Three-dimensional tomographic reconstruction and morphometric analysis of skull in gazelles (*Gazella subgutturosa*)

Bestami YILMAZ¹,a, İsmail DEMİRCİOĞLU¹,b, Faruk BOZKAYA²,c, Nazan GEZER İNCE³,d

¹Harran University, Faculty of Veterinary Medicine, Department of Anatomy, Şanlıurfa; ²Harran University, Faculty of Veterinary Medicine, Department of Genetics, Şanlıurfa; ³İstanbul Cerrahpaşa University, Faculty of Veterinary Medicine, Department of Anatomy, Istanbul, Turkey.

Abstract: This study was carried out to determine the osteometric features of the skull by using three dimensional computed tomography images in gazelles (*Gazella subgutturosa*). In the study, nine skull samples of adult gazelles (*Gazella subgutturosa*) were used. Images of the skull sections of 0.625 mm thickness were acquired by using a computer tomography device with 64 detectors applying 80 kV, 200 mA and 639 mGY. Three-dimensional images of the skull samples were reconstructed and morphometric measurements (39 linear, 1 volumetric and 1 surface area) were performed by using the software program MIMICS 12.1. Mean skull volumes in males and females were found to be 115.74±2.43 cm³ and 87.69±1.09 cm³ while the mean skull surface areas in males and females were 79.62±8.56 cm² and 77.34±1.18 cm², respectively. Significant differences between males and females for median frontal length (MFL), frontal length (FRL), upper neurocranium length (UNCL), greatest length of the lacrimal bone (GLLB), oral palatal length (OPL), length of the upper molar row (LUMR) and the greatest neurocranium breadth (GNCB) were observed. The difference in the cranial index between males and females was statistically significant (P<0.01). The data obtained in this study will contribute to detect differences between the gazelles and other species with respect to skull morphometry.

Keywords: Computed tomography, gazelle, morphometry, reconstruction, skull.

Ceylanlarda (*Gazella subgutturosa*) kafatasının üç boyutlu tomografik rekonstruksiyonu ve morfometrik analizi

Özet: Bu çalışma; ceylan kafatasının bilgisayarlı tomografi görüntülerini kullanarak kafatası kemiklerinin osteometrik özelliklerini belirlemek amacıyla yapılmıştır. Çalışmada 9 adet erişkin ceylan (*Gazella subgutturosa*) kafatası kullanıldı. Kafatasların 64 deektörlü CT cihazı ile 80 kV, 200 MA, 639 mGY ve 0,625 mm kesit kalınlığında görüntüler alınmıştı. Bu görüntüler MIMICS 12.1 programı ile üç boyutlu yapıya dönüştürülmüş, morfometrik ölçümleri (39 lineer, 1 hacim ve 1 yüzey alanı) yapılmıştır. Erkeklerde kafatasının ortalama hacim değeri 115,74±2,43 cm³, dişlerde 87,69±1,09 cm³ olarak tespit edilmişdir. Dişlerde 77,34±1,18 cm² olarak bulundu. Çalışmada, median frontal uzunluk (MFL), frontal uzunluk (FRL), üst neurocranium uzunluğu (UNCL), lacrimal kemikin maximum uzunluğu (GLLB), oral palatal uzunluk (OPL), üst molar diş sırası uzunluğu (LUMR) ve en büyük neurocranium genişliği (GNCB) parametrelerinde dişi ve erkekler arasındaki farklar istatistiksel olarak anlamlı bulunmuştu. Cranial index değerleri açısından dişi ve erkekler arasındaki fark istatistiksel olarak anlamlı bulunmuştu (P<0,01). Çalışmada elde edilen bilgilerin ceylan türlerinin tipolojisi ile diğer türlerle arasındaki farklıkların tespitine katkısı sunulmuştur.

Anahtar sözcükler: Bilgisayarlı tomografi, ceylan, kafatası, morfometri, rekonstruksiyon.

Introduction

Even among the closely related species, there are apparent differences in the skeletal systems. These differences are crucial for taxonomic classification of species and for evaluation of the archaeological or forensic findings (26). Skull is the most studied bone for reconstructing the evolutional taxonomy. However, the assignment of the species based on skull characteristics is difficult due to variation within species (1). Knowledge of cranial morphometry is also important for the diagnosis of cranial or dental deformities for designing implants or dental instruments (26, 27).
Three different techniques have been used for obtaining osteometric parameters. The first is the measurement of bones obtained from archaeological excavations or after maceration by using a compass (23). The second is the evaluation of the radiological images from the target region (16). The third one is the measurement of the images obtained by using computer tomography (CT), which is a recently more frequently used technique (27). Images of two-dimensional sections from CT are compiled to reconstruct a three dimensional (3D) image using special software programs (10, 22). The 3D modeling technique is widely employed in plastic surgery, orthopedic surgery, neurosurgery, traumatology and medical education (17).

Gazella is one of the most species-rich genus comprising numerous species within Bovidae (1). Gazelles in Sanliurfa belongs to Gazella subgutturosa, which has a wide distribution area ranging from China to North Africa. Since the second half of 20th century number of the gazelles have rapidly declined due to human activities including habitat destruction, expansion of the agricultural areas, hunting, etc. (19).

Several morphometric studies have been performed for establishing a comprehensive and reliable database in gazelles (1, 9, 31). The objective of this study was to morphometrically analyze the skulls of gazelles by using the CT images in order to provide species specific data that can be used by veterinary clinicians for managing pathological formations on the skull.

Material and Methods

Animal material: In the study nine cadavers (5 females and 4 males) of adult gazelles were used. Body weights of the cadavers were among 11.4 - 18.1 kg. The cadavers were submitted to the clinics of Harran University Animal Hospital in Sanliurfa province of Turkey for treatment yet died for various reasons. The animals had no clinical or pathological skull problems. The use of the cadavers was approved by the General Directorate of Nature Conservation and National Parks-Turkey (Approval no: 2017/209842) and Harran University Animal Experimentation Local Ethics Committee (Approval no: 2018/006-11).

CT-Imaging, reconstruction and morphometric analysis: For obtaining the CT images the gazelle cadavers were placed on a sternal position into a CT device with 64 detectors (GE Company, USA). Images of the skull sections of 0.625 mm thickness were acquired by applying 80 kV, 200 mA, and 639 mGY. The CT images were stored in DICOM format and the 3D skull images were reconstructed using the basic module of the 3D modeling program MIMICS 20.1 (The Materialise Group, Leuven, Belgium). Osteometric measurements on the digital images were performed for 39 different parameters according to the measurement points reported in the literature (25, 29). Definitions and the abbreviations of the studied parameters were shown in Table 1. After morphometric measurements, volume and surface area of the skulls were estimated by excluding the horns and mandible. Further 6 different indices were calculated based on the craniometric measurements (Table 2). The definitions were based on Nomina Anatomica Veterinaria (20).

Statistical analysis: All morphometric parameters were expressed as Mean ± Standard Error (SE). The presence of significant differences between sexes was examined by using the Mann-Whitney U test. For statistical analyses SPSS, 17.0 was used.

Results

In this study, 39 linear parameters of the skull were measured (Figure 1-4). The mean ± standard error values for each parameter in males and females were shown in Table 3. Statistically significant differences (P<0.05) between males and females for MFL (median frontal length), FRL (frontal length), UNCL (upper neurocranium length), GLLB (greatest length of the lacrimal bone), OPL (oral palatal length), LUMR (length of the upper molar row) and GNCB (greatest neuro-craniom breadth) were observed.

Furthermore, cranial volume values in males and females were detected to be 115.74±2.43 cm$^3$ and 87.69±1.09 cm$^3$, respectively. The cranial surface area in males and females was 79.62±8.56 cm$^2$ and 77.34±1.18 cm$^2$, respectively (Table 4). The difference in mean cranial volume between males and females was significant while there was no difference in cranial surface area between sexes. Data on the skull indices have been shown in (Table 5). A statistically significant difference between males and females was observed only for cranial index values.
### Table 1. Studied cranial parameters (according to Von den Driesch (30)).

| Parameter | Abbreviation | Definition |
|-----------|--------------|------------|
| 1         | TLS          | Total length of the skull: the distance between akrokranion-prosthion |
| 2         | CBL          | Condyllobasal length: caudal border of occipital condyles-prosthion |
| 3         | TLCB         | Total length of the cranial base: basion-prosthion |
| 4         | SSL          | Short skull length: basion-premolare |
| 5         | PPL          | Premolare-prosthion length |
| 6         | NCL          | Neurocranium length: basion-nasion |
| 7         | ULVC         | Upper length of the viscerocranium: nasion-prosthion |
| 8         | MFL          | Median frontal length: akrokranion-nasion |
| 9         | ACBL         | Akrokranion-bregma length |
| 10        | FRL          | Frontal length: bregma-nasion |
| 11        | UNCL         | Upper neurocranium length: akrokranion-supraorbitale |
| 12        | FCL          | Facial length: supraorbitale-prosthion |
| 13        | ACIO         | Akrokranion-infraorbitale length |
| 14        | GLLB         | Greatest length of the lacrimal bone |
| 15        | GLNB         | Greatest length of the nasal bone: nasion-rhinion |
| 16        | EOPL         | Entorbitale-prosthion length |
| 17        | DOCI         | Distance between the caudal border of occipital condyle and the infraorbitale |
| 18        | DTL          | Dental length: posidentale-prosthion |
| 19        | OPL          | Oral palatal length: palatinoorale-prosthion |
| 20        | LLPM         | Lateral length of the premaxilla: nasointermaxillare-prosthion |
| 21        | LMTR         | Length of the maxillary tooth row |
| 22        | LUMR         | Length of the upper molar row |
| 23        | LUPR         | Length of the upper premolar row |
| 24        | GIWO         | Greatest inner width of the orbit: ectorbitale-entorbitale |
| 25        | GIHO         | Greatest inner height of the orbit |
| 26        | GMB          | Greatest mastoid breadth: otion-otron |
| 27        | GBOC         | Greatest breadth of the occipital condyles |
| 28        | GBPP         | Greatest breadth at the bases of the paracondylar processes |
| 29        | GBFM         | Greatest breadth of the foramen magnum |
| 30        | HFM          | Height of the foramen magnum: basion-opisthion |
| 31        | LBP          | Least breadth of parietal |
| 32        | GBLH         | Greatest breadth between the lateral borders of the horncore base |
| 33        | GNCB         | Greatest neurocranium breadth: euryon-euryon |
| 34        | GFB          | Greatest frontal breadth: ectorbitale-entorbitale |
| 35        | LBO          | Least breadth between the orbits: entorbitale-entorbitale |
| 36        | FCB          | Facial breadth: between facial tuberosities |
| 37        | GBAN         | Greatest breadth across the nasal bones |
| 38        | GBAP         | Greatest breadth across the premaxilla |
| 39        | GPB          | Greatest palatal breadth |

### Table 2. Indices and formulas of the skulls (According to Parés-Casanova (26)).

| Studied indexes      | Formulas                                                                 |
|----------------------|--------------------------------------------------------------------------|
| Skull index          | greatest frontal breadth (var. 34) / total length of the skull (var. 1) × 100 |
| Cranial index        | greatest neurocranium breadth (var. 33) / median frontal length (var. 8) × 100 |
| For. magnum index    | height of the for. magnum (var. 30) / greatest breadth of the for. magnum (var. 29) × 100. |
| Orbital index        | orbital inner width (var. 24) / orbital inner height (var. 25) × 100 |
| Facial index         | facial width (var. 36) / facial length (var. 12) × 100. |
| Nasal index          | greatest breadth across the nasals (var. 37) / greatest length of the nasals (var. 15) × 100. |
Table 3. The mean and standard deviations of the skull measurements (mm).

| Parameter | General statistics | Females | Males | P |
|-----------|--------------------|---------|-------|---|
|           | Mean±SEM | Min. | Max. | Mean±SEM | Mean±SEM |
| TLS       | 165.59±2.78 | 155.29 | 178.92 | 164.40±4.89 | 167.08±2.28 |
| CBL       | 163.87±2.85 | 156.03 | 180.27 | 162.70±4.43 | 165.34±3.84 |
| TLCB      | 153.65±2.34 | 146.88 | 169.08 | 153.29±4.00 | 154.10±2.43 |
| SSL       | 113.10±2.12 | 104.46 | 125.48 | 111.51±3.75 | 115.10±1.04 |
| PPL       | 40.02±0.93 | 34.40 | 44.49 | 40.86±1.15 | 38.97±1.53 |
| NCL       | 103.56±1.52 | 100.01 | 113.93 | 105.51±2.41 | 101.13±0.80 |
| ULVC      | 83.71±1.88 | 73.97 | 92.27 | 84.01±2.07 | 83.33±3.75 |
| MFL       | 98.45±2.19 | 89.29 | 112.52 | 102.37±2.66 | 93.55±1.56 |
| ACBL      | 31.92±2.07 | 22.97 | 40.71 | 33.32±3.27 | 30.17±2.45 |
| FRL       | 82.41±2.91 | 71.92 | 97.85 | 88.27±3.09 | 75.08±1.58 |
| UNCL      | 72.83±3.29 | 55.76 | 90.14 | 79.14±3.26 | 64.94±3.15 |
| FCL       | 121.28±4.94 | 93.00 | 141.39 | 111.89±5.02 | 133.03±4.68 |
| ACIO      | 118.75±1.79 | 111.49 | 129.16 | 118.72±2.73 | 118.78±2.62 |
| GLLB      | 21.09±0.79 | 16.51 | 23.53 | 19.80±1.11 | 22.71±0.38 |
| GLNB      | 49.75±2.93 | 36.75 | 59.93 | 46.27±4.49 | 54.55±2.26 |
| EOPL      | 80.65±1.55 | 73.64 | 87.64 | 79.35±2.30 | 82.28±1.99 |
| DOCI      | 118.53±1.89 | 112.62 | 130.91 | 120.05±3.20 | 116.63±1.48 |
| DTL       | 94.40±1.95 | 88.18 | 105.11 | 96.98±2.93 | 91.18±1.51 |
| OPL       | 77.97±3.60 | 64.86 | 94.76 | 85.47±3.72 | 68.60±1.34 |
| LLPM      | 50.02±1.42 | 43.98 | 57.90 | 48.08±1.48 | 52.45±2.22 |
| LMTM      | 53.22±1.28 | 47.67 | 59.51 | 51.78±1.70 | 55.02±1.73 |
| LUMR      | 30.15±1.42 | 24.39 | 36.17 | 27.83±1.70 | 33.04±1.52 |
| LUPR      | 22.32±0.69 | 18.70 | 25.06 | 23.44±0.60 | 20.91±1.03 |
| GIWO      | 33.46±0.32 | 32.19 | 34.86 | 33.16±0.52 | 33.83±0.28 |
| GIHO      | 34.88±0.57 | 32.59 | 37.23 | 34.10±0.54 | 35.84±0.94 |
| GMB       | 51.95±1.04 | 46.46 | 55.96 | 52.76±1.76 | 50.94±0.83 |
| GBOC      | 33.92±1.57 | 27.31 | 40.84 | 34.13±2.31 | 33.65±2.41 |
| GBPP      | 48.28±1.67 | 39.79 | 54.17 | 48.12±2.83 | 48.47±1.83 |
| GBFM      | 16.28±0.36 | 14.57 | 18.35 | 15.87±0.41 | 16.80±0.57 |
| HFM       | 15.03±0.32 | 13.44 | 16.27 | 15.53±0.27 | 14.42±0.52 |
| LBP       | 35.74±0.96 | 30.88 | 40.14 | 36.42±1.52 | 34.89±1.11 |
| GBLH      | 55.75±2.25 | 49.95 | 65.15 | - | 55.75±3.37 |
| GNCB      | 56.84±0.84 | 52.98 | 60.25 | 55.21±0.75 | 58.88±0.89 |
| GFB       | 69.16±2.24 | 57.12 | 75.93 | 68.95±3.29 | 69.44±3.47 |
| LBO       | 82.07±1.11 | 78.56 | 88.03 | 80.80±1.83 | 83.66±0.55 |
| FCB       | 56.47±1.12 | 51.96 | 63.40 | 56.79±1.94 | 56.09±1.10 |
| GBAN      | 24.60±1.19 | 19.32 | 28.82 | 23.30±1.58 | 26.24±1.64 |
| GBAP      | 28.96±1.17 | 21.45 | 33.91 | 27.84±1.64 | 30.35±1.61 |
| GBP       | 47.39±0.87 | 44.46 | 51.77 | 47.39±1.24 | 47.40±1.40 |

S.E.: Standard error of mean.

Table 4. The mean and standard deviations of the skull volume and surface area.

| Parameter | General statistics | Females | Males | P |
|-----------|--------------------|---------|-------|---|
|           | Mean±SEM | Min. | Max. | Mean±SEM | Mean±SEM |
| Volume (cm³) | 101.71±2.31 | 69.14 | 151.67 | 87.69±1.09 | 115.74±2.43 |
| Area (cm²)  | 78.48±9.80 | 61.31 | 91.17 | 77.34±1.18 | 79.62±8.56 |

SEM: Standard error of mean, NS: Non significant.
Table 5. The mean and standard deviations of the craniofacial indices.

| Index   | General statistics | Females         | Males           | P   |
|---------|--------------------|-----------------|-----------------|-----|
|         | Mean±SEM           | Min.            | Max.            | Mean±SEM | Mean±SEM |       |
| Skull   | 41.86±1.50         | 32.94           | 46.36           | 42.12±2.45 | 41.54±1.86 | 0.730 |
| Cranial | 58.01±1.74         | 49.87           | 65.60           | 54.03±1.08 | 62.98±1.18 | 0.016 |
| For. magnum | 92.84±3.35      | 73.24           | 108.92          | 98.16±3.53 | 86.18±4.49 | 0.111 |
| Orbital | 96.09±1.49         | 90.59           | 104.02          | 97.27±1.12 | 94.61±3.15 | 0.286 |
| Facial  | 47.45±2.92         | 37.97           | 68.17           | 51.51±4.36 | 42.36±2.04 | 0.063 |
| Nasal   | 50.30±3.17         | 38.44           | 64.27           | 51.67±4.70 | 48.60±4.67 | 0.556 |

SEM: Standard error of mean.

Figure 1. Measurement points of craniometric variables in the gazelle skull (lateral view).
A: Akrokranion, Br: Bregma, Ect: Ectorbitale, Ent: Entorbitale, Ni: Nasointermaxillare If: Infraorbitale, N: Nasion, P: Prosthion, 6: Neurocranium length (NCL), 7: Upper length of the viscerocranium (ULVC), 14: Greatest length of the lacrimal bone (GLLB), 17: Distance between the caudal border of one occipital condyle and the infraorbitale of the same side (DOCI), 20: Lateral length of the premaxilla (LLPM), 24: Greatest inner width of the orbit (GIWO), 25: Greatest inner height of the orbit (GIHO).

Figure 2. Measurement points of craniometric variables in the gazelle skull (dorsal view).
A: Akrokranion, Br: Bregma, Ect: Ectorbitale, Ent: Entorbitale, Eu: Euryon, If: Infraorbitale, N: Nasion, P: Prosthion, Rh: Rhinion, Sp: Supraorbitale, 1: Total length of the skull (TLS), 8: Median frontal length (MFL), 9: Akrokranion-bregma length (ACBL), 10: Frontal length (FRL), 11: Upper neurocranium length (UNCL), 12: Facial length (FCL), 13: Akrokranion-infraorbitale length (ACIO), 15: Greatest length of the nasal bone (GLNB), 16: Entorbitale-prosthion length (EOPL), 31: Least breadth of parietal (LBP), 33: Greatest neurocranium breadth (GNCB), 34: Greatest frontal breadth (GFB), 35: Least breadth between the orbits (LBO), 36: Facial breadth (FCB), 37: Greatest breadth across the nasal bones (GBAN), 38: Greatest breadth across the premaxilla (GBAP).
Figure 3. Measurement points of craniometric variables in the gazelle skull (ventral view).

B: Basion, P: Prosthion, Pd: Postdentale, Pm: Premolare, Po: Palatinoorale, 2: Condylobasal length (CBL), 3: Total length of the cranial base (TLCB), 4: Short skull length (SSL), 5: Premolare-prosthion length (PPL), 18: Dental length (DTL), 19: Oral palatal length (OPL), 21: Length of the maxillary tooth row (LMTR), 22: Length of the upper molar row (LUMR), 23: Length of the upper premolar row (LUPR), 39: Greatest palatal breadth (GPB).

Figure 4. Measurement points of craniometric variables in the gazelle skull (occipital view).

A: Akrokranion, B: Basion, O: Opisthion, Ot: Otion, 26: Greatest mastoid breadth (GMB), 27: Greatest breadth of the occipital condyles (GOBC), 28: Greatest breadth at the bases of the paracondylar processes (GBBPP), 29: Greatest breadth of the foramen magnum (GBFM), 30: Height of the foramen magnum (HFM).

Discussion and Conclusion

Craniometric analyses have been used to differentiate species within the same genus and to investigate morphological variations within species. Several reports on craniometric measurements using traditional methods (the help of scale and digital calipers) in gazelles are found in the literature (7, 31). This study presents for the first time morphometric and volumetric measurements of the skull in gazelles by using three-dimensional CT images. Due to the lack of data on CT based measurements in gazelles, data obtained from different gazelle species by traditional methods or data obtained from sheep and goats were used for comparison.

Due to remarkable morphological variations both among gazelle species and among individuals within the same species, assigning an individual to a certain species might be difficult (28). Therefore, more data are required for assessing the morphometric variation within the species. On the other hand, craniofacial index parameters are also necessary for examining craniofacial deformities and investigating brain development (13).
between the species have been attributed to inclusion or exclusion of mandible, horn status of the animal, measurement methods used or live weight of the animal.

In conclusion, new technologies like CT presents opportunities for obtaining comprehensive data on skull morphometry in animals. This study was the first reporting the use of CT for morphometric analysis of the skull in goitered gazelle (Gazella subgutturosa). The data obtained in this study will be useful for not only the evaluation of CT images from facial, cranial of dental deformities but also for determining the sex based on bone morphometry and for taxonomical studies. However further studies are necessary for comparing the data obtained from 3D modeling and actual measurements on skulls by including larger sample size.

Financial Support
This study was supported by Scientific Research Center of Harran University (Project number: 18004).

Conflict of Interest
The authors declared that there is no conflict of interest.

References
1. Bärmann EV, Wronski T, Lerp H, et al (2013): Morphometric and genetic framework for Gazella. Zoo J Linnean Soc, 169, 673-696.
2. Best KC, Garvin HM, Cabo LL (2018): An investigation into the relationship between human cranial and pelvic sexual dimorphism. J Forensic Sci, 63, 990-1000.
3. Breiman RS, Beck JW, Korobkin M, et al (1982): Volume determinations using computed tomography. AJR Am J Roentgenol, 138, 329-333.
4. Chanpanitkitchote P, Tangphokhun W, Nomsiri R, et al (2015): Ratio of cranial and skull volumes in 25 mammalian species. Vet Integr Sci, 13, 165-177.
5. Christiansen P, Harris JM (2012): Variation in craniodental morphology and sexual dimorphism in Pantherines and the Sabercat Smilodon fatalis. PLoS One, 7, e48352.
6. Fandos P, Vigal CR (1993): Sexual dimorphism in size of the skull of Spanish ibex Capra pyrenaica. Acta Theriol, 33, 103-111.
7. Groves CP (1983): Notes on the gazelles IV: the Arabian gazelles collected by Hemprich and Ehrenberg. Z. Saugtierkd, 48, 371-381.
8. Hasan HA (2017): Three dimensional computed tomography morphometric analysis of the orbit in Iraqi population. Int Med J, 24, 147-149.
9. Hayatgheib D, Karami M, Farahmand H, et al (2011): Morphological study and comparison of western and eastern goitered gazelle (Gazella subgutturosa: Goldenstael, 1780) populations in Iran. Int J Environ Res, 5, 225-232.
10. Ince NG, Demircioglu I, Yilmaz B, et al (2018): Martolarda (Laridae spp.) cranium’un üç boyutlu modellemesi. Harran Univ Vet Fak Derg, 7, 98-101.
11. Jaslow JR (1989): Sexual dimorphism of cranial suture complexity in wild sheep (Ovis orientalis). Zoo J Linnean Soc, 95, 273-284.
12. Kamal S (2006): Morphological and craniometrical studies on the skull of Kagani goat (Capra hircus) of Jammu region. Int J Morphol, 24, 449-455.
13. Kanchan T, Krishan K, Gupta A, et al (2014): A study of cranial variations based on craniometric indices in a South Indian population. J Craniofac Surg, 25, 1645-1649.
14. Karimi I, Onar V, Pazvan G, et al (2011): The cranial morphometric and morphologic characteristics of Mehraban sheep in Western Iran. Glob Vet, 6, 111-117.
15. Kataba A (2010): Biometric and morphologic characteristics of the skull of the Gwembe Valley Dwarf Goat (Capra Hircus) breed of Zambia. MSc, University of Zambia, Lusaka, Zambia.
16. Kranioti EF (2019): Radiometry versus osteometry in sex assessment: a study of the Cretan radius. Aust J Forensic Sci, 51, 135-148.
17. Krupa P, Krsel P, Cernochova P, et al (2004): 3D real modelling and CT biomodels application in facial surgery. In: Neuroradiology, Springer, Berlin.
18. Leslie DM (2010): Procapra picticaudata (Artiodactyla: Bovidae). Mamm Species, 42, 138-148.
19. Mallon DP, Kingswood SC (2001): Antelopes. Part 4: North Africa, the Middle East, and Asia. Global Survey and Regional Action Plans. SSC Antelope Specialist Group, IUCN, Gland, Switzerland and Cambridge, UK.
20. Nomina Anatomica Veterinaria (2017): International committee on veterinary gross anatomical nomenclature (ICVGAN), Published by the Editorial Committee, Hannover.
21. Özcan S, Aksoy G, Körtül İ, et al (2010): A comparative morphometric study on the skull of the Tuj and Morkaraman sheep. Kafkas Univ Vet Fak Derg, 16, 111-114.
22. Özkurt A (2002): Üç boyutlu örneksel veri yanında yüzey modeli üretimi. DEUFMD, 4, 27–36.
23. Páral V, Tichy F, Fabšt M (2004): Functional structure of metapodial bones in Cattle. Acta Vet Brno, 73, 413-420.
24. Parés I, Casanova PM, Kamal S, et al (2010): On biometrical aspects of the cephalic anatomy of Xisqueta sheep (Catalunya, Spain). Int J Morpol, 28, 347-351.
25. Parés-Casanova PM (2014): Osteometric study of the Rasaquera White goat. J Appl Anim Res, 42, 177-185. 
26. Tecirlioğlu S (1983): Sırtlan ve köpeğin iskelet kemikleri üzerinde makro-Anatomik araştırmalar. Ankara Univ Vet Fak Derg, 30, 149-166. 
27. Teo EC, Holsgrove T, Haiblikova S (2017): 3D Morphometric analysis of human vertebrae C3-T3 using CT images reconstruction. J Spine, 6, 391.
28. Thouless CR, Al Bassri KA (1991): Taxonomic status of the Farasan island gazelle. J Zool Lond, 223, 151-159. 
29. Von Den Driesch A (1976): A guide to the measurement of animal bones from archaeological sites. Peabody Museum Bulletin 1. Cambridge, MA, Harvard University.
30. Wronski T, Sandouka M, Plath M, et al (2010): Differences in sexual dimorphism among four gazelle taxa (Gazella spp.) in the Middle East. Animal Biol, 60, 395-412.
31. Zhu L. (2012): Cranio-metrical studies on the skull of Tibetan Gazelle (Procapra Picticaudata). Int J Morphol, 30, 196-198.