Three-Dimensional Modelling and Morphometric Analysis of the Vertebral Column in Gazelles *(Gazella subgutturosa)* by using Computer Tomographic Images*

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Abstract: This study was performed to create three-dimensional (3D) images of gazelles' vertebral column bones using two-dimensional multi-detector computed tomography (MDCT) outputs and to evaluate detailed anatomical structure of the region. In the study, 10 adult (5 males and 5 females) gazelle cadavers were used. Materials were scanned under 80 kv, 200 MA, 639 mGY and 0.625 mm section thickness using a 64-detector MDCT (General Electric Revolution). The MDCT outputs were converted into 3D formats with MIMICS 20.1 (The Materialise Group, Leuven, Belgium) software. Numbers of the cervical, thoracic, lumbar, sacral and caudal vertebra were detected as 7, 13, 6, 5 and 12-16, respectively. The surface area of thoracic vertebrae was found to be 38096.52±1415.85 mm^2 in females and 51927.02±4185.70 mm^2 in males. The difference between the genders in terms of surface area of thoracic vertebrae was found to be statistically significant (P<0.05). It is considered that the findings obtained will provide reference data for further studies in anatomy, surgery and zooarchaeology in addition to determining differences or similarities of gazelle vertebral column with other species.
Keywords: *Gazelle, Vertebral column, MDCT, Three-dimensional reconstruction, Osteometry.*

Ceylanlarda (*Gazella subgutturosa*) Bilgisayarlı Tomografi Görüntülerini Kullanarak Columna Vertebralis'in Üç Boyutlu Modellemesi ve Morfometrik Analizi

Özet: Bu çalışma, ceylanlarda multidedektör bilgisayarlı tomografi (MDCT) tarayıcı verilerini kullanarak columna vertebralis'in üç boyutlu (3B) görüntülerini oluşturmak ve bölgenin ayrıntılı anatomik yapısını değerlendirmek için yapıldı. Çalışmada 10 yetişkin (5 erkek ve 5 dişi) ceylan kadavrası kullanıldı. Ceylanlar, 64-dedektörlü MDCT (General Electric Revolution) cihazı ile 80 kv, 200 MA, 639 mGY ve 0.625 mm kesit kalınlığında tarandı. MDCT'den elde edilen kaynak görüntüler, MIMICS 20.1 (The Materialize Group, Leuven, Belçika) yazılımı ile 3B modellere dönüştürüldü. Üç boyutlu modeller üzerinde yapılan incelemede; boyun, sırt, bel, sağrı ve kuyruk omurları sayısı sırasıyla 7, 13, 6, 5 ve 12-16 olarak tespit edildi. Sırt omurlarının yüzey alanı dişilerde ortalama 38096.52±1415.85 mm^2, erkeklerde ise 51927.02±4185.70 mm^2 olarak tespit edildi. Sırt omurlarının yüzey alanı açısından cinsiyetler arasındaki fark istatistiksel olarak anlamlı bulundu (P<0.05). Elde edilen bulguların ceylan omurgasının diğer türlerle olan farklılıkları veya benzerliklerinin tespitine ek olarak anatomi, cerrahi ve zooarkeoloji alanında yapılacak daha ileri çalışmalarda referans veriler sağlayacağı değerlendirilmektedir.
Anahtar kelimeler: *Ceylan, Columna vertebralis, MDCT, Üç boyutlu rekonstrüksiyon, Osteometri*

Introduction

Gazelle is one of the most important and crowded exotic species around the horned ruminants (Bovidae) (Bärmann et al., 2013). *Gazella subguttorsa* is a member of the species and their roots come from Asian antelopes. Their habitat is quite wide ranging from China to North Africa. Despite of the fact that their population was highly crowded till middle of twentieth century, it has been decreasing because of harmful human based activities such as; habitat destruction, increasing farming area and overhunting (Mallon and Kingswood, 2001; Mallon, 2008).

There has been a revolution on medical diagnosis and management of treatment procedure thanks to state art of the technologies at imaging and scanning techniques. X-ray, ultrasonography (USG), positron emission tomography (PET), magnetic resonance (MR) and computed tomography (CT) are the most used technologies on the field. Two-dimensional (2D) outputs taken from MR and CT can be easily converted to three-dimensional (3D) pictures or models with 3D reconstruction programmes. Hence, 3D and limitless data can be extracted from the limited 2D images collected from the imaging analyses. Thus, pathological lesions located on deep anatomical regions can be easily detected thanks to these techniques (Özkurt, 2002). Moreover, 3D modelling techniques has a wide using area including plastic and orthopaedic surgery, traumatology, criminal sciences, neurosurgery and medical education (Krupa et al., 2004).

There are some anatomical differential features between the closest species on body skeletons. These differences have a vital importance in respect of classification of species and evaluation of archaeological and criminal findings (Tecirlioğlu, 1983). The parts of vertebral column show some morphological and functional differences (Jones and German, 2014). Moreover, one of the used methods for gender analyses is biometric measurements taken from vertebral column (Chen et al., 2013; Özkadif et al., 2017; Sevinç et al., 2008).

In the present study, it was aimed to determine the sexual dimorphism of vertebral column and to comparatively investigate differences or similarities of vertebral column between other species with 3D models of gazelles' body skeleton through detailed macro-anatomical and osteo-metrical measurements. Moreover, it was also thought that the study can be used as a basic information source for both further scientific studies at the field and further treatment protocols. Additionally, the study might be helpful for taxonomical classifications, archaeological and criminal sciences.

Materials and Methods

Ten cadavers of adult (5 males and 5 females) gazelles were used as the study material. The cadavers of the gazelles were chosen among animals which were submitted to Harran University Veterinary Faculty Animal Hospital Clinics for treatment purpose and they were free of any contagious diseases. Gazelles were scanned under 80 kv, 200 MA, 639 mGY and 0.625 mm section thickness with 64-detector MDCT (General Electric Revolution). Prokop (2003) was taken as references to adjust scanning dose and following the scan protocol. Gazelles' CT images were taken, and the images were saved in Digital Imaging and Communications in Medicine (DICOM) format. These 3D images were reconstructed with 3D modelling software MIMICS 20.1 (The Materialise Group, Leuven, Belgium).

The statistical importance of morphometric measurements between genders were analysed with Mann Whitney- U test and the relationship between the data were analysed with Spearman Correlation test. SPSS 17.0 (SPSS Inc. Released 2008. SPSS Statistics for Windows, Version 17.0. Chicago: SPSS Inc) software was used for all statistical analyses. 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 Experimentations Local Ethics Committee (Approval no: 2018/006-9 11).

Results

CT images taken from gazelle body skeleton were modelled with MIMICS 20.1 (The Materialise Group, Leuven, Belgium) 3D modelling software. It was detected that the vertebral column was constructed of five different parts as cervical, thoracic, lumbar, sacral and caudal (Figure 1). Vertebral column's length, surface and volume are illustrated at Table 1. According to whole vertebral column analysis, there was no difference between the genders in terms of vertebral column except for thoracic spine surfaces. The correlation analysis of the vertebral column measurements is shown in Table 2.

It was detected that cervical part was constructed with 7 vertebrae (Figure 2/A). The length, surface and volume of cervical part were measured as 212.89±5,16 mm, 36554.5±1483,89 mm², 62732.7±5726.01 mm³ for females; and, 210.05±10.27 mm, 42092.55 ± 4254.95 mm², 79243.55±16239.13 mm³ for males, respectively.

Thoracic part of vertebral column had 13 vertebrae and their spinous processes continued through caudal region with a curve. The steepest processus spinosus to the body -anticlinal vertebra- was detected at 13th vertebral bone (Figure 2/B). It was detected that the height of spinous processes showed a gradual increase to 5th thoracic vertebra but then it gradually decreased. The length, surface and volume of thoracic part's vertebrae were measured as 240.43±2,75 mm, 38096.52±1415.85 mm², 56034.44±2861.31 mm³ for females; and, 240.02±8.78 mm, 51927.02±4185.70 mm², 67421.73±6097.62 mm³ for males, respectively. A statistically significant difference was observed between males and females in respect of surface area of thoracic vertebrae ($P<0.05$).

Lumbar part of vertebral column was constructed with 6 vertebrae (Figure 2/C). The lengths of the lumbar vertebrae increased till 4th

but then the lengths get shorter. Their transverse processes were highly developed and continued towards cranioventral. However, spinous processes of lumbar vertebrae were quite shorter

Table 1. Morphometric parameters of vertebral column.

Segment	Parameter	Female		Male		P
		Mean	S.E.	Mean	S.E.	
Cervical	CL (mm)	212.89	5.16	210.05	10.27	n.s.
	CV (mm³)	62732.70	5726.01	79243.55	16239.13	n.s.
	CSA (mm²)	36554.5	1483.89	42092.55	4254.95	n.s.
Thoracic	ThL (mm)	240.43	2.75	240.02	8.78	n.s.
	ThV (mm³)	56034.44	2861.31	67421.73	6097.62	n.s.
	ThSA (mm²)	38096.52	1415.85	51927.02	4185.70	*
Lumbar	LL (mm)	141.78	7.95	147.41	6.55	n.s.
	LV (mm³)	43296.77	5157.65	45761.88	6032.47	n.s.
	LSA (mm²)	25102.95	2188.08	30806.68	1009.8	n.s.
Sacral	SacL (mm)	66.89	1.38	65.73	3.16	n.s.
	SacV (mm³)	14390.77	1388.60	14103.88	3238.13	n.s.
	SacrSA (mm²)	10350.64	490.62	12034.03	1429.94	n.s.
Caudal	CaudL (mm)	183.29	5.94	177.54	10.70	n.s.
	CaudV (mm³)	3591.06	447.28	3742.09	454.64	n.s.
	CaudSA (mm²)	3971.4	382.55	4447.73	364.32	n.s.

CL: Cervical vertebrae lenght, **ThL**: Thoracic vertebrae lenght, **LL**: Lumbar vertebrae lenght, **SacL**: Sacral vertebrae lenght, **CaudL**: Caudal vertebrae lenght, **CV**: Cervical vertebrae volume, **ThV**: Thoracic vertebrae volume, **LV**: Lumbar vertebrae volume, **SacV**: Sacral vertebrae volume, **CaudV**: Caudal vertebrae volume, **CSA**: Cervical vertebrae surface area, **ThSA**: Thoracic vertebrae surface area, **LSA**: Lumbar vertebrae surface area, **SacrSA**: Sacral vertebrae surface area, **CaudSA**: Caudal vertebrae surface area. **n.s.**: no significant

Table 2. Correlation analyses of vertebral column measurements (*P<0.05, **P<0.01).

	CL	ThL	LL	SacL	CaudL	CV	ThV	LV	SacV	CaudV	CSA	ThSA	LSA	SacrSA	CaudSA
CL															
ThL	,879**														
LL	,867**	,709*													
SacL	,794**	,879**	,636*												
CaudL	,567	,283	,817**	,383											
CV	,721*	,624	,842**	,648*	,850**										
ThV	,515	,394	,503	,358	,400	,745*									
LV	,867**	,721*	,891**	,770**	,817**	,952**	,697*								
SacV	,806**	,673*	,855**	,758*	,833**	,770**	,515	,842**							
CaudV	,588	,515	,648*	,552	,733*	,915**	,636*	,842**	,552						
CSA	,661*	,467	,770**	,503	,867**	,939**	,855**	,891**	,782**	,830**					
ThSA	,491	,345	,515	,273	,417	,758*	,976**	,685*	,442	,673*	,855**				
LSA	,442	,333	,479	,200	,083	,564	,733*	,539	,212	,430	,564	,818**			
SacrSA	,600	,479	,515	,612	,500	,661*	,818**	,709*	,782**	,479	,794**	,709*	,382		
CaudSA	,430	,345	,491	,394	,600	,842**	,745*	,721*	,442	,915**	,842**	,806**	,564	,539	

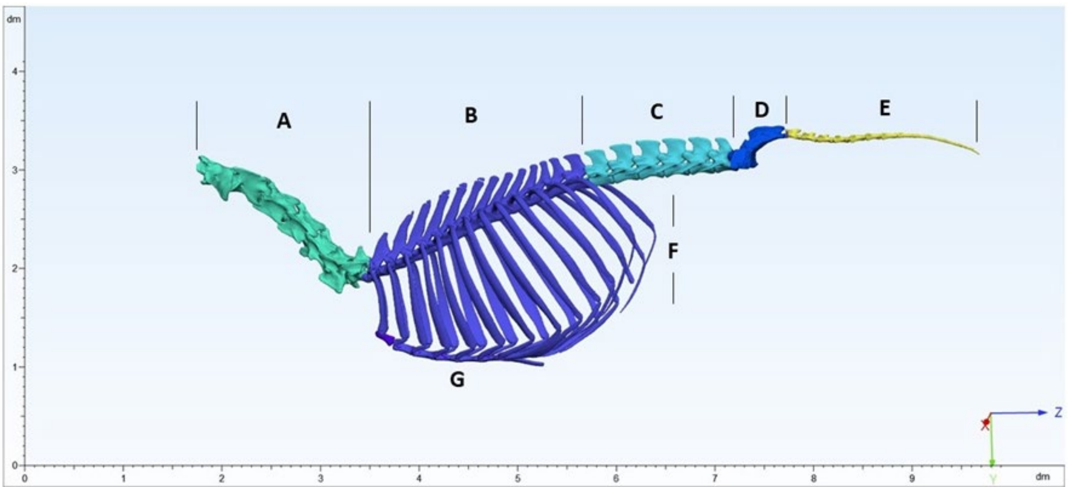

Figure 1. Three-dimensional model of vertebral column and thoracic skeleton (lateral view). A: Cervical region, B: Thoracic region, C: Lumbar region, D: Sacral region, E: Caudal region, F: Costae, G: Sternum.

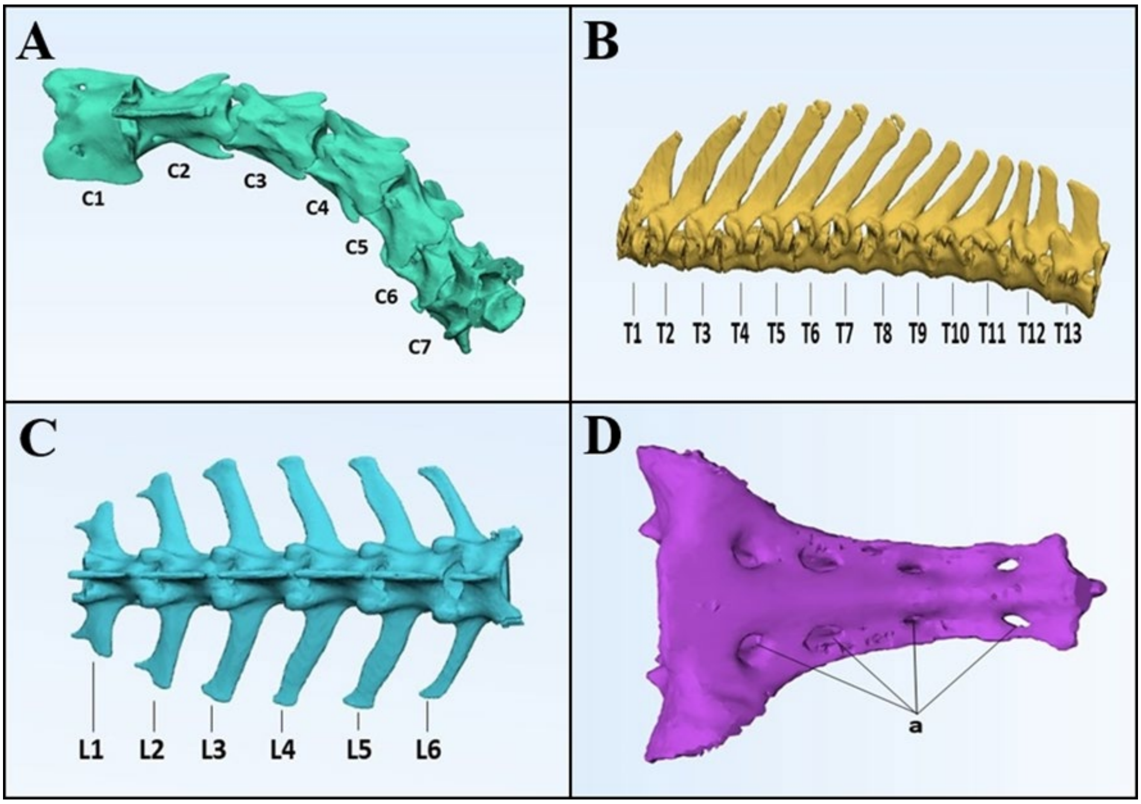

Figure 2. A: Cervical region. C1-7: cervical vertebrae. B: Thoracic region. T1-T13: thoracic vertebrae (lateral view). C: Lumbar region. L1-L6: lumbar vertebrae (dorsal view). D: three-dimensional model of sacrum. a: Foramina sacralia ventralia (ventral view).

compared with thoracic vertebrae and its aspect ratio was calculated as 1:1. The length, surface and volume of lumbar part of vertebrae were measured as 141.78±7.95 mm, 25102.95±2188.08 mm², 43296.77±5157.65 mm³ for females; and, 147.41±6.55 mm, 30806.68±1009.80 mm², 45761.88±6032.47 mm³ for males, respectively.

It was detected that sacral part of backbone was formed by 5 integrated sacral vertebrae (Figure 2/D). There were four ventral sacral foramina on convex pelvic surface (Figure 2/D). It was also detected that median sacral crest was formed by integrated spinous processes of sacral vertebrae. However, the last sacral vertebra was integrated with only corpus region and spinous processes were separated in two animals. The length, surface and volume of sacral part of vertebrae were measured as 66.89±1.38 mm, 10350.6±490.62 mm², 14390.77±1388.60 mm³ for females; and, 65.73±3.16 mm, 12034.03±1429.94 mm², 14103.88±3238.13 mm³ for males, respectively.

The caudal part of spine was composed of 12-16 interlocked vertebrae. The first two caudal vertebrae showed typical characteristic of vertebrae but, the rest of them lost their features and were shaped cylindrical toward back. The length, surface and volume of caudal part of vertebrae were measured as 183.29±5.94 mm, 3971.4±382.55 mm², 3591.06±447.28 mm³ for females; and, 177.54±10.70 mm, 4447.73±364.32 mm², 3742.09±454.64 mm³ for males, respectively.

Discussion and Conclusions

The CT and 3D modelling technologies are used to detect anatomical and pathological deformations at curved body part like vertebral column, because; traditional methods does not supply enough detail for diagnosis (Athertya and Poonguzhali, 2012).

Vertebral morphometry has a vital importance in respect of spinal analyses, diagnosis and advanced implant designment. The new technologies provide an opportunity to develop an easy and productive period to get a wide and extensive data for creating 3D model of vertebral geometry (Teo et al., 2017). According to Kim et al. (2012), the 3D modelling technology is a quite reliable technique for osteometric measurements on the skull and it reflects same results with real samples. In this regard, measurements and investigations based on 3D models are highly important due to their quick and non-invasive characteristics.

In the present study, numbers of cervical, thoracic, lumbar, sacral and caudal vertebrae in *Gazella subgutturosa* were detected as 7, 13, 6, 5 and 12-16, respectively. The numbers of thoracic vertebrae in *Gazella subgutturosa* were found as 13 like wild and Karaman sheep (Taşbaş, 1983), Spotted deer (Iniyah et al., 2015; Meena, 2012) and barking deer (Suri et al., 2012). The lengths of thoracic vertebrae increased from first to fifth thoracic vertebrae but then gradually decreased. It was also detected that spinous processes of thoracic vertebrae had an obliquity toward caudal side. The steepest spinous processes were found at 4th and 5th vertebrae on Barking deer (Suri et al., 2012), 6th and 7th vertebrae on White spotted deer (*Axis axis*) (Iniyah et al., 2015), 4th vertebrae on Spotted deer (Meena, 2012) and 11th vertebrae on Feral pigs (İlgün et al., 2013). However, the highest spinous process was marked at 5th thoracic vertebrae and the steepest spinous processes was measured at 13th thoracic vertebrae in the present study.

The number of lumbar vertebrae was detected as six which was also reported for wild sheep (*Muflon-Ovis Orientalis Anatolica*) and Karaman sheep (Taşbaş, 1983), capra hircus and ovis aries species (Bahadır and Yıldız, 2008), Spotted deer (Meena, 2012), Blackbuck (Choudhary et al., 2015), Barking deer (Suri et al., 2012), and White spotted deer (Iniyah et al., 2015). It was also detected that the directions of transverse processes were cranioventral and their lengths increased from first to fourth vertebrae then decreased. This finding was the same as in Spotted deer (Meena, 2012), Blackbuck (Choudhary et al., 2015), otter (Yılmaz et al., 2000), Barking deer (Suri et al., 2012), and White spotted deer (Iniyah et al., 2015); however, it was different from Feral pigs whose lumbar vertebrae direction was caudoventral (İlgün et al., 2013).

It was detected that sacrum was constructed with five interlocked sacral vertebrae. According to similar studies, this part of vertebral column is formed 4 sacral vertebrae at mountain and Karaman sheep (Taşbaş, 1983), 3 or 4 sacral vertebrae at Feral pigs (İlgün et al., 2013), 5 sacral vertebrae at Barking deer (Suri et al., 2012), Blackbuck (Choudhary et al., 2015), White spotted deer (Iniyah et al., 2015), Spotted deer (Meena, 2012) and Roe deer (Gültekin, 1965). The median sacral crest (crista sacralis madiana) was formed by the knitted free end of sacral vertebrae's spinous processes. This finding was in accordance with mountain sheep (Taşbaş, 1983); however, the first sacral vertebrae's spinous process does not take part for constructing of the median sacral crest at Karaman sheep (Taşbaş, 1983) and Blackbuck (Choudhary et al., 2015).

Özkadif et al. (2017) indicated that there are statistically important differences in respect of sexual dimorphism at chinchilla's all vertebral column part volume and surface measurements. According to Bergmann et al. (2006), the highest sexual dimorphism is observed at caudal region of vertebral column, then at thoracic part but the lowest dimorphism is observed at lumbar and sacral region of spine at rats. In the present study, the only statistically differences was observed at thoracic part, but result on other parts of the vertebral column did not show any significant difference between genders.

There are no findings in the literature in respect of CT technique using for morphometric and morphological analyses of body skeleton at gazelles (*Gazella subgutturosa*). In the present study, measurements on vertebral column of gazelles was assessed for the first time. We suggest that that the findings might be useful as a basic guide data for classification of the population, diagnosing of vertebral or spinal disorders using CT images. Moreover, the results might be helpful for not only typological and taxonomical classification of gazelles but also for sex determination and expanding basic anatomical knowledge about gazelles.

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