Anatomy of the sacrum

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One of the basic tenets of performing surgery is knowledge of the relevant anatomy. Surgeons incorporate this knowledge along with factors, such as biomechanics and physiology, to develop their operative approaches and procedures. In the diagnosis and management of sacral tumors, the need to be familiar with the anatomy of the sacrum is no less important than knowledge of the pathological entity involved. This article will provide an overview of the embryology and anatomy of the sacrum, along with concepts as applied to surgical intervention.

KEY WORDS • spine • sacrum • anatomy

The human spine can be thought of as a complex column in which is combined significant structural support with constrained motion located through its 24 articulating vertebrae. This load-bearing capability of the vertebral segments contributes to the morphological composition of the spinal regions, and this appears especially true for the sacrum. In comparison to primates, with only an intermittent upright gait, the human sacrum incorporates more bone segments into its fused mass and has a wider sacral ala to accept the increased axial load with upright ambulation and stance. With this increase in size of the sacrum relative to the other spinal segments, it follows that its name is derived from the Latin and Greek roots of *os sacrum* (translation of Greek *hieron*, *osteon*), meaning sacred bone.⁹

The human sacrum is a large triangular bone originating from five separate vertebra that fuses along with the intervening intervertebral discs.^{2,8} The primary cartilaginous joints between the vertebrae, as noted in children, involute in adulthood, leaving only transverse lines on the ventral aspect of the sacrum. This large wedge of bone also has a high metabolic activity, as denoted by the amount of cancellous bone present, which is enveloped by a thin layer of cortical bone.⁴

The sacrum articulates with four bones; the last lumbar vertebra above via a disc space and facet joint complex, the coccyx below with a ligamentous attachment and occasional bone union, and on either side with the ilium via the sacroiliac joint. The sacroiliac joint is a complex formed by a synovial joint anteriorly with strong ligamentous attachments posteriorly to provide motion and stabil-

ity during the transmission of loads from the axial spine to the pelvic girdle. Even with the bone unions that occur in this region with an individual's advancing age, such as with the sacrum and coccyx, the sacroiliac joint complex maintains a significant amount of mobility. Smidt and colleagues¹⁰ demonstrated that the magnitude and direction of sacroiliac motion appears to be sufficient to complement hip joint motion and influence motion at the lumbosacral junction and, therefore, low-back pain in both the direct and indirect sense. Along with the *os coxae* (formed from the union of the ilium, ischium, and pubic bones), the sacrum helps form the pelvic vault to protect the neural elements of that region and the internal organs of the pelvis.

EMBRYOLOGY

Formation of the vertebral column from the 44 mesodermal somatomes occurs in conjunction with primary neurulation down to the 30th somite, which corresponds to the S1–2 junction.⁷ The S-2 segment down to the coccyx is derived from somites 31 to 44 and arises from the caudal eminence (tailbud) during secondary neurulation and the retrogressive differentiation that follows. Developmental disorders during this time course are associated with various dysraphisms, such as with caudal or sacral agenesis if complete developmental failure occurs.

Initially in the newborn, the five sacral vertebrae resemble their lumbar counterparts until ossification of the sacral ala begins late in the 1st year of life.⁶ Each sacral vertebra has five ossification centers: a primary center, one in each epiphyseal plate, and two for the two vertebral arches (Fig. 1 upper). The lateral parts of the sacrum form

Abbreviation used in this paper: VB = vertebral body.

Fig. 1. Ossification centers of the sacrum (From Gray's *Anatomy of the Human Body*. Used with permission from Bartleby.com, Inc.).

from 10 additional ossification centers. The initial six sites derive symmetrically from the first three vertebrae, which represent the costal elements. An additional four sites are derived from the two epiphysial plates on each lateral surface, along with one for the auricular surface and another for the remaining thin lateral edge of the bone (Fig. 1 center). Fusion of the sacral vertebra starts at puberty, beginning with the costal elements. The VBs begin fusing when the individual reaches 18 years of age; this continues during the next two decades in a caudal to cranial fashion (Fig. 1 lower). Complete fusion of the sacrum has been reported to occur between Years 25 and 33 of life and is related to the load-bearing aspects of this region.^{2,5,8} In

support of the Woolf law regarding bone remodeling, children with paraplegia or those who do not bear weight across the sacral region do not form the singular osseous sacral mass from fusion of the independent vertebrae.^{1,6}

Anatomy of the Adult Sacrum

Gross morphology of the sacrum notes a triangular bone with a concave ventral surface (*facies pelvina*), a convex dorsal surface (*facies dorsalis*), and an apex (apex osseus sacri) that projects posteriorly to increase the size of the pelvic cavity.^{2,8} In the sagittal plane, the sacral base is pitched forward, and the angulation that forms between the lumbar spine and sacrum is known as the sacral promontory or sacrovertebral angle. This angle is initially approximately 20° at birth and increases progressively during growth to approximately 70° in adulthood. Often, this distinct ridge can be used as a landmark in anterior lumbosacral approaches, but the angulation must be considered in anterior instrumentation and interbody grafting.

Anterior or Pelvic Surface (facies pelvina)

The anterior or pelvic surface of the sacrum consists of a concave surface in both the rostrocaudal and transverse directions to form a bowl-shaped concavity (Fig. 2). This inner surface topography is accentuated by four transverse ridges associated with neural foramen on each side. The sacrum forms by the fusion of the five sacral VBs and the transverse ridges result from remnants of the previous intervertebral space, and the intervening bone surfaces between these transverse ridges correlate with the anterior aspects of the VBs. In addition, it follows that the morphology of the VBs should be similar in regard to their diminished height and width toward the apex, based on their load distribution and prior geometry.

Fig. 2. Ventral view of the sacrum (From Gray's *Anatomy of the Human Body*. Used with permission from Bartleby.com, Inc.).

Anatomy of the sacrum

As with other vertebral levels, neural foramina are expected to lie between adjacent vertebral segments. In the adult sacrum, the eight ventral or anterior sacral foramina (four pairs) lie between the five sacral vertebrae on each side of the corresponding transverse ridge. These neural foraminae are oriented in a slightly anterolateral direction, giving passage to the anterior divisions of the respective sacral nerves and the lateral sacral arteries. The lateral masses of the sacrum then lie lateral to the neural foramina, formed from portions of the original VBs and transverse processes.

Three main symmetrical muscular attachments are present along the anterior face of the sacrum. The smaller attachment sites of the iliacus reside at the superior lateral aspect, and the coccygeus is noted along the inferior lateral aspect. The lateral masses of the sacrum give rise to the piriformis muscle group, located just lateral to the ventral foraminae.

Posterior or Dorsal Surface (facies dorsalis)

Complementary to the concave anterior face, the dorsal surface of the sacrum is convex in shape (Fig. 3). The posterior elements of the initial vertebral segments fuse into a bone plate marked by several longitudinal crests coursing in the rostrocaudal direction. The prominent median sacral crest is primarily formed from the rudimentary spinous processes of the upper three or four sacral vertebrae, with the laminae on either side forming the sacral grooves. Often, the bone anatomy of the fourth and fifth sacral vertebrae in the region of the midline is absent and the resultant opening is termed the sacral hiatus.

Lateral to the sacral grooves lie another pair of longitudinal crests called the intermediate crests, which are formed from the fused articular processes of the sacral vertebrae. The most inferior aspect of the inferior crest forms an osseous protuberance that slightly resembles a horn and is aptly named the sacral cornua. This connects with the cornua of the coccyx. Eight dorsal sacral forami-

Fig. 3. Dorsal view of the sacrum (From Gray's **Anatomy of the Human Body**. Used with permission from Bartleby.com, Inc.).

na, four on each side, lie lateral to the intermediate crests and allow passage of the posterior divisions of the sacral nerves. These posterior neural foramina correspond to their anterior counterparts and serve as important landmarks in placement of spinal instrumentation to anchor either to the sacral pedicles or into the neighboring ilium. The inferior aspect of the sacrum thins out and ends in a projection called the inferior lateral angle that apposes with the transverse process of the first coccygeal bone to form a foramen for passage of the fifth sacral nerve.

A significant number of muscular attachments reside along the posterior aspect of the sacrum. The gluteus maximus attaches just below the sacroiliac articulation, located at the inferior lateral aspect. The multifidus, sacrospinalis, and erector spinae muscles originate from the sacral grooves medially and are surrounded at the superior aspect by the attachments of the latissimus dorsi and, occasionally, inferiorly by the extensor coccygis.

Superior Sacral Base (basis osseous sacri)

The inverted triangular form of the sacrum locates the base superiorly and the apex inferiorly. The base articulates with the last lumbar vertebra and is angled rostrally and anteriorly (Fig. 4). The spinal canal is located slightly posterior within the base, with the anterior wall of the spinal canal formed by the posterior margin of the large ovoid surface of the lumbar articulation. The remnants of the lamina and spinous processes form the posterior margin of the canal. The bone of the sacral base continues on either side of the VB as a large triangular surface called the ala or the wing. The sacral ala attaches to the psoas major and supports the lumbosacral trunk, and is formed from the transverse costal processes of the first sacral segment.

The superior articular processes of the sacrum project from the base on either side. Similar to their lumbar counterparts, the superior articular processes are oval and concave, and directed backward and medially. They are attached to the body of the first sacral vertebra and to the ala by short thick pedicles. On the upper surface of the superior most pedicle is a vertebral notch, which forms the lower part of the foramen between the last lumbar and first sacral vertebrae.

ANATOMICAL VARIATIONS

Anatomical variations occur frequently in this region, making the sacrum the most variable portion of the spine.⁵ The variation may be attributed to the dependency of the final sacral morphology to the load-related fusion of the bone structure. Failure to complete the ascending fusion may create a sixth lumbar vertebra, leaving a four-piece or "lumarized" sacrum. Conversely, continuation of sacral fusion that incorporates the last lumbar vertebra may form a six-bone sacrum. This same phenomenon may occur inferiorly as well, with incorporation of the coccyx into the sacral bone mass. Developmental malformations occur as well, ranging from variations in the sacral hiatus to caudal agenesis.⁷ Although commonly reported to be located at the S-4 level, the sacral hiatus usually occurs at a much higher level.⁵

Sex-dependent differences have been noted in the pelvic bone anatomy, and so it follows that differences exist

Fig. 4. Base of the sacrum (From Gray's **Anatomy of the Human Body**. Used with permission from Bartleby.com, Inc.).

in the male and female sacrum. Henry Gray described much of this in detail in 1918 with his publication on human anatomy, although the differences do not appear as extensive as once noted.^{3,5,8} In general, the sacrum in males is larger than that in females except at the sacral ala where the width is larger in females. The need for both an increased pelvic volume and a wider pelvic outlet for pregnancy and birthing appears to be accommodated via an increased sacrovertebral angle, placing the apex more posteriorly, and not by an increased sacral curvature.⁵

CONCLUSIONS

Surgical treatment of sacral lesions requires understanding of the underlying anatomy, a task made easier by understanding the developmental aspects and morphological changes that occur with growth. Significant strides toward this understanding have been made previously by many anatomists and surgeons, and even those observations made almost 100 years ago still hold true, as evidenced in the works of Henry Gray. There is still much to be learned, however, with the advances in surgical methods and instrumentation in the field of spinal surgery driving a continued need to better understand the anatomy of the region.

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