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Examination of the morphometric features and three-dimensional modelling of the skull in Van cats by using computed tomographic images

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Abstract: This study was conducted to make the three-dimensional modelling of the skull in Van cats by using computed tomographic images and to determine the morphometric features between sexes. The skulls of 16 adult Van cats were used in the study. The skulls of the anesthetized animals were scanned by using a Computed Tomography (CT) device and their images were obtained. These images were converted to a three-dimensional structure using MIMICS 20.1 software and their morphometric measurements were calculated. It was determined in the study that total length of the skull (TLS), facial length (FCL), upper neurocranium length (UNCL), greatest length of the nasal (GLN), maximum zygomatic width (MZW), condylobasal length (CBL), basal length (BL), median palatal length (MPL), palatal length (PL), least palatal breadth (LPB), length of the cheek tooth row (LCR), greatest inner height of the orbit (GIHO), skull height (SH), and volumetric measurement values were statistically significantly higher in the male cats; whereas, breadth dorsal to the external auditory meatus (BEAM) and neurocranium length (NL) measurement values were statistically significantly higher in the female cats ($P<0.05$). In conclusion, the statistical differences between the sexes in terms of biometric values of skull of Van cats were determined. Present study would be beneficial to veterinary physicians in the surgical and clinical practice fields and to the studies in the field of zooarchaeology as well as being guiding for determining the typology of Van cats among the cat species and its differences from other species.
Keywords: Computed tomography, morphometry, skull, three-dimensional modelling, Van cat.

Van kedilerinde kafatasının bilgisayarlı tomografi görüntüleri kullanılarak üç boyutlu modellenmesi ve morfometrik özelliklerinin incelenmesi

Özet: Bu çalışma, Van kedilerinde kafatasının bilgisayarlı tomografi görüntüleri kullanılarak üç boyutlu modellemesini yapmak ve cinsiyetler arasındaki morfometrik özelliklerini belirlemek amacıyla yapıldı. Çalışmada 16 adet erişkin Van kedisi kafatası kullanıldı. Anestezi altındaki hayvanların kafatasları Bilgisayarlı Tomografi (BT) cihazı ile taranarak görüntüleri elde edildi. Bu görüntüler MIMICS 20.1 programı aracılığıyla üç boyutlu yapıya dönüştürüldü ve morfometrik ölçümleri hesaplandı. Çalışmada kafatasının total uzunluğu (TLS), facial uzunluk (FCL), üst neurocranium uzunluğu (UNCL), en büyük nasal uzunluk (GLN), maksimum zygomatic genişlik (MZW), condylobasal uzunluk (CBL), basal uzunluk (BL), median palatal uzunluk (MPL), palatal uzunluk (PL), en küçük palatal genişlik (LPB), yanak diş sırasının uzunluğu (LCR), orbita'nın en büyük iç yüksekliği (GIHO), kafatası yüksekliği (SH) ve volüm ölçüm değerlerinin erkek kedilerde; meatus acusticus externus'un dorsal genişliği (BEAM) ve neurocranium uzunluğu (NL) ölçüm değerlerinin ise dişi kedilerde istatistik olarak önemli düzeyde daha yüksek olduğu saptandı ($P<0.05$). Sonuç olarak, Van kedilerinde kafatasının biyometrik değerlerinin istatistiksel olarak cinsiyetler arasındaki farklılıkları tespit edildi. Sunulan çalışmanın, Van kedilerinin kedi türleri arasındaki tipolojisinin belirlenmesinde ve diğer türler arasındaki farklılıklarının tespit edilmesine rehberlik etmesinin yanında, cerrahi ve klinik uygulama alanlarında veteriner hekimlere ve zooarkeoloji alanındaki çalışmalara faydalı olabileceği düşünülmektedir.
Anahtar sözcükler: Bilgisayarlı tomografi, kafatası, morfometri, üç boyutlu modelleme, Van kedisi.

Introduction

Van cats are an endemic cat species that live around the city of Van in eastern Turkey and named after here. In recent years, these cats have attracted attention due to their unique physical properties both in Turkey and throughout the world. Having a special place among worldwide cat species, these cats are known for their different eye colors (their eyes may be amber or blue or they may have heterochromia), moderately long straight nose, round face, pointed ear, triangular-shaped head, superior learning ability, and intelligence (3, 16, 47).

Skull is a strong structure composed of many bones which are paired, but some of them which are median-located and single. This structure includes the sense organs such as sight, olfactory, balance, and taste as well as upper respiratory and digestive tracts together with the brain. Cranial bones are joined with each other through sutures and with mandibulae and apparatus hyoideus through joints (12). The morphometric and morphological studies conducted on the skull not only reflect the effects of the genetic and environmental factors (such as genetic and ecophenotypic variations in general) on individual development but also underlie the clinical and surgical applications related to the region (43). Also, the morphometric measurement values of skull may show many individual differences among species and including breed, age, and the structure specific to the animal (5).

Significant changes have taken place in anatomy education by means of the technological developments in medical imaging and computer-aided learning fields, various software developed, and three-dimensional modelling (2). Especially in small pets such as cats, the computed tomography and three-dimensional modelling programs are used as a standard imaging method in the imaging of skull and the anatomic structures around it and monitoring the changes in these structures (14, 17). Also, skull and various extracranial and intracranial pathological structures around it may be determined and the effectiveness of treatment may be evaluated using these imaging methods and three-dimensional modelling software (17, 44). In addition, these imaging methods are commonly used in anthropological studies such as determining the osteometric features of the crania obtained in the excavation works conducted in various regions and obtaining their measurement values (32, 33).

The measurements obtained from the skull using computed tomography (CT) and three-dimensional modelling software may be mostly used in revealing the biometric differences between sexes (34). For this purpose, many studies have been conducted in veterinary medicine (7, 23, 37). No study was found on the skull of Van cats in the literature reviews.

This study was conducted to perform the three-dimensional modelling of the skull in Van cats by using computed tomography, display their anatomic structures, obtain their morphometric measurement values, and reveal the biometric differences of these measurement values between sexes.

Material and Methods

Animal materials: In the study, a total of 16 adult Van cats (8 males and 8 females) which had a weight of 4810 - 7050 gram, were aged between 3 and 8 years, were procured from Van Yüzüncü Yıl University Van Cat Research and Application Center. Drinking water and standard cat food were given ad libitum to the Van cats until one day before the study. This study was approved by Van Yüzüncü Yıl University Animal Experiments Local Ethics Committee (Decision no: 2020/02 and Date: 27. 02. 2020).

Anesthesia: The Van cats included in the study were numbered and they were not given any food one day before the study. On the day of examination, the combination of Ketamine (15 mg/kg, IM, Ketasol® 10% injectable, İnterhas Veterinary Drugs, Ankara) and Xylazine (1-2 mg/kg, IM, Alfazyne® 2% injectable, Ege-Vet Veterinary Drugs, İzmir) was used for the anesthesia of the cats.

Computed tomography imaging: The 16-slice computed tomography (CT) device (Somatom Sensation 16; Siemens Medical Solutions, Erlangen, Germany) available in Van Yüzüncü Yıl University Faculty of Medicine Radiology Department was used for the Computed Tomography (CT) examinations of the cats. The cats under anesthesia were positioned symmetrically in a prone head-first position on a "disposable" cover spread in the gantry of the machine. During scan, the CT device parameters were determined as KV / Effective mAs / Rotation time (sec) values 120 / 120 / 0.75; gantry rotation period 420 ms; physical detector collimation, 16 × 0.6 mm; section thickness, 0.5 mm; final section collimation 32 × 0.63 mm; feed/rotation, 6 mm; Kernel, U90u; increment 0.5 mm; and resolution 512 × 512 pixels. Dosage parameters and scanning were performed in accordance with standard protocols found in published literature (11, 31). The images obtained were recorded in DICOM format.

Three-dimensional modelling of the images and performing their measurements: Then, the modelling of these images was performed by transferring them to MIMICS 20.1 (The Materialise Group, Leuven, Belgium), a three-dimensional modelling software. Osteometric measurements were taken for 34 different parameters on the skulls whose three-dimensional modelling was performed. The morphometric measurements were taken based on the measurement points specified in the literature (4, 20, 21, 25, 42). After completing the morphometric measurements, the surface area and volumetric values of the remaining part of the skull other than mandibulae were calculated. Nine different indices were calculated using osteometric measurements. While Table 1 shows the linear measurement points obtained from the dorsal, lateral, and ventral surfaces of the skull, Table 2 shows the formula of the indices calculated by using these measurement points. Nomina Anatomica Veterinaria was used as terminology in the study (15). Also, a digital scale (TESS®, RP - LCD, Çomak Terazi, İstanbul) was used for the weight measurements of the cats used in the study.

Table 1. Studied cranial parameters (mm).

Parameter	Abbreviation	Definition
1	TLS	Total length of the skull: the distance between akrokranion-prosthion
2	FCL	Facial length: frontal midpoint-prosthion
3	UNCL	Upper neurocranium length: akrokranion-frontal midpoint
4	CL	Cranial length: akrokranion-nasion
5	VL	Viscerocranial length: nasion-prosthion
6	GLN	Greatest length of the nasals: nasion-rhinion
7	LBO	Least breadth between the orbits: entorbitale-entorbitale
8	GFB	Greatest frontal breadth: ectorbitale-ectorbitale
9	LBS	Least breadth of skull: breadth at the postorbital constriction
10	MWN	Maximum width of neurocranium: euryon-euryon
11	MZW	Maximum zygomatic width: zygion-zygion
12	CBL	Condylobasal length: caudal border of occipital condyles-prosthion
13	BL	Basal length: basion-prosthion
14	MPL	Median palatal length: staphylion-prosthion
15	LHP	Length of the horizontal part of the palatine: staphylion-palatinoorale
16	LHP-1	Length of the horizontal part of the palatine-1: the median point of intersection of the line joining the deepest indentations of the choana-palatinoorale
17	PL	Palatal length: the median point of intersection of the line joining the deepest indentations of the choana-prosthion
18	GBP	Greatest breadth of the palate: maximum width of the distal ends of the alveolus of upper P3
19	LPB	Least palatal breadth
20	BCA	Breadth at the canine alveoli
21	LPR	Length of the premolar row
22	LMR	Length of the molar row
23	LCR	Length of the cheektooth row
24	GDAB	Greatest diameter of the auditory bulla: from the most aboral point of the bulla on the suture with the jugular processes up to the external carotid foramen
25	BEAM	Breadth dorsal to the external auditory meatus: breadth between external auditory porus
26	GIHO	Greatest inner height of the orbit
27	NL	Neurocranium length: basion-nasion
28	SH	Skull height: basion-external occipital crest
29	HOT	Height of the occipital triangle: akrokranion-basion
30	HFM	Height of the foramen magnum: basion-opisthion
31	GWFM	Greates breadth of the foramen magnum
32	GBOC	Greatest breadth of the occipital condyles
33	GBJP	Greatest breadth of the bases of the jugular processes
34	GMB	Greatest mastoid breadth: otion-otion

Table 2. Indices and formulas of the skulls.

Studied indexes	Formulas
Skull index	Greatest frontal breadth (var.8) / total length of the skull (var. 1) x 100.
Cranial index	Maximum width of neurocranium (var. 10) / Cranial length (var. 4) x 100.
For. magnum index	Height of the for. magnum (var. 30) / greatest breadth of the for. magnum (var. 31) x 100.
Facial index-1	Maximum zygomatic width (var. 11) / Viscerocranial length (var. 5) x 100.
Facial index-2	Greatest breadth of the palate (var. 18) / greatest length of the nasals (var. 6) x 100.
Basal indeks-1	Maximum width of neurocranium (var. 10) / basal length (var. 13) x 100.
Basal indeks-2	Maximum zygomatic width (var. 11) / basal length (var. 13) x 100.
Palatal index-1	Greatest breadth of the palate (var. 18) / median palatal length (var. 14) x 100.
Palatal index-2	Greatest breadth of the palate (var. 18) / palatal length (var. 17) x 100.

Statistical analysis: Shapiro-Wilk test (n<50) was used to determine whether the measurement mean values were normally distributed in this study conducted to obtain the three-dimensional modelling of the skull in Van cats using computed tomographic images and examine its morphometric features. Nonparametric tests were applied as the measurement values of the variables did not generally have a normal distribution. The descriptive statistics for the measurement values in the present study were represented as mean, standard deviation, minimum and maximum. Mann-Whitney U test was used for the comparisons between sexes based on the measurements. Spearman's correlation coefficients were used in determining the correlation between the measurements, separately for each sex. The statistical significance level (α) was taken as 5% in the calculations and SPSS (IBM SPSS for Windows, Ver. 23) statistical software was used for the calculations.

Results

In the present study, 34 parameters of the skull were measured (Figure 1, 2, 3, and 4). The statistical analysis was performed to determine the group averages of the morphometric measurement values in the males and females in terms of the continuous variables and the differences between sexes. Upon the examination of the statistical results, statistically significant differences were determined between the measurement values of skull (P<0.05). Tables 3 - 5 show the measurement values assessed.

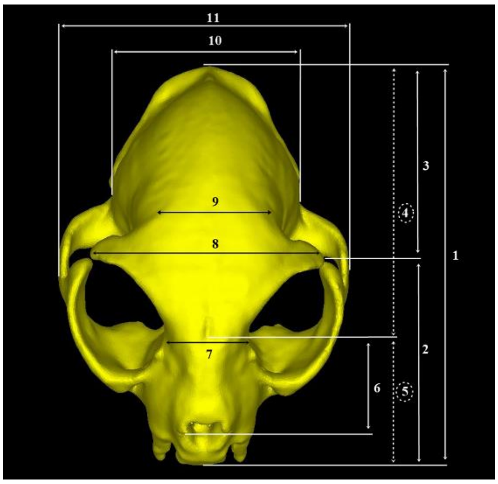

Figure 1. Measurement points of the skull in Van cats (craniodorsal view).

1- TLS: Total length of the skull; 2- FCL: Facial length; 3- UNCL: Upper neurocranium length; 4- CL: Cranial length; 5- VL: Viscerocranial length; 6- GLN: Greatest length of the nasals; 7- LBO: Least breadth between the orbits; 8- GFB: Greatest frontal breadth; 9- LBS: Least breadth of skull; 10- MWN: Maximum width of neurocranium; 11- MZW: Maximum zygomatic width**.**

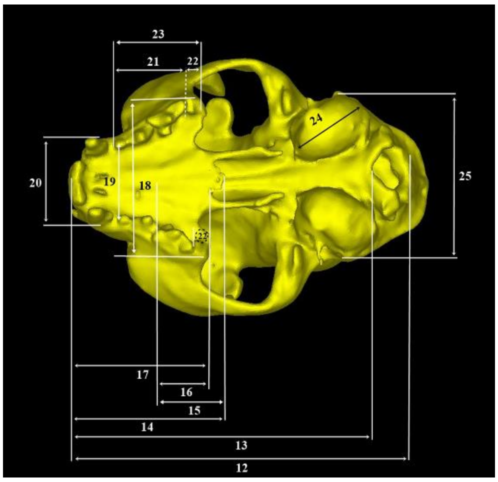

Figure 2. Measurement points of the skull in Van cats (ventral view).

12- CBL: Condylobasal length; 13- BL: Basal length; 14- MPL: Median palatal length; 15- LHP: Length of the horizontal part of the palatine; 16- LHP - 1: Length of the horizontal part of the palatine - 1; 17- PL: Palatal length; 18- GBP: Greatest breadth of the palate; 19- LPB: Least palatal breadth; 20- BCA: Breadth at the canine alveoli; 21- LPR: Length of the premolar row; 22- LMR: Length of the molar row; 23- LCR: Length of the cheektooth row; 24- GDAB: Greatest diameter of the auditory bulla; 25- BEAM: Breadth dorsal to the external auditory meatus.

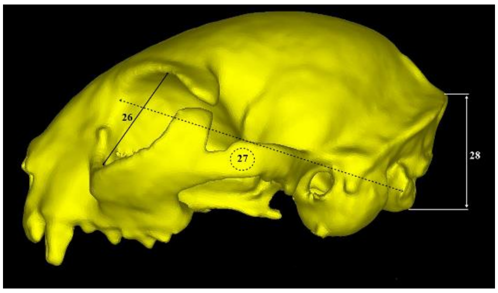

Figure 3. Measurement points of the skull in Van cats (lateral view).

26- GIHO: Greatest inner height of the orbit; 27- NL: Neurocranium length; 28- SH: Skull height.

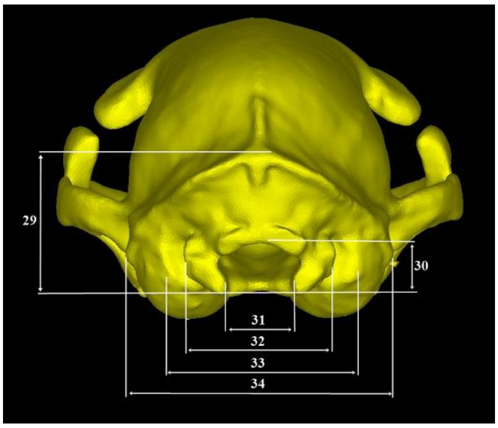

Figure 4. Measurement points of the skull in Van cats (caudal view).

29- HOT: Height of the occipital triangle; 30- HFM: Height of the foramen magnum; 31- GWFM: Greatest breadth of the foramen magnum; 32- GBOC: Greatest breadth of the occipital condyles; 33- GBJP: Greatest breadth of the bases of the jugular processes; 34- GMB: Greatest mastoid breadth.

Table 3. Descriptive statistics of the measurements of the skull according to gender.

	MALE			FEMALE			
Parameter	**Mean±S.E.**	**Min.**	**Max.**	**Mean±S.E.**	**Min.**	**Max.**	***P**
Age(A)	5.00±2.00	3.00	8.00	5.00±2.00	3.00	8.00	1.00
Weight(W) kg	6.08±0.70	5.30	7.05	5.28±0.28	4.81	5.63	0.027
TLS	96.16±6.38	89.38	108.44	87.38±2.71	83.93	93.08	0.002
FCL	52.14±2.99	49.08	58.85	48.91±2.77	43.27	52.23	0.036
UNCL	56.41±2.93	53.95	61.53	51.32±1.93	48.49	53.37	0.001
CL	73.32±3.05	68.79	78.17	72.12±2.76	67.80	74.83	0.600
VL	26.38±1.67	23.78	28.72	24.79±2.39	22.10	29.62	0.074
GLN	20.37±2.11	18.43	24.95	17.77±1.14	15.54	19.33	0.003
LBO	21.82±1.08	20.44	23.40	20.16±2.02	16.90	23.07	0.074
GFB	49.48±2.41	46.08	52.62	48.28±2.34	45.85	51.85	0.248
LBS	32.04±1.62	30.00	34.97	32.37±1.04	30.95	34.07	0.599
MWN	41.87±1.44	40.19	45.01	46.37±10.39	38.99	64.56	0.834
MZW	66.64±3.66	62.50	72.24	56.11±8.81	41.38	62.33	0.001
CBL	86.42±4.55	78.52	93.39	80.83±4.64	71.16	86.74	0.027
BL	79.86±4.34	73.43	87.36	73.96±2.99	69.53	79.08	0.012
MPL	37.39±1.54	34.63	39.70	34.37±2.13	32.20	38.44	0.015
LHP	15.78±2.76	12.95	21.08	14.50±0.96	13.33	16.34	0.462
LHP-1	13.65±2.33	11.11	17.06	13.35±1.27	12.14	16.11	0.916
PL	34.63±2.32	30.21	37.95	32.83±2.06	30.17	37.09	0.046
GBP	37.78±2.28	34.89	41.56	37.33±2.44	34.42	41.88	0.636
LPB	22.96±1.00	21.93	24.68	21.64±.90	20.19	23.37	0.009
BCA	22.17±1.67	20.08	25.09	21.49±1.56	18.94	23.87	0.753
LPR	16.46±1.13	14.34	17.78	15.46±1.12	13.86	17.21	0.083
LMR	7.83±0.89	6.77	9.31	8.62±0.97	7.34	9.64	0.115
LCR	23.52±1.10	22.12	25.26	21.49±1.72	18.77	23.77	0.016
GDAB	18.85±1.48	17.61	21.05	18.60±0.87	17.06	19.85	0.916
BEAM	33.36±2.45	29.85	36.37	37.35±1.26	34.97	38.71	0.002
GIHO	25.67±0.50	24.79	26.22	24.47±1.12	23.17	26.38	0.027
NL	61.36±2.52	58.44	64.43	64.34±3.72	59.22	71.23	0.046
SH	29.72±2.68	25.65	32.99	24.25±1.76	21.74	27.02	0.002
HOT	26.04±0.73	25.01	27.10	25.27±1.08	22.88	26.28	0.115
HFM	11.47±1.09	10.25	13.09	12.38±0.59	11.54	13.57	0.126
GWM	13.69±0.75	12.85	14.88	13.49±0.79	12.43	14.67	0.640
GBOC	20.87±1.19	19.40	22.42	21.08±1.18	19.26	22.67	0.605
GBJP	28.00±1.82	25.69	30.78	28.13±2.00	25.39	31.57	0.916
GMB	41.39±1.66	38.73	43.21	40.21±1.06	38.25	41.72	0.093
Volume(cm^3)	28.44±4.36	25.28	35.56	22.96±2.03	19.96	26.20	0.003
Area (cm^2)	329.41±26.07	290.04	375.02	303.80±37.49	226.30	354.75	0.172

*P<0.05; Mann whitney U test; S.E.: Standard error of mean.

Table 4. Correlation between skull measurements according to gender.

		MALE		FEMALE	
Parameter		**A**	**W**	**A**	**W**
W	r	0.957**		0.390	
TLS	r	0.781*	0.814*	-0.195	0.667
FCL	r	0.537	0.611	0.000	0.738*
UNCL	r	0.732*	0.707	-0.123	0.240
CL	r	0.927**	0.946**	0.000	0.262
VL	r	0.146	0.096	0.245	0.024
GLN	r	0.878**	0.898**	0.049	0.310
LBO	r	0.732*	0.635	0.439	0.262
GFB	r	0.732*	0.683	0.293	0.119
LBS	r	-0.146	-0.407	0.515	-0.144
MWN	r	0.732*	0.707	-0.098	-0.286
MZW	r	0.586	0.623	0.390	0.619
CBL	r	0.781*	0.886**	-0.146	0.262
BL	r	0.634	0.755*	0.195	0.357
MPL	r	0.293	0.263	0.195	0.381
LHP	r	-0.195	-0.252	-0.244	-0.214
LHP-1	r	-0.293	-0.431	0.439	0.071
PL	r	0.781*	0.766*	0.146	0.500
GBP	r	0.781*	0.826*	0.634	0.286
LPB	r	0.634	0.515	-0.172	-0.707
BCA	r	0.683	0.503	0.098	0.095
LPR	r	0.293	0.419	-0.146	-0.262
LMR	r	-0.390	-0.431	0.098	-0.500
LCR	r	0.146	0.036	-0.244	-0.167
GDAB	r	0.732*	0.659	0.390	0.500
BEAM	r	-0.098	-0.084	-0.244	0.024
GIHO	r	0.390	0.383	0.293	0.238
NL	r	0.830*	0.946**	-0.491	0.311
SH	r	0.488	0.575	-0.098	-0.333
HOT	r	0.927**	0.898**	0.390	0.167
HFM	r	-0.293	-0.419	-0.293	-0.429
GWM	r	-0.049	-0.084	-0.195	-0.143
GBOC	r	0.683	0.671	-0.439	0.190
GBJP	r	0.736*	0.795*	0.146	0.429
GMB	r	0.933**	0.934**	0.342	0.095

**P<0.01; *P<0.05; r: Spearman's rho Nonparametric Correlations Coefficients.

Table 5. Descriptive statistics of the measurements of the craniofacial indices according to gender.

	MALE			FEMALE			
Parameter	**Mean±S.E.**	**Min.**	**Max.**	**Mean±S.E.**	**Min.**	**Max.**	***P**
Skull index	51.62±3.64	43.43	55.91	55.27±2.41	52.73	58.70	0.021
Cranial index	57.14±1.46	55.00	59.28	64.85±17.37	52.97	95.22	0.674
For. magnum index	83.74±5.89	77.67	93.54	91.97±5.48	81.46	99.12	0.016
Facial index-1	253.63±23.00	230.40	291.51	228.39±43.29	155.56	282.04	0.462
Facial index-2	186.17±9.08	166.57	195.77	210.44±13.53	194.35	238.03	0.002
Basal indeks-1	52.50±1.80	50.59	55.47	63.01±15.67	52.87	92.85	0.021
Basal indeks-2	83.53±3.84	76.89	88.91	75.81±11.27	55.63	86.75	0.115
Palatal index-1	101.15±6.84	94.10	112.48	108.76±6.31	97.77	114.93	0.027
Palatal index-2	109.34±7.17	102.47	122.24	113.77±5.02	106.87	122.61	0.115

*P<0.05; Mann whitney U test; S.E.: Standard error of mean.

Table 3 shows the morphometric measurement values of the skull based on sex. Accordingly, it was observed that W, TLS, FCL, UNCL, GLN, MZW, CBL, BL, MPL, PL, LPB, LCR, GIHO, SH, and volumetric measurement values were higher in the male cats compared to the female cats. Furthermore, it was determined that BEAM and NL measurement values were higher in the female cats compared to the male cats. These differences in the male and female Van cats were statistically significant ($P<0.05$).

Table 4 shows the correlation between the morphometric measurement values of the skull in male and female Van cats and their ages and body weights. Accordingly, a positive significant correlation was determined between age and W, TLS, UNCL, CL, GLN, LBO, GFB, MWN, CBL, PL, GBP, GDAB, NL, HOT, GBJP, and GMB measurement values in the male cats ($P<0.05$). Also, a positive significant correlation was found between body weight and TLS, CL, GLN, CBL, BL, PL, GBP, NL, HOT, GBJP, and GMB measurement values ($P<0.05$). In the female cats, a positive significant correlation was observed only between body weight and FCL measurement value ($P<0.05$).

Table 5 illustrates the craniofacial index measurement values obtained from the morphometric measurement value of the skull based on sex. Accordingly, it was determined that the skull index, foramen magnum index, facial index-2, basal index-1, and palatal index-1 measurement values were statistically significantly higher in the female cats compared to the male cats ($P<0.05$).

Discussion and Conclusion

The morphometric measurements of the skull in animals may be used to investigate different species among the animal genera and to determine the morphological variations in a species (46). The shape of the skull is one of the most important criteria used in determining the standard cat breeds. Especially the size and shape of skulls between the domestic and wild cats are significantly compared to the other mammals (36). Also, the skull indices obtained from these cranial measurements are quite effective in distinguishing or identifying morphological types (22). For this reason, various craniometric measurements have been used in the studies in determining the morphological variations between the domestic and wild cat species (6, 7, 14, 30, 35-37). The medical imaging methods such as computed tomography is used commonly in displaying a skull and the related complex anatomic structures especially in the pets such as cat, obtaining craniometric and volumetric measurement values from these images, and assessing the pathological conditions in the region (14, 17). The present study is the first attempt to determine the morphometric and volumetric values of the skull using CT and three-dimensional modelling in adult Van cats and reveal the biometric differences of these values between the males and the females.

In general, it has been determined that the craniometric measurement values are higher mostly in males compared to females in both humans and animals (8, 24, 26, 30, 34, 46). It was also determined that 28 measurement parameters among 37 measurement parameters obtained in Van cats together with the volumetric measurement value and the surface area of the skull were higher in the male cats compared to the female cats, which is compatible with the literature data. These measurement values are present in Table 2. This pointed out that the skull was larger in males compared to females.

It has been reported that the morphometric measurements of the skull or cranium are used for sex determination in most mammal species (40). However, in the morphometric study conducted by Pitakarnnop et al. (30), on 38 dried domestic cat skulls to determine the sexual dimorphism between sexes they determined that there no statistically significant difference in the parameters of the skull measured between males and females. However, the fact that the morphometric measurements of the skull cannot be used in sexual dimorphism although the animals have been adults in the studies has varied based on age and body weight (6, 38). In the present study, it was determined that W, TLS, FCL, UNCL, GLN, MZW, CBL, BL, MPL, PL, LPB, LCR, GIHO, SH, and volumetric measurement values were higher in the male cats compared to the female cats; on the other hand BEAM and NL measurement values were higher in the female cats compared to the male cats. It was observed that these differences in the male and female Van cats were statistically significant ($P<0.05$).

Age and body weight are quite important in the morphometric measurements of the skull. It has been generally reported in the studies that there is mostly a positive correlation between the morphometric measurement parameters of the skull and the age and body weight of the male and female animals (13, 38). In parallel with this information, it was observed in the present study that the measurement parameters of the skull in the males and females had mostly a positive correlation with age and body weight. Among these measurement parameters, it was determined that there was a positive significant correlation between age and W, TLS, UNCL, CL, GLN, LBO, GFB, MWN, CBL, PL, GBP, GDAB, NL, HOT, GBJP, and GMB measurement values and between body weight and TLS, CL, GLN, CBL, BL, PL, GBP, NL, HOT, GBJP, and GMB measurement values in the male cats ($P<0.05$). In the female cats, on the other hand, no significant correlation was found between age and skull measurement parameters and a positive significant correlation was observed only between body weight and FCL measurement value ($P<0.05$).

In their study, Saber et al. (35), grouped the Australian domestic cats as flat-head and round-head skull based on their head types and calculated the cranial, skull, and facial indices from the craniometric measurements and determined that these measurement values were 56.0 ± 4.0, 71.1 ± 4.4, 298.1 ± 34.0 in flat-head skull cats and 66.6 ± 4.9, 71.3 ± 2.4, 279.8 ± 31.9 in round-head skull cats, respectively. In another study conducted by Saber and Gummow (36) on cats, they found these values as 121.24 ± 18.29, 80.79 ± 6.08, and 121.67 ± 19.51, respectively. In Van cats, mean values were calculated as 60.99 ± 9.41 for the cranial index, 53.44 ± 3.02 for the skull index, 241.01 ± 33.14 for the facial index-1, and 198.30 ± 11.30 for the facial index-2. Additionally, no basal index and palatal index measurements have been found in cats in the literature review. In Van cats, mean values were determined as 57.75 ± 1.68 for the basal index-1, 79.67 ± 7.55 for basal index-2, 104.95 ± 6.57 for palatal index-1, and 111.55 ± 6.09 for palatal index-2. Also, it was found in the present study that the skull index, facial index-2, basal index-1, and palatal index-1 measurement values among these measurement indices were statistically significantly higher in the female cats compared to the male cats ($P<0.05$).

In their study, Uddin et al. (41), determined that in domestic cats for. magnum index (average: 90.72 ± 4.93) was 86.98 ± 2.78 in the males and 94.42 ± 3.52 in the females. They found that this difference between male and female cats was statistically significant ($P<0.001$). Also, in parallel with the finding of that study, the results of the present study revealed that for. magnum index (average: 87.85 ± 5.68) was 83.74 ± 5.89 in the male cats and 91.97 ± 5.48 in the female cats and this difference was statistically significant. In addition, for. magnum index has been calculated in many studies on mole rat 88.41 (27), Pekingese dog 93.4 (39), German Shepherd dogs 92.67 - 93.51 (24), Red fox 80.84 - 74.63 (21), rabbit 74.78 (10), African giant rat 81.42 (19), West African dwarf goat 102.5 (18), One-Humped Camel 108.72 (45), Australian domestic cats 128 (35), and gazelles 92.84 (46).

The measurement values of the skull and the anatomic structures around it such as volume and surface area especially in small pets such as dogs and cats can be calculated using CT and various software and the quantitative data of the normal anatomic structure are obtained and the diagnosis and treatment activities of various pathological situations can be assessed (1, 17). In the present study, the CT images of the cats were used and the volume and surface areas of the skull were calculated by using 3D modelling software. It was determined that the volume of the skull was determined to be 22.96 ± 2.03 cm^3 in females and 28.44 ± 4.36 cm^3 in males. Its surface area was 303.80 ± 37.49 cm^2 in females and 329.41 ± 26.07 cm^2 in males. In addition, Piechocki (29) reported that the cranial volumes were 32.5 - 50 cm^3 in the wild cats and were 20 - 25 cm^3 in domestic cats. Also, Saber et al. (35) determined in their study that the cranial volume value was 30 ± 5.2 cm^3 in the flat-headed skull cats and 25.2 ± 3.8 cm^3 in the round-head skull cats. Thus, it can be asserted that Van cats are generally domestic and more likely to have a round-head skull.

The images of the relevant anatomic structure of animals can be obtained with a desired thickness, without giving any physical harm under anesthesia by using the computed tomography and the three-dimensional modelling software and the morphometric and volumetric measurements of these anatomic structures can be calculated easily and quickly (2, 17). Due to these properties, computed tomography imaging and three-dimensional modelling software are increasingly and commonly used in the field of veterinary anatomy in recent times together with computer-aided technological developments (9, 28, 47).

Consequently, the statistical differences in biometric values of the skull between male and female Van cats were determined using CT and three-dimensional modelling software. The recent technological developments in the field of medical imaging methods have provided opportunities to obtain broader and comprehensive data on cranial morphometry. It is thought that the results of this study may be used as a guide in the assessment of the CT images of Van cats with various extracranial and intracranial pathological disorders related to the skull and they may be used in determining the taxonomic classification of Van cats among the cat species and sex determination. Also, we think that the present study would be beneficial to veterinary physicians in the surgical and clinical practice fields, primarily the anatomy education related to skull of Van cats and to the studies in the field of zooarchaeology.

Ethical Statement

This study was approved by Van Yüzüncü Yıl University Animal Experiments Local Ethics Committee (Decision no: 2020/02 and Date: 27.02.2020).

Conflict of Interest

The authors declared that there is no conflict of interest.

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