A Review Paper

Surgical Anatomy of the Sacrum

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Abstract

Treatment in spinal disorders, sacroiliac joint disruption, and sacral fractures may involve instrumentation of the sacrum. Proper screw placement is essential for obtaining adequate bony purchase for solid fixation. Injury to adjacent vital structures during screw placement remains a major concern because of the complex anatomy of the sacrum. This article reviews the bony anatomy of the sacrum.

The sacrum is a complex anatomical structure. Instrumentation of the sacrum is a widely accepted treatment in spinal disorders, sacroiliac joint disruption, and sacral fractures. Proper screw placement is essential for obtaining adequate bony purchase for solid fixation. Injury to adjacent vital structures during screw placement remains a major concern because of the complex anatomy of the sacrum.[1-3] Understanding this anatomy is critical if surgeons are to obtain fixation and avoid neurovascular injury. In this article, we review the bony anatomy of the sacrum.

Base of the Sacrum

The cephalad surface of the body of the first sacral vertebra represents the base of the sacrum (Figure 1). The anterior portion of the first sacral vertebra is the sacral promontory, an important anterior landmark in the anterior approach to the lumbosacral junction.

Posterior to the first sacral vertebra is the triangle-shaped sacral canal (Figure 1). The superior facets of the first sacral vertebra lie immediately lateral to the sacral canal, facing posteriorly and medially. The point lateral and inferior to the S1 facet is the most common entrance for dorsal sacral screw insertion. The S1 pedicles lie lateral to the sacral canal, connecting the sacral arch to the vertebral body, and are the largest pedicles in the spine. The cephalad margin of the S1 pedicles lie under the most anterior aspect of the superior facet. The caudal margin is the superior edge of the S1 dorsal aperture. The medial margin of the pedicle is the lateral edge of the sacral canal.[4] The lateral margin of the S1 pedicle has yet to be defined. This has led to developing the "2 zone" concept (includes zones 1 and 2; Figure 2) for the S1 pedicles. Zone 2 is ideal for S1 pedicle screw placement because it is wider and longer than zone 1 (Tables I and II).[5]

Lateral to the sacral body, pedicle, and superior facet is the lateral sacral mass, which consists of fused costal elements and transverse processes. The superior part of the lateral sacral mass is the ala of the sacrum. The wing-shaped ala courses in an anterior-inferior direction. It is important to note that the cephalad aspects of the S1 vertebral body and ala are not in the same plane. The sloped angle of the ala relative to the cephalad border of the S1 vertebral body is approximately 30° caudally to the frontal plane.[6] Knowing this relationship may be beneficial in sacral screw placement. The midanterior cortex of the sacral ala has the highest bone density and therefore is optimal for screw purchase.[7]

"Zone 2 is ideal for S1 pedicle screw placement because it is wider and longer than zone 1."

Lateral Aspect of the Sacrum

The lateral surface of the sacrum consists of the union of the costal elements and transverse processes. This triangular surface is articular anteriorly and nonarticular

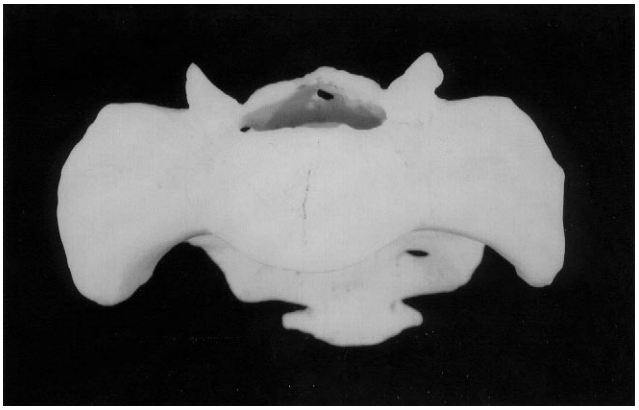

Figure 1. Base of sacrum (specimen).

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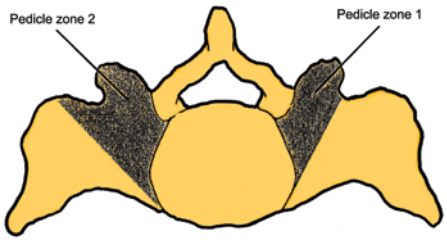

Figure 2. S1 pedicle zones 1 and 2.

posteriorly (Figure 3). The articular surface is L-shaped, with superior and inferior limbs; the nonarticular surface is posterior to the articular surface and is the site of attachment for the interosseous sacral ligaments. The lateral sacral mass is commonly used for iliosacral screw placement.[6] In iliosacral screw fixation, it is beneficial to know the usual location of the lateral sacral mass on the outer table of the ilium.[8]

The anatomical relationships of the projection of the lateral sacral mass to the posterior superior iliac spine (PSIS) and posterior inferior iliac spine (PIIS) are shown in Figure 4. The longitudinal axis of this projection on the outer table of the ilium is useful in determining the entrance point for screw fixation. On 6 cadaveric pelvises, we measured the distance from this axis to the PSIS and to the PIIS (respective means, 30 mm and 27 mm) (Table III). The superior portion of the projection consists mainly of the nonarticular surface of the lateral sacral mass. This zone is ideal for screw placement, as it provides a certain range of angulation for screw placement. Screw placement in this area may have less chance of violating the sacroiliac joint and neurovascular structures anterior to the sacrum (Figure 4). For treatment of vertical fractures involving the sacral foramina, iliosacral screw placement into the sacral vertebral body may be required. Computed tomography (CT) guidance provides the surgeon with excellent detail of the path for screw insertion, and optimal bone purchase is found in the vertebral body.[9] Anatomical studies have shown that the projection point of the S1 pedicle axis on the outer ilium is approximately 32 mm anterior to the posterior limit of the ilium. Mean length of this axis was 105 mm. The projection point of the S2 pedicle axis is 15 mm superior and 25 mm posterior to the apex of the sciatic notch.[10]

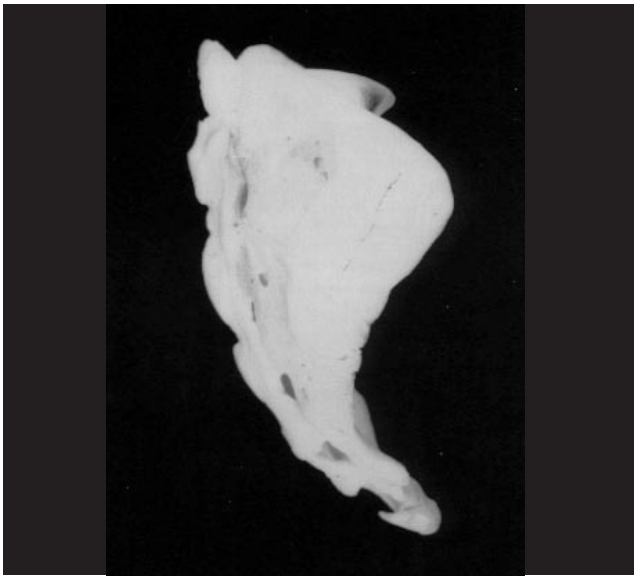

Figure 3. Lateral aspect of sacrum (specimen).

Ventral Aspect of the Sacrum

The ventral aspect of the sacrum is concave in the vertical and horizontal planes (Figure 5) and is smoother than the dorsal aspect. The medial portion consists of 5 fused anterior surfaces of the sacral vertebral bodies. The fusion sites are called *transverse ridges*. The first sacral vertebral body is the largest and the most common area for dorsal or iliosacral screw purchase. Lateral to the transverse ridges are the 4 pairs of anterior sacral foramina where the ventral rami of the first 4 sacral nerves exit from the sacrum and pass into the pelvis. The foramina are oval in shape and directed laterally. The S1 foramina course laterally approximately 15° inferior to the horizontal plane.[11-13] The area between the foramina is the costal elements or functional pedicles, or the area where iliosacral screws are passed into or through. Lateral to the foramina is the union of the costal elements or lateral sacral mass.

Dorsal Aspect of the Sacrum

The dorsal aspect of the sacrum is convex and irregular (Figure 6). In the midline are 3 or 4 tubercles, the S1 tubercle usually being prominent and distinct from the rest. These tubercles represent the spinous processes of the sacral vertebrae. Lateral to the tubercles on each side are the fused laminae. The lamina of the fifth sacral vertebra does not fuse in the midline, giving rise to the opening known as the *sacral*

Table I. Anatomical Parameters of S1 Pedicle Zone 1

	PW (mm)		PH (mm)		PL (mm)		MA (°)	
	M	F	M	F	M	F	M	F
Mean	10.9	10.44	21.19	20.15	34.65	34.91	10.17	10.71
Median	11	10.3	21	20.6	36.1	35.5	10	10.8
Range	8.2-13.4	8-13.4	16-26	14-24	32-44.4	28-40	6.8-13	8-14.2
SD	1.17	1.08	1.78	2.05	2.97	2.79	1.31	1.5

Abbreviations: PW, pedicle width (mm); PH, pedicle height (mm); PL, pedicle length (mm); MA, medial angle (°); M, male; F, female.

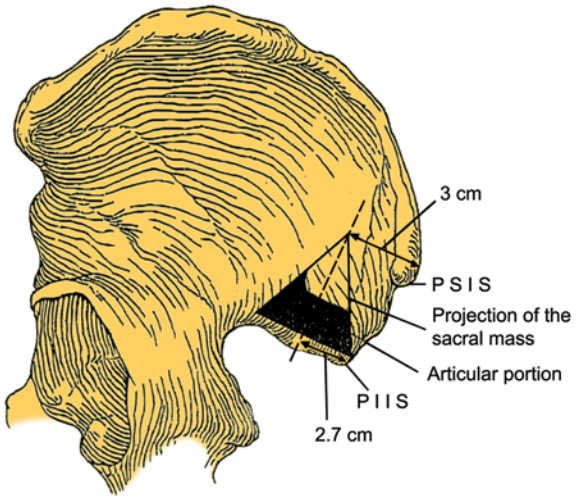

Figure 4. Projection of lateral sacral mass on outer table of posterior ilium. Abbreviations: PSIS, posterior superior iliac spine; PIIS, posterior inferior iliac spine.

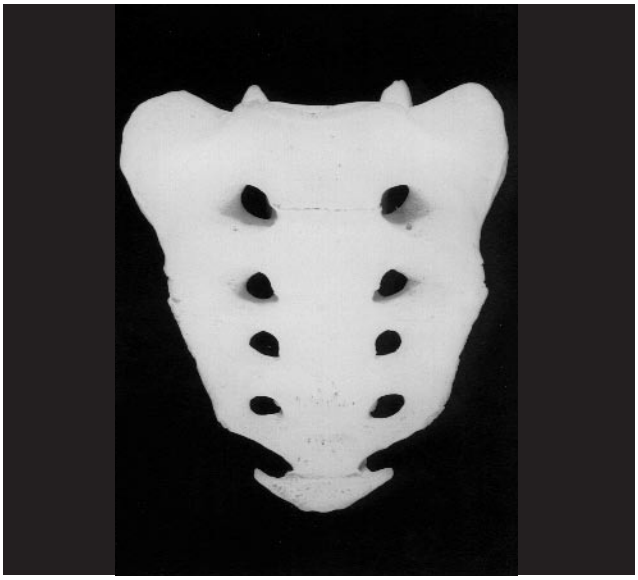

Figure 5. Ventral aspect of sacrum (specimen).

hiatus. Lateral to the laminae is a series of indistinct intermediate tubercles representing the fused articular processes. The intermediate tubercle of the fifth sacral vertebra represents the sacral cornua, which articulate with the corresponding coccygeal cornua. Lateral to the intermediate tubercles are the 4 pairs of dorsal foramina, which are much smaller and less regular than the corresponding anterior sacral foramina. The most lateral body structure on the dorsal aspect of the sacrum is a series of lateral sacral tubercles formed by the fused transverse processes, which give rise to the origin of the posterior sacroiliac ligaments. Anterior sacral nerve root injury associated with dorsal sacral screw placement remains a potential concern.

Familiarity with the anatomical relationship between the anterior and posterior sacral foramina on the dorsal aspect of the sacrum may minimize this complication, as the S1 and S2 dorsal foramina represent useful landmarks during posterior screw placement. The area above the S1 anterior foramen projection and between the S1 and S2 anterior foramina projections may be the safety zone for dorsal screw placement (Figure 7).[13] Instrumentation extending to the second sacral vertebra may enhance the strength of the sacral fixation by partial removal of the medial aspect of the ilium if sound bony purchase cannot be achieved by S1 pedicle or alar screw placement (Figure 8).[10] On evaluation of the upper sacrum by 3-dimensional CT, it was found that the "critical area," or optimal area for bony purchase and

Table II. Anatomical Parameters of S1 Pedicle Zone 2

	PW (mm)		PH (mm)		PL (mm)		MA (°)	
	M	F	M	F	M	F	M	F
Mean	15.6	14.73	21.19	20.15	43.73	41.7	39.42	39.38
Median	15.3	14.7	21	20.6	43.4	41	40	39.1
Range	12.6-21	12-17	16-26	14-24	39-49.8	37-48	35-45	34-46
SD	1.4	1.18	1.78	2.05	2.75	2.76	2.38	2.71

Abbreviations: PW, pedicle width (mm); PH, pedicle height (mm); PL, pedicle length (mm); MA, medial angle (°); M, male; F, female.

Table III. Linear Measurements (in mm) of Projection of Lateral Sacral Mass on Outer Table of Ilium From 6 Bony Pelvises

	Width 1	Width 2	Height	PSIS Axis	PIIS Axis
Mean	5.5	3.0	6.3	3.2	2.7
Maximum	6.2	3.7	7.0	4.0	3.1
Minimum	5.0	2.4	5.6	2.6	2.5
SD	0.43	0.49	0.50	0.58	0.23

Abbreviations: PSIS, posterior superior iliac spine; PIIS, posterior inferior iliac spine.

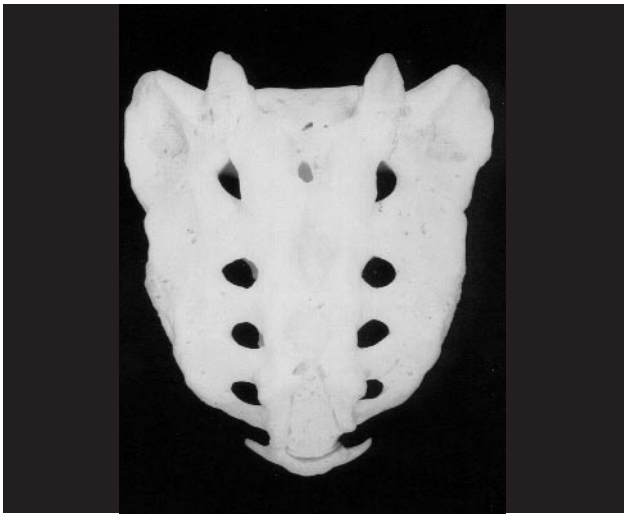

Figure 6. Dorsal aspect of sacrum (specimen).

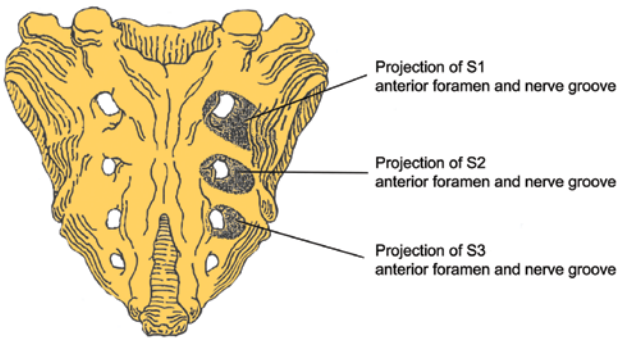

Figure 7. Projection of S1, S2, and S3 anterior foramina and nerve roots relative to corresponding posterior foramina.

avoiding the foramina, is at the junction of the pedicle and the vertebral body.[14] Screw fixation from the S1 pedicle to the iliac wing may also be done when there are SI joint disruptions and sacral fractures lateral to the foramina.[15]

Ebraheim and colleagues[16] conducted an anatomical study of CT-guided screw paths and screw lengths originating from the dorsal sacrum for S1 and S2 instrumentation. Four paths were chosen on axial CT scan at the S1 vertebra at the level of the inferior portion of the S1 superior facet. Path 1 was from the lateral border of the superior facet to the anterior cortex of the sacrum at 30° of medial inclination. Path 2 was from the midpoint between the medial and lateral borders of the superior facet to the anterior cortex along the lateral cortex of the sacral canal. Path 3 was from the medial border of the superior facet to the anterior cortex along the lateral cortex of the sacral canal. Path 4 was from the lateral border of the superior facet to the most anterior cortex of the ala. The longest screw lengths (mean, 36.9 mm) were achieved in path 4.

Ebraheim and colleagues[16] concluded that the optimal medial screw paths for S1 are paths 1 and 2 starting just

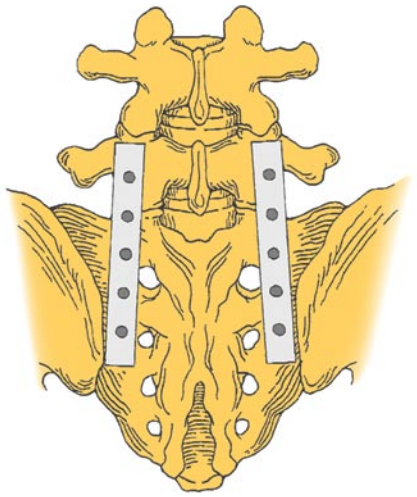

Figure 8. Two-plate placement extending to S2 region by removal of partial posterior ilium.

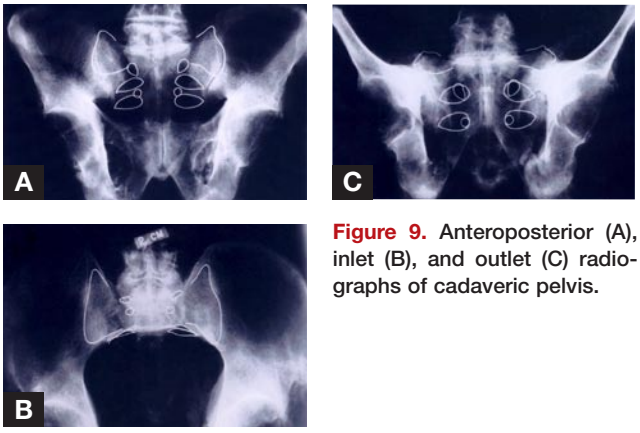

Figure 9. Anteroposterior (A), inlet (B), and outlet (C) radiographs of cadaveric pelvis.

lateral and inferior to the superior facet and angling 30° anteromedially or anterolaterally. They also concluded that the mean distance from screws inserted in this fashion to the lateral aspect of the sacral canal would be 5 to 6 mm. Mean length of the anteromedial screw was 33 mm, and mean length of the anterolateral screw was 37 mm. The authors were concerned about how close path 3 was to the lateral aspect of the sacral canal.

Ebraheim and colleagues[16] conducted a similar review at the S2 level with 2 "paths." Both screws began at the posterior midpoint of the medial mass and were taken to the anterior sacral cortex. The anterolateral screw (mean length, 32 mm) angled 46° laterally, and the anteromedial screw (mean length, 24 mm) was directed 30° medially. Mean lengths were longer for anterolateral screws, though there is controversy about the superiority of laterally versus medially directed screws at this level.

Finally, Ebraheim and colleagues[16] studied the relationships of the L5, S1, and S2 nerve roots to commonly used entrance points from S1 and S2 pedicle screws. They used (at S1) a starting point at the junction of the inferolateral portion of the L5–S1 facet joint and the lateral sacral crest at an angle of 30° medially directed and parallel to the S1

endplate. This starting point is similar to the just mentioned "path 1." The authors found the L5 root to be a mean of 10.4 mm superior, the S1 root a mean of 8.7 mm inferior, and the S1 root a mean of 7.8 mm medial. The starting point for the S2 pedicle, also evaluated, corresponded to "point 2" at the S2 level mentioned earlier. The S1 root was 7.6 mm superior, the S2 root 6.4 mm inferior, and the S3 root 7.7 mm medial.

Radiographic Evaluation of the Sacrum

Plain radiographs, including anteroposterior (AP), inlet, outlet, and lateral views, are the common intraoperative or postoperative radiological modalities for pelvis evaluation. The AP radiograph shows the general contours of the sacrum, ilium, ischium, and pubis (Figure 9A); the inlet radiograph shows the relationship of the sacral canal and sacroiliac joints and shows the most anterior border of the S1 vertebral body and sacral alae (Figure 9B); the outlet radiograph shows the cephalad border of the sacrum and sacral foramina as well as the height of the sacral pedicles (Figure 9C); and the lateral radiograph shows the anterior limit of the vertebral bodies of the sacrum but does not show the sacroiliac joint and alae.[6] Knowledge of where the anatomical structures are located in relation to one another, as seen on the lateral radiograph, may aid in dorsal screw placement.[17] The inlet and outlet radiographs are useful in evaluation of dorsal sacral screw or iliosacral screw placement. A screw violating the anterior foramen can best be appreciated on a proper outlet radiograph. A screw penetrating the anterior cortex of the sacrum, sacral canal, or sacroiliac joint can best be detected on an inlet radiograph.[6]

Conclusions

The sacrum is a complex anatomical structure. Proper screw placement is essential for obtaining adequate bony purchase for solid fixation. Understanding the anatomy of the sacrum is critical if surgeons are to obtain fixation and avoid neurovascular injury.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

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