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Three-dimensional modeling and morphometric investigation of computed tomography images of brown bear's (*Ursus arctos*) ossa cruris (Zeugopodium)

Short title: Three-dimensional modeling and morphometric investigation of CT images of brown bear's (*Ursus arctos*) ossa cruris (Zeugopodium)

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Abstract

This study was aimed to examine the detailed morphometrical and morphological characteristics of the bone by creating three-dimensional images through Multidetector Computed Tomography images of ossa cruris in brown bears. 4 brown bear ossa cruris were used in the study. It was observed that tibia and fibula articulated at proximal and distal epiphysis and they combined, and ossa cruris were shaped in this way. Cochlea tibiae were determined to be sagittally oriented. The length of the tibia was determined to be 268.97 mm and 266.32 mm at right and left sides, respectively. The length of the fibula was determined to be 249.16 mm and 250.19 mm on average at the right and left sides, respectively. In consequence of the correlation analysis, statistical relationships at different rates were

detected between the measured values. Detailed anatomical examinations are very important in terms of determining the similarities and differences of bear bones with those of the other species in the order Carnivora. Therefore, it is thought that this study will reveal detailed characteristics of ossa cruris of bears and provide data for further studies on archeological and forensic sciences.

Key words: brown bear, ossa cruris, 3D modeling, morphometry

INTRODUCTION

Brown bears (*Ursus arctos*) are one of the biggest carnivores commonly found in Turkey. They have large habitats dating back to twenty million years ago and ranging from seashores to steppes [22, 13]. The habitats of brown bears, which have a wide range in also our country, have been limited to Blacksea and Eastern Anatolian Regions today due to human impacts and destructions of forests [1, 5]. Because of these reasons, Brown bear (*Ursus arctos*) has been listed among the species of the least concern in the redlist that the International Union for Conservation of Nature and Natural Resources (IUCN) published in 2017 [14].

The skeletal system of brown bears is like the basic skeletal system of carnivores. But, as its body weight is greater when compared with the other carnivores, the bones consisting of its skeletal system are shorter and more durable. Although many carnivores are digitigrade, bears are plantigrade. Being plantigrade helps them to stand on their two legs comfortably [8, 13]. As the bears have existed throughout many periods of human history, the findings of bears are commonly found in archeological excavations and they can be confused with human bones [10].

In mammals, ossa cruris consist of two bones, tibia and fibula. Tibia is a long bone that joins the structure of the knee joint in all mammals; the surface of tibial cochlea shows anatomical differences according to ankle's degree of stabilization and ability to move [20]. While fibula is found shrunken in ruminants and equidae, its length is equal to that of the tibia in sus and carnivores [4].

Today, three-dimensional modeling technology is among the most frequently preferred methods in the fields of medicine and veterinary. Detailed examinations can be performed in tissues and organs that are viewed three-dimensionally using the medical imaging techniques that take cross-sectional images. Also, while these models provide a better understanding of complicated anatomical and pathological structures, they also provide benefit for forensic sciences and anthropological studies [6, 23].

There are various studies on the osteology of lynxes [19], dogs [9], martens [3], badgers [18], and Van cats [25], which are among the various species in the order carnivora. However, no information on ossa cruris of today's brown bears could be reached in the literature reviews. Therefore, our study was planned to reveal the three-dimensional model of brown bear's ossa cruris using multidetector computed tomography (MDCT) images and examine its macro anatomical and morphometric characteristics through these three-dimensional modelings.

MATERIALS AND METHODS

Ossa cruris of four male brown bears (eight ossa cruris) were used in our study. General Directorate of Nature Conservation and National Parks, Ministry of Agriculture and Forestry of the Republic of Turkey (E.2242114/2018) granted the necessary permission for the study. The bone materials that were used in the study were scanned with 64-detector CT (General Electronic Revolution) device with 80 kV, 200 MA, 639 mGY and cross-sectional thickness of 0.625 mm. In determining the dose and scanning protocol, Prokop [21] was taken as reference. After the scanned images were saved in DICOM format, they were transferred into the MIMICS 20.1 (The Materialise Group, Leuven, Belgium) program to create a 3D model and the relevant measurements and examinations on the bone were carried out. Osteometrical measurements were taken on the created three-dimensional images (Figure 4). Von Den Driecsh [7] was taken as reference in determining these measurement points.

The measurement points that were taken on the models obtained from the computed tomography images of ossa cruris:

GL1: Length of Tibia

GL2: Length of Fibula

Bp: Proximal width of Tibia

Bd: Distal width of tibia

Sd: The smallest width of Tibia diaphysis

TMD (Cr-c): Craniocaudal diameter of Tibia's cavum medullare

TMD (LM): Lateromedial diameter of Tibia's cavum medullare

TV: Tibia volume

TSA: Tibia surface area

FV: Fibula volume

FSA: Fibula surface area

Statistical analysis

SPSS (22.0 version) software package was used for the statistical analyses in the study. Mean values and standard deviations of the measured parameters, and correlation coefficients between these parameters were detected and statistical evaluations were made. Shapiro-Wilk test was used to determine the normality of the data. The relationship between the measurement parameters was determined with the Pearson correlation (r) test.

Canon EOS-700D camera was used in taking macro photographs. The study was based on Nomina Anatomica Veterinaria [24] (2017).

Findings

It was observed that in brown bears ossa cruris were fully developed and made up of tibia and fibula that articulated at proximal and distal with each other. Condyles, which are found in the epiphysis proximalis of tibia, were found to separate from each other via incisura poplitei in caudal. Eminentia intercondylaris, a nonarticular area between condylus lateralis and condylus medialis, were observed to exist (Figure 2). It was detected that this area was divided into two as tuberculum intercondylare mediale and tuberculum intercondylare laterale, and tuberculum intercondylare mediale was slightly higher than tuberculum intercondylare laterale.

It was observed that cochlea tibia, which is located in the distal part of the tibia, had two straight articular pits. Malleolus medialis was found to exist in the medial of the tibia and a distinct sulcus malleolaris was detected on it (Figure 3). The fibula was found to extend to distal, retaining its bone-shaped thickness and end by shaping malleolus lateralis. Also, the

distal part of the fibula was determined to exceed tibia. It was observed that spatium interosseum, found between tibia and fibula, was fixed along the lengths of the bones (Figure 1).

The morphometric values found in the study were presented in Table I. Based on this, the length of the tibia was determined to be 268.97 mm and 266.32 mm in the right and left side, respectively. The length of the fibula was measured to be 249.16 mm and 250.19 mm in the right and left side, respectively. When all the determined morphometric parameters were compared in terms of direction (right-left), no statistical difference was found ($P>0.05$).

The correlation values of the morphometric data obtained in the study were presented in Table II. In consequence of the correlation analysis, it was found that the GL1 value showed a highly positive correlation ($P<0.05$) with the Bp, SD, Bd, GL2, TV, TYA, FV values, but it showed a weak negative correlation with the TME (Cr-C) value ($P>0.05$).

DISCUSSION

Many different conservation measures are implemented so that brown bears, which have a very common habitat on earth, sustain their potentials. Despite these measures, reductions are observed in the populations of brown bears due to poaching or conservation [2]. When considered along with the other species that are extinct or endangered, it is important to increase the brown bear population or preserve the number in terms of the presence of the species and the other species affected. In this sense, bone materials of four male brown bear were used in the study to record the morphological and osteometric data of ossa cruris of brown bear, one of the wild animals that exist today, to transfer them to the future. The limitations of the study have been the number of bone materials belonging to this animal, which is forbidden to hunt and kill. Therefore, it was not possible to compare female and male samples and reveal the osteometric means in more samples.

Tibia and fibula, which make up the ossa cruris of brown bears, were observed to articulate and combine at proximal and distal. Özgel and Aykut [19], Atalar and Özdemir [3], Özdemir and Karan [18], reported similar findings in their studies on lynx (*Lynx lynx*), martens (*Martens foina*), and badger (*Meles meles*), respectively. However, Yılmaz et al. [26] reported that these two bones knitted at proximal and articulated at distal in Indian porcupines (*Hystrix cristata*). Dyce KM [8] reported that spatium interosseum extended to distal along

the entire course of the bone in sus, and this aperture was limited to the proximal part in canis. In this study, spatium interosseum was found to extend from proximal to distal.

It was observed that tuberculum intercondylare mediale, found in the epiphysis proximalis of tibia, was higher than tuberculum intercondylare laterale with a slight difference. The obtained finding was found to be in parallels with the other domestic mammals [12] except for sus [12] and wild boars [11]. While cochlea tibia was reported to be sagittally oriented in humans [10], Indian porcupines (*Hystrix cristata*) [26], wild boars (*Sus scrofa*) [11], squirrels (*Sciurus vulgaris*) [17], it was reported to be obliquely oriented in lynxes (*Lynx lynx*) [19] and dogs [9]. In the study, cochlea tibiae of brown bears were observed to be sagittally oriented.

In their studies on humans and American Black bears, Orcholl et al. [16] reported the length, mediolateral diameter, and anteroposterior diameter of the tibia to be 359.6 mm and 230 mm, 20.4 mm and 20.1 mm, and 29.9 mm and 26.7 mm, respectively. The length of the fibula was determined to be 359.8 in humans and 209.9 mm in American Black bears. In the measurements of canine tibiae that were excavated in the Van-Yoncatepe excavations, Onar and Belli [15] reported the length of tibia to be 181.3 mm at the right side, 179.2 mm at the left side, and the middle diaphysis diameter to be 12.2 mm at the right and 12.4 mm at the left. In our study, the length of the tibia, craniocaudal and lateromedial diameters were found to be 268.97 ± 12.81 mm, 11.5 ± 0.06 mm, and 11.3 ± 0.04 mm at the right side, and 266.32 ± 12.46 mm, 11.6 ± 0.014 mm, and 11.3 ± 0.05 mm at the left side, respectively. Based on this, it is seen that the brown bear tibia is longer when compared with American Black bear [16] and canine [15] tibia, and shorter than human tibia [16].

The literature was reviewed and no studies in which MDCT technique was used in the macroanatomical and morphometric analysis of brown bear's (*Ursus arctos*) ossa cruris was reached. With this study, parameters of ossa cruris of the brown bear were obtained and it is thought that these values may be a reference to studies in the field of osteoarcheological and forensic sciences in the taxonomical classification of species because of their similarities with human osteology. Also, we are of the opinion that the basic anatomical data on brown bears will be enriched with this study.

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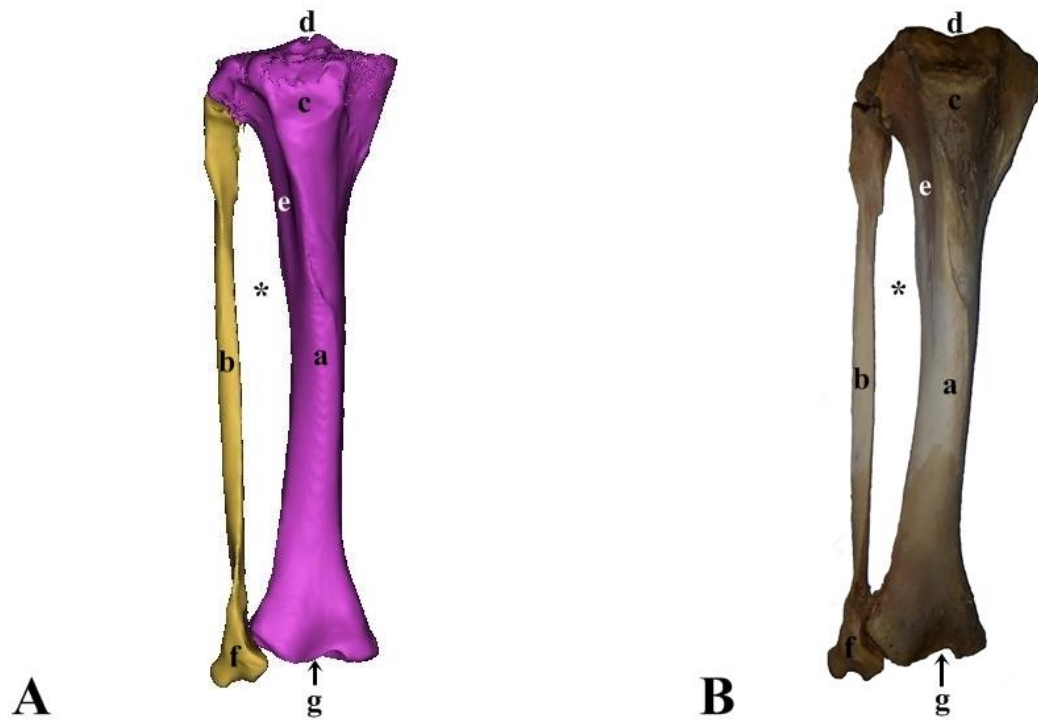


Figure 1: View of ossa cruris from cranial. **A:** 3D view, **B:** Macroanatomical view.

a: tibia, **b:** fibula, **c:** tuberositas tibia, **d:** eminentia intercondylaris, **e:** sulcus extensorius, **f:** distal of the fibula, **g:** cochlea tibia

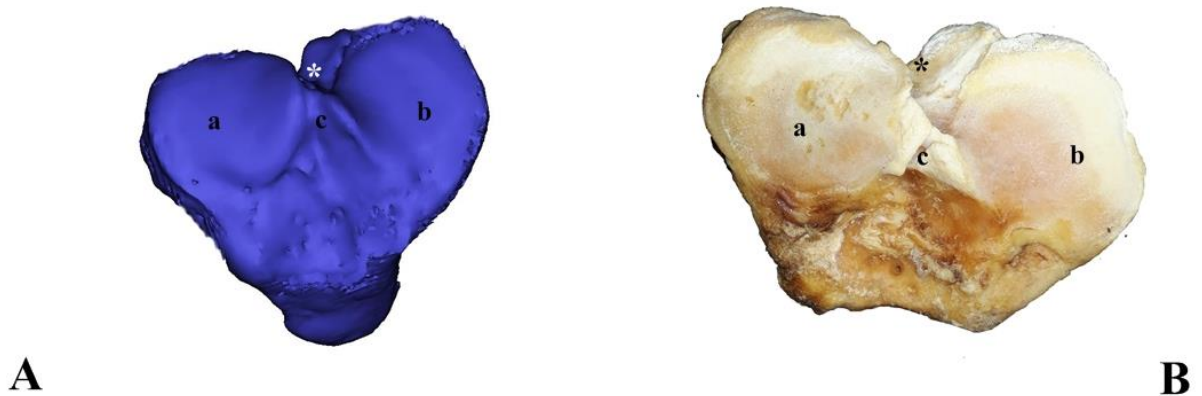


Figure 2: View of tibia from proximal. **A:** 3D view, **B:** Macroanatomical view.

a: condylus lateralis, **b:** condylus medialis, **c:** eminentia intercondylaris, *****: incicura poplitei

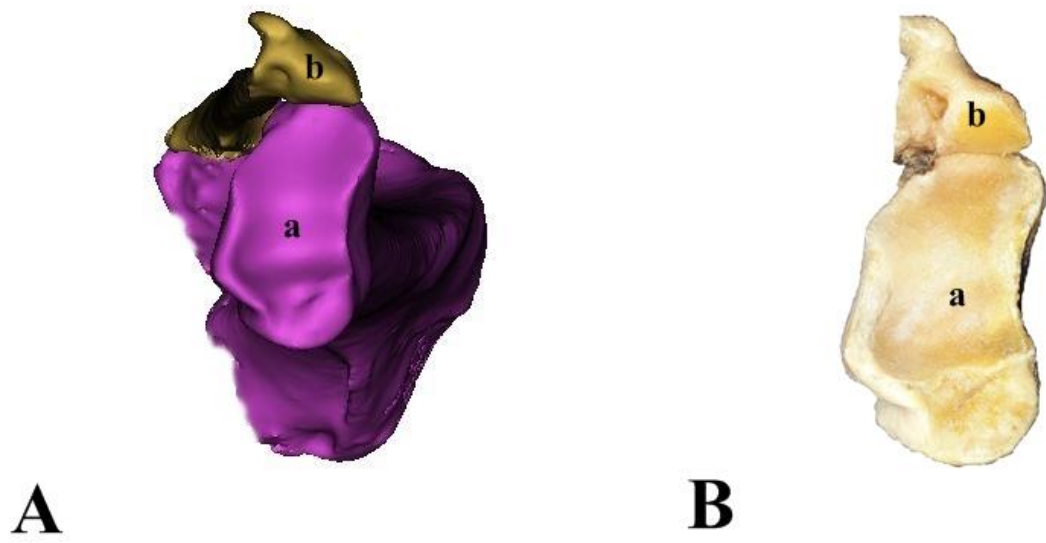


Figure 3: View of ossa cruris from distal. **A:** 3D view, **B:** Macroanatomical view.

a: cochlea tibia, **b:** distal of fibula

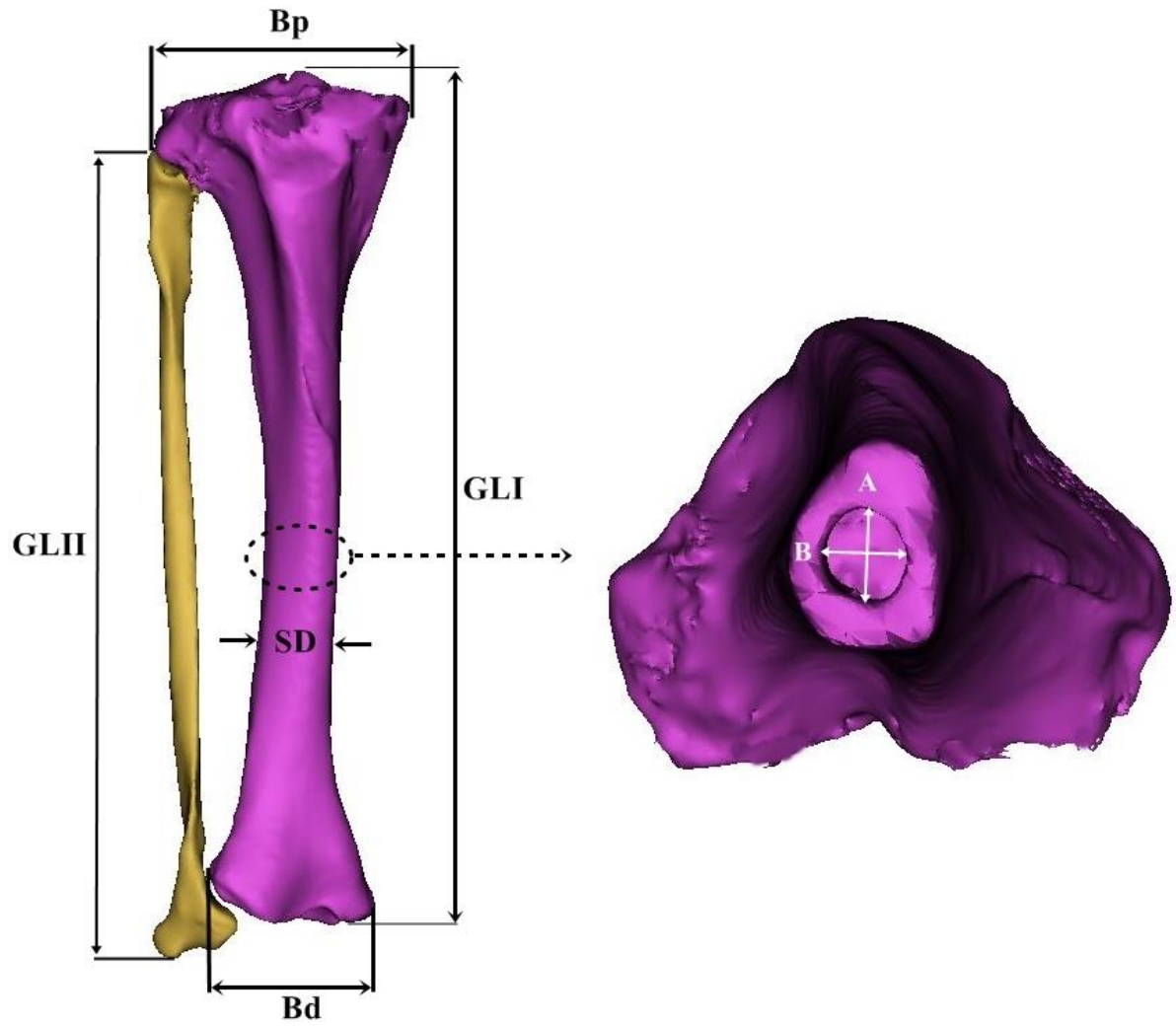


Figure 4: Reference measurement points of ossa cruris. (**A:** Craniocaudal diameter of cavum medullare, **B:** Lateromedial diameter of cavum medullare)