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Comparative Morphometry of the Skull of Hair Goat (*Capra aegagrus hircus*) using Different Measurement Methods: a Methodological Study

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Abstract

Morphometry is the branch of science that deals with the problems that arise in terms of shape by using various methods. In this sense, different measurement methods are used. The traditional morphometry technique that has been going on for years is based on measurements with digital callipers. With technological developments, three-dimensional (3D) modelling from images obtained with imaging systems has increased, which gives morphometric results closer to reality in irregular structures. For 3D modelling, images obtained from imaging systems such as CT and MRI are modelled using different software and morphometric data are obtained. In addition to these imaging systems, 3D models can also be created from images obtained with a tool called photogrammetry. The aim of this study is to determine the craniometric data of Hair goats by using different measurement methods. For this purpose, a total of 14 Hair goat skulls, 7 female and 7 male, were used. From each skull, 38 parameters were measured with the specified measurement methods (digital calliper, modelling with photogrammetry and modelling with the 3D-slicer programme). Seven index calculations and statistical analyses were performed. As a result of the analyses, a statistical difference was determined between the techniques in 16 parameters in male goats, while the difference was observed in 13 parameters in female goats. In addition, facial index 1 and orbital index values in male goats differed between the methods, while differences were observed in facial index 1, basal index, and palatal index values in female goats ($p<0.05$). As a result of the study, it was thought that the use of images and 3D models obtained from bones scanned with different methods should be a priority in osteometric measurements, especially since the results of measurements made in a digital environment provide closer results to reality. Since the skull bones used in the study consist of irregular bones, it is thought that differences may be observed, but statistical differences between the methods should not be ignored.

Keywords: Craniometry, Hair goat, methodology, photogrammetry, 3D modelling

Introduction

Morphometry is a field that addresses questions that arise in terms of shape and provides results by using statistical analyses (1). Morphometric measurements are carried out using various methods today.

Traditional morphometry, which is the first of these methods, measures the parameters such as width, length, and depth of the structures by using angles, anatomical points, and ratios on the structure. The data obtained are analyzed by statistical methods (2). Differences in the shape of the organism examined with this method are generally explained by comparing them to geometric objects of known shape (3).

The method used with technological developments in recent years is three-dimensional (3D) modelling using different programmes. With modelling, the bone structures whose CT images are taken are modelled with certain programmes and their morphometric properties are determined (4-7). Photogrammetry is the method that can be used in the investigation of the anatomy and morphometry

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of large-sized animals, which are very difficult to obtain CT or MR images, with advantages such as low cost and not exposing the animal to radiation (8,9). Photogrammetry is a useful tool for obtaining morphometric data in anatomical structures that are difficult to measure. In addition, the ability to make measurements on the photographic projection of the object makes photogrammetry advantageous (10), and it has been reported as a reliable method in osteometric examinations and evaluations (11).

The brain, which has a very complex structure within the skull, contains vital centers related to vision, hearing, and balance. In addition, the initial parts of the digestive and respiratory systems are also located here (12-14). The reason why the skull is the most frequently used skeletal bone in taxonomy is that, together with the mandible and all the formations on it, it allows distinction between races and species and even between sexes (15-17). It is a fact that the biometric details of the skull should be well-known in clinical and surgical applications (18). Cranium morphometry is frequently used in disciplines such as dentistry, taxonomy, forensic medicine, and zooarchaeology in the design of implants or instruments produced by diagnosing cranial or dental deformities (19-23).

The domesticated goat (*Capra hircus*) is a member of the family Bovidae and Caprinae subfamily of animals (24). The hair goat (*Capra aegagrus hircus*) is one of the breeds that belong to the Capra species. Hair goats are bred all around Turkey, but particularly in the Mediterranean and Aegean regions. These goats can make good use of inadequate grazing conditions and are resilient to adverse environmental conditions (25).

This study aimed to compare the osteometric features of the cranium bones of Hair goats using different measurement methods (digital calliper, photogrammetry, 3D-slicer modelling) and to determine the relationship between the methods. In addition, another aim is to determine the craniometric characteristics and to determine the similarities and differences with other goat breeds.

Materials and Methods

Skulls of 7 female and 7 male Hair goats were used in our study. The bones were collected from goats slaughtered in the slaughterhouse of Elazığ province. The animals whose skulls were collected were healthy and adult (1-3 years old) animals raised on the same farm.

With the ethics committee Document date and number is 30.12.2024-30020, the Fırat University Experimental Animals Application and Research Centre approved the procedures used in our investigation.

Three different techniques were used in the study. After the maceration process, the skulls were measured with digital callipers. The skulls were then scanned via photogrammetry and modeled. In the last stage, computed tomography (CT) images were taken and modeled in 3D-Slicer software. For each technique, 38 parameters were measured from the skulls. The measurement parameters were determined according to von Driesch (26) and Güzel and İşbilir, (27).

1.1.Digital calliper (Mitutoyo, CDN-20C, Japan)

After maceration on the skulls, 38 measurement parameters were measured manually with a digital calliper (Figure 1).

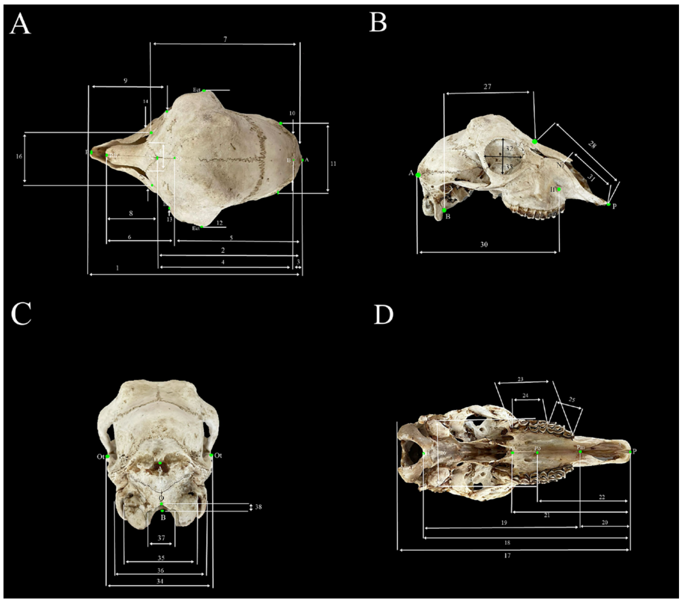

Figure 1. Skull measurement points with digital caliper. A: Dorsal, B: Lateral, C: Caudal, D: Ventral.

1.2.Photogrammetry technique

Skulls prepared for morphometric analysis were modeled using a Shining 3D EinScan Pro 2X 3D scanner. The HD (high-resolution) scanning mode was specifically selected to provide detailed and accurate digital representations of the skulls. During the scanning process, manual scanning mode was used, which allowed the operator to carefully move the scanner around the skull to capture all angles and features. The scan speed was set to 20 frames per second, which provided a balance between capturing detail and managing the data processing load. The point distance, which determines the resolution of the scan, was also set to a maximum of 0.2 mm. This good resolution allowed even the smallest morphological features of the skulls to be accurately recorded.

1.3. 3D-slicer technique

The Hair goat skulls were scanned with a 64-slice Siemens computer tomography device at 80 kV, 200 MA, 639 mGY, and a section thickness of 0.625 mm. For this purpose, scans were performed at the Department of Radiology, Faculty of Medicine, Dicle University. The images obtained were saved in DICOM format. Afterward, 3D reconstruction images were created from the images with 3D-Slicer 5.6.2 software. Figure 2 shows the measurement points with the 3D-slicer.

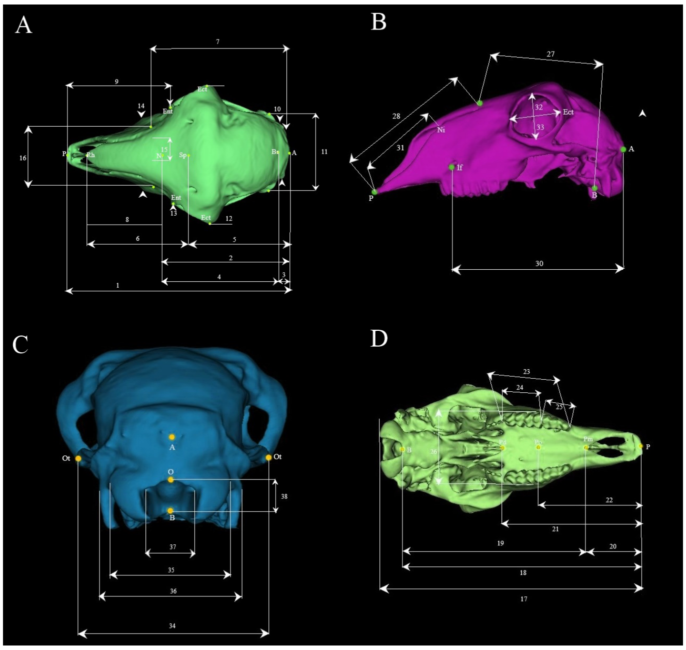

Figure 2. Skull measurement points with 3D-slicer software. A: Dorsal, B: Lateral, C: Caudal, D: Ventral.

The following osteometric measurements were made with each technique.

Craniometric parameters:

C1. The total skull length
C2. Greatest breadth of the skull
C3. Akrokranion-bregma
C4. Frontal length greatest length of nasals bone
C5. Upper neurocranium length
C6. Facial length
C7. Akrokranion-infraorbitale of one side
C8. The Greatest length of nasals bone
C9. Short lateral facial length
C10. Least breadth of the parietal bone
C11. Greatest neurocranium breadth
C12. Greatest breadth across the orbits
C13. Least breadth between the orbits
C14. Facial breadth
C15. Greatest breadth across the nasals
C16. Greatest breadth across the premaxillae
C17. The condylobasal length – from incisive bone to the occipital Condyles
C18. Basal length
C19. Short skull length
C20. Premolare-prosthion
C21. Dental length
C22. Oral palatal length
C23. Length of the cheek tooth row
C24. Length of the molar row
C25. Length of the premolar row
C26. Greatest palatal breadth
C27. Neurocranium length
C28. Viscerocranium length
C29. Greatest length of the lacrimal bone
C30. From the aboral (Between the foramen infraorbital and the upper
point of the foramen magnum)
C31. Lateral length of the premaxilla
C32. Greatest inner length of the orbit
C33. Greatest inner height of the orbit
C34. Greatest mastoid breadth of the paraoccipital processes.
C35. Greatest breadth of the occipital condyles
C36. Greatest breadth at breadth of the paraoccipital processes
C37. Greatest breadth of the foramen magnum
C38. Height of the foramen magnum

In this study, 7 craniofacial indexes were calculated as follows (28).

Skull index: Greatest breadth of the skull/Total length × 100

Facial index 1: Facial breadth/Viscerocranium length × 100

Facial index 2: Greatest breadth of the skull/Viscerocranium length × 100

Basal index: Greatest breadth of the skull/Basal length × 100

Palatal index: Greatest palatal breadth/Dental length × 100

Orbital index: Greatest inner height of the orbit/Greatest inner length of the orbit × 100

Foramen magnum index: Height of the foramen magnum/Greatest breadth of the foramen magnum × 100

The obtained measurement data were statistically evaluated with the SPSS 22.0 program. A One-way ANOVA test was used to evaluate the differences between the techniques after analyzing the normal distribution of the data.

Results

In our study, we compared 38 measurement parameters taken from the skull of a Hair goat with three different measurement techniques. The measurements obtained showed that females were larger in some parameters, while males were larger in some parameters. As a result of the measurement with 3D-slicer, the C1 parameter was higher in both males and females compared to the other techniques. C1 measurement result was statistically insignificant in males when all three techniques were compared ($p>0.05$). In females, a statistical difference was observed between digital callipers and the other two measurement techniques

Table 1. Measurement parameters of photogrammetry, digital calliper and 3D-slicer on male skulls of Hair goat (One-way ANOVA).

		N	Mean	Std. Error	Minimum	Maximum
C1	1.00	7	184.48$^{(a)}$	3.655	173.90	196.30
	2.00	7	194.10$^{(a)}$	6.203	177.60	224.60
	3.00	7	199.07$^{(a)}$	.432	197.65	201.36
C2	1.00	7	98.81$^{(a)}$	2.985	89.01	110.40
	2.00	7	107.25$^{(a)}$	2.831	97.50	114.10
	3.00	7	111.35$^{(b)}$	.424	109.98	113.20
C3	1.00	7	16.73$^{(a)}$	.456	14.91	17.99
	2.00	7	21.25$^{(a)}$	3.711	12.40	40.70
	3.00	7	17.82$^{(a)}$	.260	17.10	18.68
C4	1.00	7	92.05$^{(a)}$	2.511	81.42	101.80
	2.00	7	93.11$^{(a)}$	3.385	78.20	102.70
	3.00	7	98.44$^{(a)}$	.195	97.99	99.18
C5	1.00	7	89.72$^{(a)}$	1.455	81.94	93.46
	2.00	7	84.18$^{(a)}$	4.605	66.90	100.00
	3.00	7	85.19$^{(a)}$	.735	83.65	88.82
C6	1.00	7	87.60$^{(a)}$	8.279	65.65	120.00
	2.00	7	91.52$^{(a)}$	4.737	74.00	106.30
	3.00	7	106.13$^{(a)}$	.375	104.95	108.02
C7	1.00	7	132.71$^{(a)}$	3.549	121.50	149.10
	2.00	7	130.60$^{(a)}$	4.959	106.70	144.00
	3.00	7	143.69$^{(b)}$	.387	142.08	145.35
C8	1.00	7	59.57$^{(a)}$	3.737	49.13	75.88
	2.00	7	66.90$^{(a)}$	4.554	54.00	81.70
	3.00	7	72.66$^{(b)}$	.319	71.35	74.15
C9	1.00	7	98.56$^{(a)}$	2.535	90.10	107.80
	2.00	7	99.38$^{(a)}$	3.177	92.30	114.90
	3.00	7	96.50$^{(a)}$	.431	95.21	98.10
C10	1.00	7	43.81$^{(ab)}$	3.304	14.59	39.50
	2.00	7	42.04$^{(b)}$	1.561	38.40	49.80
	3.00	7	45.21$^{(a)}$	.604	43.05	47.65
C11	1.00	7	46.58$^{(a)}$	3.370	34.48	62.40
	2.00	7	58.67$^{(b)}$	2.651	47.40	66.50
	3.00	7	54.44$^{(a)}$	.343	52.99	55.95
C12	1.00	7	89.85$^{(a)}$	2.707	75.36	97.86
	2.00	7	92.10$^{(a)}$	2.137	81.50	99.70
	3.00	7	96.94$^{(a)}$	.502	94.66	98.45
C13	1.00	7	68.18$^{(a)}$	1.747	63.54	74.51
	2.00	7	67.01$^{(a)}$	.789	63.70	69.90
	3.00	7	70.09$^{(a)}$	.345	68.85	71.25
C14	1.00	7	56.62$^{(a)}$	1.048	53.55	61.87
	2.00	7	58.87$^{(a)}$	.716	57.10	62.90
	3.00	7	56.09$^{(b)}$	.284	54.98	56.95
C15	1.00	7	24.48$^{(a)}$	1.082	20.66	28.47
	2.00	7	25.28$^{(a)}$	1.233	21.30	30.10
	3.00	7	22.71$^{(a)}$	.200	22.01	23.56
C16	1.00	7	32.84$^{(a)}$	1.314	25.94	36.45
	2.00	7	32.45$^{(a)}$	.935	30.00	36.40
	3.00	7	32.68$^{(a)}$	.461	30.65	34.10
C17	1.00	7	178.00$^{(a)}$	3.343	169.60	191.80
	2.00	7	177.41$^{(a)}$	3.781	163.10	191.20
	3.00	7	185.54$^{(a)}$	8.234	136.20	195.20
C18	1.00	7	159.70$^{(a)}$	3.222	151.20	173.80
	2.00	7	160.28$^{(a)}$	2.832	151.20	172.70
	3.00	7	181.63$^{(b)}$	.784	178.65	184.20
C19	1.00	7	127.56$^{(a)}$	2.483	118.80	137.40
	2.00	7	122.38$^{(a)}$	3.717	109.40	136.60
	3.00	7	127.86$^{(a)}$	.513	125.68	129.52
C20	1.00	7	38.39$^{(a)}$	2.291	34.07	50.96
	2.00	7	39.68$^{(a)}$	2.959	28.10	49.70
	3.00	7	44.69$^{(a)}$	.538	43.64	47.62
C21	1.00	7	90.75$^{(a)}$	1.665	84.98	98.17
	2.00	7	91.14$^{(a)}$	2.071	84.80	100.10
	3.00	7	98.43$^{(b)}$	.298	97.41	99.64
C22	1.00	7	73.21$^{(a)}$	1.362	68.14	79.61
	2.00	7	63.80$^{(a)}$	3.681	53.50	80.30
	3.00	7	71.97$^{(b)}$	.476	69.98	73.25
C23	1.00	7	50.51$^{(a)}$	1.429	45.45	55.69
	2.00	7	49.87$^{(a)}$	1.132	45.80	54.80
	3.00	7	47.51$^{(a)}$	.471	45.82	49.35
C24	1.00	7	35.80$^{(a)}$	1.216	30.97	40.82
	2.00	7	36.07$^{(a)}$	1.404	32.00	42.50
	3.00	7	29.78$^{(b)}$	.302	28.64	31.20
C25	1.00	7	15.58$^{(a)}$	.269	14.61	16.58
	2.00	7	15.54$^{(a)}$	.431	14.50	17.50
	3.00	7	15.18$^{(a)}$	.191	14.20	15.68
C26	1.00	7	58.07$^{(a)}$	2.041	50.13	67.77
	2.00	7	56.18$^{(a)}$	1.663	51.80	64.40
	3.00	7	52.74$^{(a)}$	.602	50.20	54.10
C27	1.00	7	103.77$^{(a)}$	1.653	97.82	111.30
	2.00	7	105.90$^{(a)}$	1.991	97.30	110.90
	3.00	7	109.26$^{(b)}$	.357	107.98	110.36
C28	1.00	7	100.52$^{(a)}$	3.298	82.58	108.60
	2.00	7	106.27$^{(a)}$	2.062	99.40	112.30
	3.00	7	112.04$^{(b)}$	.286	111.09	113.50
C29	1.00	7	34.78$^{(a)}$	2.644	24.24	43.78
	2.00	7	36.54$^{(a)}$	4.185	19.30	57.20
	3.00	7	30.02$^{(a)}$	.347	28.65	31.20
C30	1.00	7	124.45$^{(a)}$	2.688	115.40	134.90
	2.00	7	134.04$^{(b)}$	3.120	123.60	144.70
	3.00	7	138.95$^{(b)}$	.305	138.20	140.31
C31	1.00	7	57.57$^{(a)}$	1.724	51.75	62.85
	2.00	7	56.15$^{(a)}$	3.781	38.50	66.00
	3.00	7	62.73$^{(a)}$	.399	61.01	64.05
C32	1.00	7	35.34$^{(a)}$	.704	32.41	38.03
	2.00	7	35.91$^{(a)}$	.999	32.30	40.50
	3.00	7	33.81$^{(a)}$	.413	32.10	35.46
C33	1.00	7	36.17$^{(a)}$	1.738	31.26	43.17
	2.00	7	33.74$^{(a)}$	.705	31.90	37.50
	3.00	7	32.05$^{(b)}$	.307	31.02	33.05
C34	1.00	7	81.44$^{(a)}$	1.495	76.93	87.30
	2.00	7	76.54$^{(a)}$	2.883	64.20	85.00
	3.00	7	62.64$^{(b)}$	.375	61.05	64.10
C35	1.00	7	46.36$^{(a)}$	1.374	42.74	53.14
	2.00	7	50.27$^{(a)}$	2.971	42.60	66.00
	3.00	7	46.15$^{(a)}$	.641	44.20	48.25
C36	1.00	7	60.85$^{(a)}$	.994	58.81	65.26
	2.00	7	62.74$^{(a)}$	2.021	57.90	73.00
	3.00	7	57.79$^{(b)}$	.205	57.02	58.48
C37	1.00	7	19.20$^{(a)}$	1.206	16.46	25.32
	2.00	7	19.40$^{(a)}$	.571	17.40	21.50
	3.00	7	16.78$^{(a)}$	.684	14.95	19.65
C38	1.00	7	19.79$^{(a)}$	.528	18.09	21.64
	2.00	7	19.55$^{(a)}$	.419	17.90	21.30
	3.00	7	18.38$^{(a)}$	.228	17.50	19.50

a,b,ab:Values within a column with different superscripts are significantly different ($p < 0.05$).

1.00: photogrammetry; 2.00: Digital calliper; 3.00: 3D-slicer

Table 2. Measurement parameters of photogrammetry, digital calliper and 3D-slicer on female skulls of Hair goat (One-way ANOVA)

		N	Mean	Std. Error	Minimum	Maximum
C1	1.00	7	198.67$^{(a)}$	2.903	187.20	207.70
	2.00	7	195.82$^{(b)}$	3.661	184.20	209.20
	3.00	7	206.03$^{(a)}$	.569	204.28	208.65
C2	1.00	7	111.56$^{(a)}$	2.764	99.15	120.60
	2.00	7	111.70$^{(a)}$	3.311	100.70	124.10
	3.00	7	112.90$^{(a)}$	1.372	105.10	116.25
C3	1.00	7	15.76$^{(a)}$	.787	12.92	18.20
	2.00	7	17.52$^{(a)}$	1.383	11.00	22.80
	3.00	7	19.20$^{(b)}$	.129	18.65	19.62
C4	1.00	7	96.53$^{(a)}$	4.007	82.80	108.50
	2.00	7	99.57$^{(a)}$	3.427	88.00	111.30
	3.00	7	102.39$^{(a)}$	.229	101.37	103.26
C5	1.00	7	100.73$^{(a)}$	2.838	88.59	110.90
	2.00	7	93.55$^{(a)}$	3.024	87.20	109.70
	3.00	7	84.44$^{(b)}$	.399	83.45	86.10
C6	1.00	7	98.77$^{(a)}$	12.532	68.45	165.60
	2.00	7	91.91$^{(a)}$	5.012	70.70	108.30
	3.00	7	108.12$^{(a)}$	.207	106.98	108.65
C7	1.00	7	141.85$^{(a)}$	2.132	133.60	148.40
	2.00	7	140.60$^{(a)}$	1.394	136.00	146.50
	3.00	7	150.82$^{(b)}$	.288	149.65	152.02
C8	1.00	7	62.48$^{(a)}$	4.250	40.74	75.49
	2.00	7	64.17$^{(a)}$	3.365	52.30	77.80
	3.00	7	74.12$^{(a)}$	.396	73.25	76.38
C9	1.00	7	106.71$^{(a)}$	2.296	96.19	112.70
	2.00	7	107.02$^{(a)}$	2.835	92.90	113.90
	3.00	7	112.48$^{(a)}$	.386	110.25	113.15
C10	1.00	7	32.72$^{(a)}$	2.916	19.11	40.42
	2.00	7	38.58$^{(b)}$	1.140	34.10	42.50
	3.00	7	44.17$^{(b)}$	.477	42.95	46.44
C11	1.00	7	54.39$^{(a)}$	4.177	37.29	65.03
	2.00	7	64.42$^{(a)}$	4.067	43.60	77.00
	3.00	7	62.97$^{(a)}$	.238	61.95	63.50
C12	1.00	7	101.94$^{(a)}$	1.168	97.25	105.50
	2.00	7	91.87$^{(a)}$	7.868	45.60	103.90
	3.00	7	101.37$^{(a)}$	.230	100.35	102.12
C13	1.00	7	74.88$^{(a)}$	2.226	70.31	87.65
	2.00	7	68.41$^{(a)}$	3.347	56.30	82.40
	3.00	7	71.19$^{(a)}$	.196	70.85	72.35
C14	1.00	7	61.14$^{(a)}$	1.631	54.02	67.24
	2.00	7	61.27$^{(a)}$	2.499	53.70	75.00
	3.00	7	63.72$^{(a)}$	.167	63.10	64.20
C15	1.00	7	24.77$^{(a)}$	1.286	19.79	30.66
	2.00	7	30.92$^{(b)}$	1.710	24.80	36.40
	3.00	7	22.18$^{(a)}$	.340	21.10	23.50
C16	1.00	7	36.19$^{(a)}$	.889	33.14	40.34
	2.00	7	33.87$^{(a)}$	1.264	29.00	38.30
	3.00	7	24.00$^{(b)}$	.344	22.98	25.65
C17	1.00	7	190.57$^{(a)}$	3.066	179.90	199.10
	2.00	7	189.78$^{(a)}$	4.633	167.90	206.40
	3.00	7	196.45$^{(a)}$	.626	194.06	198.56
C18	1.00	7	172.11$^{(a)}$	2.337	163.80	178.00
	2.00	7	171.15$^{(a)}$	3.469	155.40	183.50
	3.00	7	176.92$^{(a)}$	.510	175.35	179.03
C19	1.00	7	131.94$^{(a)}$	3.819	118.00	140.50
	2.00	7	124.74$^{(a)}$	3.653	109.90	136.10
	3.00	7	125.63$^{(a)}$	.777	122.98	128.65
C20	1.00	7	48.90$^{(a)}$	3.441	36.18	59.44
	2.00	7	46.51$^{(a)}$	1.444	40.50	51.80
	3.00	7	52.80$^{(a)}$	.203	52.12	53.45
C21	1.00	7	101.35$^{(a)}$	3.434	93.82	120.40
	2.00	7	100.90$^{(a)}$	3.281	89.30	113.00
	3.00	7	102.06$^{(a)}$	.338	100.71	103.45
C22	1.00	7	77.72$^{(a)}$	3.550	63.70	94.33
	2.00	7	74.95$^{(a)}$	2.813	66.50	89.10
	3.00	7	67.21$^{(b)}$	.713	64.52	69.20
C23	1.00	7	57.18$^{(a)}$	1.499	49.16	61.39
	2.00	7	55.44$^{(a)}$	2.745	46.23	64.10
	3.00	7	54.39$^{(a)}$	.634	52.15	57.35
C24	1.00	7	40.86$^{(a)}$	2.250	32.89	48.39
	2.00	7	39.18$^{(a)}$	2.819	28.70	49.10
	3.00	7	31.63$^{(b)}$	.442	30.20	33.55
C25	1.00	7	15.65$^{(a)}$	.683	13.94	19.26
	2.00	7	17.31$^{(a)}$	.796	14.90	20.80
	3.00	7	16.98$^{(a)}$	.371	15.45	18.52
C26	1.00	7	57.20$^{(a)}$	2.244	50.15	67.50
	2.00	7	62.24$^{(a)}$	3.963	55.00	78.80
	3.00	7	55.31$^{(a)}$	.413	54.18	57.43
C27	1.00	7	108.10$^{(a)}$	1.406	104.20	115.70
	2.00	7	113.12$^{(a)}$	2.521	105.10	124.20
	3.00	7	110.98$^{(a)}$	.262	110.24	112.20
C28	1.00	7	116.61$^{(a)}$	7.646	101.20	161.20
	2.00	7	115.87$^{(a)}$	3.989	101.80	129.80
	3.00	7	115.15$^{(a)}$	.443	113.98	117.55
C29	1.00	7	37.92$^{(a)}$	1.637	31.88	43.23
	2.00	7	36.68$^{(ab)}$	2.754	23.20	45.30
	3.00	7	25.60$^{(b)}$	.388	24.54	27.50
C30	1.00	7	138.84$^{(a)}$	3.068	126.90	148.90
	2.00	7	138.97$^{(a)}$	2.838	125.60	148.30
	3.00	7	140.79$^{(a)}$	.305	140.18	142.35
C31	1.00	7	61.39$^{(a)}$	2.243	51.13	67.56
	2.00	7	67.44$^{(a)}$	2.945	54.30	76.10
	3.00	7	64.45$^{(a)}$	.458	63.17	66.54
C32	1.00	7	37.53$^{(a)}$	.399	36.52	39.22
	2.00	7	35.81$^{(a)}$	.936	32.30	38.90
	3.00	7	32.48$^{(b)}$	.339	31.20	34.19
C33	1.00	7	35.19$^{(a)}$	1.390	32.19	43.18
	2.00	7	33.72$^{(a)}$	.833	30.70	37.10
	3.00	7	33.25$^{(a)}$	.333	32.14	34.52
C34	1.00	7	88.66$^{(a)}$	1.256	83.74	94.05
	2.00	7	89.08$^{(a)}$	1.414	82.20	93.20
	3.00	7	64.05$^{(b)}$	.536	62.18	66.27
C35	1.00	7	46.50$^{(a)}$	.733	42.74	48.41
	2.00	7	48.68$^{(a)}$	.863	45.80	52.30
	3.00	7	48.81$^{(a)}$	.390	47.05	49.81
C36	1.00	7	62.96$^{(a)}$	.388	61.47	64.67
	2.00	7	62.67$^{(a)}$	.836	59.90	65.50
	3.00	7	58.83$^{(b)}$	.238	57.98	59.88
C37	1.00	7	20.47$^{(a)}$	.495	18.64	22.03
	2.00	7	20.80$^{(a)}$	.578	18.20	22.70
	3.00	7	18.77$^{(b)}$	.320	17.56	19.85
C38	1.00	7	19.06$^{(a)}$	.794	16.76	21.97
	2.00	7	19.41$^{(a)}$	.847	16.20	22.20
	3.00	7	16.98$^{(a)}$	.414	15.51	18.45

a,b,c,Values within a column with different superscripts are significantly different ($p < 0.05$).

1.00: photogrammetry; 2.00: Digital calliper; 3.00: 3D-slicer

Table 3. Comparative male Hair goat Indexes of skulls (One-way ANOVA)

		N	Mean	Std. Error	Minimum	Maximum
SI	1.00	7	56.21(a)	1.538	49.23	60.33
	2.00	7	57.02(a)	1.201	53.20	62.54
	3.00	7	54.80(a)	.682	51.18	56.91
FI1	1.00	7	53.38(a)	2.804	39.80	60.47
	2.00	7	53.30(a)	2.883	41.37	64.60
	3.00	7	55.34(b)	.244	54.20	56.14
FI2	1.00	7	98.18(a)	6.595	61.51	111.05
	2.00	7	97.04(a)	4.256	82.22	115.23
	3.00	7	98.08(a)	1.500	89.41	101.47
BI	1.00	7	64.89(a)	1.816	55.95	69.77
	2.00	7	65.25(a)	1.291	59.26	69.55
	3.00	7	63.82(a)	.850	59.15	66.30
PI	1.00	7	56.54(a)	1.862	51.45	65.28
	2.00	7	61.91(a)	4.015	50.60	82.43
	3.00	7	54.19(a)	.523	52.80	57.03
OI	1.00	7	109.97(a)	4.343	100.59	134.94
	2.00	7	105.40(b)	2.602	95.94	115.94
	3.00	7	103.91(c)	1.041	100.44	107.88
FMI	1.00	7	92.98(a)	2.245	83.38	99.73
	2.00	7	94.35(a)	6.535	71.37	121.98
	3.00	7	90.54(a)	2.341	82.37	99.77

a,b,c: Values within a column with different superscripts are significantly different ($p < 0.05$).

1.00: photogrammetry; 2.00: Digital calliper; 3.00: 3D-slicer

Table 4. Comparative female Hair goat Indexes of skulls (One-way ANOVA)

		N	Mean	Std. Error	Minimum	Maximum
SI	1.00	7	53.61(a)	1.525	45.61	57.03
	2.00	7	55.47(a)	1.796	50.29	61.52
	3.00	7	55.93(a)	.198	55.30	56.82
FI1	1.00	7	56.74(a)	2.371	51.64	69.73
	2.00	7	55.55(a)	1.485	50.85	61.25
	3.00	7	50.06(b)	.263	49.00	50.76
FI2	1.00	7	98.59(a)	2.674	86.21	107.79
	2.00	7	101.13(a)	3.175	87.60	111.37
	3.00	7	99.39(a)	.488	98.11	101.90
BI	1.00	7	61.88(a)	1.436	54.65	65.67
	2.00	7	66.89(b)	1.181	62.65	70.55
	3.00	7	61.31(a)	.262	59.88	61.97
PI	1.00	7	64.03(a)	2.140	56.31	72.24
	2.00	7	61.71(a)	1.677	57.94	70.31
	3.00	7	53.58(b)	.530	51.53	55.00
OI	1.00	7	102.84(a)	6.256	84.56	133.20
	2.00	7	94.09(a)	1.259	91.06	100.00
	3.00	7	94.89(a)	1.728	87.48	100.25
FMI	1.00	7	104.97(a)	5.964	83.25	131.47
	2.00	7	101.20(a)	3.113	92.02	114.52
	3.00	7	110.33(a)	3.306	94.50	120.74

a,b: Values within a column with different superscripts are significantly different ($p < 0.05$).

1.00: photogrammetry; 2.00: Digital calliper; 3.00: 3D-slicer

($p<0.05$). In male goats, there was no statistical difference between photogrammetry and digital calliper measurements in the C2 parameter ($p>0.05$), there was a statistically significant difference between these two measurement techniques and 3D-slicer measurement ($p<0.01$). When Table 1 was analyzed, C3, C4, C5, C6, C9, C12, C13, C15, C16, C17, C19, C20, C23, C25, C26, C29, C31, C32, C35, C37, C38 in terms of measurement parameters in male goats did not have statistically significant differences between the three measurement techniques ($p>0.05$). Table 2 was analyzed, and it was determined that the measurement parameters of C3, C5, C7, C16, C22, C24, C32, C36, and C37 in female goats were not statistically significant ($p>0.05$) in terms of photogrammetry and digital calliper measurements. These parameters had a significant difference between the results of 3D-slicer and other techniques ($p<0.01$).

In our study, skull indices were calculated using three measurement methods. When the skulls of Hair male goats were examined (Table 3), 3D-slicer measurement results showed a statistically significant difference in facial index 1 compared to the other two techniques ($p<0.05$). The orbital index value was found to be statistically significant between all three techniques in male goats ($p<0.05$). In female Hair goats (Table 4), facial index 1 was similar to male goats and 3D-slicer results were different from the other two techniques ($p<0.05$). In female goats, digital calliper results were found to be different from the other two methods in basal index value, while 3D-slicer results showed a statistically significant difference in palatal index value compared to other techniques ($p<0.05$). Other index parameters for female and male goats did not differ for the three techniques ($p>0.05$).

Discussion

The three-dimensional modelling technique, which is used in the industrial field, has started to be used in medical sectors in terms of providing a better understanding of the details of the structure (29). The advantages of the technique are particularly evident in plastic surgery, orthopedic surgery, neurosurgery, traumatology, medical education, veterinary surgery, and anatomy education (30-31). In addition, alternative methods without radiation exposure are being investigated in the investigation of the anatomy and morphometry of large-sized animals that are difficult to perform imaging such as CT and MRI. one of these alternative methods has been recognized as photogrammetry (8). This method is used in archaeology, forensic sciences, digital arts, and medicine (33-35).

The number of methodological studies on models obtained using traditional morphometry and different imaging methods is limited (36-38). Courtenay et al. (39) compared for the first time two-dimensional (2D) and 3D methods for cut mark interpretation and classification solutions. Although it was stated that both approaches were equally valid and the use of advanced 3D methods did not contribute to an improvement in accuracy (39), there are studies indicating that computer software programs have higher accuracy of measurement data in osteometric studies (36, 40). In our study, craniometric data of 3D models obtained from two different scanners were compared with the traditional morphometry technique.

The C1 parameter in Markhoz goats was reported as 18.67 ± 0.66 cm when measured with a digital caliper (42). While this value was reported as 16.55±0.27 cm in a 3D modelling study in gazelles (Gazella subgutturosa) (42), it was found as 26.25±0.201 cm in males and 24.71±0.113 cm in females by 3D modelling in the study in Siirt-colored mohair goats (43).

In our study, no statistical difference was observed between the values obtained by photogrammetry, digital calliper, and 3D-slicer in male goats and the results were consistent with each other ($p>0.05$). In females, digital caliper data were statistically smaller than the other two methods ($p<0.05$).

Koçyiğit and Demircioğlu (44), in their methodological study on the skulls of New Zealand rabbits, stated that 3D scanning and digital calliper measurement results are compatible with each other according to the Bland-Altman (45,46) method and can be used as an alternative.

Özkadif et al. (18) reported that models obtained from CT images and models obtained from photogrammetry can be used as an alternative to each other in their study on Chinchilla femur. In this study, 10 parameters were measured and it was reported that volume and surface values showed statistical differences between the methods.

Güzel et al. (38) compared digital calliper, 3D-slicer, Mimics and ImageJ methods and programmes in sheep metacarpus and determined that 10 of the 14 measurement parameters in females and 8 in males had statistical differences between digital calliper and 3D-slicer software.

In our study, 38 parameters were measured in the skull. While no statistical difference was observed between the measurement methods in 22 parameters in male goats, a difference was found in 16 parameters. This difference showed that 3D-slicer measurement was different from other techniques in 13 parameters and digital calliper measurement was different from the other two techniques in 2 parameters. In parameter C10, 3D-slicer and digital calliper measurements differed among themselves. In female goats, 25 parameters did not differ between the methods, while 13 parameters did. It was determined that the 3D-slicer was different from the other two techniques in 10 parameters, the digital calliper was different from the other two techniques in 2 parameters and photogrammetry was different from the other two techniques in 1 parameter. In parameter C29, photogrammetry and 3D-slicer techniques differed among themselves.

According to our study results, facial index 1 and orbital index values in male goats differed between the methods, while differences were observed in facial index 1, basal index, and palatal index values in female goats ($p<0.05$). While Özkadif et al. (18) reported that there was no statistical difference between the MIMICS program and photogrammetry in femur index parameter, Koçyiğit & Demircioğlu (44) reported a difference only in cranial index values between genders in rabbit skulls in a comparison of 3D modelling and digital calliper.

In our study, cranial morphometry for both sexes in Hair goats was presented with three different measurement techniques. The results obtained suggest that the use of images and 3D models obtained from bones scanned with different methods should be a priority in osteometric measurements for reasons such as ensuring regular recording of data, preservation of archaeological materials (47) and obtaining closer to reality results in digital measurements.

Conclusion

As a result of the study, it was concluded that images and 3D models obtained from bones scanned using different methods should be prioritized in osteometric measurements, particularly because measurements taken in a digital environment provide results that are closer to reality. Although our study results suggest that the differences in measurement techniques may be due to the fact that the skull bones consist of irregular bones, the statistical differences between the methods should not be underestimated.

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