Original Article

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Anatomical evaluation of sacrum in dry bones

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Abstract

Objectives: The sacrum is a critical bone in various clinical procedures, including caudal epidural blocks, iliosacral screw placements, fetal growth assessment, and sacral nerve stimulation. This study aims to investigate the morphometry and variational morphology of the anatomical formations in the pelvis and dorsal surface of the sacrum.

Methods: Morphometric and morphological characteristics of 30 sacral bones of unknown age and sex were examined. Measurements were made using a digital caliper.

Results: The mean height of the sacrum was 106.67±10.16 mm, while their mean width was 103.60±6.78 mm. The morphometric analysis revealed that the mean length of the sacral hiatus was 18.51±7.44 mm, and the distance between the sacral cornua was 11.80±2.46 mm. The sacral hiatus was most commonly observed in an inverted 'U' shape, while the least common form was bifid. The sacral canal typically displayed a V-shaped morphology. It was determined that the apex of the sacral hiatus most frequently started at the S4 level (80%) compared to the sacral vertebra, and the base of the sacral hiatus mostly ended at the S5 level (93.4%).

Conclusion: Morphometry of the sacrum is essential in guiding clinicians, especially in interventions such as anesthesia and orthopedics. Discrepancies in parameter studies conducted in some countries suggest the significance of ethnic factors. Therefore, it is essential for the number of studies to increase and for physicians to follow the parameters of their society regarding the effectiveness of the treatments.

Keywords: caudal epidural block; sacral canal; sacral hiatus; sacrum

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Introduction

The sacrum is an important bone in our body that connects the trunk and lower extremities and joins the structure of the pelvis, which has an essential place in force transfer. The sacrum, formed by the union of five vertebrae, has two surfaces: the dorsal and pelvic surfaces. It is a triangular bone with its base above and its apex below. Its base articulates with the last lumbar vertebra above. Its apex is the lower part of the sacrum and articulates with the coccyx. Inside the sacrum is a passage called the sacral canal, which is a continuation of the vertebral canal. The four holes on the lateral side of the intermediate sacral crest are called dorsal sacral foramina. The posterior branches of the sacral spinal nerves pass through these foramina.[1,2]

The sacrum is an important bone for clinicians. The sacral length is an essential guide in evaluating fetal growth in obstetrics and gynecology.[3] In pelvic floor disorders such as constipation, fecal, and urinary incontinence, percutaneous electrodes are placed through the dorsal sacral foramina, and sacral nerve stimulation is performed.[4,5] The caudal epidural block is frequently used for anesthesia in various surgeries and for analgesia in diseases such as chronic low back pain and lumbar spinal disorders. Caudal epidural block is the injection of an anesthetic/analgesic agent into the sacral epidural region through the sacral hiatus (SH).[6,7] The protrusion at the bottom of the intermediate sacral crest, the remnant of the inferior articular process of the last sacral vertebra, is called sacral horn (corn). The SH is the opening between the sacral cornua on both sides.[8] During the caudal epidural block, compli-

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cations arise due to shape variations and size differences of the SH or technical reasons, and the success rate decreases. These complications include direct injury to spinal nerves, epidural abscess, massive subdural tear, epidural hematoma, ischemia, and hemorrhage. Therefore, caudal epidural block requires precise localization of the SH.[9,10] Any stabilization procedure with instrumentation of the sacrum may be necessary due to the sacrum fractures and associated joint injuries.[11] The iliosacral screw insertion provides stable fixation, and the iliosacral screw applied to the body of the sacrum passes through the S1 pedicle.[12] Although pedicle screws placed in the sacrum are an effective system to provide stabilization, they cause instrument loss and pseudoarthrosis at a higher rate than those applied to the lumbar vertebrae.[13] It is necessary to know the anatomy of the sacrum well to ensure safe intervention in screw-plate applications and to reduce the problems encountered.[12]

The sacrum is an important bone for various clinical situations as mentioned above. Anatomical verification and knowledge of standard structural features of the sacrum are required for a successful procedure. In addition, the procedures' reliability and success depend on the sacrum's anatomical variations. This study aims to measure the morphometry of the anatomical formations in the pelvic and dorsal surfaces of the sacrum and to investigate various variations by obtaining information about their morphology.

Materials and Methods

In this study, morphometric and morphological characteristics of 30 sacral bones of unknown age and sex were examined in the Department of Anatomy. Missing or broken sacrum were excluded from the study. Measurements of anatomical structures were made using a digital caliper (Insize 1108/ Suzhou, People's Republic of China) with a measurement range of 0–150 millimeters (mm) and sensitivity of 0.03 mm.

The following parameters were measured in the morphometric evaluation of the sacrum (**Figure 1**):

- The SH length (distance from the top of the SH to the end of the sacral cornua),
- The distance from the apex of the sacrum to the highest point of the SH,
- The length between the sacral cornua,
- The distance between the dorsal sacral foramina at the S2 level and the top of the SH,
- The distance between the upper border of the S1 vertebra and the top of the SH,
- The distance between the dorsal sacral foramina at the S2 level and the apex of the sacrum,
- The distance of the highest point of the SH to the highest point of the right lateral sacral crest,
- The distance from the highest point of the SH to the highest point of the left lateral sacral crest,

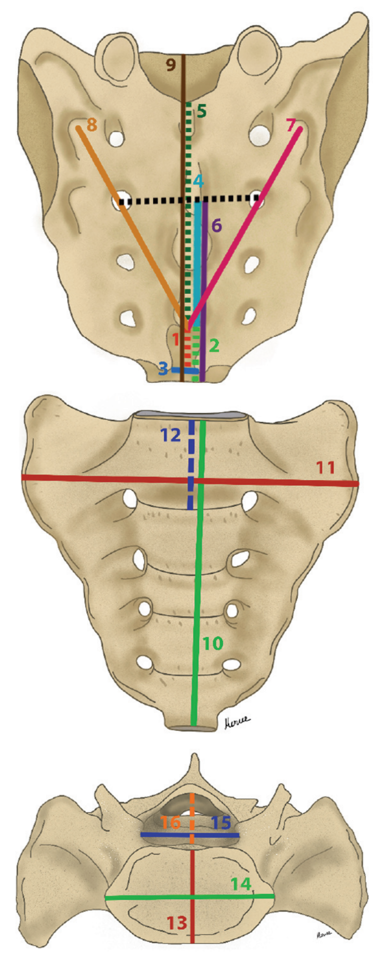

Figure 1. Morphometric measurements of the sacrum. (**a**) Posterior (dorsal) surface; **1.** Length of the sacral hiatus; **2.** The distance from the apex of the sacrum to the highest point of the SH; **3.** The length between the sacral cornua; **4.** The distance between the dorsal sacral foramina at the S2 level and the top of the SH; **5.** The distance between the upper border of the S1 vertebra and the top of the SH; **6.** The distance between the dorsal sacral foramina at the S2 level and the apex of the sacrum; **7.** The distance of the highest point of the SH to the highest point of the right lateral sacral crest; **8.** The distance from the highest point of the SH to the highest point of the left lateral sacral crest; **9.** The height of the sacrum from the dorsal surface. (**b**) Anterior (pelvic) surface; **10.** The sacral height: The distance from the apex of the sacrum to its base (promontory); **11.** The sacral width: The widest distance between the alas; **12.** The mid-height of the body of S1 (distance between the apex and base of the body of S1). (**c**) Superior aspect (base); **13.** The median diameter of the body of S1; **14.** The maximum transverse width of the body of S1; **15.** The sacral canal's maximum width; **16.** The median diameter of the sacral canal.

- The height of the sacrum from the dorsal surface,
- The sacral height: The distance from the apex of the sacrum to its base (promontory),
- The sacral width: The widest distance between the alas,
- The mid-height of the body of S1 (distance between the apex and base of the body of S1),
- The median diameter of the body of S1,
- The maximum transverse width of the body of S1,
- The sacral canal's maximum width,
- The median diameter of the sacral canal.

The following morphological features of the sacrum were also evaluated:

- The shape of the SH (**Figure 2**),
- The shape of the opening of the sacral canal (**Figure 3**),
- The shape of the articular surfaces of the superior articular process (**Figure 4**),
- The dorsal sacral foramina numbers (**Figure 5**),
- The level of the apex of the SH relative to the sacral vertebra (**Figure 6**),
- The level of the base of the SH relative to the sacral vertebra (**Figure 6**).

The sacral height, width, and mid-height of the body of S1 were measured from the pelvic surface. The measurements were repeated twice by the same researcher with an interval of 15 days and evaluated based on their means. Intraclass correlation coefficient (ICC) was computed to assess intra-observer reliability. We found excellent reliability as values were greater than 0.9 in all parameters (**Table 1**).

Statistical analysis was performed with IBM SPSS (Statistical Package for the Social Sciences) Statistics Version 22.0 (Armonk, NY, USA). Each parameter's mean, standard deviation, minimum, and maximum values were calculated. The summary of data was expressed as mean ± standard deviation and percentage.

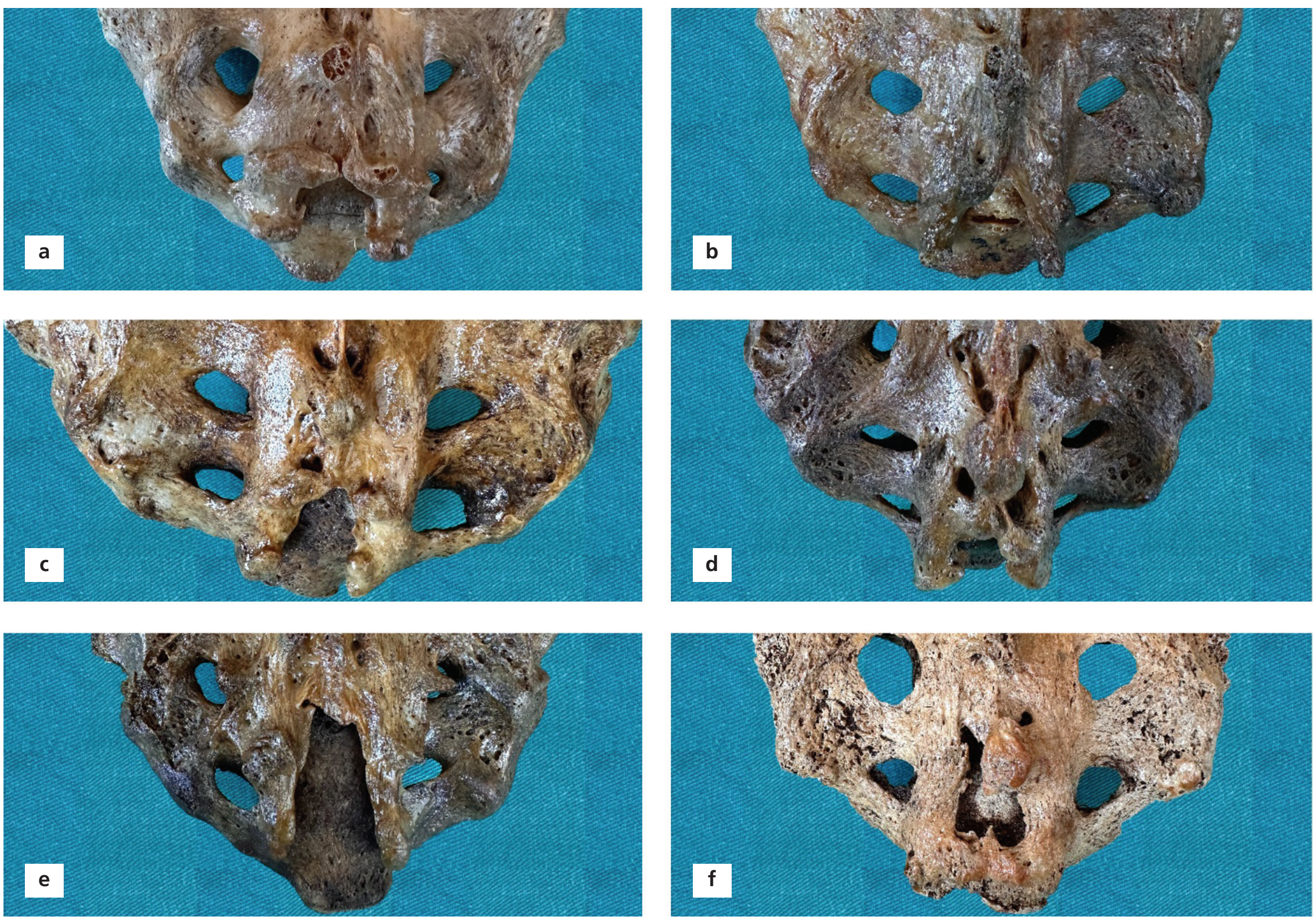

Figure 2. The shape of the sacral hiatus: (**a**) inverted 'U' shape; (**b**) inverted 'V' shape; (**c**) dumbbell shape; (**d**) 'M' shape; (**e**) irregular shape; (**f**) bifid shape.

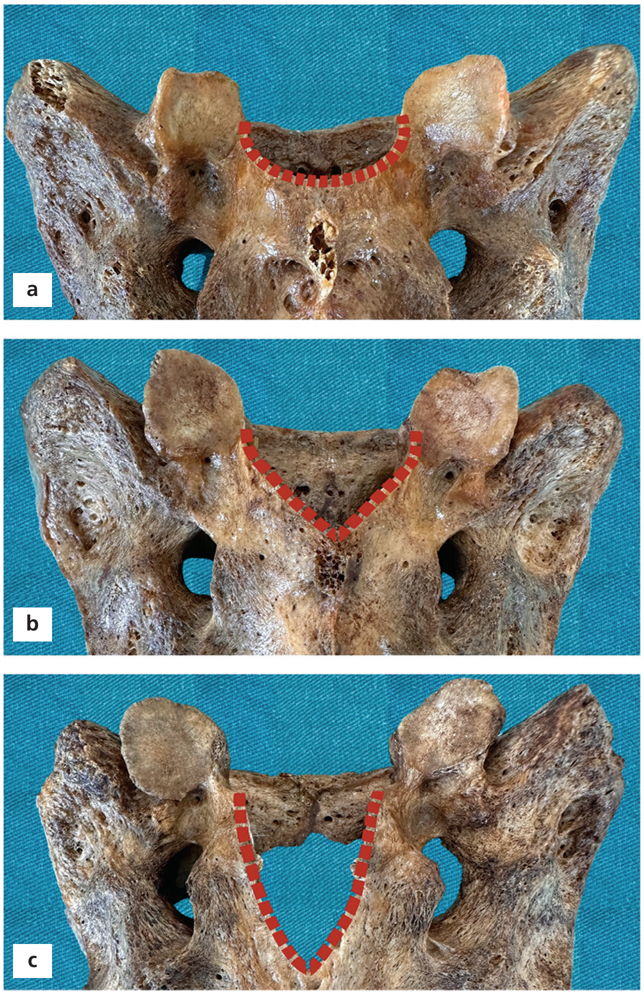

Figure 3. The shape of sacral canal: (**a**) 'U' shape, (**b**) 'V' shape, (**c**) deep 'V' shape.

Figure 4. The shape of the articular process: (**a**) bilateral concave; (**b**) bilateral flat; (**c**) right flat; left concave.

Results

The distance between the top point of the SH to the top point of the right lateral sacral crest and the top point of the left lateral sacral crest was similar. The right and left distances were measured as 73.88±8.09 mm and 74.71±8.25 mm, respectively (**Table 2**).

The shape of the SH was evaluated based on the study of Bagheri and Govsa.[10] In the form of a sacral canal, a new typing was made by evaluating the bones (**Table 3**). The SH is most commonly seen as an inverted U (n=11, 36.7%) and least as bifid (n=1, 3.4%) (**Figure 2**). The sacral canal was most commonly seen in a 'V' shape (n=15, 50%) (**Table 3**) (**Figure 3**).

The shape of the articular surfaces of the superior articular process was evaluated. While bilateral concave (53.3%) type joint surfaces were seen in 16 of 30 sacral bones, bilateral flat (33.3%) type joint surfaces were seen in 10. The remaining part (n=4, 13.4%) was found to be unilateral flat, or concave (**Figure 4**). The number of dorsal sacral foramina is generally four (n=26, 86.7%), and a small number of five foramina are seen (n=4, 13.3%) (**Figure 5**). While the top of the SH most commonly starts at the S4 level (n=24, 80%) compared to the sacral vertebral body, it has also been observed that it starts at the S3 (n=3, 10%) and S5 (n=3, 10%) levels in a small number of sacral bones. The base of the SH ends at the S5 level in 93.4% (n=28) of the sacral bones (**Figure 6**).

Discussion

The sacrum is an important bone with a broad clinical spectrum and concerns departments such as obstetrics and gynecology, anesthesia, forensic medicine, orthopedics, general surgery, and anatomy. Although there are various studies in the literature covering the sacrum and

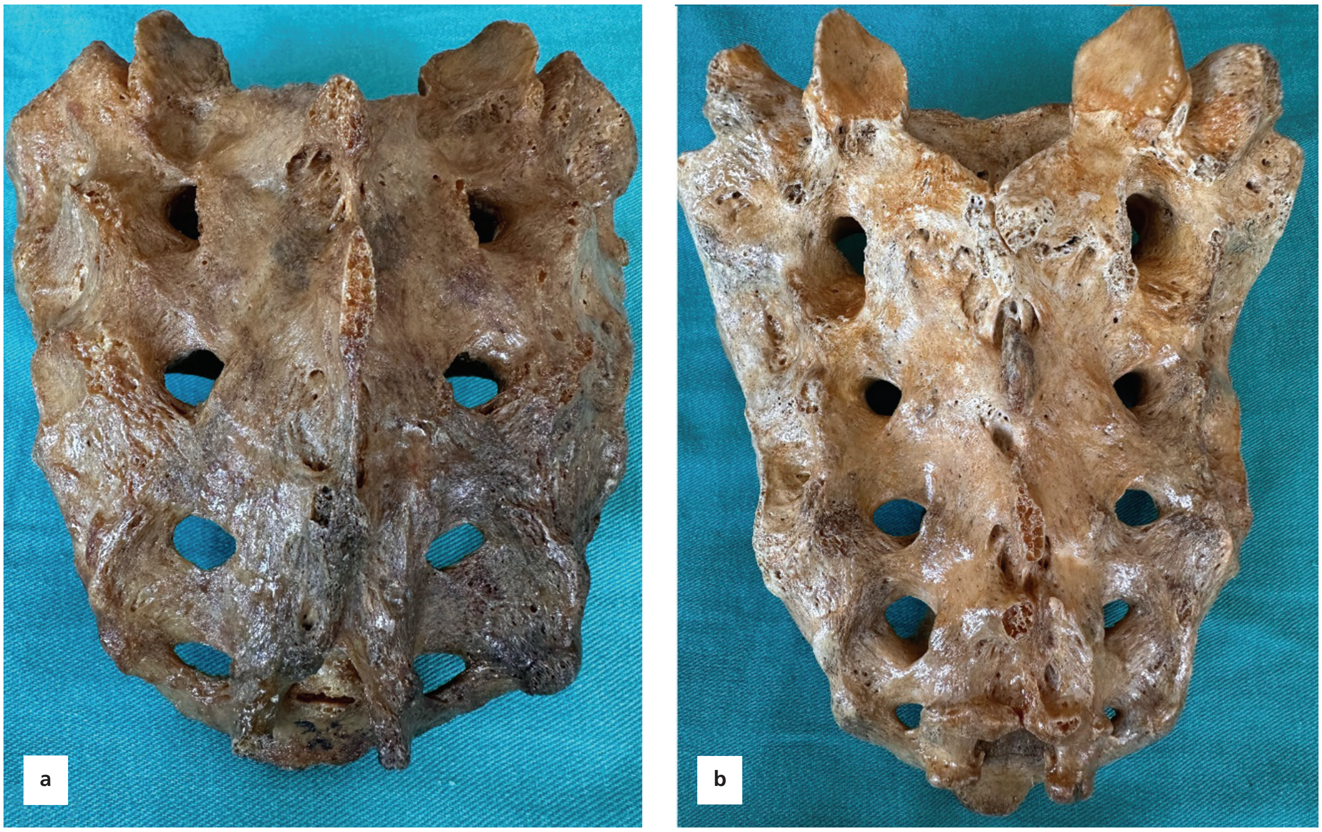

Figure 5. The number of dorsal sacral foramina: (**a**) four; (**b**) five.

Table 1
Intraclass correlation coefficients (ICC) for determination of the intra-observer correlation.

Parameter	ICC	Lower	Upper
1	0.989	0.976	0.995
2	0.926	0.852	0.964
3	0.983	0.965	0.992
4	0.997	0.994	0.999
5	0.986	0.972	0.993
6	0.945	0.888	0.973
7	0.963	0.924	0.982
8	0.996	0.992	0.998
9	0.986	0.971	0.993
10	0.997	0.993	0.998
11	0.981	0.961	0.991
12	0.986	0.970	0.993
13	0.934	0.867	0.968
14	0.973	0.944	0.987
15	0.943	0.886	0.973
16	0.932	0.864	0.967

1. The length of sacral hiatus (SH); **2.** The distance from the apex of the sacrum to the highest point of the SH; **3.** The length between the sacral cornua; **4.** The distance between the dorsal sacral foramina at the S2 level and the top of the SH; **5.** The distance between the upper border of the S1 vertebra and the top of the SH; **6.** The distance between the dorsal sacral foramina at the S2 level and the apex of the sacrum; **7.** The distance of the highest point of the SH to the highest point of the right lateral sacral crest; **8.** The distance from the highest point of the SH to the highest point of the left lateral sacral crest; **9.** The height of the sacrum from the dorsal surface; **10.** The sacral height: The distance from the apex of the sacrum to its base (promontory); **11.** The sacral width: The widest distance between the alas; **12.** The mid-height of the body of S1 (distance between the apex and base of the body of S1); **13.** The median diameter of the body of S1; **14.** The maximum transverse width of the body of S1; **15.** The sacral canal's maximum width; **16.** The median diameter of the sacral canal.

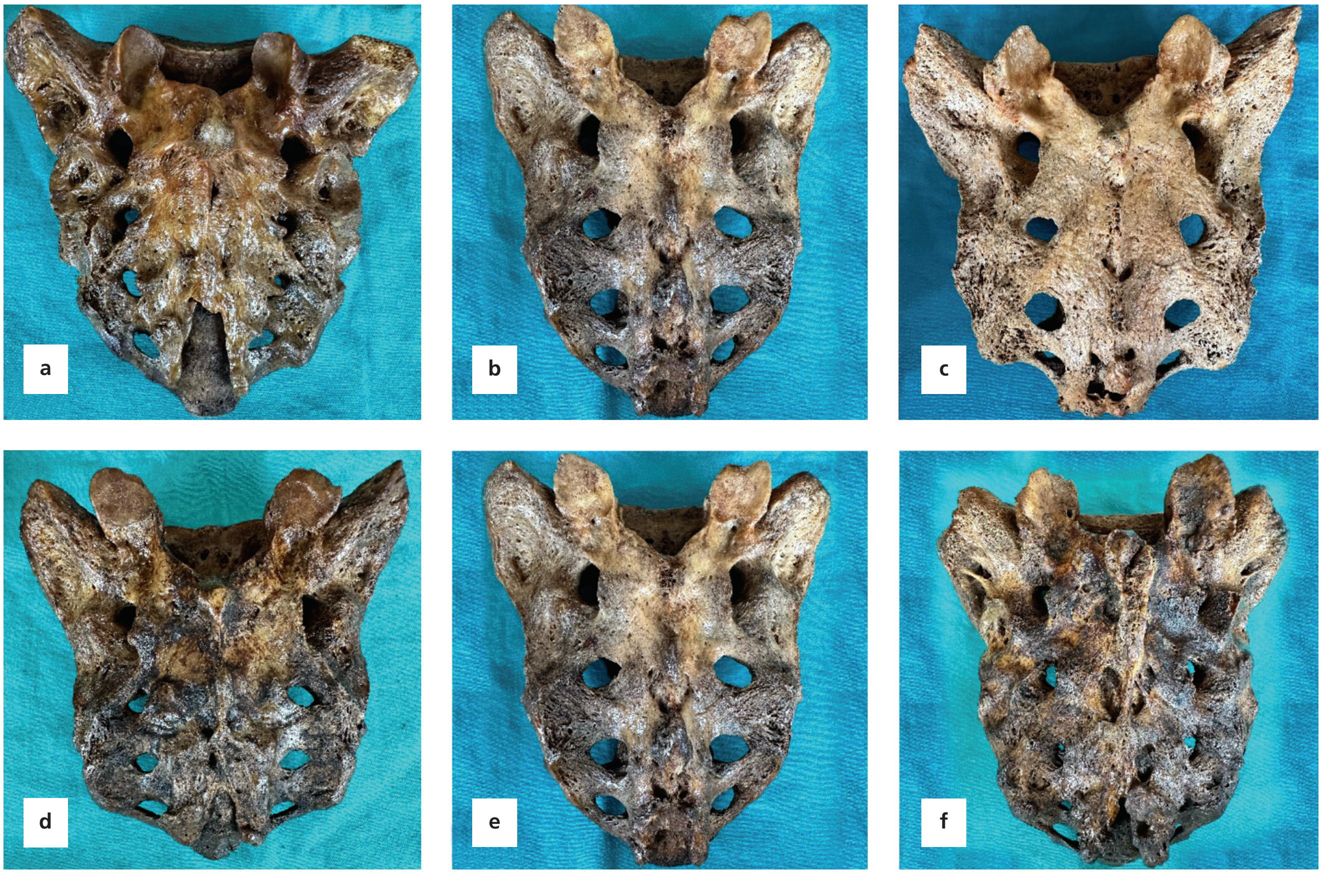

Figure 6. The proximal beginning of sacral hiatus: (**a**) S3, (**b**) S4, and (**c**) S5. The distal end of sacral hiatus: (**d**) S4, (**e**) S5, (**f**) Co1.

related clinical conditions, some of them were also conducted in the field of anatomy. Anatomical structures in the sacrum and the distances between them were evaluated in dry bones belonging to the Anatolian population by measuring them with calipers or the Image J program.[10,11,14] The shape, base, and apex views of the SH of the sacrum are grouped according to classifications.[10,15] Radiological studies such as computed tomography have also been performed in this region.[16]

The procedures performed in the caudal epidural block are performed through the SH, and various medications are administered in the epidural section. SH is usually detected by palpating the sacral cornua.[10] In order to perform a successful caudal epidural block, the length of the SH and the distance between the sacral cornua are essential. SH length has been defined in different ways in studies in the literature. In the studies of Aggarwal et al.,[9] Yılmaz et al.,[14] and Singh et al.,[17] SH length was defined as the distance from the top of the SH to the end of the sacral cornua. Senoglu et al.[6] and Bagheri and Govsa[10] defined the SH length as the distance of the sacrum's apex to the SH's highest point. Due to these differences in the literature, we made both measurements in our research. SH length measurement in study of Aggarwal et al.[9] was considered our first parameter, and SH length measurement in study of Senoglu et al.[6] was considered our second parameter (**Table 2**). Our SH length measurement is similar to the studies by Aggarwal et al.,[9] Yılmaz et al.,[14] and Singh et al.[17] Our measurement of the distance of the apex of the sacrum to the highest point of the SH is compatible with the studies of Senoglu et al.[6] and Bagheri and Govsa.[10] In a caudal epidural block, the distance between the SH and the dural sac is essential regarding the risk of dural puncture. In adults, the dural sac usually ends at the second sacral vertebra (S2) level.[6] In order to determine the distance required to avoid complications, in our study, we measured the distance of the level of the S2 vertebra to the top of the SH and the apex of the sacrum. In our study, the distance of the level of the S2 vertebra to the top of the SH and the sacrum's apex was higher than the values found in study of Singh et al.[17] (**Table 4**). We think this is due to genetic and environmental factors caused by ethnicity. In addition, the fact that values are different between societies reveals that it is essential for each population to create its reference values. We think that our study may contribute to the literature to determine the reference values of the Turkish population.

Another clinically significant feature of the sacrum is its use in iliosacral screwing. Data about the sacrum are essential for the treatment method used in various orthopedic diseases. The iliosacral screw is applied to the body of first sacral vertebra (S1) for the treatment of sacrum fractures and associated joint injuries.[12,18] S1 screwing can be applied anteriorly, anteromedially, and anterolaterally.[13] The diameter of the S1 vertebra was found to be 31±3 mm in study of Basaloglu et al.,[12] while it was 29.47±2.43 mm in study of Sinha et al.[18] Our study found it to be 29.55±2.87 mm, which is similar to the literature. While Morales-Ávalos et al.[19] measured the transverse width of the S1 as 48.72±4.64 mm, it was measured as 49.40±5.89 mm in study of Arman et al.[20] Our study determined it as 46.38±5.65 mm, consistent with the literature.

In our study, the heights of the sacrum were measured separately from the dorsal and pelvic surfaces. Since the inner face of the os sacrum is concave, the height of its outer face was found to be higher than the height of its inner face. These results were consistent with the study of Yılmaz et al.[14] in the Turkish population. However, when we examine the sacral height and width, there are differences due to ethnicity, and in some of the studies, unlike our study, it is observed that the sacral width is greater than the sacral height.[11,19,21]

The shape of the joint surfaces of the superior articular process appears different from each other. Like the study conducted by Elvan et al.,[15] the most common bilateral concave type of joint surface is seen. However, there may be various reasons for the appearance of joint surfaces in different shapes. It may be due to the patient's weight and height, previous diseases, and individual morphological differences.

Although the SH shape has been typed differently in the literature, inverted 'U' and inverted 'V' are included in most studies.[22–25] In our study, SH was classified according to the study of Bagheri and Govsa's[10] classification. Consistent with studies in the literature, the most common inverted 'U' shape is seen in our study.[9,15,17,26] (**Table 5**). Few studies evaluate the shape of the sacral canal in the accessible literature. Since some appear as a deeper 'V' shape, we made a new classification for the shape of the sacral canal and divided it into three different groups. Elvan et al.[15] divided the shape of the sacral canal into two groups, 'V' and 'U', and found that the 'V' shape was seen most frequently in 74% of sacrums. Although the 'V' shape was seen most frequently in our study, it was found to be present in 50% (**Table 3**), unlike the study of Elvan et al.[15]

Table 2
The morphometric parameters of the sacrum (mm).

Parameter	Mean±SD (n=30)	Range (min–max)
1	18.51±7.44	4.54–40.1
2	30.94±8.74	16.77–54.82
3	11.80±2.46	6.02–15.94
4	40.05±8.23	25.75–60.21
5	72.06±13.06	43.76–98.63
6	67.37±8.32	55.8–85.29
7	73.88±8.09	57.07–90.24
8	74.71±8.25	61.07–91.83
9	108.55±9.86	94.47–129.31
10	106.67±10.16	87.65–129.53
11	103.60±6.78	83.79–116.33
12	30.66±2.85	26.49–37.38
13	29.55±2.87	23.07–36.94
14	46.38±5.65	37.08–60.37
15	31.66±2.38	26.63–37.94
16	15.26±2.50	8.35–19.03

1. The length of sacral hiatus (SH); **2.** The distance from the apex of the sacrum to the highest point of the SH; **3.** The length between the sacral cornua; **4.** The distance between the dorsal sacral foramina at the S2 level and the top of the SH; **5.** The distance between the upper border of the S1 vertebra and the top of the SH; **6.** The distance between the dorsal sacral foramina at the S2 level and the apex of the sacrum; **7.** The distance of the highest point of the SH to the highest point of the right lateral sacral crest; **8.** The distance from the highest point of the SH to the highest point of the left lateral sacral crest; **9.** The height of the sacrum from the dorsal surface; **10.** The sacral height: The distance from the apex of the sacrum to its base (promontory); **11.** The sacral width: The widest distance between the alas; **12.** The mid-height of the body of S1 (distance between the apex and base of the body of S1); **13.** The median diameter of the body of S1; **14.** The maximum transverse width of the body of S1; **15.** The sacral canal's maximum width; **16.** The median diameter of the sacral canal.

Table 3
The results of sacral hiatus and sacral canal shapes.

The shape of the sacral hiatus	Frequency (n)	Percentange (%)
Inverted 'U'	10	33.4
Inverted 'V'	8	26.6
Dumbbell	5	16.6
M	4	13.4
Irregular	2	6.6
Bifid	1	3.4
The shape of the sacral canal	**Frequency (n)**	**Percentange (%)**
V	15	50
U	12	40
Deep V	3	10

Table 4
The morphometric parameters of the sacrum in studies (mean±SD, mm).

Parameter	Senoglu et al.[6] (2005)	Aggarwal et al.[9] (2009)	Bagheri and Govsa[10] (2017)	Yılmaz et al[14] (2018)	Singh et al.[17] (2018)	Present study (2024)
1	-	18.81±7.58	-	19.84±9.32	21.73±8.92	18.51±7.44
2	32.09±9.92	-	28.07±7.1	29.84±11.05	-	30.94±8.74
3	17.47±3.23	11.95±2.78	13.48±2.69	12.63±3.02	11.59±3.25	11.80±2.46
4	35.37±10.4	30.16±14.07	34.68±7.09	21.69±6.86	30.3±11.01	40.05±8.23
5	68.74±13.16	-	72.85±10.99	-	59.58±14.66	72.06±13.06
6	65.25±9.39	-	-	-	52.03±6.54	67.37±8.32
7	67.10±9.95	59.92±8.4	62.82±5.58	64.34±9.91	57.54±10.02	73.88±8.09
8	67.53±9.48	59.99±8.31	61.44±5.5	67.81±11.93	58.32±10.59	74.71±8.25
9	-	-	-	104.65±14.38	-	108.55±9.86
Parameter	**Basaloglu et al.[12] (2005)**	**Arman et al.[20] (2009)**	**Hassanein[21] (2011)**	**Morales-Ávalos[19] (2012)**	**Sinha et al.[18] (2013)**	**Present study (2024)**
10	103.1±11.3	-	114.3±8.8	97.49±7.16	100.07±7.9	106.67±10.16
11	105.3±7.1	-	103.9±9.1	110.04±5.97	101.78±6.97	103.6±6.78
12	30.2±2.8	30.22±2.35	30.7±4.7	31.11±2.8	28.06±2.3	30.66±2.85
13	31±3	31.42±2.83	33.6±5	31.93±2.91	29.47±2.43	29.55±2.87
14	52.6±7	49.4±5.89	54.5±6.4	48.72±4.64	46.02±4.64	46.38±5.65
15	30.3±2.5	31.31±3.16	29.4±3.9	31.07±2.65	27.77±3.83	31.66±2.38
16	15±3.2	21.81±3.66	16.4±2.7	15.13±2.4	11.95±3.79	15.26±2.5

1. The length of sacral hiatus (SH); **2.** The distance from the apex of the sacrum to the highest point of the SH; **3.** The length between the sacral cornua; **4.** The distance between the dorsal sacral foramina at the S2 level and the top of the SH; **5.** The distance between the upper border of the S1 vertebra and the top of the SH; **6.** The distance between the dorsal sacral foramina at the S2 level and the apex of the sacrum; **7.** The distance of the highest point of the SH to the highest point of the right lateral sacral crest; **8.** The distance from the highest point of the SH to the highest point of the left lateral sacral crest; **9.** The height of the sacrum from the dorsal surface; **10.** The sacral height: The distance from the apex of the sacrum to its base (promontory); **11.** The sacral width: The widest distance between the alas; **12.** The mid-height of the body of S1 (distance between the apex and base of the body of S1); **13.** The median diameter of the body of S1; **14.** The maximum transverse width of the body of S1; **15.** The sacral canal's maximum width; **16.** The median diameter of the sacral canal).

In addition to measuring the parameters related to the SH, it was also determined at which level it started relative to the vertebrae. In the relevant studies in the literature, it is seen that it most frequently starts at the S4 level and ends most frequently at the S5 level. It is also stated that it is also dokepleted at the Co1 level in fewer bones.[9,17,25,27] The findings of our study were consistent with the literature. Although the most common dorsal sacral foramina in

Table 5
The shape of sacral hiatus defined in previous studies (n).

Study	n	Country	Inverted "U'	Inverted 'V'	Dumbbell	M	Irregular	Bifid
Aggarwal et al.[9] (2009)	114	India	46	36	-	1	18	5
Nadeem[22] (2014)	100	Saudi Arabia	56	14	10	-	16	2
Malarvani et al.[24] (2015)	100	Nepal	35	32	3	-	14	2
Vasuki et al.[23] (2016)	75	India	27	15	16	-	13	3
Bagheri and Govsa[10] (2017)	87	Turkey	29	17	6	9	17	3
Kujur and Gaikwad[26] (2017)	45	India	20	11	4	-	7	2
Singh et al.[17] (2018)	56	India	34	14	2	2	4	-
David[25] (2019)	61	India	14	8	2	-	14	2
Elvan et al.[15] (2021)	20	Turkey	5	3	5	3	2	-
Present study (2024)	30	Turkey	10	8	5	4	2	1

the sacrum is four, it is stated that there are sometimes five and sometimes three foramina in the literature.[15,27,28] In our study, although there were four foramina most frequently (n=26, 86.7%), there were also five foramina in a few bones (n=4, 13.3%). The number of foramen may change due to lumbalization of the sacrum or sacralization of the lumbar and coccygeal vertebrae.[15]

One of the limitations of our study was that it was a dry bone study, so age and gender could not be determined. It is a known fact that there are differences between genders in the pelvis and sacrum. Our study does not include differences between genders. Additionally, the number of bones used in our study is relatively small. Conducting a national study on this subject and using a higher number of bones may contribute to determine reference values according to ethnicity.

Conclusion

Considering all these, morphometric measurements of the sacrum are essential to guide clinicians, especially in applications such as caudal epidural block and iliosacral screwing. The fact that there are differences between studies for some parameters in studies conducted in various countries in the literature shows that ethnicity is important. For this reason, it is essential to increase the number of studies for physicians to follow their population's parameters regarding the treatments' effectiveness.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

Author Contributions

AGÖ: Project development, data collection, data analysis, manuscript writing; ES: project development, data analysis, manuscript writing; MCT: project development, manuscript writing; AKK: project development, manuscript editing.

Ethics Approval

This study involving human participants was conducted in accordance with the ethical standards established by the Institutional and National Research Committee, following the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study approved by the Selçuk University Faculty of Medicine noninvasive clinical research ethics committee (Date: 01.08.2023, Meeting No: 2023/15, Decision No: 2023/370).

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