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Morphometric analysis of the skulls of domestic cattle (*Bos taurus* L.) and water buffalo (*Bubalus bubalis* L.) in Turkey

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Abstract: A total of 20 domestic cattle (*Bos taurus* L.) and 15 water buffalo (*Bubalis bubalis* L.) skulls were analyzed in this study. All of the specimens belonged to female individuals. Using a total of 27 craniometric measurements from each of the skulls, 9 indices were calculated. Although there were statistically significant differences between the linear measurements of the skulls of both species, while calculating the indices with their ratios, the values of the measurements of the facial area were determinative in the craniology. Among these indices, the facial index 1 value was statistically significant ($P < 0.01$) in the comparison of these two species. On the other hand, while considering the orbit and foramen magnum measurements, in contrast with the transversal measurement, the height was more determinant for their index and form.

Key words: Cattle, water buffalo, skull, morphometry, Turkey

1. Introduction

The measurement and documentation of cattle skulls has been of great importance in discussions about the origin of cattle [1]. Rütimeyer's work led to the beginning of addressing the skull type, particularly in the study of evolutionary origin and classification of cattle [2]. However, cattle classification according to skull measurements was first carried out by Wilckens [3] in 1876, inspired by the works of Rütimeyer [4] and Nathusius [5] in 1867 and 1872, respectively [2].

The Linnaean taxonomy system, which mainly emphasizes morphological differences, led to the categorization of cattle species based on their cranial shape, as well as the lengths and curves of their horns. In this classification system, therefore, the classification of cattle skulls in an archaeological assemblage is likely to be possible [2] since craniology has also been used for the identification and comparison of *Bos* species at prehistoric sites [6].

The origin of the craniometric study of cattle dates back to the end of the 18th century [1]. However, it was reported that following this period, archaeozoologists gradually shifted their attention in domestic cattle studies [2]. Since the similarities and differences between the species can only be revealed by comparative studies, skull morphometry has been a significant topic, not only for the study of individuals of the same species but also animals from different species [7].

The tribe Bovini in the subfamily Bovinae was reported to have three main genera [8]: *Bos* (domestic cattle), *Bubalis* (water and swamp buffalo), and *Syncerus* (African buffalo) [8]. Morphologically and genetically, cattle breeds were described as two main types, respectively, as modern European cattle breeds as Primigenius and Indian cattle breeds as Zebu [9]. On the other hand, buffalo were grouped into two main types, correspondingly, as African wild buffalo and Asian buffalo. The domestic buffalo were further divided into 2 groups as river buffalo and swamp buffalo [10–12]. However, the buffalo in Turkey are called Anatolian buffalo, and they originated from the Mediterranean buffalo under the subgroup of river buffalo [13].

Although there is some information about the craniology and craniometry of domestic cattle [6,14–19] and some studies about the craniology of nondomesticated bovine species [8,20,21], in general, there are scarce data regarding this field. Moreover, it was observed that these craniometric studies were based on the study by Duerst [22] and were mainly developed through these measurements.

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It was argued, in a study on the craniology of domestic cattle breeds [6] that the results were quite variable, especially regarding the horn length of *Bos taurus*, and there was a possibility of finding intraspecies differences. One of the Indian breeds, Zebu, was reported to possess a very long and narrow skull with a narrow protuberantia intercornualis in the aboral part of the frontal region, particularly in the region between the horns [23]. The osteology of the Savannah buffalo was reported as not similar to that of domestic cattle, Egyptian water buffalo, or Asian water buffalo [8]. The swamp buffalo was reported to have a long skull with the effect of the width on its skull shape [20].

On the other hand, despite having a different cranium, Neolithic cattle were recognized as an archetype of domestic cattle, assuming that the cattle cranium remained relatively unchanged over time [2]. However, it was also reported that the absolute size was variable among cattle craniums and the lowest coefficient of variation was found for basal length [6].

For the postnatal ontogeny of cattle, two basic indices have been used in the estimation of the changes in the skull ratios: the frontal and facial indices, which were reported to have been used as a common denominator, showing significant changes in the maximum width (Ect-Ect), median frontal length (MFL) (Op-N), and viscerocranium length (VL) ratios of the skull compared to their mutual values [24]. However, there was an effect of the sex of the individual on some skull dimensions, such as the width and height measurements, which commonly tended to be larger in bulls, while the length measurements were the same in both sexes [6,14].

Originating from the river buffalo, and unlike the swamp buffalo, Anatolian buffalo are raised mainly for milk production. It was also reported that these buffalo are genetically different from the swamp buffalo [25]. They are widely found animals [10] and have a unique genotype adapted to the ecological conditions of Anatolia [26]. By comparing the basic craniometric characteristics, this study attempts to illustrate the similarities and differences between the skull morphometry of domestic cattle (*Bos taurus*) and Anatolian buffalo (*Bos bubalis*).

2. Materials and methods

The skulls of 20 cattle (*Bos taurus* L.) and 15 buffalo (*Bubalis bubalis* L.), aged between 3 and 7 years, were used as samples in this study. All of the skulls belonged to female individuals. The specimens are currently available in the collection of the Department of Anatomy, Faculty of Veterinary Medicine, İstanbul University-Cerrahpaşa, Turkey. A total of 27 morphometric measurements were taken from each of the skull samples based on the method of von den Driesch [27] using a 0.5-mm digital caliper.

The morphometric measurements (Figures 1A–1H) obtained in this study are presented below:

1. Total length (TL): acrocranion-prosthion
2. Condylobasal length (CBL): aboral border of the occipital condyles-prosthion
3. Basal length (BL): basion-prosthion
4. Short skull length (SSL): basion-premolare
5. Premolare-prosthion (PP)
6. Viscerocranium length (VCL): nasion-prosthion
7. Median frontal length (MFL): acrocranion-nasion
8. Greatest length of the nasals (GLN): nasion-rhinion
9. Lateral facial length (LFL): ectorbitale-prosthion
10. Dental length (DL): postdentale-prosthion
11. Lateral length of the premaxilla (LLP): nasointermaxillare-prosthion
12. Greatest inner length of the orbit (GILO): ectorbitale-entorbitale
13. Greatest inner height of the orbit (GIHO)
14. Greatest mastoid breadth (GMB): otion-otion
15. Greatest breadth of the occipital condyles (GBOC)
16. Greatest breadth at the bases of the paraoccipital processes (GBPP)
17. Greatest breadth of the foramen magnum (GBFM)
18. Height of the foramen magnum (HFM): basion-opisthion
19. Least occipital breadth (LOB): distance between the most medial points of the aboral borders of the temporal grooves
20. Least frontal breadth (LFB): breadth of the narrowest part of the frontal aboral of the orbits
21. Greatest breadth of the skull (GBS): ectorbitale-ectorbitale
22. Least breadth between the orbits (LBO): entorbitale-entorbitale
23. Facial breadth (FB): across the facial tuberosities
24. Breadth across the premaxillae on the oral protuberances (BPOP)
25. Greatest palatal breadth (GPB): measured across the outer borders of the alveoli
26. Greatest height of the occipital region (GHOR): basion-highest point of the intercornual ridge in the median plane
27. Least height of the occipital region (LHOR): opisthion-highest point of the intercornual ridge in the median plane

A total of 9 indices were calculated using the obtained morphometric measurements. The index calculations were based on a comparison of both the data obtained from these two species and the data available in the literature.

The calculated indices in this study are presented below:

Skull index = GBS / TL × 100

Facial index 1 = FB / VCL × 100

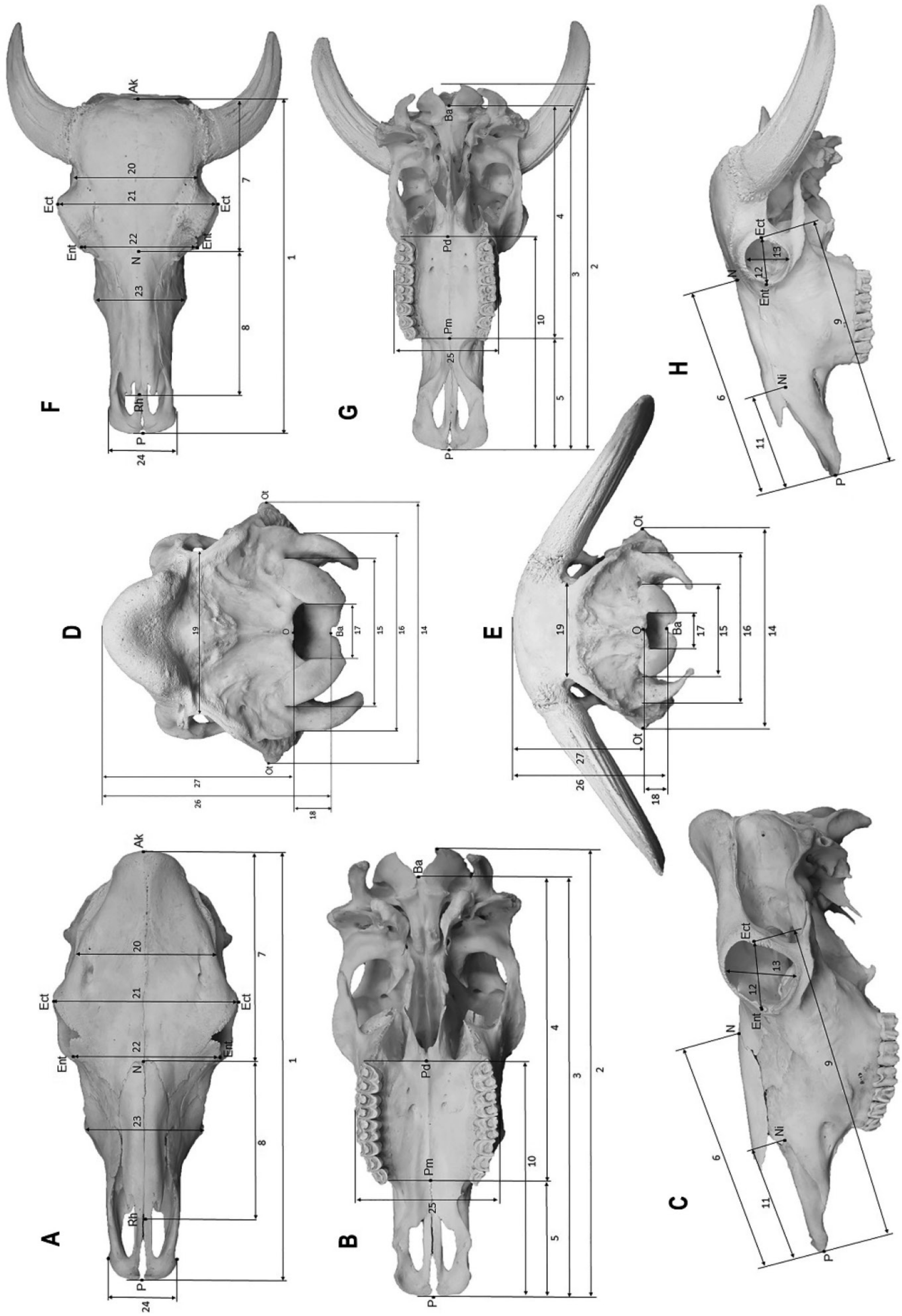

Figure 1. Measurements of the cranium taken in this study. (A) Dorsal view of the cattle skull, (B) basal view of the cattle skull, (C) lateral view of the cattle skull, (D) occipital view of the cattle skull, (E) occipital view of the water buffalo skull, (F) dorsal view of the water buffalo skull, (G) basal view of the water buffalo skull, (H) lateral view of the water buffalo skull. Ak: Acrocranion, Ba: basion, Ect: ectorbitale, Ent: entorbitale, N: nasion, Ni: nasointermaxillare, O: opisthion, Ot: otion, Rh: rhinion, P: prosthion, Pd: postdentale, Pm: premolare.

Facial index 2 = GBS / VCL × 100
Frontal index = GBS / MFL × 100
Basal index = GBS / BL × 100
Length-length index = MFL / VCL
Palatal index = GPB / DL × 100
Orbital index = GIHO / GILO × 100
Foramen magnum index = HFM / GBFM × 100

The mean values and standard deviations of all of the craniometric measurements and indices were calculated using SPSS 21 (IBM Corp., Armonk, NY, USA). In addition, the values of both the cattle and buffalo were compared using Student's t-test in the same software program.

3. Results

The cattle and buffalo skull measurements were evaluated in three different groups. The first group included the general skull and orbit measurements (Table 1), the second group included the neurocranium measurements (Table 2), and the third group included the viscerocranium measurements (Table 3). The orbit measurements were evaluated with the general skull group because of its location at the border of the neurocranium and viscerocranium.

Except for the orbit, the differences between the mean values of the general skull measurements were significant ($P < 0.01$) for these species. However, the values were higher in the cattle than in buffalo.

Almost the same value was found for the greatest inner length measurement of the orbit among the cattle and buffalo. The minimal difference between them was statistically insignificant. However, the inner height measurement of the orbit was observed to have a higher mean value in cattle (66.35 ± 4.83 mm). On the other hand, the difference between the values in the buffalo was statistically significant ($P < 0.01$). This further indicated that the orbit of the buffalo was transverse oval, whereas the orbit of the cattle had a longitudinal oval structure. Significant correlations were also noticed between the correlation of the orbital index and the self-forming factors: positive with the height measurement, negative with the transverse lengths, and varying between $P < 0.05$ and $P < 0.01$.

With the exception of the LFB and greatest breadth measurements of the foramen magnum, the other neurocranium measurements of the skulls presented significant differences ranging from $P < 0.05$ to $P < 0.01$. While measuring the LFB, one of the measurements from the frontal region, no statistically significant difference was found among the buffalo in contrast to a higher value in the cattle. The foramen magnum had a more rounded shape in the cattle, while it was more oval in the buffalo. However, only the difference between the height values of the foramen magnum was statistically significant. This also showed the effect of height on the shape of the foramen magnum in both species.

The differences between the mean values of both species were insignificant in 4 of the 10 viscerocranial measurements. These were the prosthion-premolare, DL, LLP, and breadth across the premaxillae on the oral protuberance measurements, respectively. Except for these 4 particular measurements, the 6 other measurements had higher values in the buffalo samples, but the differences were not statistically significant. The VCL was greater in the cattle than in the buffalo. Since the VCL was longer, the facial region was longer than the neurocranium in the cattle samples. It was also observed that the facial index 1 value was larger in cattle than in buffalo, and the difference between the mean values of both species was statistically significant (Table 4).

Although the skull size in the cattle was larger than in the buffalo, the index values were almost the same in both

Table 1. Means of the general skull and orbit measurements.

Species	Statistics	TL	CBL	BL	SSL	GILO	GIHO
Cattle	Mean	529.52**	519.56**	486.24**	336.58**	60.34^{NS}	66.35**
	N	20	20	20	20	20	20
	SD	15.88	15.85	15.76	11.46	2.55	4.83
	Minimum	499.73	485.73	454.96	317.26	56.51	59.96
	Maximum	558.05	543.40	512.92	357.76	66.04	75.14
Water buffalo	Mean	471.97**	482.34**	450.13**	295.23**	60.58^{NS}	57.49**
	N	15	15	15	15	15	15
	SD	45.77	45.93	44.99	28.06	6.88	4.32
	Minimum	410.68	420.82	389.66	256.42	54.58	50.83
	Maximum	528.40	541.75	505.15	332.63	75.47	68.98

^{NS}: Not significant, **: $P < 0.01$.

Table 2. Means of the neurocranial part of the skull.

Species	Statistics	MFL	GMB	GBOC	GBPP	GBFM	HFM	LOB	LFB	GBS	GHOR	LHOR
Cattle	Mean	233.49**	231.51**	113.28**	172.59**	42.74^{NS}	38.87**	136.77**	169.95^{NS}	228.93**	170.32*	131.32**
	N	20	20	20	20	20	20	20	20	20	20	20
	SD	12.06	11.25	5.68	8.14	2.97	2.23	12.70	9.56	10.16	7.45	7.32
	Minimum	214.06	205.42	103.22	150.92	36.60	34.63	119.71	157.64	207.15	156.60	114.69
	Maximum	255.86	245.54	129.92	184.63	50.27	42.56	159.93	185.37	243.74	184.66	144.93
Water buffalo	Mean	213.89**	199.23**	98.41**	151.30**	40.78^{NS}	34.48**	101.38**	172.39^{NS}	202.80**	177.49*	168.36**
	N	15	15	15	15	15	15	15	15	15	15	15
	SD	16.38	22.40	5.71	14.64	5.38	3.66	7.50	9.48	19.23	11.85	12.46
	Minimum	183.72	167.70	89.17	126.91	29.51	29.05	89.53	155.14	169.85	154.96	140.63
	Maximum	239.13	226.75	107.78	174.61	56.21	45.09	115.52	191.49	228.00	191.70	184.53

^{NS}: Not significant, *: P < 0.05, **: P < 0.01.

Table 3. Means of the viscerocranial part of the skull.

Species	Statistics	VCL	PP	GLN	LFL	DL	LLP	LBO	FB	BPOP	GPB
Cattle	Mean	297.95*	151.12^{NS}	199.88*	359.99*	284.70^{NS}	160.25^{NS}	177.14**	173.39**	92.04^{NS}	148.41**
	N	20	20	20	20	20	20	20	20	20	20
	SD	15.04	8.46	13.08	29.76	12.70	12.20	8.10	8.45	4.99	5.92
	Minimum	271.24	138.72	178.47	243.92	247.16	138.33	161.21	159.76	82.29	137.26
	Maximum	326.77	168.73	229.74	389.13	306.43	184.42	191.25	190.22	102.50	157.71
Water buffalo	Mean	273.45*	155.87^{NS}	182.43*	333.09*	286.79^{NS}	165.98^{NS}	135.56**	133.36**	88.73^{NS}	125.75**
	N	15	15	15	15	15	15	15	15	15	15
	SD	37.38	17.60	24.58	34.67	32.76	26.45	16.28	17.84	23.64	16.40
	Minimum	229.20	133.37	143.28	284.93	230.49	133.45	107.44	106.60	26.29	103.61
	Maximum	322.56	178.56	219.70	371.12	331.27	211.63	158.67	158.55	112.08	148.55

^{NS}: Not significant, *: P < 0.05, **: P < 0.01.

species and the minimal difference between them was not significant when evaluated according to the skull index.

A negative correlation was observed between the skull index and the TL. On the other hand, a positive correlation was found between the skull index and GBS (Table 5). However, the level of both correlations was quite low and statistically insignificant.

There were significant differences between the facial index 1 values of the cattle and buffalo (P < 0.01). The cattle and buffalo had a ratio of 1.72 and 2.05 between the skull length and FB, respectively. The facial region was narrower when compared to the skull length in the buffalo. A similar situation was seen for the palatal index evaluated in the viscerocranial part.

A positively significant correlation (Table 5) was found between the facial index 1 and the FB. On the other hand, a low relationship was found between the VCLs. A significance of P < 0.01 between the facial index 1 values of the two species was observed due to the fact that the facial index was more effective than the VCL.

While observing the correlation between the factors producing the basal index values in both species, the GBS value was statistically significant when compared to the others.

4. Discussion

Since Rütimeyer's work in 1867, scientific studies of bovine skulls have been the center of attention for

Table 4. Cranial indices of the cattle and water buffalo.

Species	Statistics	Skull index	Facial index 1	Facial index 2	Frontal index	Basal index	Length index	Palatal index	Orbital index	Foramen magnum index
Cattle	Mean	43.23^{NS}	58.28**	76.91^{NS}	98.29^{NS}	47.08**	0.786^{NS}	52.20**	110.01**	91.31*
	N	20	20	20	20	20	20	20	20	20
	SD	1.50	3.27	2.96	6.79	1.43	0.060	2.60	7.24	7.68
	Min	39.77	51.78	70.54	89.08	44.33	0.655	48.43	97.04	79.94
	Max	45.97	66.90	81.48	113.87	50.48	0.868	59.21	122.82	108.63
Water buffalo	Mean	43.01^{NS}	48.88**	74.70^{NS}	94.87^{NS}	45.11**	0.791^{NS}	43.82**	95.56**	85.03*
	N	15	15	15	15	15	15	15	15	15
	SD	1.84	3.12	5.69	6.28	1.99	0.087	2.25	8.48	6.73
	Min	39.58	41.41	65.98	83.71	42.05	0.665	39.21	81.59	78.18
	Max	46.04	52.58	84.74	106.73	48.31	0.957	47.48	105.05	104.61

^{NS}: Not significant, *: P < 0.05, **: P < 0.01, Min: minimum, Max: maximum.

Table 5. Correlation analysis between the indices and theirs factors.

	TL	GBS	FB	VCL	MFL	BL	GPB	DL	GIHO	GILO	HFM	GBFM
Skull index	–0.090^{NS}	0.324^{NS}										
Facial index 1			0.793**	0.174^{NS}								
Facial index 2		0.077^{NS}		–0.493**								
Frontal index		0.590^{NS}			–0.197^{NS}							
Basal index		0.535**				0.088^{NS}						
Length-length index				–0.723**	0.208^{NS}							
Palatal index							0.756**	–0.116^{NS}				
Orbital index									0.737**	–0.394*		
Foramen magnum index											0.393*	–0.442**

^{NS}: Not significant, *: P < 0.05, **: P < 0.01.

archaeozoologists. The documentation of craniometric measurements concentrating on the origins of cattle has also been of great importance in terms of ontogenetic studies [1]. However, there has been greater emphasis on craniological evaluations of domesticated bovid species [1,6,9,14–19,24] than on nondomesticated ones [8,21]. Whether they were carried out on domesticated or nondomesticated species, it is indisputable that both interspecies and intraspecies studies have provided great contributions to the research on the origin and domestication of bovid species. The aspiration to classify cattle skulls from archaeological assemblages was also the basis of this research [2]. Unlike the macroanatomy of the skulls [28,29], the morphometric analysis of the skulls of two bovid species, i.e. cattle and buffalo, was carried out in this study. These two species have made great contributions to humanity due to their economic value as suppliers of meat, milk, leather, and fertilizer, as well as their supply of sheer physical labor [30] and an animal-based economy.

As a member of the tribe Bovini, the water buffalo originated from the Indian river buffalo. It is a more resistant and adaptive species than cattle, in addition to being able to better benefit from pasture and forest pasture habitats [13]. Craniometric data have been revealed from intraspecies studies on domestic cattle [1,6,7,9,14,15,31]. However, although it has selective advantages, the skull morphometry of the water buffalo has not thus far been extended beyond macroanatomic evaluations [28,29]. It is also possible to access the craniometric data of the swamp buffalo (*B. bubalis carabenesis*) [20], which is morphologically and genetically a different subspecies of the tribe Bovini [25]. However, because of the uncertainty of the measurement points, it is not possible to use these data for a comparison with other Bovini species.

On the other hand, the length and shape of cattle horns vary strongly [6], and their anatomical differences are also obvious [28]. Therefore, examining and evaluating the horns was excluded in this study. The skull measurements in this study were evaluated within 3 distinct groups: general, viscerocranial, and neurocranial. Generally, two indices (facial and frontal) are emphasized to predict changes in skull ratios during the postnatal ontogenesis of cattle [24]. However, for a wider evaluation of the comparison between the cattle and buffalo skulls, 9 index calculations were produced. It has been argued that the GBS, MFL, and VCL ratios could be used as a common denominator of significant changes while predicting changes in the skull ratios [24]. However, considering the indices calculated in this study, it seems that this has no significant contribution in the comparison of these two species, because when the index values (e.g., skull, facial 2, frontal indices) used in the GBS measurement of this calculation are compared, the differences between them are not statistically significant (Table 4).

Although the GBS value had a positive correlation when compared with the TL, in the general skull rating there was a low level and statistically insignificant relationship between them. Overall, the TL and GBS linear measurements were larger in the cattle than in the buffalo. This probably occurred because of the effect of sex. However, the data obtained in this study were not sufficient to reach a conclusion regarding this. The facial index 1 presented the size of the changes in the facial area, although the proportional values of VCL and MFL were not significant in the comparison of the two species. There was a high positive correlation between the FB and facial index 1. This index value was lower in the buffalo and the difference between the average values in the cattle was significant ($P < 0.01$). This also showed that, compared to the skull length, the facial area was narrower in buffalo.

On the other hand, the GBS value was only effective on the basal index calculation. This was probably related to the longitudinal curve of the skull.

The visible morphology, as well as the length of the horns, was different in both species. The statistical analyses in this study indicated changes in the viscerocranial part of the skull, although it was thought that this difference commonly had an effect on the neurocranium due to the frontal region of the skull. In particular, the width measurements in the facial area showed a smaller value when compared to both the skull and the VCL in the buffalo samples. This also indicated that the buffalo skulls had a narrower structural feature with a longer viscerocranium. Although it was argued that they had a longer skull shape structure [20], the uncertainty of the reference points in swamp buffalo created a limitation for their comparison with the water buffalo, a different genotype [25] used in this study.

It was reported that the ox has a slightly dorsoventrally flattened orbit, in which its transversal diameter is slightly larger than its height; however, the water buffalo was reported to usually have a circular foramen magnum [29]. In this study, on the other hand, the transversal measurement of the orbit, which was the GILO, presented almost the same length in the two species, with a statistically insignificant difference between them. The basic difference in the orbital measurements was only in the height. While the orbit had a greater height than its transverse length in cattle skulls, a statistical difference was seen in the same measurements obtained from buffalo skulls. Contrary to the argument that the orbit was dorsoventrally flattened in cattle skulls [29], it was dorsoventrally elongated in this study. In contrast, the orbit of the buffalo skulls was slightly dorsoventrally flattened when compared to the transversal length. This was also reflected in the index value. A similar situation was also valid for the measurements of the foramen magnum, since the height measurement was more determinative in its index value.

In conclusion, it can be argued that there are statistically significant differences between the linear measurements of the skulls in both species. However, when the index calculation was obtained by their ratios, the values of the measurements of the facial area were determinative in the craniology. For the orbit and foramen magnum measurements, on the other hand, the measurement of the altitude was seen as more determinative than the transversal measurement in their index and form.

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