Pakistan Veterinary Journal

ISSN: 0253-8318 (PRINT), 2074-7764 (ONLINE)
DOI: 10.29261/pakvetj/2024.238

RESEARCH ARTICLE

Computed Tomography-Based Evaluation of Skull Measurements and Eye Biometrics in Brachycephalic vs. Non-Brachycephalic Cats

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ARTICLE HISTORY (24-414)

Received:	July 20, 2024
Revised:	August 15, 2024
Accepted:	August19, 2024
Published online:	August 27, 2024

Key words:
Cranium
Orbita
Ocular
Feline
Shorthair Brachycephaly

ABSTRACT

Brachycephaly in cats, characterized by shortened facial and skull length and a rounder head due to inherited defects in skull bone development, can lead to respiratory and ocular problems, particularly in popular breeds like Exotic Shorthair, British Shorthair, Persian and Scottish Fold. Eye diseases in cats and dogs can result from various factors, including infectious agents, metabolic disorders, physical trauma and breed-specific congenital abnormalities, with brachycephalic cats being particularly prone to chronic corneal diseases and glaucoma due to their anatomical features. Despite challenges such as cost, the need for anesthesia and radiation exposure, understanding normal eye measurements and biometrics through imaging techniques like ultrasound, MRI and CT is essential for diagnosing eye diseases in veterinary ophthalmology. This study aimed to utilize computed Tomography (CT) images to measure intraocular structures in healthy cats with varying skull structures and establish the correlation between these measurements and skull morphometric data. In the study, a total of 24 cats from brachycephalic and 27 cats from non-brachycephalic breeds (both sexes) were included. Two- dimensional CT scans of cats were reconstructed into 3D models using the 3D Slicer 5.4.0 program, which was also used for intraocular and skull measurements. Results demonstrated that the anterio-posterior distance of the lens and postorbital breadth measurements were higher, while greatest length of the skull was lower, in brachycephalic than in non-brachycephalic cats ($p<0.05$). According to the results of Discriminant Function analysis, when considering head types, it was observed that 92.6% of animals with non-brachycephalic head and 79.2% of animals with brachycephalic head types were accurately classified. These findings emphasize the importance of considering anatomical variations in brachycephalic and non-brachycephalic cats for accurate diagnosis of eye health issues in these cats.

To Cite This Article: Özkan E, Pazvant G, Kaya DA, Uğur S, Akçasiz ZN, Yalin EE, Karabağli M and Kurt T, 2024. Computed tomography-based evaluation of skull measurements and eye biometrics in brachycephalic vs. non-brachycephalic cats. Pak Vet J, 44(3): 910-916. http://dx.doi.org/10.29261/pakvetj/2024.238

INTRODUCTION

Brachycephaly in cats is characterized by a decrease in facial and skull length and a more rounded head (Künzel *et al.*, 2003). This head shape stems from an inherited defect in the development of skull bones (Gündemir *et al.*, 2024). In brachycephalic cats, facial and nasal bone shortening alters anatomy of the face. This condition usually results in breathing difficulties and various eye problems in cats. Brachycephalic cat breeds are widespread globally and have become increasingly popular in recent years. Among these, the most common are Exotic Shorthair, British Shorthair, Persian breeds and Scottish Fold (Künzel *et al.*, 2003; Schlueter *et al.*, 2009; Schmidt *et al.*, 2017; Şenol *et al.*, 2022).

The eye is a crucial sensory organ for the continuation of a quality life, as well as for safety, in most animals. It consists of the eyeball and the soft tissues responsible for its movement. However, in carnivores, the absence of the arcus orbitalis results in the eye being surrounded by various anatomical structures (Dursun, 2007).

Eye diseases in cats and dogs can be congenital or acquired, stemming from factors such as infectious agents, metabolic disorders and physical trauma. Additionally, congenital abnormalities specific to species and breeds may also occur (Gültekin *et al*., 2022; Demir *et al*., 2023). Congenital or acquired eye and eyelid diseases are commonly encountered in both cats and dogs (Narfström, 1999).

According to Schlueter *et al*. (2009), cats with severe or extreme brachycephaly (category III or IV) should not be used for breeding purposes, while cats with broader facial bones should be selected. Cats with brachycephalic skull shapes, which can lead to respiratory, cardiac and ophthalmological problems, may encounter these problems throughout their lives, or even experience recurrence despite treatment. Brachycephalic cats are susceptible to a range of eye diseases due to their prominent and protruding eyeballs, which can cause permanent damage to all components of the eye. Among these, corneal diseases hold significant importance in veterinary ophthalmology due to their persistent and recurrent nature (Stiles, 1995). Particularly, chronic corneal diseases are commonly observed in brachycephalic cats (Pentlarge, 1989; Nasisse *et al*., 1998). As a result of shallow eye sockets and prominent eyeballs, decreased corneal sensitivity and ulcerative keratitis are frequently encountered in these breeds (Appelboam, 2016). Glaucoma is a condition characterized by increased intraocular pressure, which can alter eye biometrics and damage the optic nerve (Evangelho *et al*., 2024). In cats, glaucoma is mostly associated with intraocular tumors and chronic uveitis (Blocker and Van Der Woerdt, 2001; McLellan and Teixeira, 2015), and can lead to blindness as it progresses. Because the disease progresses insidiously and develops gradually, cats are often not presented for clinical evaluation until later stages of the disease.

The knowledge about normal measurements for ocular structures can assist in identifying structural abnormalities and diagnosing ocular disorders. The identification of eye diseases according to breeds can positively support treatment processes and also help inform animal owners, thereby aiding veterinarians (Ermutlu *et al*., 2024). For these reasons, knowledge of normal eye biometrics is effective in diagnosing many eye diseases. Eye biometrics involves the detailed evaluation of anatomical measurements and features of the eye and is an essential medical and scientific method for assessing eye health and diagnosing eye problems. Some of these technologies commonly used in determining eye biometrics are the use of ultrasound, MRI (magnetic resonance imaging) and CT (computed tomography) scanning. CT and MRI can provide cross-sectional and three-dimensional images, facilitating the evaluation of spatial relationships among anatomical structures (Akbaş *et al*., 2023; Gundemir *et al*., 2023; Manuta *et al*., 2023). MRI and CT have been identified as excellent imaging methods for diagnosing a range of ophthalmic diseases. CT is used to evaluate anatomical differences between brachycephalic and non-brachycephalic cats. However, there is limited information available regarding normal eye sizes in different cat breeds and the relationship between eye size and skull measurements. Nevertheless, the most detailed measurement of eye biometrics and the diagnosis of eye diseases are possible with CT and require less scanning time than MRI. However, the cost and the need for anesthesia and exposure of animal to radiation during CT scanning present disadvantages.

In veterinary anatomical literature, the dog has predominantly been the focus as the representative of the Carnivora order, resulting in a relative neglect of feline anatomy (Abouelela *et al*., 2022; Jashari *et al*., 2022). Therefore, anatomical studies of cats employing advanced imaging techniques such as CT are of significant value (Yılmaz, 2021). The aim of this study was to use CT images to measure intraocular structures in healthy cats with different skull structures and to define the relationship between these measurements and skull morphometric data. Knowledge about the CT appearance of the eye and the normal intraocular dimensions in brachycephalic and non-brachycephalic cats forms the basis for evaluating CT in patients with diseases that may cause changes in the appearance and dimensions of the eye due to eye diseases.

MATERIALS AND METHODS

Study population: In the study, a total of 24 cats (11 males and 13 females) from brachycephalic breeds and 27 cats (15 males and 12 females) from non-brachycephalic breeds were included. The brachycephalic group consisted of 14 British Shorthairs, 7 Scottish Folds, and one each of Exotic Shorthair, Persian and Chinchilla. The non-brachycephalic group included 22 mixed-breed cats, 2 Ankara cats, and one each of Siamese, Russian Blue and Bombay. These experimental cats used in the study were over one year in age. CT images of the head, obtained from the archive records of the Department of Radiology at Istanbul University-Cerrahpaşa Faculty of Veterinary Medicine, during the year 2023 were used in the study. Cats with eye-related complaints documented in their medical history or those with any eye-related abnormalities identified in the CT images by the veterinarian were excluded from the study. Moreover, for consistency, only left eyes were included in the study, resulting in a total of 51 eyeballs being used. As the study utilized archive data, there were no requirements for approval from an animal welfare committee.

Intraocular and skull measurements: The CT imaging was conducted using the Siemens SOMATOM Scope VB30 machine with the following parameters: slice thickness of 0.6mm, tube voltage of 110kV, and tube current of 28mA, with an exposure time of 14 seconds. During data processing, patients were excluded if the slice thickness exceeded 0.6mm, as this could lead to measurement calculation errors.

For brachycephalic and non-brachycephalic cats, intraocular measurements were obtained from multi-planar reformatting parasagittal images optimized for globe size. Measurements taken from 2D CT images were performed by a single veterinarian for consistency.

Intraocular measurements were separately recorded for brachycephalic and non-brachycephalic cats, as well as for males and females. These measurements were: Anterio-posterior distance of the globe, anterio-posterior distance of the anterior chamber, anterio-posterior distance of the lens, anterio-posterior distance of the vitreous chamber, latero-medial distance of the lens and globe height (Fig. 1). Three-dimensional reconstructions of the skull of the same animal were created using their head CT scans, and measurements related to the skull, including greatest length of the skull (GLS), skull width (SW), zygomatic breadth (ZB), postorbital breadth (POB) and greatest breadth of braincase (GBB), were taken from these reconstructions (Fig. 2). Intraocular measurements were made from 2D CT images, followed by 3D modeling using the 3D Slicer 5.4.0 program, and skull measurements were taken from these models.

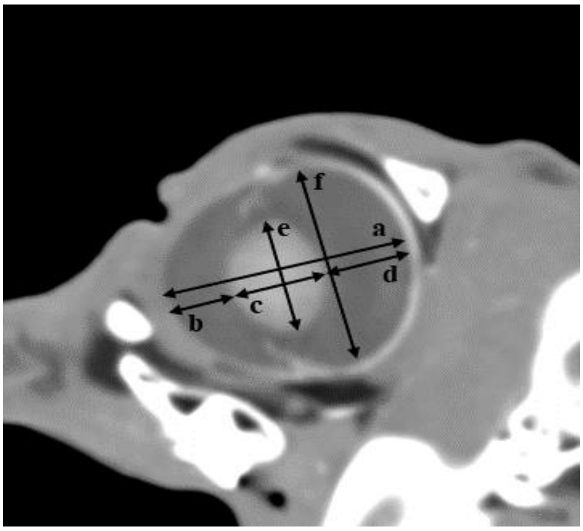

Fig. 1: Showing the intraocular measurements taken from the 2D CT images made from parasagittal sections. Note: a: The anterio-posterior distance of the globe, b: The anterio-posterior distance of the anterior chamber, c: The anterio-posterior distance of the lens, d: The anterio-posterior distance of the vitreous chamber, e: The latero-medial distance of the lens, f: Globe height.

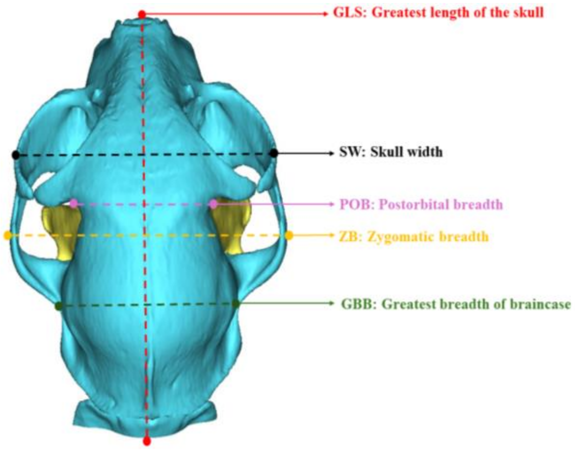

Fig. 2: Measurements of the skull taken via three-dimensional modeling (The distances between points of the same color were measured when calculating the length and width).

Statistical analysis*:* Statistical analyses were performed using IBM SPSS Statistics 21 after the data were saved in Excel format. Means, standard deviations, and comparisons between groups were conducted using this program. T-tests and Discriminant Function (DF) analyses were utilized for intergroup comparisons for brachycephalic and non-brachycephalic head types and between male and females. The Pearson correlation coefficients between intra-ocular and cranial measurements were calculated utilizing the same statistical software program.

RESULTS

In the present research, statistical evaluations were performed, taking into consideration intraocular (Fig. 1) and cranial measurements (Fig. 2), while considering the head types and sex of cats. For intraocular measurement "anterio-posterior distance of the lens", the mean for brachycephalic cats was significantly higher ($p<0.05$) than for non-brachycephalic cats (Table 1). When examining cranial measurements, it was observed that in cats with brachycephalic skull type, the mean value for GLS was significantly lower, while the mean value for POB was higher compared to cats with non-brachycephalic skull type ($p<0.05$). The differences in mean values for other intraocular and cranial measurements were statistically non-significant (Table 1).

In the second phase of our results, all measured values were separated into female and male groups, both within each group (brachycephalic or non-brachycephalic) and across all cats regardless of head type (Table 2). Considering cranial measurements in cats with non-brachycephalic head types, the values for GLS, ZB and GBB were higher in male than those in female cats ($p<0.05$). When examining cranial measurements in brachycephalic cats, male animals showed significantly higher SW compared to females ($p<0.05$). When evaluating female and male groups for the total population regardless of skull type, statistically significant differences ($P<0.05$) were observed in the mean values between groups for intraocular measurement "anterio-posterior distance of the globe" and cranial measurements for SW, ZB and GBB, values being higher in males than in females. For all other intraocular and cranial measurements, the differences in mean values between female and male groups were statistically non-significant (Table 2).

In the present study, correlation analysis was conducted between intraocular and cranial measurements, considering skull types. In cats with brachycephalic skull types (Table 3), significant positive correlations were observed between intraocular measurement "anterio-posterior distance of the globe" and cranial measurements GLS, SW, ZB ($p<0.01$), POB and GBB ($p<0.05$). For cats with non-brachycephalic skull types (Table 4), significant positive correlations ($p<0.01$) were observed between intraocular measurement "anterio-posterior distance of the globe" and cranial measurements ZB and GBB. Additionally, in these cats, a positive correlation at the $p<0.01$ level was also observed between intraocular measurement "globe height" and cranial measurement GLS. Correlations of $p<0.05$ level were observed between various intraocular and cranial measurements in cats with both brachycephalic and non-brachycephalic skull types, as shown in Table 3 and Table 4.

Discriminant Function (DF) analyses were conducted in addition to the analyses mentioned above, based on the measurements taken. According to the results of DF analysis, when considering head types, it was observed that 92.6% of animals with non-brachycephalic head types and 79.2% of animals with brachycephalic head types were accurately classified. The analysis was conducted using the stepwise method, and the most suitable parameters for distinguishing head types were selected. The measurements that were most discriminatory in determining the head type among the measured values were transformed into formulas using Canonical Discriminant Function Coefficients results of DF analysis. The formulated equation is given below:

Table 1: The mean values (±SD) of the intra-ocular and cranial measurements for cats of two groups.

Measurements (mm)	Brachycephalic (n=24)	Non-brachycephalic (n=27)
AP distance of the globe	20.92±1.30	21.17±0.95
AP distance of the anterior chamber	4.88±0.66	4.77±0.47
AP distance of the vitreous chamber	8.80±0.87	8.98±0.73
AP distance of the lens	8.00±0.89*	7.50±0.69*
LM distance of the lens	10.98±1.15	10.99±0.92
Globe height	20.60±1.00	20.77±0.96
Greatest length of the skull	80.68±8.95*	88.60±8.84*
Skull width	62.81±5.89	60.33±4.50
Zygomatic breadth	64.65±5.97	65.60±5.33
Postorbital breadth	36.29±4.67*	33.03±2.94*
Greatest breadth of braincase	41.58±1.97	41.16±1.88

*: The difference between the mean values within the same row is statistically significant (P<0.05); AP=Anterio-posterior; LM= Latero-medial.

Table 2: The mean (±SD) values for intra-ocular and cranial measurements in females and males

Measurements (mm)	Head Type	Female		Male	
		N	Mean±SD	N	Mean±SD
AP distance of the globe	Brachycephalic	13	20.67±1.40	11	21.22±1.16
	Non-brachycephalic	12	20.80±0.87	15	21.46±0.94
	Total	25	20.73±1.15*	26	21.36±1.02*
AP distance of the anterior chamber	Brachycephalic	13	4.69±0.67	11	5.10±0.61
	Non-brachycephalic	12	4.73±0.48	15	4.81±0.48
	Total	25	4.71±0.58	26	4.93±0.55
AP distance of the lens	Brachycephalic	13	8.81±0.91	11	8.79±0.86
	Non-brachycephalic	12	8.85±0.87	15	9.08±0.61
	Total	25	8.83±0.87	26	8.96±0.72
AP distance of the vitreous chamber	Brachycephalic	13	7.98±0.57	11	8.03±1.20
	Non-brachycephalic	12	7.43±0.79	15	7.56±0.62
	Total	25	7.72±0.72	26	7.76±0.92
LM distance of the lens	Brachycephalic	13	10.84±1.17	11	11.14±1.17
	Non-brachycephalic	12	10.96±0.84	15	11.01±1.00
	Total	25	10.9±1.01	26	11.06±1.05
Globe height	Brachycephalic	13	20.80±0.93	11	20.37±1.07
	Non-brachycephalic	12	20.42±0.77	15	21.06±1.02
	Total	25	20.62±0.86	26	20.77±1.08
Greatest length of the skull	Brachycephalic	13	79.01±9.97	11	82.66±7.55
	Non-brachycephalic	12	86.55±2.93*	15	90.24±5.50*
	Total	25	82.63±8.27	26	87.04±7.37
Skull width	Brachycephalic	13	60.64±3.96*	11	65.37±6.89*
	Non-brachycephalic	12	58.82±2.50	15	61.54±5.40
	Total	25	59.76±3.40*	26	63.16±6.25*
Zygomatic breadth	Brachycephalic	13	62.62±3.06	11	67.05±7.69
	Non-brachycephalic	12	62.73±2.54*	15	67.90±5.92*
	Total	25	62.67±2.76*	26	67.54±6.59*
Postorbital breadth	Brachycephalic	13	34.64±4.80	11	38.24±3.85
	Non-brachycephalic	12	32.27±3.26	15	33.64±2.61
	Total	25	33.5±4.23	26	35.58±3.89
Greatest breadth of braincase	Brachycephalic	13	41.22±2.07	11	42.01±1.85
	Non-brachycephalic	12	40.22±1.42*	15	41.90±1.91*
	Total	25	40.74±1.83*	26	41.95±1.85*

AP=Anterio-posterior; LM= Latero-medial.

Table 3: The correlation coefficients between intra-ocular and cranial measurements in the brachycephalic head type cats.

Measurements	a	b	d	c	e	f	GLS	SW	ZB	POB	GBB
a		0.439^{*}	0.551^{**}	0.411^{*}	0.538^{**}	0.620^{**}	0.529^{**}	0.726^{**}	0.634^{**}	0.463^{*}	0.429^{*}
b	0.439^{*}		0.055	-0.067	0.241	0.120	0.362	0.305	0.308	0.041	0.080
d	0.551^{**}	0.055		0.068	0.068	0.580^{**}	0.216	0.271	0.146	0.170	0.081
c	0.411^{*}	-0.067	0.068		0.556^{**}	0.268	0.071	0.419^{*}	0.407^{*}	0.472^{*}	0.288
e	0.538^{**}	0.241	0.068	0.556^{**}		0.320	0.259	0.481^{*}	0.402	0.508^{*}	0.295
f	0.620^{**}	0.120	0.580^{**}	0.268	0.320		0.402	0.330	0.226	0.156	0.225
GLS	0.529^{**}	0.362	0.216	0.071	0.259	0.402		0.420^{*}	0.454^{*}	-0.034	-0.089
SW	0.726^{**}	0.305	0.271	0.419^{*}	0.481^{*}	0.330	0.420^{*}		0.961^{**}	0.761^{**}	0.573^{**}
ZB	0.634^{**}	0.308	0.146	0.407^{*}	0.402	0.226	0.454^{*}	0.961^{**}		0.676^{**}	0.459^{*}
POB	0.463^{*}	0.041	0.170	0.472^{*}	0.508^{*}	0.156	-0.034	0.761^{**}	0.676^{**}		0.809^{**}
GBB	0.429^{*}	0.080	0.081	0.288	0.295	0.225	-0.089	0.573^{**}	0.459^{*}	0.809^{**}	

*: The correlation is statistically significant (P<0.05).**: The correlation is statistically significant (P<0.01). a: The anterio-posterior distance of the globe, b: The anterio-posterior distance of the anterior chamber, c: The anterio-posterior distance of the lens, d: The anterio-posterior distance of the vitreous chamber, e: The latero-medial distance of the lens, f: Globe height, GLS: Greatest length of the skull, SW: Skull width, ZB: Zygomatic breadth, POB: Postorbital breadth, GBB: Greatest breadth of braincase.

Table 4: The correlation coefficients between intra-ocular and cranial measurements in the non-brachycephalic head type cats.

Measurements	a	b	d	c	e	f	GLS	SW	ZB	POB	GBB
a		0.350	0.272	0.106	0.327	0.482^{*}	0.302	0.332	0.659^{**}	0.359	0.551^{**}
b	0.350		0.100	-0.094	-0.121	-0.055	0.018	0.110	0.208	0.085	0.181
d	0.272	0.100		-0.624^{**}	-0.349	0.238	0.211	0.367	0.204	-0.018	0.339
c	0.106	-0.094	-0.624^{**}		0.663^{**}	-0.016	-0.139	-0.250	0.057	0.165	-0.211
e	0.327	-0.121	-0.349	0.663^{**}		0.315	0.223	0.094	0.176	0.371	0.031
f	0.482^{*}	-0.055	0.238	-0.016	0.315		0.507^{**}	0.412^{*}	0.430^{*}	0.349	0.399^{*}
GLS	0.302	0.018	0.211	-0.139	0.223	0.507^{**}		0.753^{**}	0.596^{**}	0.457^{*}	0.481^{*}
SW	0.332	0.110	0.367	-0.250	0.094	0.412^{*}	0.753^{**}		0.502^{**}	0.541^{**}	0.461^{*}
ZB	0.659^{**}	0.208	0.204	0.057	0.176	0.430^{*}	0.596^{**}	0.502^{**}		0.581^{**}	0.633^{**}
POB	0.359	0.085	-0.018	0.165	0.371	0.349	0.457^{*}	0.541^{**}	0.581^{**}		0.297
GBB	0.551^{**}	0.181	0.339	-0.211	0.031	0.399^{*}	0.481^{*}	0.461^{*}	0.633^{**}	0.297	

*: The correlation is statistically significant ($P < 0.05$); **: The correlation is statistically significant ($P < 0.01$); a: The anterio-posterior distance of the globe, b: The anterio-posterior distance of the anterior chamber, c: The anterio-posterior distance of the lens, d: The anterio-posterior distance of the vitreous chamber, e: The latero-medial distance of the lens, f: Globe height, GLS: Greatest length of the skull, SW: Skull width, ZB: Zygomatic breadth, POB: Postorbital breadth, GBB: Greatest breadth of braincase.

D = GLS*0.159–SW*0.167–3.179
D>0 for non-brachycephalic; D<0 for brachycephalic (centroid 0.785 for non-brachycephalic, −0.884 for brachycephalic)

DISCUSSION

Brachycephaly is characterized by a decrease in the length of the face and skull of the affected individual and the skull becomes more rounded, "dome-shaped" (Künzel *et al.*, 2003). Despite the decrease in the size of the face, there is no corresponding decrease in the size of the soft tissues of the head. Externally, the skin of the face tends to appear folded, whereas internally, the mucous membranes of the nose and respiratory passages are disproportionately large. This disproportionate structuring leads to respiratory, cardiac, and ophthalmological problems in brachycephalic breeds. Schlueter *et al.* (2009) categorized brachycephalic skull deformities in cats into 4 categories based on the severity (mild, moderate, profound and severe). The risk of diseases associated with brachycephalic skull structure may increase in parallel with the degree of brachycephaly (degree of abnormality in head shape). Understanding the relationships between skull type and ocular measurements in brachycephalic and non-brachycephalic cat breeds will shed light on important issues such as disease diagnosis.

In our study, the mean "anterio-posterior distance of the globe" evaluated from the eye measurements was measured as 20.92±1.30mm for brachycephalic and 21.17±0.95mm for non-brachycephalic cat breeds. Salgüero *et al.* (2015) reported an average value of 20.90±0.14mm for the same measurement in the left eye of different dog breeds regardless of skull types. In a study conducted on humans (Igbinedion and Ogbeide, 2013), it was noted that the gender factor affected eye measurements. In our study, it was observed that, in general, males had higher values than females for most of the ocular measurements in both brachycephalic and non-brachycephalic cats. When a t-test was applied without distinguishing skull types, a statistically significant difference was observed for measurement "anterio-posterior distance of the globe" ($P<0.05$). However, when differences between female and male groups were examined within skull types, there was no difference. The fact that sex differences yield statistically different results suggests that studies investigating these differences should consider skull types when conducting research. Yuwatanakorn *et al.* (2021) reported an average value of 20.2±0.04mm for the same measurement (anterio-posterior distance of the globe) for brachycephalic and non-brachycephalic cats. In the same study, it was reported that the differences between skull types were statistically non-significant when the mean values of the "anterio-posterior distance of the anterior chamber", "anterio-posterior distance of the vitreous" and "globe height" were examined. When comparing the results, it can be concluded that our study reached the same conclusion that the difference between the two skull types is statistically non-significant.

According to Yuwatanakorn *et al.* (2021), no difference was observed between brachycephalic and non-brachycephalic skull types for the "anterio-posterior distance of the lens". However, in our study, a statistically significant difference ($P<0.05$) was found between these two skull types for this measurement, mean value was higher for brachycephalic than non-brachycephalic cats. The reason for this discrepancy between the two studies regarding measurement "anterio-posterior distance of the lens" is believed to be due to differences in the brachycephalic cats used in the two studies. Brachycephalic cat breeds used in our study predominantly included British Shorthair and Scottish Fold. We also included Exotic Shorthair and Persian breeds which are categorized as severe (extreme) brachycephalic, while Yuwatanakorn *et al.* (2021) included American Shorthair and mixed breeds in thier study. At this point, it is considered important to take into account the categorization of brachycephalic skull types into subgroups and the statistical diversity it creates when evaluating brachycephalic and non-brachycephalic skull types.

Mirshahi *et al.* (2014) evaluated the relationship between cranial morphometrics and ocular biometrics using a method commonly employed in clinics such as ultrasonography. These workers indicated that one of the primary factors influencing feline ocular biometrics via ultrasonography was cranial circumference. Cats of Persian breed were included in their study, and a positive correlation was noted between cranial circumference and eye measurements "anterio-posterior distance of the globe" and "anterio-posterior distance of the lens". In our investigation, while focusing on brachycephalic cat breeds, it was observed that ocular measurements, particularly "anterio-posterior distance of the globe", exhibited a positive correlation with all cranial vault measurements, while measurement "anterio-posterior distance of the lens" demonstrated a positive correlation with three specific cranial vault measurements SW, ZB and POB (p<0.05). Conversely, in non-brachycephalic cat breeds, measurement "anterio-posterior distance of the globe" displayed a positive correlation with two cranial measurement points ZB and GBB (p<0.01), whereas measurement "anterio-posterior distance of the lens" showed no correlation with any of the cranial measurements. Both Mirshahi *et al.* (2014) and our study suggest that cranial measurements exert an influence on eye measurements "anterio-posterior distance of the globe" and "anterio-posterior distance of the lens". However, when considering the measurement of the "anterio-posterior distance of the anterior chamber", both studies observed that the type of skull did not affect this measurement.

Another method used in our study to elucidate the relationship between groups is DFA (Discriminant Function Analysis), which is a statistical technique used to differentiate or classify groups by utilizing multiple variables to determine differences between groups. It identifies the variables that best distinguish groups by creating models and then evaluates the accuracy and effectiveness of the model. DFA is used to predict the group to which individuals in the study belong to (Gündemir *et al.*, 2020; Pazvant *et al.*, 2022). Using the Stepwise discriminant functions, we found that cranial measurements GLS and SW were useful variables. In the study conducted by Pazvant *et al.* (2022) on seagulls, discriminant functions were derived from measurements obtained from head metrics, resulting in four functions with high separation rates. In all four functions, the head length measurement (which is GLS in our study) was included in the formula, which parallels our study. In both studies, head length measurements were observed to have highly discriminative features in the DF analyses.

In our study, results of DFA results showed a separation rate of 92.6% in non-brachycephalic cat breeds, while this rate was found to be 79.2% in brachycephalic cat breeds. The lower separation rate in brachycephalic cat breeds is thought to be due to the different degrees of brachycephaly within these breeds. Since there are various types of brachycephalic skull shapes with different degrees of brachycephaly (Schlueter *et al.*, 2009), it is considered important to apply DFA to brachycephalic cat breeds with different degrees of brachycephaly to make brachycephalic cat categorization more distinct.

Conclusions: In conclusion, our findings indicate that skull type influences the size and structure of the eyes at certain points, including anterio-posterior distance of the lens, greatest length of the skull and postorbital breadth. At these points, the difference between brachycephalic and non-brachycephalic skulls was significant (P<0.05). Additionally, with DF analysis, it was observed that 92.6% of skulls with non-brachycephalic head types and 79.2% of skulls with brachycephalic head types were accurately classified. These data serve as an important guide for understanding the relationship between eye measurements and skull type in brachycephalic and non-brachycephalic cats.

Authors contributions: EÖ and GP conceived the idea and designed the study. MK managed acquisition of images. DAK, SU, ZNA, EEY and TK carried out image evaluation and measurements. EÖ and GP performed statistical analysis of data. All authors reviewed the manuscript for important intellectual contents and approved the final version.

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