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Analysis and 3D Imaging of Morphometric - Mineral Structure Changes in Skulls of Male and Female Guinea Pigs During and After Developmental Period

Análisis e Imágenes 3D de Cambios Morfométricos y de Estructura Mineral en Cráneos de Cobayas Machos y Hembras Durante y Después del Período de Desarrollo

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SUMMARY: Even though morphometric and mineral studies related to the guinea pig (*Cavia porcellus*) skull have been carried out, this study is the first attempt to evaluate all developmental stages of male and female guinea pigs. This study aims to this study is to create 3D modeling of CT images obtained from the skulls of male and female guinea pigs during the developmental period (prepuberty and the period between puberty and adulthood) and following periods (young adulthood and old adulthood), to analyze some biometric bone data such as volume, surface area and length, and to assess the developmental analysis of the mineral matter change in their skulls. The CT-scanned skulls were transferred to 3D Slicer (5.0.2), which is used for 3D modeling. The surface area and volume were calculated by measuring the measurement points on the models. In addition, the XRF device was used to show elemental ratio changes during different developmental stages. According to metric measurements, a gradual increase was observed during the life period. The metric measurements of the skull bone had a higher measurement value in male guinea pigs than in their female counterparts. While Ca/P ratio increased up to the third group and partially decreased in the fourth group in males, it gradually increased from the first group to the fourth group in females. This study revealed that puberty, adulthood and sex were effective in the physical and chemical characterization of skull bone structure in guinea pigs.

KEY WORDS: Skull; Guinea pig; *Cavia porcellus*; 3D; Morphometry; XRF.

INTRODUCTION

The guinea pig (*Cavia porcellus*) is a species of rodent belonging to the family Caviidae of the order Rodentia. Guinea pigs are easily affected by changes in temperature and humidity (Lök, 2009). They are frequently used in experimental studies on immunology, toxicology, pharmacology, and physiology. While guinea pigs are native to South America, wild ones are herbivorous rodents inhabiting in Peru (Yavru &Yavru, 2000). They have large heads and small ears and tails (Lök, 2009). Adult guinea pigs have a length of 27-33 cm and weigh 700-1200 g. They live for 2-8 years (Harkness & Wagner, 1995; Yavru &Yavru, 2000).

A bone that has completed its development contain calcium phosphate (approximately 85 %) and calcium carbonate (10 %). It also has a small amount of magnesium phosphate and calcium fluoride (Çalıslar, 1996; Tasbas, 2001).

Mineralized tissues such as bones, teeth, and horns are basic storage sites in animals. These tissues contain both major elements such as calcium (Ca), phosphorus (P), magnesium (Mg), and sulfur (S) as well as trace elements such as iron (Fe), zinc (Zn), and manganese (Mn). Most of the related studies have focused on key elements, especially Ca, P, and Mg because they play a critical role in bone metabolism (Dermience *et al*., 2015).

X-ray fluorescence (XRF) is used for routine, relatively non-destructive chemical analysis of rocks, minerals,

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sediments and fluids, and can provide information about main components of various biological specimens such as bone (Gonzalez-Rodriguez & Fowler, 2013, Nganvongpanit *et al*., 2016b) teeth (Christensen *et al*., 2012; Nganvongpanit *et al*., 2015) and horn (Kierdorf *et al*., 2014) and to forensically determine the type of body residues (Christensen *et al*., 2012; Gonzalez-Rodriguez & Fowler, 2013).

Morphometry is a research method that investigates the shape differences of objects and organisms and their relationship with other variations. This method is sometimes used to analyze the relationship between the sex of the species and growth factors and the effects of the treatment applied (Lack, 2014). Conventional morphometry is a multiple variance statistical analysis performed with quantitative (length, width, and height) variables. Morphological and morphometric studies have easily revealed differences in the growth of the organism depending on the environmental components and genetic structure (Wehausen & Ramey, 2000).

Biomedical imaging methods are used to diagnose and treat numerous diseases (Eken & Gezici, 2002; Witkowska *et al*., 2014). The computed tomography (CT) method, which is one of the medical imaging techniques, displays the structures in a cross-sectional view and the images are much more detailed than those obtained by X-ray (Alkan, 1999). In recent years, CT has played an important role in the anatomical studies and accurate diagnosis of diseases in veterinary medicine. CT is used effectively in biometric researches and diagnose diseases (Eken & Gezici, 2002; Ohlerth & Scharf, 2007).

Reconstruction is three-dimensional (3D) modelling of transverse and longitudinal sections obtained from CT and other medical imaging techniques (Fretias *et al*., 2011; Özkadif, 2015). This method is used to arrange and process the 3D information obtained by the reconstruction of the first cross-section images and to present such information in various ways and has been accepted in medical sciences, especially in anatomy, surgery, and clinical treatment (Kim *et al*., 2012; Özkadif, 2015).

The aim of this study is to evaluate the metric measurements of the bones, volume and surface area by creating 3D modeling of the skulls of male and female guinea pigs during the developmental period (prepuberty and the period between puberty and adulthood) and following periods (young adulthood and old adulthood), to assess the developmental analysis of the mineral matter change in their skulls. Furthermore, even though morphometric and mineral studies related to the guinea pig skull have been carried out, this study is the first attempt to evaluate all developmental stages of male and female guinea pigs.

MATERIAL AND METHOD

Animals. In this study, 20 female and 20 male guinea pig (*Cavia porcellus*) skulls obtained from the T.R Ministry of Agriculture and Forestry Elazig Veterinary Control Institute were used. The guinea pigs were grouped based on their developmental stages (prepuberty and the period between puberty and adulthood, young adulthood and old adulthood) (Anderson *et al*., 1982; Harkness & Wagner, 1995; Horsfall, 1994) and necessary dissection procedures were completed.

3D imaging. MDCT images of the skulls were obtained with 64 slice, multi-detector, spiral computed tomography device (General Electronic Revolution) at 80 kV, 200 mA, and 639 mGY with 0.625 mm slice thickness. MDCT images were converted to DICOM format for modelling. The data was transferred to 3D Slicer (5.0.2), that is used for 3D modeling.

X-ray fluorescence (XRF). The skulls of guinea pigs were scanned and mapped in 70-µm diameter areas using the XRF device located in Bilecik Seyh Edebali University, Central Research Laboratory, Application and Research Center (MARAL). The samples were ground and made homogeneous so that they were assessed by loose powder method. They were filled into 4 µm mylar film-coated vessels and read in the Omnian (semi-quantitative analysis) software using a 2.4 kW XRF device. In XRF analysis, percentage concentrations of Mg (MgO), Al (Al_2O_3), Si (SiO_2), P (P_2O_5), Cl (Cl), K(K_2O), Ca (CaO), Fe (Fe_2O_3), Ni (NiO), Zn (ZnO)), and Sr (SrO) elements were determined.

Statistical analysis. The surface area and volume values were calculated by measuring the osteometric parameters [39] of the skulls specified in Tables I and II on the models created. SPSS 22.0 was used for statistical analysis.

Table I. Definitions and abbreviations of osteometric parameters measured in the skull and mandible.

Skull	ABBREVIATION	DEFINITION
1	TL	Total length
2	CBL	Condylobasal length
3	BL	Basal length
4	DL	Dental length
5	GLN	Greatest length of the nasals
6	PL	Parietal length
7	FL	Frontal length
8	VL	Viscerocranium length
9	GBOC	Greatest breadth of the occipital condyles
10	GNB	Greatest neurocranium breadth
11	GNL	Greatest neurocranium length
12	BS	Breadth of skull
13	OZB	Oral zygomatic breadth
14	GBN	Greatest breadth of the nasals
15	PB	Palatal breadth
Mandible		
1	LA	Length from angle
2	LC	Length of the cheektooth row
3	LD	Length of the diastema
4	L	Length
5	HVR	Height of the vertical ramus

Table II. Descriptive statistics and p values for group and sex according to cranium measurement points in guinea pigs.

Metric measurements	Sex	Group 1 (mean ±SD) (mm)	Group 2 (mean± SD) (mm)	Group 3 (mean± SD) (mm)	Group 4 (mean± SD) (mm)	p value for group	p value for sex	p value for group*sex
TL	Male	48,822±1,726	50,000±1,464	62,564±3,259	65,192±2,583	<0,001	0,183	0,008
	Female	43,454±2,712	49,176±2,134	63,072±1,433	66,946±2,294			
BL	Male	41,706±0,496	41,248±1,235	54,904±4,121	59,504±2,457	<0,001	0,587	0,006
	Female	37,058±2,366	43,850±1,557	56,710±2,186	59,220±2,030			
CBL	Male	45,272±0,362	44,944±0,978	59,400±3,311	61,266±2,511	<0,001	0,071	<0,001
	Female	38,586±2,507	46,096±1,036	58,224±2,891	62,870±1,814			
DL	Male	27,002±1,614	27,552±1,281	34,888±1,921	36,136±0,756	<0,001	0,780	0,035
	Female	25,074±0,500	28,774±0,922	34,966±0,773	37,220±1,689			
GLN	Male	16,076±0,890	16,582±1,493	22,010±1,870	21,512±1,164	<0,001	0,560	0,003
	Female	14,168±1,122	15,990±0,635	22,728±1,481	24,266±1,386			
PL	Male	9,858±0,368	9,824±0,781	18,786±2,861	21,144±1,162	<0,001	0,891	0,765
	Female	8,698±1,218	11,510±2,025	19,038±3,676	19,726±8,797			
FL	Male	17,022±1,556	17,050±0,979	20,480±0,534	22,222±0,611	<0,001	0,445	0,639
	Female	16,144±0,394	16,886±0,784	20,778±1,518	21,974±1,055			
VL	Male	16,160±0,676	15,472±0,500	21,600±1,322	22,440±1,364	<0,001	0,509	0,014
	Female	13,998±1,021	16,304±0,459	21,254±1,684	23,198±1,014			
GBOC	Male	6,390±0,417	7,154±1,379	7,978±1,012	7,208±0,970	<0,001	0,779	0,514
	Female	6,612±0,319	6,964±0,362	8,674±1,154	6,794±0,724			
GBEAM	Male	20,784±0,224	20,008±1,021	24,316±1,743	27,320±2,004	0,527	0,359	0,507
	Female	36,892±39,819	19,910±0,259	24,982±1,648	27,300±2,661			
GNB	Male	17,996±0,409	17,984±0,705	22,548±1,215	22,878±1,427	<0,001	0,289	0,046
	Female	17,268±0,713	18,548±0,702	22,206±0,644	24,926±2,156			
BS	Male	27,356±0,348	27,018±0,859	34,970±1,872	36,348±0,464	<0,001	0,069	0,027
	Female	24,682±1,447	27,418±0,486	34,164±1,320	36,572±1,684			
OZB	Male	10,754±1,508	10,594±0,602	12,190±1,283	14,404±0,899	<0,001	0,745	0,686
	Female	10,152±0,351	10,666±0,714	12,598±0,867	14,120±1,093			
GBN	Male	7,668±0,566	7,566±0,447	10,128±0,554	11,068±0,546	<0,001	0,649	0,248
	Female	7,516±0,334	8,248±0,713	9,870±0,561	11,118±0,624			
PB	Male	3,668±0,557	3,160±0,608	4,122±0,822	4,726±0,379	0,012	0,002	0,018
	Female	3,528±0,345	3,158±0,464	3,442±0,663	3,244±0,208			
Volume	Male	6592,800±44,617	8778,200±132,942	11475,600±200,965	16495,400±327,086	<0,001	<0,001	<0,001
	Female	6338,200±41,722	7013,400±112,607	10737,800±193,152	14064,600±124,072			
Surface area	Male	4172,800±162,347	4772,000±122,305	6275,200±107,518	11265,200±102,846	<0,001	<0,001	<0,001
	Female	3872,600±75,613	4503,200±24,540	6139,800±162,829	9278,200±149,059			

RESULTS AND DISCUSSION

Morphometric measurements. Volumetric 3D rendered images of the guinea pig head clearly showed various cranial and facial bones of the skull. The mandible is one of the facial bones in the skeleton of lower jaw. The 3D images show the measurement points craniodorsal and ventrally on the skulls (Fig. 1).

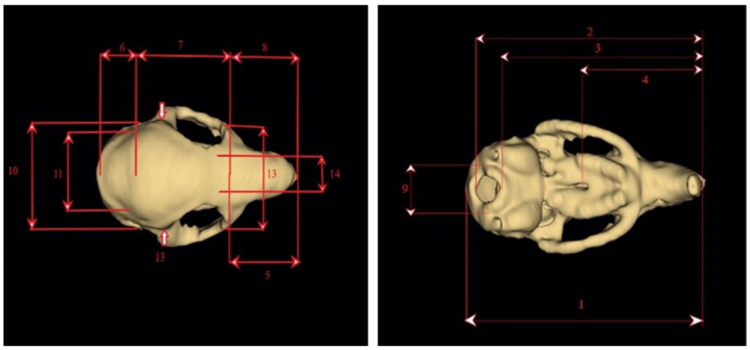

Fig. 1. Measurement points of the skull in Guinea pig (craniodorsal and ventral view).

TL, BL, CBL, DL, GLN, VL, GNB and BS measurement points were statistically significant in terms of group change according to group and sex (p<0.05) (Table III). When considering all measurement points for these variables, the average change increased from the first group to the fourth group in both males and females. Especially the increased from group 2 to group 3 was the highest at all measurement points.

Group change was quite significant for the PL and FL variables (p<0.001). The increase was developmentally significant in these two measurement points. Finally, the PB variable was significant according to the group, sex, and the change in the sex (p<0.05).

Male guinea pigs had a higher measurement value than female guinea pigs and body development increased with age. However, the measurement points of the females were higher in the third and fourth groups in TL, the third group in BL, the fourth group in CBL and DL, the third and fourth groups in GLN, the second and third groups in PL, the second group in VL, the second and fourth groups in GNB, and the second group in GBN when compared to the measurement points of the males. Sex change did not show a statistically significant difference for all measurement points (p>0.05).

It was observed that there was a gradual increase in the skull volume and surface area measurements from the first group to the fourth group in both males and females; however, males had higher values than females in all 4 groups. In volume and surface area, p value between groups, p value between sexes and p value between group and sex were statistically significant in all groups (p<0.001). These data were highest in the 4th group during and after the developmental period.

Table III. Descriptive statistics and p values of the guinea pig group according to mandible measurement points.

Metric measurements	Sex	Group 1 (mean ±SD) (mm)	Group 2 (mean± SD) (mm)	Group 3 (mean± SD) (mm)	Group 4 (mean± SD) (mm)	p value for group	p value for gender	p value for group*sex
LA	Male	33,760±1,354	37,608±1,198	48,944±1,340	47,764±0,528	<0,001	0,230	0,412
	Female	34,072±1,300	36,282±1,167	48,896±0,693	47,034±1,364			
LCR	Male	10,334±0,388	11,296±0,323	14,614±0,600	13,996±0,898	<0,001	0,008	0,440
	Female	10,282±0,404	11,796±0,236	14,624±0,299	14,674±0,223			
L	Male	18,638±0,735	21,466±0,826	27,794±1,003	29,792±0,983	<0,001	0,750	0,001
	Female	19,634±0,772	20,788±1,026	29,072±0,826	27,812±1,270			
LD	Male	8,524±0,631	10,816±0,596	13,190±0,854	13,362±0,998	<0,001	0,452	0,090
	Female	9,076±0,760	10,714±0,652	14,098±0,316	12,696±0,740			
HVR	Male	11,248±0,953	12,756±0,946	19,060±1,241	19,330±0,839	<0,001	0,042	0,844
	Female	11,666±1,397	13,734±0,850	20,074±1,169	19,710±0,782			
Volume	Male	2174,600±100,793	2321,600±69,859	4712,000±61,502	5191,000±28,810	<0,001	<0,001	0,012
	Female	2027,600±35,865	2090,800±10,330	4491,200±18,308	4874,000±33,053			
Surface area	Male	1952,000±63,659	2018,600±4,930	3556,000±17,664	4159,800±49,641	<0,001	<0,001	<0,001
	Female	1760,270±79,207	1915,800±9,706	3144,200±28,048	3717,600±78,859			

In the present study, the 3D images show the measurement points on the mandible (Fig. 2). It was observed that there was a gradual increase in mandibular volume and surface area measurements from the first group to the fourth group in both males and females, but higher values were observed in males compared to females (Table IV).

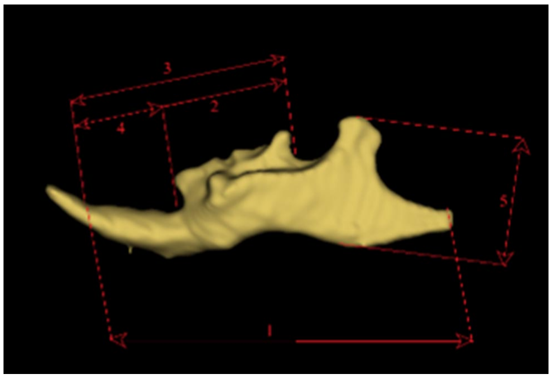

Fig. 2. Measurement points of the mandible in Guinea pig (*Cavia porcellus*).

Table IV shows descriptive statistics and p values of the guinea pig group according to the mandibular measurement points. Accordingly, the group change for LA, LCR, L, LD and HVR measurement points statistically significantly increased (p<0.001). Moreover, sex change was also statistically significant for LCR and HVR measurement points. In these two measurement points, the mean values of male subjects were higher than the values of female subjects.

In the measurements of the volume and surface area of the mandible, the p-value between the groups, the p-value between sexes, and the p-value between the groups and sexes were statistically significant in all groups (p<0.001). The data were highest in the fourth group.

XRF Measurements. For Si, P, K, Ca, Ni, Zn, Sr, and Ca/P variables, p value between the groups, p value between sexes and p value between the group and sex were statistically significant in all groups.

For Al and Cl variables, the p value between sexes and the p value between the group and sex were statistically significant in all groups (p<0.001).

Table IV. Guinea pig skull mean % element concentration.

Elements	Sex	Group 1 (mean± SD) (%)	Group 2 (mean± SD) (%)	Group 3 (mean± SD) (%)	Group 4 (mean± SD) (%)	p value for group	p value for sex	p value for group *sex
Mg	Male	0,159±0,224	0,047±0,002	0,035±0,002	0,091±0,001	0,735	0,240	0,313
	Female	0,088±0,002	0,068±0,002	0,088±0,002	0,054±0,002			
Al	Male	0,000±0,000	0,007±0,002	0,000±0,000	0,000±0,000	0,007	<0,001	<0,001
	Female	0,004±0,002	0,000±0,000	0,000±0,000	0,000±0,000			
Si	Male	0,024±0,002	0,021±0,001	0,016±0,001	0,025±0,002	<0,001	<0,001	<0,001
	Female	0,065±0,002	0,014±0,002	0,015±0,002	0,016±0,002			
P	Male	7,051±0,001	8,717±0,002	10,862±0,005	10,175±0,001	<0,001	<0,001	<0,001
	Female	7,188±0,002	7,335±0,001	9,301±0,002	10,006±0,002			
Cl	Male	0,076±0,002	0,093±0,002	0,107±0,002	0,111±0,002	0,089	<0,001	<0,001
	Female	0,075±0,002	0,089±0,002	0,114±0,002	0,106±0,001			
K	Male	0,315±0,002	0,397±0,002	0,306±0,002	0,419±0,001	<0,001	<0,001	<0,001
	Female	0,275±0,002	0,336±0,002	0,313±0,002	0,382±0,002			
Ca	Male	24,164±0,002	27,387±0,003	33,497±0,002	32,264±0,002	<0,001	<0,001	<0,001
	Female	23,925±0,002	24,760±0,002	29,815±0,002	31,350±0,002			
Fe	Male	0,054±0,002	0,092±0,002	0,054±0,002	0,057±0,003	0,144	0,535	0,388
	Female	0,070±0,002	0,054±0,001	0,047±0,002	0,040±0,002			
Ni	Male	0,000±0,000	0,012±0,002	0,000±0,000	0,015±0,002	<0,001	<0,001	<0,001
	Female	0,012±0,002	0,009±0,002	0,008±0,002	0,011±0,001			
Zn	Male	1,317±0,002	0,886±0,004	0,228±0,002	0,357±0,002	<0,001	<0,001	<0,001
	Female	1,214±0,002	0,334±0,002	0,163±0,002	0,042±0,002			
Sr	Male	0,062±0,002	0,057±0,002	0,057±0,002	0,045±0,002	<0,001	<0,001	<0,001
	Female	0,056±0,002	0,051±0,002	0,044±0,002	0,043±0,002			
Ca/P	Male	3,428±0,002	3,143±0,002	3,085±0,002	3,172±0,002	<0,001	<0,001	<0,001
	Female	3,375±0,002	3,329±0,001	3,208±0,002	3,135±0,002			

While Ca and P concentrations increased in males until the third group, there was a partial decrease in the fourth group and there was a gradual increase in females from the first group to the fourth group. The highest Ca/P ratio in both sexes was seen in the first group and gradually decreased until the fourth group in females and until the third group in males.

As an exotic animal, the guinea pig is an animal model used in many experimental studies in the field of health (Yavru &Yavru, 2000). CT and 3D modeling are currently used to diagnose and treat many diseases (Eken & Gezici, 2002; Perez de Freitas *et al*., 2011; Kim *et al*., 2012). Head region is important in animals. Radiographic imaging is used as a diagnostic tool in a distressed situation (Thrall, 2018). However, due to its complex anatomy, it is difficult for the physician to diagnose skull lesions through conventional radiography (Forrest, 2018). Therefore, many researchers use CT as it provides good detail and contrast (Thrall & Robertson, 2015).

In addition, CT is the imaging modality of choice to evaluate lesions of nose, paranasal sinuses, periorbital region, middle ear, and brain (Stickle & Hathcock, 1993). The 3D reconstruction of CT images has an advantage over the traditional CT cross-section view as it allows one to visualize the 3D orientation of the head region. 3D modeling can be used to detail the skull and as an anatomical reference for anatomical and clinical CT imaging studies of this region (Arencibia & Jáber, 2014).

The studies (Miller & German, 1999; Kara, 2002) reported that measurements of male rates were higher than female ones in morphometric measurements of male and female rat bones in both control and experimental groups. In the present study, it was observed that the cranium measurement points were compatible with the values reported in the studies, but the mandible measurement points were higher in females in all the groups.

In their study, Anbuhl *et al*. (2017), examined the morphological development of the skull from birth to adulthood in 63 guinea pigs (*Cavia porcellus*) and stated that the skull enlarged significantly in the first 8 weeks of their life. In the present study, it was observed that total skull length increased gradually from the first group to the fourth group.

Cox & Jeffery (2011) reported total skull measurements of adult squirrels, guinea pigs, and rats as 48.22 mm, 57.51 mm, and 43.40 mm, respectively. In the third group, to which adult guinea pigs were assigned, the total skull measurement was 62.564±3.259 mm in males and 63.072±1.433 mm in females.

Studies have indicated that many elements in the same bone show significant differences between species (Nganvongpanit *et al*., 2015; Buddhachat *et al*., 2016). The elemental content of mineralized tissues can be useful for species differentiation and/or forensic classification and biological protection.

In addition, numerous studies have revealed the differences in the effect of age factor on bone mineral level (Ioannidou, 2003; Maciejewska *et al*., 2014). Accordingly, it is possible to evaluate both the change in the element content of the same bone in different species and the change (developmental and sex) in the elemental content of the same species by using the XRF technique. In this study, the differences in both developmental and inter-sex element contents of guinea pigs were evaluated.

Maciejewska *et al*. (2014), also reported that Zn, Sr, and Fe elements were high in newborn rats and decreased with age. In the present study, it was observed that while Zn and Sr elements were high in the first group, they decreased towards the fourth group. The Fe element was the highest in the second group in males and in the first group in females. There was no proportional increase or decrease.

The Ca/P ratio in bones is an important parameter for osteoporosis (Fountos *et al*., 1999). Nganvongpanit *et al*. (2016a), found the highest Ca/P ratio in the dog bone, 4.09 in the patella bone, and 2.22 in the lowest left carpus bone. The mean percentage concentration of Ca/P ratio was 2.21 in humans (Tzaphlidou & Zaichick, 2003), 2.17 in pigs (Dickerson, 1962), 1.69 in cattle (Legros *et al*., 1987), 1.28 in rabbits, and 2.12 in rats (Tzaphlidou *et al*., 2005). Legros *et al*. (1987), also reported that the Ca/P ratio was lower in young rats, increased with increasing age, and was 1.51 at birth, 1.60 at 30 days of age, and 1.65 at one year of age. However, in the present study, it was observed that the Ca/P ratio of guinea pigs varied between 3.085 and 3.428 during the development period. In the present study, the Ca/P ratio was higher in young people as reported by Legros *et al*. (1987). However, the fact that the values were higher than the reported ones may be due to the differences in the measurement technique.

CONCLUSIONS

In conclusion bones are a fascinating area of anatomy to study. Bones have to adapt to changing body weights and activities during and after developmental periods.

Consequently, 3D modelling, metric measurements, volume and surface area measurements of the skull bone were created in guinea pigs for prepuberty, puberty-adulthood, young adulthood and old adulthood periods and the effect of mineral structure change and sex on this change during and after developmental period was investigated. This study is the first attempt to evaluate both metric and mineral changes in guinea pigs during four developmental stages. We believe that data of the study will be a valuable reference in future studies on age-related structural change of skull bone.

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Ethical statement. In this study, 20 female and 20 male guinea pig skulls obtained from the T.R Ministry of Agriculture and Forestry Elazig Veterinary Control Institute were used and the related permission was obtained from the Fırat University, Local Ethics Committee for Animal Experiments (dated 26.11.2021 and numbered 5271).

BAYGELDI, S. B.; YILMAZ, Y.; GÜZEL, B. C.; KANMAZ, Y. A.; KARAN, M.; HARK, B. D. & YILMAZ, S. Análisis e imágenes 3D de cambios morfométricos y de estructura mineral en cráneos de cobayos machos y hembras durante y después del período de desarrollo. *Int. J. Morphol., 42(2)*:530-537, 2024.

RESUMEN: Aunque se han realizado estudios morfométricos y de minerales relacionados con el cráneo del cobayo (*Cavia porcellus*), esta investigación es el primer intento de evaluar las etapas de desarrollo de cobayos machos y hembras. El objetivo de este estudio fue crear un modelado 3D de imágenes de tomografía computarizada obtenidas de los cráneos de cobayos machos y hembras durante el período de desarrollo (prepubertad y el período entre la pubertad y la edad adulta) y los períodos siguientes (edad adulta joven y edad adulta mayor), para analizar algunos datos biométricos de los huesos, como el volumen, la superficie y la longitud, y además, analizar el cambio de materia mineral en sus cráneos durante el desarrollo. Los cráneos escaneados se transfirieron a 3D Slicer (5.0.2), que se utiliza para el modelado 3D. El área de superficie y el volumen se calcularon midiendo los puntos de medición en los modelos. Además, se utilizó el dispositivo XRF para mostrar los cambios en las proporciones elementales durante diferentes etapas de desarrollo. Según mediciones métricas, se observó un aumento gradual durante el período de vida. Las medidas métricas del hueso del cráneo tuvieron un valor de medición más alto en los cobayos machos que en las hembras. Mientras que la relación Ca/P aumentó hasta el tercer grupo y disminuyó parcialmente en el cuarto grupo en los machos y aumentó gradualmente del primer grupo al cuarto grupo en las hembras. Este estudio reveló que la pubertad, la edad adulta y el sexo fueron efectivos en la caracterización física y química de la estructura ósea del cráneo en cobayos.

PALABRAS CLAVE: Cráneo; Conejillo de Indias; *Cavia porcellus*; 3D; Morfometría; XRF.

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