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Neuroanatomical Study

The human sacrum and safe approaches for screw placement

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ABSTRACT

The human sacrum is the target of lumbosacral instrumentation and decompression procedures. Such surgical interventions require detailed knowledge of the anatomy of the human sacrum. The aim of this study was to measure surgically relevant parameters. Several factors, including the one-piece composition of the sacrum, the angles of the sacral pedicles and the anteroposterior diameter of the sacral vertebral bodies distinguish the sacrum from other parts of spine. Thirty-two measurements of shape, angles and distances between parts were taken of the sacra of 100 adult West Anatolian people using a Vernier caliper accurate to 0.1 mm and goniometer. According to this morphometric study, when measured from the sagittal, the S1 facet angle was measured as 35.71° ± 9.59 and 34.70° ± 9.66, the sacral pedicle anteromedial screw trajectory angle was 35.65° ± 4.73 and 31.95° ± 3.95 and the anterolaterally oriented sacral wing screw trajectory angle was 32.65° ± 3.51 and 29.10° ± 3.14, on the right and left sides, respectively. The distance of the midline oriented S1 pedicle screw was 51.12 mm and 51.26 mm on the right and left side, respectively. The distance for sacral wing oriented screw placement was 50.13 mm and 50.46 mm on the right and left side, respectively. The anteroposterior and transverse diameter of the sacral spinal canal were 21.81 mm and 31.31 mm, respectively. Thus, this study describes anatomical specifications of the sacrum. These defined morphometric details should be taken into consideration during surgical procedures. This study also describes anatomical landmarks which will allow injury of the sacrum during surgery to be avoided.

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1. Introduction

Lumbosacral fusion and instrumentation are common procedures for several spinal disorders including spondylolisthesis, lumbar scoliosis and for metastatic, infectious, degenerative and traumatic diseases affecting the sacrum.[1–3] Sacral screws can be inserted into the S1sacral wing (anterolaterally) or into the S1 promontorium (anteromedially). If the S1 vertebra is inadequate for screw placement, screws can be inserted into the S2 sacral wing or the vertebral body to stabilize the lumbosacral junction.[4] Clinical and anatomical variations require morphometric knowledge of the sacrum.

Thus, the purpose of this study was to define the detailed anatomy of the sacrum and find the safest approach for sacral screw placement.

2. Materials and methods

This study was performed on the sacra of 100 adult West Anatolian people. The following linear and angular parameters were measured.

2.1. Linear parameters

The height and width of the first and second anterior and posterior sacral foramina (Fig. 1, arrows a1, a2, c1, c2 and Fig. 2, arrows b1, b2, d1, d2).

The interforaminal anterior and posterior transverse distances (Fig. 1, arrows e1, e2 and Fig. 2, arrows f1, f2).

The interforaminal anterior and posterior vertical distances (Fig. 1, arrow g2 and Fig. 2, arrow i).

The S1 pedicle height (Fig. 1, arrow g1 and Fig. 2, arrow h).

The S1 pedicle depth (Fig. 4, arrow l).

The sacral pedicle and sacral wing borders (Fig. 4, arrows j, k, m).

The height and the width of S1 facet joint (Fig. 2, arrows n, o).

The distance between two S1 facet joints (Fig. 2, arrow p).

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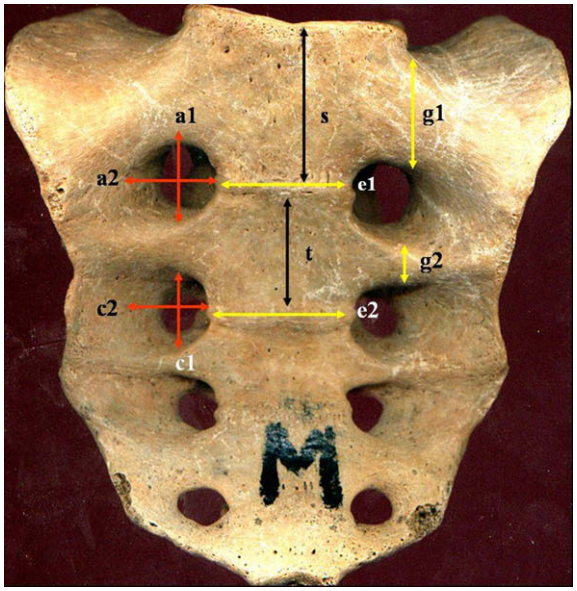


Fig. 1. Anterior face, linear parameters: (a1) the height of the first anterior sacral foramina; (a2) the width of the first anterior sacral foramina; (c1) the height of the second anterior sacral foramina; (c2) the width of the second anterior sacral foramina; (e1) the transverse distance between the first anterior sacral foramina; (e2) the transverse distance between the second anterior sacral foramina; (g1) the distance between the first anterior sacral foramen and the superior border of sacrum (anterior pedicle height); (g2) the distance between the inferior border of the first anterior sacral foramen and the superior border of the second anterior sacral foramen; (s) the height of the S1 vertebra body; (t) the height of the S2 vertebra body. This figure is available in colour at www.sciencedirect.com.

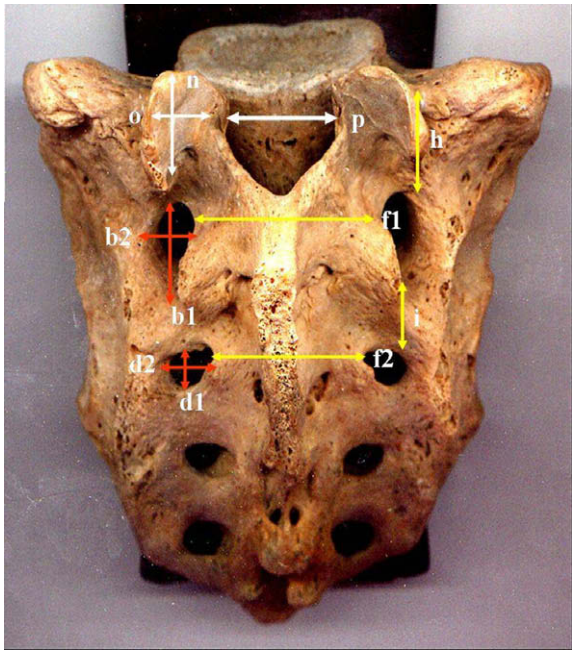


Fig. 2. Posterior face, linear parameters: (b1) the height of the first posterior sacral foramina; (b2) the width of the first posterior sacral foramina; (d1) the S2 posterior sacral foramen height; (d2) the S2 posterior sacral foramen width; (f1) the transverse distance between the first posterior sacral foramina; (f2) the transverse distance between the second posterior sacral foramina; (h) the distance between the first posterior sacral foramen and the superior border of the sacrum (posterior pedicle height); (n) the height of the S1 facet joint; (o) the width of the S1 facet joint; (p) the distance between two facet joints. This figure is available in colour at www.sciencedirect.com.

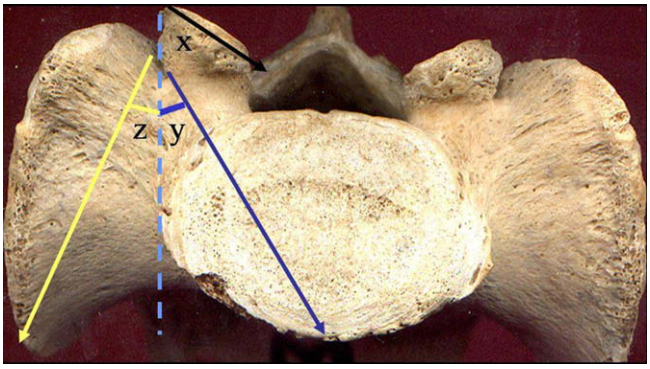


Fig. 3. Angular parameters (from the sagittal – dotted line): (x) the S1 facet angle; (y) the sacral pedicle anteromedial screw trajectory angle; (z) the anterolaterally-oriented sacral wing screw trajectory angle. This figure is available in colour at www.sciencedirect.com.

The S1 body superior surface anteroposterior and transverse diameters (Fig. 4, arrows q, r).

The height of the S1 and S2 bodies (Fig. 1, arrows s, t).

The sagittal and transverse diamaters of the spinal canal at superior aperture (Fig. 4, arrows u, v).

2.2. Angular parameters

The S1 facet angle (Fig. 3, arrow x).

The sacral pedicle anteromedial screw trajectory angle (Fig. 3, arrow y).

The anterolaterally-oriented sacral wing screw trajectory angle (Fig. 3, arrow z).

The measurements were performed using a Vernier caliper sensitive to 0.1 mm and a goniometer. All measurements are expressed as mean ± standard deviation. The angular measurements were performed on scopic radiograms after insertion of a Kirschner wire into the S1 vertebra both laterally to the sacral wing and medially to the promontory. The results are listed in Tables 1 and 2.

3. Results

3.1. Linear parameters

The height and width of the first anterior sacral foramen were 13.66 ± 2.11 mm and 13.95 ± 2.12 mm, respectively. The height and width of the second anterior sacral foramen were 13.60 ± 2.12 mm and 14.22 ± 2.48 mm, respectively (Fig. 1).

The height and width of the first posterior sacral foramen were 12.47 ± 3.16 mm and 7.97 ± 1.89 mm, respectively. The height and width of the second posterior sacral foramen were 7.62 ± 1.54 mm and 7.92 ± 1.74 mm, respectively (Fig. 2).

The transverse distance between the first anterior sacral foramina was 30.48 ± 2.78 mm. The transverse distance between the second anterior sacral foramina was 28.31 ± 2.81 mm (Fig. 1).

The distance between the first posterior sacral foramina was 38.32 ± 3.63 mm. The distance between the second posterior sacral foramina was 31.62 ± 3.27 mm (Fig. 2).

The distance between the first anterior sacral foramen and the superior border of the sacrum (anterior pedicle height) was 14.81 ± 2.32 mm. The distance between the inferior border of the first anterior sacral foramen and the superior border of the second anterior sacral foramen was 10.54 ± 2.25 mm (Fig. 1).

The distance between the first posterior sacral foramen and the superior border of the sacrum (posterior pedicle height) was 20.98 ± 2.34 mm. The distance between the inferior border of the

Table 1
The results of the linear measurements in millimeter (mm).

	Right (mm)	Left (mm)	Mean value (mm)
a1: The height of the first anterior sacral foramina	13.58 ± 2.16	13.74 ± 2.0	13.66 ± 2.11
a2: The width of the first anterior sacral foramina	13.78 ± 2.12	14.13 ± 2.1	13.95 ± 2.12
b1: The height of the first posterior sacral foramina	12.50 ± 3.31	12.44 ± 3.01	12.47 ± 3.16
b2: The width of the first posterior sacral foramina	8.14 ± 1.97	7.80 ± 1.82	7.97 ± 1.89
c1: The height of the second anterior sacral foramina	13.48 ± 2.26	13,72 ± 1,98	13,60 ± 2,12
c2: The width of the second anterior sacral foramina	13.97 ± 2.69	14.46 ± 2.27	14.22 ± 2.48
d1: The height of the second posterior sacral foramina	7.62 ± 1.54	7.61 ± 1.55	7.62 ± 1.54
d2: The width of the second posterior sacral foramina	8.04 ± 1.70	7.81 ± 1.78	7.92 ± 1.74
e1: The transverse distance between the first anterior sacral foramina	–	–	30.48 ± 2.78
e2: The transverse distance between the second anterior sacral foramina	–	–	28.31 ± 2.81
f1: The transverse distance between the first posterior sacral foramina	–	–	38.32 ± 3.63
f2: The transverse distance between the second posterior sacral foramina	–	–	31.62 ± 3.27
g1: The distance between the first anterior sacral foramen and the superior border of the sacrum (anterior pedicle height)	14.88 ± 2.38	14.75 ± 2.26	14.81 ± 2.32
g2: The distance between the inferior border of the first anterior sacral foramen and the superior border of the second anterior sacral foramen	10.79 ± 2.38	10.29 ± 2.11	10.54 ± 2.25
h: The distance between the first posterior sacral foramen and superior border of the sacrum (posterior pedicle height)	20.74 ± 2,50	21.23 ± 2.18	20.98 ± 2.34
i: The distance between the inferior border of the first posterior sacral foramen and the superior border of the second posterior sacral foramen	15.92 ± 2.05	15.92 ± 2.11	15.92 ± 2.08
j: The distance between the S1 pedicle entry point (inferolateral aspect of S1 facet joint) and the anteromedial point of the S1 vertebra	51.12 ± 4.83	51.26 ± 4.72	51.19 ± 4.77
k: The distance between the S1 pedicle entry point and the anterolateral sacral wing	50.13 ± 3.63	50.46 ± 3.51	50.30 ± 3.57
l: The S1 pedicle depth	24.69 ± 3.92	24.60 ± 3.75	24.65 ± 3.84
m: The sacral wing depth	53.88 ± 4.65	53.92 ± 4.12	53.90 ± 4.39
n: The height of the S1 facet joint	14.55 ± 1.82	14.69 ± 1.84	14.62 ± 1.83
o: The width of the S1 facet joint	16.44 ± 2.20	16.30 ± 2.08	16.37 ± 2.14
p: The distance between the S1 facet joints	–	–	25.68 ± 3.80
q: The S1 vertebral body anteroposterior diameters	–	–	31.42 ± 2.83
r: The S1 vertebral body transverse diameters	–	–	49.40 ± 5.89
s: The height of the S1 vertebral body	–	–	30.22 ± 2.35
t: The height of the S2 vertebral body	–	–	26.34 ± 6.09
u: The sagittal diamater of the spinal canal at the superior aperture of the sacrum	–	–	21.81 ± 3.66
v: The transvers diamater of the spinal canal at the superior aperture of the sacrum	–	–	31.31 ± 3.16

Table 2
The results of the angular measurements

	Right	Left	Mean value
x: S1 facet angle	35.71° ± 9.59	34.70° ± 9.66	35.20° ± 9.62
y: Sacral pedicle anteromedial screw trajectory angle	35.65° ± 4.73	31.95° ± 3.95	33.80° ± 4.34
z: Anterolaterally oriented sacral wing screw trajectory angle	32.65° ± 3.51	29.10° ± 3.14	30.87° ± 3.32

first posterior sacral foramen and the superior border of the second posterior sacral foramen was 15.92 ± 2.08 mm (Fig. 2).

The distance between the S1 pedicle screw entry point and the most anteromedial point of the S1 vertebra was 51.19 ± 4.77 mm. The distance between the S1 pedicle screw entry point and the anterolateral sacral wing was 50.30 ± 3.57 mm (Fig. 4).

The S1 pedicle depth was 24.65 ± 3.84 mm. The sacral wing depth was 53.90 ± 4.39 mm (Fig. 4).

The height and the width of the S1 facet joint were 14.62 ± 1.83 mm and 16.37 ± 2.14 mm, respectively. The distance between the S1 facet joints was 25.68 ± 3.80 mm (Fig. 2).

The S1 vertebral body anteroposterior and transverse diameters were 31.42 ± 2.83 mm and 49.40 ± 5.89 mm, respectively (Fig. 4).

The height of the S1 vertebral body was 30.22 ± 2.35 mm. The height of the S2 vertebral body was 26.34 ± 6.09 mm (Fig. 1).

Sagittal and transverse diameters of the spinal canal at the superior aperture were 21.81 ± 3.66 mm and 31.31 ± 3.16 mm, respectively (Fig. 4).

3.2. Angular parameters

The S1 facet angle was measured as 35.71° ± 9.59 and 34.70° ± 9.66, the sacral pedicle anteromedial screw trajectory angle was measured as 35.65° ± 4.73 and 31.95 ° ± 3.95 and the anterolaterally oriented sacral wing screw trajectory angle was measured as 32.65° ± 3.51 and 29.10° ± 3.14 for the right and left sides, respectively (Fig. 3).

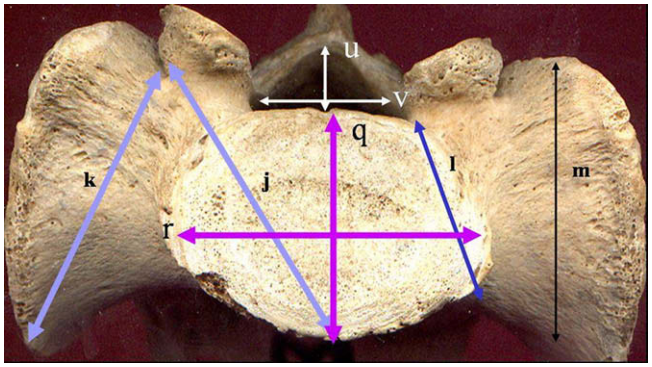


Fig. 4. Linear parameters, pedicle and wing: (j) the distance between the S1 pedicle entry point (inferolateral aspect of the S1 facet joint) and the anteromedial point of the S1 vertebra; (k) the distance between the S1 pedicle entry point and the anterolateral sacral wing; (l) the S1 pedicle depth; (m) the sacral wing depth; (q) the S1 vertebral body anteroposterior diameter; (r) the S1 vertebral body transverse diameter; (u) the sagittal diameter of the spinal canal at the superior aperture of the sacrum; (v) the transverse diameter of the spinal canal at the superior aperture of the sacrum. This figure is available in colour at www.sciencedirect.com.

4. Discussion

The sacrum is a target point for sacral fixation during posterior lumbar body fusion (PLIF) and anterior lumbar body fusion (ALIF) procedures. Such instrumentation may carry the risks for

neurovascular injury resulting in morbidity, and even mortality. This dictates detailed knowledge of the sacrum and its regional anatomy.

4.1. The S1 Pedicle

The S1 pedicle is quite different from the other spinal pedicles. There are two main screw trajectories for posterior sacral fixation, including the anteriomedial trajectory through the pedicle to the promontory and the anterolateral trajectory to the sacral wing. Using an entry point just inferolateral to the S1 facet, this study determined the distance between the entry point of a screw in the dorsal surface of the sacrum and anteromedial cortex of the S1 promontory, as well as the distance between the same dorsal point and the anterolateral cortex of the sacral wing. Additionally, the mean angles for appropriate screw placement was also measured for both anteromedial and anterolateral orientations.

The measured anteromedial distance was 51 mm and the anterolateral distance was 50 mm in the current study. Mirkovic et al. reported that the length of laterally-oriented sacral screws depends mainly on the degree of orientation.[2] According to Mirkovic et al., using a 30° screw angulation, the length of the screw was 38 mm (range 25–48 mm), whereas using a 45° angulation, the mean length was 44 mm (range 30–56 mm).[2]

Okutan et al. reported that the S1 anteromedial length was 50.7 ± 3.7 mm in females and 51.8 ± 3.5 mm in males.[5] Okutan et al., also found that S1 pedicle screw distance was 52.3 ± 3.1 mm on the right and 52.3 ± 3.9 mm on the left for men, whereas the same length was 50.9 ± 3.9 mm on the right and 51.1 ± 3.7 mm on the left for women.[6] In our study, the distance between the S1 pedicle entry point and anteromedial point of S1 vertebra was 51.12 ± 4.83 mm on the right and 51.26 ± 4.72 mm on the left.

The mean angle in the present study for appropriate placement of the anteromedial transpedicle screw was found to be 35° and 31° on the right and left sides, respectively. The mean angle for appropriate placemtent of an anterolaterally-oriented sacral wing screw was found to be 32° on the right side and 29° on the left side.

Xu et al. reported the mean S1 pedicle medial angle was 39.4° and the mean S1 pedicle length was 43.7 mm for men and 41.7 mm for women.[7] Although our angle is very similar to that reported by Xu et al, the length of the pedicle was found to be 8–10 mm longer in our study.

The angle of the pedicle is of importance as there is a risk of injury to neurovascular structures with poorly placed screws. Mirkovic et al. found that 45° laterally-oriented screws to the sacral wing had a high potential for lumbosacral trunk impingement (55%) and the rate of sacroiliac joint injury was 10%.[2] Similarly, Morse et al., using the average angles for anteromedial and anterolateral S1 screw placement, defined the unnecessary risks to important structures. They proposed preoperative CT scan verification to determine safe angles to minimize the risks.[3]

The S1 pedicle height is greater than other pedicles. The height of the S1 vertebral body has been reported to be 28.9 mm for men and 27.7 mm for women.[7] In our study, the mean value was 30.22 ± 2.35 mm. Esses at al. found the distances from the superior surface of the first sacral body to the upper border of the first sacral foramen were 22.70 mm anteriorly and 23.07 mm posteriorly.[8] Ebraheim et al. performed a study on 50 bony spines and reported that the S1 pedicle height was 21.2 mm in men and 20.2 mm in women.[7] In our study, we found and anterior pedicle height of 14.81 ± 2.32 mm and a posterior pedicle height of 20.98 ± 2.34 mm. These distances reflect the vertical limits for screw placement without risk at S1.

4.2. The body of the sacrum

The anteroposterior and transverse diameters of the S1 body need to be taken into consideration during PLIF and ALIF procedures. The anteroposterior diameter of the S1 body has been reported to be 45.4 mm for men and 41.7 mm for women, whereas the transverse diameter was found to be 30.5 mm for men and 29.3 mm for women.[7] In our study, the S1 body anteroposterior and transverse diameters were 31.42 ± 2.83 mm and 49.40 ± 5.89 mm, respectively.

4.3. The sacral wing

The sacral alar depth reflects the length needed for sacral wing screws. The sacral alar depth has been reported as 45.8 ± 1.9 mm (43–48 mm) by Ebraheim at al.[9] In the present study the sacral alar depth was 53.90 ± 4.39 mm. The significant difference between two studies can be explained by the differences in screw entry points.

4.4. The sacral spinal canal

Xu et al. reported an average sacral spinal canal diameter of 12.3 mm for men and 12.2 mm for women and an average sacral spinal canal width of 27.5 mm for men and 26.4 mm for women.[7] In our study, sagittal and transverse diameters of the spinal canal at the superior aperture were 21.81 ± 3.66 mm and 31.31 ± 3.16 mm, respectively.

5. Conclusion

The lumbosacral spine is a junctional region of the spine. Technological improvements have led to an increase in the number and types of surgical procedures in this region. Posterior decompressive procedures and fusion and internal fixation procedures need detailed information regarding the anatomy of the spinal canal and the S1 body. The reported data in the current study serves these aims. This study also shows that there is no significant difference in the distances for anteromedially- (into the promontorium) and anterolaterally- (into the sacral wing) directed screw paths. The main factors affecting the length and angle of an S1 anteromedially- or anterolaterally-placed screw is the location of the screw entry point.

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