *Herpestes ichneumon* L., 1758 (Mammalia: Carnivora: Herpestidae) in Hatay province Turkey. *KFBD*, 2, 74-81, 2012.

4. Ozkurt SO: Karyological and some morphological characteristics of the Egyptian mongoose, *Herpestes ichneumon* (Mammalia: Carnivora), along with current distribution range in Turkey. *Turk J Zool*, 39, 482-487, 2015. DOI: 10.3906/zoo-1403-25

5. Galvez-Lopez E: Quantifying morphological adaptations using direct measurements: The carnivoran appendicular skeleton as a case study. *Anat Rec*, 304, 480-506, 2021. DOI: 10.1002/ar.24453

6. Samuels JX, Meachen JA, Sakai SA: Postcranial morphology and the locomotor habits of living and extinct carnivorans. *J Morpol*, 274, 121-146, 2013. DOI: 10.1002/jmor.20077

7. Martin-Serra A, Figueirido B, Palmqvist P: A three-dimensional analysis of the morphological evolution and locomotor behaviour of the carnivoran hind limb. *BMC Evol Biol*, 14, 1-13, 2014. DOI: 10.1186/1471-2148-14-129

8. Fostowicz-Frelik L: The hind limb skeleton and cursorial adaptations of the Plio-Pleistocene rabbit *Hypolagus beremendensis. Acta Palaeontol Pol*, 52, 447-476, 2007.

9. Boonsri B, Pitakarnnop T, Buddhachat K, Changtor P, Nganvongpanit K: Can feline *(Felis catus)* flat and long bone morphometry predict sex or skull shape? *Anat Sci Int*, 94, 245-256, 2019. DOI: 10.1007/s12565-019-00480-8

10. Schumann S, Liu L, Tannast M, Bergmann M, Nolte LP, Zheng G: An integrated system for 3D hip joint reconstruction from 2D X-rays: A preliminary validation study. *Ann Biomed Eng*, 41, 2077-2087, 2013. DOI: 10.1007/s10439-013-0822-6

11. Fuller CB, Farnsworth CL, Bomar JD, Jeffords ME, Murphy JS, Edmonds EW, Pennock AT, Wenger DR, Upasani VV: Femoral version: Comparison among advanced imaging methods. *J Orthop Res*, 36, 1536-1542, 2018. DOI: 10.1002/jor.23785

12. Phombut C, Rooppakhun S, Sindhupakorn B: Morphometric measurement of the proximal tibia to design the tibial component of total knee arthroplasty for the Thai population. *J Exp Ortop*, 8:118, 2021. DOI:

10.1186/s40634-021-00429-9

13. Samuel OM, Wanmi N, Usende L: Rostro-dorsal and rostro-lateral skull morphologic variability in three age-groups of the Egyptian mongoose *(Herpestes ichneumon)* (Linnaeus, 1758): Implications of certain orbital parameters-angular geometric approach. *Folia Morphol*, 75, 527-535, 2016. DOI: 10.5603/FM.a2016.0022

14. Taylor ME, Matheson J: A craniometric comparison of the African and Asian mongooses in the genus *Herpestes* (Carnivora: Herpestidae). *Mammalia*, 63, 449-464, 1999. DOI: 10.1515/mamm.1999.63.4.449

15. Ocal MK, Dabanoglu I, Kara ME, Turan E: Computed tomographic pelvimetry in German shepherd dogs. *Dtsch Tierarztl Wochenschr*, 110, 17-20, 2003.

16. Nganvongpanit K, Pitakarnnop T, Buddhachat K, Phatsara M: Gender-related differences in pelvic morphometrics of the retriever dog breed. *Anat Histol Embryol*, 46, 51-57, 2016. DOI: 10.1111/ahe.12232

17. Ozkadif S, Haligur A, Eken E: A three-dimensional reconstructive study of pelvic cavity in the red fox (*Vulpes vulpes*). *Anat Histol Embryol*, 51, 215-220, 2022. DOI: 10.1111/ahe.12780

18. Karan M, Yılmaz S, Ozkan ZE, Baygeldi B: Vaşaklarda *(Lynx lynx)* arka bacak kemiklerinin makro-anatomik olarak incelenmesi. *Vet Sci Pract*, 11 (2): 207-211, 2016. DOI: 10.17094/avbd.48020

19. Monchot H, Gendron D: Disentangling long bones of foxes *(Vulpes vulpes* and *Alopex lagopus)* from arctic archaeological sites. *J Archaeol Sci*, 37, 799-806, 2010. DOI: 10.1016/j.jas.2009.11.009

20. Onar V, Belli O: Estimation of shoulder height from long bone measurements on dogs unearthed from the Van- Yoncatepe early iron age necropolis in Eastern Anatolia. *Revue Med Vet*, 156, 53-60, 2005.

21. Yılmaz O, Demircioğlu *İ*: Morphometric analysis and three-dimensional computed tomography reconstruction of the long bones of femoral and crural regions in Van cats. *Folia Morphol*, 80, 186-195, 2020. DOI: 10.5603/FM.a2020.0116

22. Yılmaz O, Demircioglu I: Computed tomography-based morphometric analysis of the hip bones *(Ossa coxae)* in Turkish Van cats. *Kafkas Univ Vet Fak Derg*, 27, 7-14, 2021. DOI: 10.9775/kvfd.2020.24449

23. Demircioğlu İ, Kirbaş Doğan G, Aksünger Karaavci F, Gürbüz İ, Demiraslan Y: Three-dimensional modelling and morphometric investigation of computed tomography images of brown bear's (*Ursus arctos*) ossa cruris (Zeugopodium). *Folia Morphol*, 79, 811-816, 2019. DOI: 10.5603/FM.a2019.0125

24. Prokop M: General principles of MDCT. *Eur J Radiol*, 45, 4-10, 2003. DOI: 10.1016/S0720-048X(02)00358-3

25. Kalra MK, Maher MM, Toth TL, Hamberg LM, Blake MA, Shepard JA, Saini S: Strategies for CT radiation dose. *Radiology*, 230, 619-628, 2004. DOI: 10.1148/radiol.2303021726

26. Özkadif S, Eken E, Kalaycı I: A three-dimensional reconstructive study of pelvic cavity in the New Zealand rabbit *(Oryctolagus cuniculus). Sci World J*, 2014:489854, 2014. DOI: 10.1155/2014/489854

27. Bakici C, Akgun RO, Ekim O, Batur B, Bakici M, Ozen D, Soydal C: Three dimensional modeling and quantitative analysis of long bone parameters of rabbit using micro-computed tomography. *Iran J Vet Res*, 22 (2): 140-145, 2021. DOI: 10.22099/ijvr.2021.39092.5688

28. Sevil F, Kara ME: The effects of ovariectomy on bone mineral density, geometrical, and biomechanical characteristics in the rabbit femur. *Vet Comp Orthop Traumatol*, 23, 31-36, 2010. DOI: 10.3415/VCOT-08-09-0085

29. Carrier DR, Chase K, Lark KG: Genetics of canid skeletal variation: Size and shape of the pelvis. *Genome Res*, 15, 1825-1830, 2005. DOI: 10.1101/gr.3800005

30. Roussiakis SJ, Theodorou GE, Iliopoulos G: An almost complete skeleton of *Metailurus parvulus* (Carnivora, Felidae) from the late Miocene of Kerassia (Northern Euboea, Greece). *Geobios*, 39, 563-584, 2006. DOI: 10.1016/j.geobios.2005.04.002

31. Ferretti MP: Evolution of bone-cracking adaptations in hyaenids (Mammalia, Carnivora). *Swiss J Geosci*, 100, 41-52, 2007. DOI: 10.1007/s00015-007-1212-6

32. Zhang Z, Zhang Q, Zhao G, Huang J, Chen Z, Jin Z, Qiu Y: Morphological measurements of the normal distal femur and proximal tibia between Han Chinese and Mongolian Chinese in a healthy Chinese population. *Int J Morphol*, 37, 664-670, 2019. DOI: 10.4067/S0717-95022019000200664

33. Crockford SJ: Osteometry of makah and coast salish dogs. 22nd ed., 70, Archaeology Press Simon Fraser University, Canada, 1997.

34. Abdulrahman B, Abubakar Sadiq J: Anatomical study of some selected bones of the hind limb of local domestic dog *(Canis lupus familiaris). Cytol Histol Int J*, 5 (1):000127, 2021.

35. Crokera SL, Reed W, Donlona D: Comparative cortical bone thickness between the long bones of humans and five common non-human mammal taxa. *Forensic Sci Int*, 260, 104-117, 2016. DOI: 10.1016/j.forsciint.2015.12.022

36. Delibes M, Aymerich M, Cuesta L: Feeding habits of the Egyptian mongoose or ichneumon in Spain. *Acta Theol*, 29, 205-218, 1984. DOI: 10.4098/AT.arch.84-21

37. Do Linh San E, Maddock AH, Gaubert P, Palomares F: *Herpestes ichneumon. The IUCN Red List of Threatened Species,* 2016:e.T41613A45207211, 2016. DOI: 10.2305/IUCN.UK.2016-1.RLTS.T41613A45207211.en