Digit Bones (Acropodium) of Gazella (Gazella subgutturosa); Three-Dimensional Modelling and Morphometry

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Abstract
The present study was conducted to identify morphometric values and to reveal differences between sexes through three-dimensional modeling of digit bones (ossa phalanges) of gazella by using computed tomography images. A total of 14 (7 female, 7 male) adult gazella (Gazella subgutturosa) cadavers were used in the study. The images were extracted by scanning acropodium bones of gazella at 64-detector Multi Detector Computed Tomography (MDCT) in cross section thickness of 0.625mm. Using MIMICS 20.1 program, three-dimensional models of these images were prepared and morphometric measurements were taken. In GLpe and Bd measurements of Phalanx proximalis, a statistically significant difference was established between females and males in terms of the left forelimb internal, the right forelimb internal, the right forelimb external, and the right hindlimb external bones (P<0.05). There was a statistically significant difference between females and males in terms of volume of phalanx proximalis and surface area of the right forelimb internal phalanx proximalis (P<0.001). In GLpe measurements, a statistically significant difference was determined between females and males in terms of the left forelimb internal, the right forelimb internal, the right hindlimb internal, the left forelimb external, the right forelimb external, and the right hindlimb external phalanx media (P<0.05). A statistically significant difference was determined between females and males in terms of the data related to volume and surface areas of the left hindlimb internal the right hindlimb internal, the left hindlimb external, and the right hindlimb external phalanx distalis (P<0.05).

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INTRODUCTION

Gazella subgutturosa or goitered gazella is the most common species of Asian antelope spreading from eastern Turkey to the Tigris-Euphrates basin (Mallon and Kindsgwood, 2001; Castelló, 2016; Khosravi et al., 2018). Their population has started to decrease rapidly because of poaching, widespread agricultural areas, and unsustainable consumption of biological resources and they are included within the red list of threatened species published by the International Union for Conservation of Nature (IUCN) (IUCN, 1996; IUCN, 2008; IUCN, 2017). Ruminants have two developed digits and each digit has three phalanxes. They are called as phalanx proximalis, phalanx media, and phalanx distalis (Bahadir and Yıldız, 2008; Bharti and Singh, 2018; König and Liebich, 2020). Phalanx proximalis is the longest one among them (Nourinezhad et al., 2012; Al-Sharoot, 2013). Phalanx media is almost half of phalanx proximalis in length. Phalanx distalis looks like an irregular prism on blackbuck and blue bull (Choudhary and Singh, 2016; Bharti and Singh, 2018). X-rays have been used for numerous medical imaging methods. Another medical imaging method using X-ray is computed tomography (CT) (Kalender, 2006; Kier et al., 2019). X-rays that are shot to any anatomic region reach to the detector through
a certain level of absorption based on the density of tissue and the absorption difference of X-ray is calculated by detectors. By this way, two-dimensional images are extracted in Hounsfield Units (HU) by the computer. These images are commonly used in diagnosis and treatment (Ohlerth and Scharf, 1989; Kılıç, 2008; Birlik, 2015; Bulut, 2016). Three-dimensional (3D) CT images, on the other hand, are created by reconstruction of two-dimensional images (Dugelay et al., 2008; Jung et al., 2015; Villarraga-Gómez et al., 2019).

Morphometry is a research area examining the differences using the distance between certain points, width, angle and rates through various statistical methods (Rohlf and Marcus, 1993; Mitteroecker and Gunz, 2009; Salvagno and Albarella, 2017; Gündemir et al., 2020). In terms of surgery, knowing the detailed anatomy of the region is very important in terms of both the bone and the extensor and flexor muscles adhering to the bone. It is also important in understanding the biomechanical structure of gazelles from the antelope class. That is why, this study was designed to take measurements of digit bones using computed tomography sections in gazelles, to contribute to species-specific data and the veterinary surgery field.

MATERIALS AND METHODS

A total of 14 (7 females, 7 males) adult gazelle (Gazella subgutturosa) cadavers were used in the study. The average age of gazelles was 2-3 years and their average weight is 20-30 kilograms. Permission for the study was obtained from the General Directorate of Nature Conservation and National Parks (Approval number: 21264211-288.04- E.1158739) and Harran University Animal Experiments Local Ethics Committee (Approval number: 2020/003/03). Gazelles’ acropodium bones were scanned in a 64-detector Multi-Detector Computed Tomography (MDCT) device with a slice thickness of 0.625mm, 80kv, 200MA, and 639mGY. Prokop (2003) and Kalra et al. (2004) were taken as references in the screening and dosing protocol. The reconstruction of the finger bones from images recorded in DICOM (Digital Imaging and Communications in Medicine) format was performed using the MIMICS 20.1 (The Materialize Group, Leuven, Belgium) software program (Bahar et al., 2013; Dayan et al., 2019). Morphometric measurements were based on Von den Driesch (1976).

Phalanx Proximalis (Fig. 1)
1. GLpe: Greatest length of the abaxial half (GLpe)
2. Bp: Breadth of the proximal end (Bp)
3. SD: Smallest breadth of the diaphysis (SD)
4. Bd: Breadth of the distal end (Bd)
5. GL: Greatest length (in dorsal direction)

Phalanx Media (Fig. 2)
1. GLpe: Greatest length of the abaxial half
2. Bp: Breadth of the proximal end
3. SD: Smallest breadth of the diaphysis
4. Bd: Breadth of the distal end
5. GL: Greatest length (in dorsal direction)

Phalanx Distalis (Fig. 3)
1. DLS: Greatest diagonal length of the sole
2. Ld: Length of the dorsal surface
3. MBS: Middle breadth of the sole

Volume (cm³)
Surface area (cm²)

After the measurements were completed, three indices (Bp * 100 / GLpe, SD * 100 / GLpe, Bd * 100 / GLpe) were calculated for phalanx proximalis and phalanx media, and 1 index (MBS * 100 / DLS) was calculated for phalanx distalis (Gündemir et al., 2020). The data obtained in the study were analyzed with a statistically independent t-test according to gender and differences of limbs. For statistical analysis, SPSS 17.0 was used. Nomina Anatomica Veterinaria (2012) terminology was used in this study.
RESULTS

Osteometric measurements of the bones were taken following a 3-dimensional modeling process was made for each bone to be examined through tomographic cross-sections. Table 1 shows osteometry of phalanx proximalis, Table 2 shows its index results, and Table 2 shows its volume and surface area values. When Table 1 was examined, GLpe and Bd measurements revealed a statistically significant difference between females and males in the left forelimb internal, the right forelimb internal, the right forelimb external, and the right hindlimb external bones (P<0.05) and no significant difference in the other bones (P>0.05). Any sexual dimorphism was determined statistically in Rp and SD measurements and in terms of the left hindlimb internal, the left forelimb external, the right hindlimb external phalanx media in GL measurement (P<0.05). When index values in Table 2 were examined, a statistically significant sexual dimorphism was observed in Rp*100/GLpe index for the left forelimb internal, the right forelimb internal, the right hindlimb internal, the right hindlimb external, and the right hindlimb external phalanx media (P<0.05). A statistically significant difference was determined in Sp*100/GLpe index for the right hindlimb internal phalanx media (P<0.05). When volume and surface area values of phalanx media bones in Table 2 were examined, there was a statistically significant difference (P<0.001) between females and males in terms of volume value of the right hindlimb internal phalanx media and surface area of the left forelimb internal, the right hindlimb internal, and the right hindlimb external phalanx media.

Table 1 shows osteometric measurements of phalanx proximalis, shows its index values and shows its volume and surface area values. When Table 1 was examined, a statistically significant difference was determined between females and males in terms of the left forelimb internal, the right forelimb internal, the right hindlimb internal, the left forelimb external, the right forelimb external, and the right hindlimb external phalanx media in GLpe measurement (P<0.05). Any sexual dimorphism was not statistically detected in Rp and SD measurements. There was a statistically significant difference between females and males in terms of the left forelimb internal, the left hindlimb internal, the right hindlimb internal, and the right hindlimb external phalanx media in Bd measurement and in terms of the right hindlimb internal, the left forelimb external, and the left hindlimb external phalanx media in GL measurement (P<0.05). When index values in Table 2 were examined, a statistically significant sexual dimorphism was observed in Rp*100/GLpe index for the left forelimb internal, the right forelimb internal, the right hindlimb internal, the right hindlimb external, and the right hindlimb external phalanx media (P<0.05). A statistically significant difference was determined in Sp*100/GLpe index for the right hindlimb internal phalanx media (P<0.05). When volume and surface area values of phalanx media bones in Table 2 were examined, there was a statistically significant difference (P<0.001) between females and males in terms of volume value of the right hindlimb internal phalanx media and surface area of the left forelimb internal, the right hindlimb internal, and the right hindlimb external phalanx media.

Table 3 shows osteometric measurements of phalanx distalis, shows its index values and shows its volume and surface area values. As Table 3 was examined, a statistical difference was determined between females and males in terms of all phalanx distalis in Dl measurement and the left hindlimb internal and external, and the left forelimb external phalanx distalis in Dls value (P<0.05). There was a statistically significant difference in the left

Table 1: Osteometric measurements of Phalanx proximalis and Phalanx media

| Parameter | Gender | GLpe Mean | SD | Bd Mean | SD | Gl Mean | SD |
|-----------|--------|-----------|----|---------|----|---------|----|
| Phalanx proximalis | Male | 37.24 | 0.85 | 10.32 | 0.57 | 8.03 | 0.56 |
| | Female | 35.46 | 1.95 | 9.94 | 0.77 | 7.59 | 0.23 |
| | IRF | 37.40 | 0.51 | 10.55 | 0.69 | 8.19 | 0.89 |
| | ILF | 32.97 | 0.72 | 10.36 | 0.65 | 8.49 | 0.88 |
| | ILF | 31.55 | 1.93 | 10.44 | 0.65 | 8.02 | 0.41 |
| | IRH | 33.00 | 1.57 | 10.97 | 0.78 | 8.21 | 0.8 |
| | ELF | 37.58 | 1.07 | 10.61 | 0.57 | 8.04 | 0.65 |
| | ERF | 37.96 | 0.38 | 10.43 | 0.28 | 7.89 | 0.71 |
| | Female | 36.47 | 1.7 | 9.93 | 0.69 | 7.76 | 0.25 |
| | ELH | 32.75 | 2.24 | 10.84 | 0.69 | 7.95 | 0.71 |
| | Female | 31.34 | 1.79 | 10.44 | 0.72 | 7.75 | 0.77 |
| | Male | 33.19 | 0.48 | 10.58 | 0.64 | 8.14 | 0.87 |
| | Female | 31.68 | 1.56 | 10.48 | 0.47 | 7.7 | 0.37 |
| | IRF | 20.49 | 0.81 | 10.8 | 0.81 | 6.91 | 1.16 |
| | Female | 18.71 | 1.08 | 11.23 | 0.65 | 6.27 | 0.42 |
| | IRF | 20.80 | 0.94 | 10.69 | 0.98 | 6.71 | 0.92 |
| | Female | 18.85 | 0.67 | 10.74 | 0.94 | 6.28 | 0.36 |
| | ILH | 19.91 | 1.28 | 10.91 | 1.07 | 6.75 | 0.6 |
| | Female | 19.07 | 1.22 | 11.1 | 0.42 | 6.49 | 0.43 |
| | IRH | 19.98 | 1.18 | 10.7 | 0.85 | 6.54 | 0.41 |
| | Female | 18.31 | 0.65 | 10.53 | 0.78 | 6.91 | 1.03 |
| | Male | 20.36 | 0.7 | 10.68 | 0.88 | 6.88 | 1.11 |
| | Female | 18.53 | 1.28 | 10.82 | 0.5 | 6.12 | 0.38 |
| | ERF | 20.63 | 1.04 | 10.8 | 1.17 | 6.77 | 0.89 |
| | Female | 19.15 | 0.68 | 10.85 | 0.69 | 6.50 | 0.26 |
| | ELH | 19.99 | 1.26 | 10.82 | 0.85 | 6.66 | 0.42 |
| | Female | 19.02 | 1.01 | 11.03 | 0.54 | 6.53 | 0.36 |
| | ERH | 20.20 | 1.42 | 10.88 | 1.2 | 6.73 | 0.52 |

ILF: Internal of Left Forelimb, IRF: Internal of Right Forelimb, ILH: Internal of Left Hindlimb, IRH: Internal of Right Hindlimb, ELF: External of Left Forelimb, ERF: External of Right Forelimb, ELH: External of Left Hindlimb, ERH: External of Right Hindlimb, a: There is significant difference legs (P<0.05), b: There is significant difference between the genders (P<0.001).
Table 2: Index values, volume and surface area of Phalanx proximalis and Phalanx media

| Parameter          | Bp*100/GLpe (mm) | Bd*100/GLpe (mm) | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
|--------------------|------------------|------------------|------|-----------|------|-----------|------|-----------|------|-----------|------|-----------|
| ILF                | Male 27.73a 1.72 | 21.58b 1.7     | 25.03 1.25 | 2.52 0.46 | 16.24c 1.06 |
| Female 28.16a 3.2  | 21.45c 1.34     | 24.6 1.35     | 2.38 0.22 | 14.86c 1.57 |
| IRF                | Male 28.22a 1.95 | 21.89c 2.3     | 25.19 1.41 | 2.55 0.46 | 16.29 1.02 |
| Female 27.94a 2.94 | 21.65c 1.33     | 24.29 1.85     | 2.47 0.16 | 14.76 1.34 |
| ILH                | Male 31.46a 2.32 | 25.72c 2.31   | 28.78 3.02 | 2.31 0.37 | 14.22 0.99 |
| Female 31.77a 2.63 | 25.46c 1.43     | 27.74 0.87     | 2.18 0.28 | 13.22 1.34 |
| IRH                | Male 33.35a 3.44 | 24.96c 3.09    | 28.96 2.16 | 2.41 0.34 | 14.54 0.59 |
| Female 32.32a 2.89 | 24.62c 1.59     | 27.34 0.77     | 2.18 0.34 | 14.45 1.08 |
| ELF                | Male 28.26a 1.85 | 21.42c 1.84    | 25.13 1.72 | 2.51 0.45 | 15.91 1.13 |
| Female 28.34a 2.45 | 22c 1.38        | 24.57 1.81     | 2.42 0.28 | 14.94 1.48 |
| ERF                | Male 27.56a 0.52 | 20.83c 1.8     | 24.28 2.62 | 2.55 0.44 | 16.39 0.91 |
| Female 27.98a 3.06 | 21.74c 1.32     | 24.47 1.75     | 2.44 0.17 | 14.82 1.57 |
| ELH                | Male 32.83a 2.08 | 24.27c 2.05    | 28.02 1.54 | 2.26 0.37 | 13.95 0.84 |
| Female 31.07a 2.66 | 24.79c 2.56     | 28c 1.54       | 2.23 0.30 | 13.09 1.07 |
| ERH                | Male 31.88a 1.75 | 24.51c 2.33    | 28.02 0.95 | 2.35 0.27 | 14.44 0.71 |
| Female 33.15a 2.24 | 24.31c 0.7      | 27.02 1.54     | 2.15 0.34 | 14.18 1.37 |

Table 3: Osteometric measurements, index values, volume and surface area of Phalanx distalis

| Parameter   | LD (mm) | DLS (mm) | MBS (mm) | MBS*100/DLS | Volume (cm³) | Surface area (cm²) |
|-------------|---------|----------|----------|-------------|--------------|--------------------|
| Digit       | Gender  | Mean     | Std. Dev.| Mean        | Std. Dev.    | Mean   | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Phalanx     | ILF     | Male 19.38a 1.36 | 23.25 1.9 | 4.94 0.57 | 21.22c 1.57 | 0.82 0.22 | 6.24 0.66 |
|              | Female 17.12a 1.62 | 21.57 1.58 | 5.22 0.39 | 24.30c 2.7 | 0.69 0.17 | 5.47 0.85 |
|              | IRF     | Male 19.15c 1.14 | 23.27 2.12 | 5.17 0.89 | 22.15 2.4 | 0.84 0.28 | 6.37 0.89 |
|              | Female 17.36a 1.64 | 22.01 1.53 | 5.15 0.38 | 23.5 2.37 | 0.78c 0.17 | 5.77 0.64 |
|              | ILH     | Male 18.81a 1.15 | 22.62 1.63 | 5.25 0.5 | 23.24 1.73 | 0.81c 0.18 | 5.86 0.72 |
|              | Female 16.53a 1.44 | 20.12c 1.3 | 5.17 0.55 | 25.78 3.04 | 0.64c 0.09 | 4.96c 0.67 |
|              | IRH     | Male 18.58a 1.29 | 22.42 1.35 | 5.02 0.68 | 22.35 2.47 | 0.85c 0.17 | 5.85c 0.68 |
|              | Female 17.02a 1.05 | 21.17 1.37 | 5.02 0.35 | 23.75 1.92 | 0.63c 0.08 | 4.98c 0.56 |
|              | ELH     | Male 19.27a 1.28 | 23.04a 1.74 | 5.05 0.75 | 21.91 2.59 | 0.80 0.22 | 6.13 0.75 |
|              | Female 17.84a 1.08 | 20.56b 0.83 | 4.95 0.33 | 24.08 2.08 | 0.70 0.16 | 5.42c 0.73 |
|              | ERF     | Male 19.44a 1.25 | 23.21 1.44 | 5.25 0.58 | 22.45 2.11 | 0.81c 0.18 | 5.86c 0.68 |
|              | Female 18.01a 1.11 | 21.97 1.53 | 5.14 0.38 | 23.47 2.05 | 0.78c 0.18 | 5.81c 0.82 |
|              | ELH     | Male 18.68a 1.03 | 22.19b 1.74 | 5.17 0.45 | 23.46 2.18 | 0.80c 0.16 | 5.79c 0.64 |
|              | Female 16.76a 1.38 | 20.02a 1.15 | 5.06 0.44 | 25.34 2.43 | 0.61c 0.08 | 4.78c 0.63 |
|              | ERH     | Male 18.52a 1.43 | 21.86b 1.56 | 5.33 0.66 | 24.36 2.45 | 0.84c 0.14 | 5.87c 0.57 |
|              | Female 16.91a 0.76 | 20.97 1.41 | 4.97 0.42 | 23.81 2.67 | 0.63c 0.11 | 5.01c 0.53 |

ILF: Internal of Left Forelimb, IRF: Internal of Right Forelimb, ILH: Internal of Left Hindlimb, IRH: Internal of Right Hindlimb, ELF: External of Left Forelimb, ERF: External of Right Forelimb, ELH: External of Left Hindlimb, ERH: External of Right Hindlimb. a: There is significant difference between the genders (P<0.05). b: There is significant difference between the genders (P<0.001).

DISCUSSION

The present study morphometrically analyzed digit bones of gazella in terms of sex and direction factors through images extracted from computed tomography. As stated in the studies on Antelopes cervicapra (Choudhary and Singh, 2016), goat (Makungu and Merere, 2017) and blue bulls (Bharti and Singh, 2018) forelimb and hindlimb of phalanx proximalis were observed to be the longest bone among all phalanges in the present study as well (Choudhary and Singh, 2016; Makungu and Merere, 2017; Bharti and Singh, 2018). Previous research reported that there was no statistical difference between the right and left phalanges in cattle and water buffaloes (Ocal et al., 2004; Nourinezhad et al., 2012). Results of the present study support these studies. In the study by Peters (1989) it was highlighted that phalanx proximalis was thinner in the forelimb of gazella. However, this was not found in
the present study. In contrast to Gündemir et al. (2020) and Ocal et al. (2004), GLpe measurement of phalanx proximalis was higher in forelimbs than hindlimbs. It might be thought that this situation developed in order to spend less energy and escape from predators (Taylor et al., 1974; Sorkin, 2008). In the study conducted by Nourinezhad et al. (2012) on buffaloes, the breadth of the distal end (Bd) of phalanx proximalis was reported to have a statistically significant difference. In the present study, the same measurement in females and males was found to be statistically significant (P<0.05). Length (GLpe) and breadth (Bp) of phalanx media were indicated to be 1.88±0.03cm and 0.94±0.05cm, respectively, in the measurements on Black Bengal goats carried out by Siddiqui et al. (2008). The same parameters were found to be 1.95±0.59cm and 10.82±4.38cm, respectively in the present study. GL, SD, and Bp values of phalanx media were reported to be statistically significant in the studies on water buffaloes by Nourinezhad et al. (2012) and on domestic cattle by Gündemir et al. (2020). It was found in the present study that only SD value was statistically significant regardless of sex (Nourinezhad et al. 2012., Nourinezhad et al., 2015). GLpe parameter was significant for all limbs other than the left hindlimb phalanx media based on sexual dimorphism (P<0.05). Güdemir et al. (2020) calculated that LD and DLS measurements of phalanx distalis were higher in forelimbs and reported no statistical difference. The present study revealed that LD value was significant (P<0.05) in all bones in terms of sexual dimorphism. DLS parameter was statistically significant between the left hindlimb and the left forelimb external bones in terms of sexual dimorphism (P<0.05). In the present study, digit bones of gazella that are under the risk of extinction were analyzed via classical morphometric methods using 3D images. Besides, data obtained based on sex and direction criteria were compared statistically.

Conclusions: Consequently, the results of the study are considered to be useful for Ruminantia taxonomy and zooarcheological surveys of the species. Besides, it is also thought that these results obtained in the study can be used for comparison in degenerations and regeneration that may occur in the digit bones. As a result of the study, it was observed that mean values of the bones had a statistically significant difference in terms of both sexes and direction. Considering the compact texture of ossa phalanges, it can be predicted that it cannot be consumed easily by carnivore animals. Also, it is likely to assert that these bones are highly limited for human consumption. Therefore, it would be correct to state that ossa phalanges has a structure allowing the maintenance of these characteristics under the earth for long years due to its strong structure indicating characteristics of the species. This study made a morphometric analysis of the finger bones of gazelle with 3D models created using two-dimensional images of computed tomography and it is thought to contribute to studies in this field and it is thought that it will contribute to the studies in the field.

Authors contribution: MOD and SA designed this study objectives. ID and AK prepared three-dimensional models and obtained measurements from anatomical points. BY analyzed the data and NGİ and YD wrote the manuscript. All authors accomplished critical corrections to the final version of the article.

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