IMAGING ANATOMY OF THE HUMAN SPINE
A Comprehensive Atlas Including Adjacent Structures

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Preface

To my mind, the spine is a constant source of wonderment. There is no other anatomic structure that can match the spine in terms of the combination of strength, structural stability, and the capability of multidirectional motion. On superficial inspection, the spine appears to be a simple structure with a repetitive design. However, a deeper look reveals an exceptionally complex structure with highly specialized anatomy at each level.

An overarching goal of this text is to introduce the reader to the subtleties of the spine that may not be commonly covered in radiological anatomy textbooks. Components of this work will resemble the traditional anatomic atlas. However, the reader will also notice several points of departure from the anatomic atlas model. Radiological anatomy is presented in multiple imaging modalities, including plain radiographs, fluoroscopy, myelography, computed tomography, and magnetic resonance imaging. The configuration and composition of the spine presents unique challenges to conventional imaging studies. Wherever possible, detailed anatomic concepts are presented in the imaging modality that is best suited to displaying that anatomy. Text is used sparingly to broaden the reader’s understanding of the anatomic concepts and to provide a foundation upon which the anatomy displayed on the images can be understood. The result is something of a hybrid between an anatomic atlas and an anatomic textbook, designed to provide the best of both worlds to the reader.

The greatest point of departure of this work from standard radiological anatomy textbooks is the introduction of the reader to the world of spine intervention, a discipline that has its base in a firm understanding of spine imaging anatomy. Numerous images from spine intervention procedures are included to buttress the principles of spinal anatomy covered in the text and to illustrate how a detailed knowledge of spinal anatomy is exploited by the interventionalist.

Each chapter is organized into a brief introduction, a detailed gallery of images in a traditional atlas format, discussion of developmental anatomy, image gallery of developmental anatomy, a detailed description of adult anatomy with accompanying detailed figures, a gallery of anatomic variants and common congenital anomalies, and an extensive collection of suggested readings. The final chapter is a collection of computed tomographic and magnetic resonance images displaying the anatomy of the paraspinal musculature.

This work is written with the lifelong learner in mind, from the earliest exposure to this material in medical or graduate school to the resident, fellow, and practicing attending physician in the fields of diagnostic radiology, interventional radiology, neurology, neurosurgery, anesthesia, general surgery, orthopedics, and other closely related fields. Ultimately, it is my hope that readers gain an appreciation of the complex anatomy of the spine that carries them through their training into practice.

Scott E. Forseen
Acknowledgments

This work would not be possible without the seemingly endless patience of my wife of 20 years, Caralee. In the process of preparing this manuscript, she assumed nearly all of the primary responsibilities of our daily lives, allowing me to slip into a prolonged zombie-like state. My sons Mathias and Brendan have shown patience beyond their years in waiting for their father to return to the basketball court to play with them. Boys, it’s me versus the two of you ... your ball first.

William B. Bates III has been a tireless advocate for my wife and me since our earliest days at the Medical College of Georgia. Much of the venous imaging in this text comes directly from his early morning calls to let me know about the good cases he has encountered since our last conversation. It is my hope that the vascular imaging contained within meets his expectations for “pretty pictures.”

Thanks is due to several people who assisted in this project, including Dr. Bruce Gilbert for his advice on many aspects of the manuscript, Dr. Brenten Heeke for generating 3D reformat of the sacrum, and Kyle Osteen for his willingness to share his talents in creating beautiful book quality MR images. Thanks is also due to Dr. Nathan Yanasak and Teresa Mills who set the standard for MR imaging quality at Georgia Regents University.

Last, I would like to thank Neil Borden for inviting me to co-author this book. I am honored that he would consider me to be a worthy contributor to this project. He sets the bar for excellence in the practice of neuroradiology and I strive to meet his expectations each time I log onto the workstation or step into the procedure room.

In the late stages of completing this manuscript, Dr. Bruce Dean of the Barrow Neurological Institute (BNI) passed on after a long battle with multiple myeloma. The outpouring of praise for this exceptional man by current and former BNI fellows after his passing had a profound impact on me. Dr. Dean motivated others not just to be better neuroradiologists, but to be better persons. We will miss you.
Imaging Anatomy of the Human Spine
The Craniocervical Junction

The craniocervical junction is the anatomic region located at the transition from the skull to the cervical spine that houses the medulla, cervical spinal cord, multiple cranial nerves, blood vessels, and lymphatics. Included in the craniocervical junction are the occipital bone, atlas (C1), and axis (C2), six synovial joints, and multiple ligamentous structures. The paired atlanto-occipital (C0–C1) and atlantoaxial (C1–C2) joints allow for significant multidirectional mobility at the craniocervical junction that is distinct from the subaxial spine. In fact, most of the movement of the cervical segments takes place at the craniocervical junction.
THE ATLAS

The atlas (Figures 1.7a–b) is a bony ring that lacks a vertebral body and a spinous process. Superior and inferior articular processes arise from lateral masses on each side of the midline, forming the atlanto-occipital and atlantoaxial joints with the occipital condyles and superior articular processes of the axis, respectively. The lateral masses and foramina transversaria of the atlas are more laterally located than that of the rest of the cervical spine. There is a small anterior midline tubercle upon which the anterior longitudinal ligament attaches. There is a shallow groove on the dorsal margin of the anterior arch that forms an articular facet with the anterior surface of the dens. The medial tubercles arise from the lateral masses and serve as attachments for the transverse ligament. Along the superior surface of the neural arch, just posterior to the lateral masses on both sides of the midline, are shallow grooves for the vertebral arteries. The C1 nerves course with the vertebral arteries within these grooves. In approximately 15% of the population, a partial or complete bony arch forms that spans from the retrochondral tubercle to the neural arch, most commonly referred to as the ponticus posticus (Figure 1.8). The rectus capitus posterior minor muscles attach to the posterior tubercle.

FIGURES 1.7a–c  Bony surface anatomy of the atlas (C1) depicted in (a) superior oblique 3D, (b) inferior 3D, and (c) axial reformatted CT images. AA—anterior arch, AT—anterior tubercle, D—dens, DF—dens facet, FT—foramen transversarium, GVA—groove for vertebral artery, IAF—inferior articular facet, LM—lateral mass, MT—medial tubercles (transverse ligament attachments), NA—neural arch, PT—posterior tubercle, SAF—superior articular facet, TP—transverse process.
THE AXIS

The unique configuration of the axis (Figures 1.9a–c) is primarily due to the dens, an elongated bony process that extends superiorly from the C2 vertebral body and forms a pivot joint with the atlas. The lateral masses give rise to superior and inferior articular processes that articulate with the C1 inferior articular processes and C3 superior articular processes, respectively. There are shallow depressions along the dorsolateral surface of the dens at the alar ligament attachment sites. Inferior to the alar ligament attachments on the dorsal surface of the dens is a transversely oriented groove for the transverse ligament. The anterior surface of the dens is an articular facet with the anterior arch of the atlas. There is a small midline anterior tubercle that serves as the attachment for the anterior longitudinal ligament. The spinous process is generally bifid and is the attachment for the ligamentum nuchae and several muscles, including semispinalis cervicis, spinalis cervicus, inferior oblique, rectus capitis posterior major, interspinalis, and multifidus.

FIGURES 1.8a,b  Sagittal (a) and surface (b) reconstructed CT images demonstrating the arcuate foramen (AF) and ponticulus posticus (PP).

FIGURES 1.9a–c  Bony anatomy of the axis (C2) depicted in (a) superior oblique 3D (b) lateral, and (c) anterior 3D reformatted CT images. AFA—articular facet for the atlas, ALA—alar ligament attachments, AT—anterior tubercle for anterior longitudinal ligament attachment, D—dens, FT—foramina transversarium, GTL—groove for the transverse ligament, IAF—inferior articular facet, IAP—inferior articular process, L—lamina, P—pedicle, PI—pars interarticularis, SAF—superior articular facet, SP—spinous process, TP—transverse process, VB—vertebral body.
Figures 1.15c–e

**Key**
- Arch: aortic arch
- CCA: common carotid artery (R = right, L = left)
- CCAB: common carotid artery bifurcation
- D: dens
- ECA: external carotid artery
- INMTA: innominate artery
- MB: muscular branch
- OCCA: occipital artery
- Subclav: subclavian artery
- V1: initial extraforaminal segment of vertebral artery
- V2: intraforaminal segment of vertebral artery
- V3h: horizontal portion V3 segment of vertebral artery
- V3v: vertical portion V3 segment of vertebral artery
- V4: intradural segment of vertebral artery

(continued)
MENINGES AND SPACES OF THE CRANIOCERVICAL JUNCTION

The characteristics of the meninges and spaces of the craniocervical junction are similar to the rest of the spine. The features of the spinal meninges and spaces that are unique to the craniocervical junction will be discussed here. A detailed description of the spinal meninges is found in Chapter 2.

The denticulate ligaments are triangular, longitudinally-oriented extensions of the pia mater that extend from the lateral margins of the spinal cord to the lateral margins of the thecal sac between the ventral and dorsal nerve roots caudal to C1. The first denticulate ligaments arise along the lateral margins of the cervicomedullary junction and attach to the outer layer of the dura of the marginal sinus at the level of the foramen magnum. One-fifth of the time, the first denticulate ligaments attach to the proximal V4 segment. The first denticulate ligaments are broader medially and thicker laterally. They travel immediately superior to the vertebral arteries as they course through the posterior atlanto-occipital membrane and dural openings. The vertebral arteries are normally positioned along the anterior border of the denticulate ligaments. The spinal accessory nerves, C1 nerve roots, and posterior spinal arteries are positioned along the posterior border. The hypoglossal nerves are located just superior to the lateral attachments of the intracranial denticulate ligaments to the outer layer of the marginal sinuses.

The spinal cord occupies approximately one-half of the subarachnoid space at C1, versus three-quarters of the spinal canal in the subaxial cervical spine. Viewed on sagittal images, the subarachnoid space is greater in diameter, tapering superiorly to inferiorly and forming a funnel shape (Figures 1.25a,b).

FIGURES 1.25a,b  The unique, tapering configuration of the subarachnoid spaces at the craniocervical junction demonstrated on (a) sagittal TSE and (b) sagittal CT myelography images. C—clivus, CORD—spinal cord, DSAS—dorsal subarachnoid space, VSAS—ventral subarachnoid space.
The Subaxial Cervical Spine

The subaxial cervical spine is the anatomic region that includes the C3–C7 vertebrae, the cervical spinal cord, C3–C8 spinal nerves, the spinal accessory nerve, blood vessels, multiple synovial joints, ligaments, and lymphatics. As opposed to the specialized structure and function of the C1 and C2 segments, the subaxial cervical segmental morphology is more uniform. As such, the subaxial cervical segments are commonly referred to as the typical cervical segments.
MULTIMODALITY ATLAS IMAGES OF THE SUBAXIAL CERVICAL SPINE

The primary modalities used to image the subaxial cervical spine are plain films, computed tomography (CT), and magnetic resonance imaging (MRI). The basic anatomy of the subaxial cervical segments is presented in Figures 2.3a–r in order to provide a foundation prior to the more detailed anatomic descriptions to follow.

■ PLAIN FILMS (FIGURES 2.3a–2.3e)

FIGURES 2.3a–r Multimodal image gallery demonstrating the anatomy of the subaxial cervical spine on plain films (a–e), CT (f–l), and MR (m–r).

KEY
- EC: Echancrure
- IAP: Inferior articular process
- ILS: Intervertebral disc space
- IVDS: Intervertebral disc space
- LM: Lamina
- Mand: Mandible
- SAP: Superior articular process
- SLL: Spinolaminar line
- SP: Spine
- TP: Transverse process
- UP: Uncinate process
- ZJ: Zygopophyseal joint
- red line: Anterior spinal line
- blue line: Posterior spinal line
- green line: Spinolaminar line
OSTEOMETRY OF THE C3–C7 SEGMENTS

The long axis of the C3–C7 vertebral bodies is transverse. There is relatively little difference between the anterior and posterior heights of the C3–C7 vertebral bodies. The cervical lordosis is primarily derived from the configuration of the intervertebral discs in the subaxial cervical segments. The anterior to posterior length and transverse width of the vertebral bodies increases from C3 to C7. The anterior to posterior length of the inferior endplates is consistently larger than that of the adjacent superior endplate of the next caudal vertebral body. Projecting superiority from the posterolateral margins of the C3–C7 superior endplates are the uncinate processes. The uncinate processes articulate with shallow depressions in the posterolateral margins of the adjacent inferior endplates, forming the uncovertebral or Luschka joints (Figures 2.4a–d).

The transverse processes arise from the lateral aspects of the vertebral bodies on both sides of the midline. The transverse processes are composed of ventral and dorsal bony bars that terminate laterally in the anterior and posterior tubercles, respectively. The anterior bar is the homologue of the thoracic rib and is called the costal process or costal element. The anterior tubercles progressively increase in size from C3 to C6. The anterior tubercles at C6 are variable in shape and size and are referred to as the carotid tubercles of Chassaignac (Figures 2.5a–c), against which the carotid arteries can be compressed. The Chassaignac tubercles are also a target for the stellate ganglion blockade. The anterior and posterior tubercles are joined laterally by a short bony bridge referred to as the costotransverse bar or costotransverse lamella. The foramina transversaria are formed by the pedicles medially, anteriorly by the ventral bar and anterior tubercle, laterally by the costotransverse lamella, and posteriorly by the transverse process. Rarely, the transverse foramina are duplicated or triplicated. The foramina transversaria arise more anteriorly from the vertebral bodies from C3 to C6 and return to a more posterior position at C7. The distance between the foramina transversaria increases progressively from C3 to C7. The C7 foramina transversaria tend to be smaller in caliber due to the fact that they typically do not transmit the vertebral arteries.

**FIGURES 2.4a–d** (a) coronal surface rendered CT, (b) curved reformatted CT, (c) axial CT, and (d) axial T2 turbo spin echo (TSE) images demonstrating the anatomy of the uncovertebral joints. EC—echancrure, IEP—inferior endplate, IVDS—intervertebral disc space, SEP—superior endplate, TP—transverse process, UP—uncinate process.

(continued)
THE ZYGAPHYSEAL (FACET) JOINTS

The superior and inferior articular processes arise from the pedicle lamina junction. The superior articular facets arise on the dorsal surface of the superior articular process and face superiorly. The inferior articular facets arise on the ventral surface of the inferior articular process and face inferiorly (Figure 2.11). The facet surfaces are lined by a thin layer of smooth articular cartilage, are surrounded by a fibrous capsule, and are lubricated by synovial fluid. The cervical zygapophyseal joint capsules are lax and elongated compared with the thoracic and lumbar segments.

The zygapophyseal joints are variable in their orientation within the subaxial cervical spine. The C3 superior articular facets are oriented posteromedially. Approximately 75% of the time, the C4 superior articular facets are oriented posteromedially. The C7 superior articular facets are oriented posterolaterally. The transition from posteromedial to posterolateral facet orientation most commonly occurs at C6 and is gradual. The angle of inclination of the zygapophyseal joints, as measured in the sagittal plane, increases progressively from C3 to T1.

FIGURE 2.11 Lateral projection surface rendered CT image demonstrating the zygapophyseal joints (ZJ) of the subaxial cervical spine. Superior (SAP) and inferior articular processes (IAP) arise from the lateral masses that have relatively flat articular facets (SAF, IAF) that appose to form the ZJ. The bone located between the superior and inferior articular processes is the pars interarticularis (PI).

THE UNCOVERTEBRAL (LUSCHKA) JOINTS

The uncovertebral joints are formed by the uncinate processes and the echancrures. The uncinate processes arise from the posterosuperior margins of the C3–C7 superior endplates. The echancrures are shallow depressions located along the posterosuperior margins of the inferior endplates that appose the uncinate processes. The uncovertebral joints form the anterior wall of the neural foramina from C3 to C7 and are in close proximity to the medial wall of the transverse foramina (Figures 2.4a–d).

Distinct capsules surround the uncovertebral joints and synoviocytes have been demonstrated in the lateral capsular tissue. The uncinate processes progressively shift from a more anterior position at C3 to a more posterior position at C7. The C7 uncinate processes are occasionally absent and distinct uncinate processes are rarely observed at T1 and T2. Rudimentary uncinate processes are visible in full-term neonates and continue to enlarge until 9 to 14 years of age.
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IMAGES 12a,b  Hypoplastic left C7–T1 zygapophyseal joint. (a) Surface rendered image from a CT myelogram captured from a posterior projection showing a hypoplasia of the left C7–T1 zygapophyseal joint (*). The patient has undergone a left C6 laminotomy (top white arrow) and left C7 laminectomy (bottom white arrow). (b) Axial image from a CT myelogram demonstrating the significant asymmetry in the size of the left (black arrow) and right (white arrow) zygapophyseal joints. The left-sided laminectomy is better visualized (white arrowheads).

IMAGES 13a,b  Omovertebral bones. Surface rendered (a) and axial (b) CT images from a posterior projection displays bilateral omovertebral bones (OVB), projecting from the C5 spinous processes to high-riding scapulae (SCAP). There are segmentation anomalies of the C5 and C6 posterior elements.
The thoracic spine is the longest portion of the spine, containing 12 segments. The thoracic kyphosis is one of the primary curves of the spine, forming during fetal development along with the sacral kyphosis. The unique anatomy of the thoracic segments results in relative immobility in comparison to the cervical and lumbar segments.
FIGURES 3.3q–s

KEY

AIVP  anterior internal vertebral venous plexus
AV  azygous vein
C  centrum
CM  conus medullaris
CVJ  costovertebral joint
IAF  inferior articular facet
IAP  inferior articular process
ILEFP  interlaminar epidural fat pad
IVF  intervertebral foramen
L  lamina
LF  ligamentum flavum
RH  rib head
SAF  superior articular facet
SAP  superior articular process
SC  spinal cord
SP  spinous process
SSL  supraspinous ligament
ZJ  zygapophyseal joint

(continued)
The thoracic spinous processes have an elongated rectangular shape, similar to the C7 spinous process. The T1–T4 spinous processes are oriented in the horizontal plane. The T5–T8 spinous processes are oriented inferiorly. The T9–T12 spinous processes take on features of the lumbar spinous processes, such as a more square configuration and orientation in the horizontal plane (Figures 3.12a,b). The posterior margins serve as attachment points for the supraspinous ligaments. The superior and inferior margins are the attachment points for the interspinous ligaments. Muscles that attach to the thoracic spinous processes include the trapezius, latissimus dorsi, rhomboid major and minor, serratus posterior superior and inferior, erector spinae and transversospinalis.

The thoracic vertebrae at the cervicothoracic and thoracolumbar transitions differ from the “typical” thoracic segments that have been described in the preceding paragraphs. The T1 retains certain cervical vertebral features, including uncovertebral joints, superior vertebral notches, and a rectangular shape. The lower thoracic segments progressively take on lumbar features. The T10 segment typically has oval facets that articulate with the T10 rib heads and variable facets on the transverse processes that articulate with the anterior tubercles of the T10 ribs. The T11 segment has facets arising from the pedicles that articulate with the T11 ribs. There are generally no facets arising from the T11 vertebra that articulate with the T11 ribs. The T12 segment has small processes that are homologues of the transverse processes, mammillary, and accessory processes (Figures 3.13a–c).

The boundaries of the thoracic spinal canal include the vertebral body anteriorly, pedicles anterolaterally, laminae posterolaterally, and spinous processes posteriorly. The width of the thoracic spinal canal decreases from T1 to T6 and increases from T7 to T12. The length increases from T1 to T5 and decreases from T6 to T12. This results in a more rounded configuration of the thoracic spinal canal than the cervical and lumbar regions. The caliber of the thoracic spinal canal is smaller than the cervical and lumbar spinal canal.

The thoracic intervertebral foramina are formed by the inferior vertebral notch of the pedicle superiorly, posterolateral margin of the vertebral body anterosuperiorly, demifacets and rib head anterointeriorly, superior vertebral notch inferiorly, and the superior articular process posteriorly (Figure 3.14). The intervertebral foramina of the thoracic spine are oriented laterally, like those of the upper lumbar segments.
FIGURES 3.12a,b  Surface rendered CT reformatted images in the (a) lateral and (b) posterior projections display the typical horizontal orientation of the T1–T4 spinous processes (SP) and inferior orientation of the T5–T8 SPs. The T9–T12 SPs progressively take on a squared, “lumbar” appearance.

FIGURES 3.13a–c  Axial maximum intensity projection CT images at (a) T10, (b) T11, and (c) T12 demonstrating the typical progression to “lumbar” features. The T10 rib heads (RH) articulate with a single oval-shaped facet (OF) and there are variable costotransverse joints (CTJ). Small articular facets (AF) arise from the lateral margins of the pedicle (P) and articulate with rib heads (RH) to form the costovertebral joints (CVJ). There are no CTJ at T11, the transverse costal facets (TCF) are absent and rib tubercles (RT) may be absent (left) or rudimentary (right). The T12 vertebra has rudimentary transverse processes (TP) and mammillary processes (MP).
NEURAL ANATOMY OF THE THORACIC SPINE

The thoracic spinal cord has a circular elliptical shape in the upper thoracic segments. The caudal-most, tapering portion of the cervical enlargement is found at T1–T2. The transverse diameter of the thoracic spinal cord decreases progressively T1–T7. The transverse diameter of the cord is relatively constant T7–T11, beginning to increase at T12 in association with the lumbar enlargement (Figure 3.23). The AP diameter of the spinal cord decreases slightly T1–T7 and increases slightly T8–T12. The length of the thoracic cord segments increases T1–T7 and decreases T8–T12.

As has been stated previously, the central canal of the spinal cord tends to narrow and occlude with increasing age. Stenosis of the central canal is most common from T2 to T8 and occlusion occurs earliest at T6. Next to the L5–S2 segments, the lowest patency rates of the central canal are found in the mid- to lower thoracic spine. In approximately 1.5% of the population, there is persistence of the central canal that is visible on MR examinations. The persistent central canal in these cases is characterized by a filiform or fusiform shape, caliber measuring 2 to 4 mm, and predominantly mid- to lower thoracic cord location (Figures 3.24a,b).

The T1 nerve roots arise from the spinal cord at the level of the C7 vertebral body and ultimately exit through the T1–T2 intervertebral foramen. The T2 nerve roots arise from the spinal cord one and one-half vertebral segments above the level of their exit through the intervertebral foramina 75% of the time. The T3–T12 nerve roots arise from the spinal cord two vertebral segments above their eventual exit points through the intervertebral foramina (Figures 3.25a,b).

The C8 spinal nerves exit through the C7–T1 neural foramina. From T1–T2 to T12–L1, the exiting spinal nerves are numbered according to the vertebral segment above. For example, the T7 spinal nerves exit the T7–T8 intervertebral foramina.

FIGURE 3.23 Curved reformatted coronal CT myelogram displaying thoracic spinal cord (SC) contour. The transverse diameter of the thoracic SC decreases T1–T7, is relatively constant T7–T11, and increases at the lumbar enlargement (LE). CE—cauda equina, CM—conus medullaris.
The Lumbar Spine

The lumbar spine is the most intensively investigated of the spinal regions, owing to the ubiquity of low back pain in adults. It is typically composed of five mobile vertebrae. The mobility of the lumbar segments stands in stark contrast to the restricted mobility of the thoracic segments above and immobility of the sacral segments below. No other region of the spine possesses the remarkable combination of strength, stability, multidirectional mobility, and flexibility of the lumbar spine.
CT (FIGURES 4.4d–4.4q)

FIGURES 4.4d–f

**KEY**

- IAP: inferior articular process
- SAP: superior articular process
- IEP: inferior endplate
- SEP: superior endplate
- IVF: intervertebral foramen
- IVD: intervertebral disc
- SIJ: sacroiliac joint
- L: lamina
- SP: spinous process
- SVN: superior vertebral notch
- PI: pars interarticularis
- TP: transverse process
- ZJ: zygapophyseal joint
- R: rib

(continued)
OSTEOLOGY OF THE LUMBAR SEGMENTS

The lumbar lordosis is more pronounced than the cervical lordosis and results from a combination of vertebral body and intervertebral disc wedging. The vertebral body wedging at L4 and L5 is the opposite of that seen in the thoracic segments, with greater height anteriorly than posteriorly. The lumbar vertebral bodies are greater in size in the transverse dimension than the anterior to posterior dimension. In the axial plane, the L1–L4 vertebral bodies have a dorsal concavity that produces a kidney shape (Figure 4.5). The L5 vertebral body has a convex dorsal margin, forming an ellipse (Figure 4.4y). The bone mineral content, trabecular density, volume, and compressive strength of the lumbar vertebral bodies increase L1–L3 and decrease slightly L4–L5. The strength and stiffness of the posteros lateral aspect of the L3–L5 vertebral endplates is greater than the central aspects of the vertebral endplates.

The lumbar pedicles are shorter than the thoracic pedicles. They are larger in height than width. The width of the lumbar pedicles increases L1–L5 (Figure 4.6). They arise more inferiorly from the vertebral body than the thoracic pedicles, forming shallow superior vertebral notches. The inferior vertebral notches, formed by upward concavity along the inferior margin of the pedicles, are comparatively deep. The L1 pedicles are smaller in caliber than the T10–T12 pedicles. They are angled anteromedial to posterolateral in the transverse plane. This angle increases from L1 to L5. In the sagittal plane, the lumbar pedicles are angled slightly anterosuperior to posteroinferior. The lumbar pedicle is commonly accessed for percutaneous vertebral biopsies (Figure 4.7a), vertebral augmentation (Figures 4.7b–d), and occasionally disc aspiration/biopsy.

The transverse processes of the lumbar segments are flat and primarily oriented in the coronal plane, with slight posteros lateral angulation. They increase in length L1–L3 and
THE INTERVERTEBRAL DISCS OF THE LUMBAR SPINE

Intervertebral disc and vertebral shape are the primary determinants of the lumbar lordosis. The lumbar intervertebral discs are taller anteriorly than posteriorly, particularly at L4–L5 and L5–S1 (Figures 4.4r, 4.4s). The lumbar discs are the tallest of the spinal column and increase in cross-sectional area L1–L2 to L4–L5. The L5–S1 disc is shorter than the rest of the lumbar discs. The weight-bearing capacity of the lumbar intervertebral discs is greater than that of the cervical and thoracic discs. This is likely related to a preferential accumulation of degenerative changes within the lumbar intervertebral discs that has been documented in a variety of age groups. The proportion of the L5–S1 disc composed of nucleus pulposus is higher than any other intervertebral disc and its rate of degeneration is more rapid.

The appearance of the intervertebral discs varies with age on T2-weighted MR images. The nucleus pulposis and inner annulus fibrosis display hyperintense signal while the outer annulus fibrosis displays low signal (Figures 4.19a, 4.19b). In the first decade, the hyperintense T2 signal of nucleus pulposis and inner annulus is well-delineated from the low signal of the thin outer annulus. As early as the third decade, a thin, transversely oriented band of low signal may be seen at the center of the nucleus pulposis on sagittal MR images that correlates with collagen deposition, referred to as the internuclear cleft (Figure 4.20). With increasing age, there is a progressive decrease in water and proteoglycan content and an increase in collagen content within the intervertebral discs that correlates with decreasing T2 signal. In the eighth and ninth decades, the fibrous content of the intervertebral discs is marked, correlating with diffusely decreased signal on T2 and reduced delineation of the nucleus pulposis and annulus fibrosis.

**FIGURES 4.19a,b** Lumbar intervertebral disc (IVD). (a) Sagittal and (b) axial T2-weighted TSE images demonstrate the hypointense outer annulus fibrosis (AF) and hyperintense nucleus pulposis (NP). The inner AF is hyperintense on T2-weighted images and is indistinguishable from the nucleus pulposis. IEP—inferior endplate, SAS—subarachnoid space, SEP—superior endplate.

**FIGURE 4.20** Sagittal T2-weighted TSE image demonstrating thin hypointense lines (internuclear clefts) bisecting the nucleus pulposis (NP) at multiple levels (arrows).
GALLERY OF ANATOMIC VARIANTS AND VARIOUS CONGENITAL ANOMALIES

**IMAGE 1** Large field of view gradient echo image obtained for counting vertebrae shows a patient with 7 cervical, 12 thoracic, and 4 mobile presacral segments. The L5 vertebra is incorporated into the sacrum (“sacralized”).

**IMAGE 2** Large field of view T2-weighted image of the whole spine demonstrates 7 cervical, 12 thoracic, and 6 mobile presacral segments. The S1 segment is not incorporated into the sacrum (“lumbarized”).

**IMAGES 3a,b**
(a) Sagittal reformatted CT image demonstrating partial fusion of the L4 and L5 vertebral bodies (arrowhead) and spinous processes (arrows). (b) Sagittal T2-weighted TSE image displaying partial fusion of the L2 and L3 vertebral bodies and a rudimentary L2-L3 intervertebral disc (arrow).
The Sacrum and Coccyx

The complex structure of the sacrum reflects its multiple functions, including: allowing for bidirectional axial load shifting between the upper body and the lower extremities, formation and stabilization of the pelvic girdle, protection and transmission of the sacral spinal nerves, and serving as an origin or attachment site for several lower extremity muscles. The varied articulations of the sacrum include an amphiarthrodial (symphyseal) joint with the coccyx below, fibrous and synovial joints with the iliac bones bilaterally, discovertebral and zygapophyseal joints with the lumbar spine above.
surface that forms an attachment site for the interosseous sacroiliac ligament and posterior sacroiliac ligament, called the *sacral tuberosity*. Inferior to the auricular surface, the lateral surface is thin and tapers progressively to the *inferior lateral angle*. The gluteus maximus and coccygeus muscles attach along the inferior lateral angles. The sacrospinous and sacrotuberous ligaments attach along the dorsal margins of the inferior lateral angles.


ARTERIAL ANATOMY OF THE LUMBAR SPINE

The segmental branches supplying the sacral segments arise from the longitudinal arteries of the sacrum, which include the middle sacral and lateral sacral arteries (Figures 5.22a,b). The middle sacral artery typically arises from the dorsal side of the aorta, just proximal to the aortic bifurcation at the L4–L5 level, and travels along the ventral midline of the sacrum and coccyx, forming rich anastomoses with the iliolumbar and lateral sacral arteries. The lateral sacral arteries typically arise as the second branch of the internal iliac arteries. Occasionally, a lateral sacral artery may originate from the superior gluteal artery.

There are two divisions of the lateral sacral arteries, superior and inferior. The superior divisions course inferiorly and medially to anastomose with branches of the middle sacral artery. The superior divisions of the lateral sacral arteries then enter the S1 ventral foramina, where they supply the sacral nerve roots and meninges, and exit through the S1 dorsal foramina to supply the adjacent muscles and skin (Figure 5.23). The inferior divisions course over the

FIGURES 5.22a,b  (a) Surface rendered CT angiogram showing the arterial supply to the sacrum. The middle sacral artery (MSA) in this individual ends in lumbar segmental arteries (SA). (b) Anterior oblique surface rendered CT angiogram shows the superior lateral sacral artery (arrowhead) and the inferior lateral sacral artery (arrow) arising from the posterior division of the internal iliac artery (PD-IIA). The superior lateral sacral artery enters the S1 ventral foramen. The inferior lateral sacral artery courses along the ventral surface of the sacrum. AD-IIA—anterior division internal iliac artery, CIA—common iliac artery, EIA—external iliac artery, IEA—inferior epigastric artery, IIA—internal iliac artery, IMA—inferior mesenteric artery, MSA—median sacral artery, PD-IIA—posterior division internal iliac artery, SA—segmental artery, SMA—superior mesenteric artery, SPr—sacral promontory.

FIGURE 5.23  Axial oblique reformatted maximum intensity projection image showing the superior lateral sacral arteries (arrows) entering the S1 ventral sacral foramina (VSF), where they supply the sacral nerve roots and meninges, and exiting through the S1 dorsal sacral foramina (DSF) to supply the adjacent muscles and skin.
THE COCCYX

The coccyx typically consists of four segments (70%–80%), ranging from three to five segments. The coccygeal segments decrease in size cranially (base) to caudally (apex). The coccygeal cornua are vestigial superior articular processes that form a zygapophyseal joint with similar, inferiorly projecting sacral cornua. An S5-Coc1 fibrous disc allows a small amount of flexion and extension. However, fusion across the sacrococcygeal joint is common (57%). There is variable fusion across the intercoccygeal joints, with two (54%) and three (34%) bony segments the most common configurations. There is a range of coccygeal shapes that may be considered normal, including the presence of bony spicules, severe angulation, and subluxation (Table 5.1). The anatomy of the coccygeal segments is presented in multiple imaging modalities in Figures 5.30a–d.

The coccygeal segments serve as sites of attachment for several muscles and ligaments. The gluteus maximus attaches to the dorsolateral margins of the coccyx and levator ani muscles attach to the apex (Figure 5.27). The anterior sacrococcygeal ligament is the downward extension of the anterior longitudinal ligament that attaches to the anterior margin of Coc1 and Coc2. The posterior sacrococcygeal ligament has deep and superficial components. The deep component is the downward extension of the posterior longitudinal ligament on the ventral margin of the sacral canal that attaches to the dorsal surface of the coccyx. The superficial component covers the sacral hiatus and attaches to the dorsal coccyx (Figures 5.27 and 5.30). Additional ligaments that have attachments to the coccyx include the intracornual, lateral sacrococcygeal, and anococcygeal ligaments. The sacrotuberous and sacrospinous ligaments have extensions that attach to the posterolateral margins of the coccyx.

TABLE 5.1 Morphological Types of the Coccyx

<table>
<thead>
<tr>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slight coccygeal curvature with apex pointing inferiorly.</td>
</tr>
<tr>
<td>2</td>
<td>More pronounced coccygeal curvature with apex pointing anteriorly.</td>
</tr>
<tr>
<td>3</td>
<td>Sharply angulated between Cx1-Cx2 or Cx2-Cx3</td>
</tr>
<tr>
<td>4</td>
<td>Anterior subluxation of the sacrococcygeal joint or Cx1-Cx2</td>
</tr>
<tr>
<td>5</td>
<td>Retroverted coccygeal apex</td>
</tr>
</tbody>
</table>

FIGURES 5.30a–d Anatomy of the coccyx on (a) plain radiograph, (b) sagittal reformatted CT, (c) surface reformatted CT, and (d) contrast enhanced T1-weighted FSE images. CCo—coccygeal cornua, Coc—coccygeal nerve, SacC—sacral canal, SCo—sacral cornua.

(continued)
FIGURES 5.30c, d  (continued) CCo—coccygeal cornua, Coc—coccygeal nerve, DSF—dorsal sacral foramina, MSC—median sacral crest, SCo—sacral cornua, SH—sacral hiatus, SPSL—superficial posterior sacrococcygeal ligament.
The Paraspinal Musculature

A complete understanding of the anatomy of the spine must include knowledge of the paraspinal musculature. Functions attributed to the paraspinal muscles include protection of the spine, limiting excess motion, maintenance of spinal alignment, and motion. In this chapter, the anatomy of the paraspinal muscles of the cervical, thoracic, lumbar, and sacral spine is presented as a series of images in order from craniad to caudad with the use of two modalities, MR and CT.

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- Lumbosacral Paraspinal Muscles  280
CERVICAL PARASPINAL MUSCLES

KEY

| LC  | longissimus capitis muscle |
| LCap | longus capitis muscle |
| LColi | longus colli muscle |
| LevS | levator scapulae muscle |
| Multifid | multifidis muscle |
| OCI | obliquus capitis inferior muscle |
| OCS | obliquus capitis superior muscle |
| PBD | posterior belly of the digastric muscle |
| RCA | rectus capitis anterior muscle |
| RCL | rectus capitis lateralis muscle |

| RCPm | rectus capitis posterior minor muscle |
| RCPM | rectus capitis posterior major muscle |
| SCM | semispinalis capitis muscle |
| SemiC | semispinalis cervicis muscle |
| OCI | obliquus capitis inferior muscle |
| OCS | obliquus capitis superior muscle |
| PBD | posterior belly of the digastric muscle |
| RCA | rectus capitis anterior muscle |
| RCL | rectus capitis lateralis muscle |

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**KEY**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS</td>
<td>anterior scalene muscle</td>
</tr>
<tr>
<td>IlioC</td>
<td>iliocostalis cervicis muscle</td>
</tr>
<tr>
<td>LC</td>
<td>longissimus capitis muscle</td>
</tr>
<tr>
<td>LCap</td>
<td>longus capitis muscle</td>
</tr>
<tr>
<td>LColi</td>
<td>longus coli muscle</td>
</tr>
<tr>
<td>LevS</td>
<td>levator scapulae muscle</td>
</tr>
<tr>
<td>LN</td>
<td>ligamentum nuchae</td>
</tr>
<tr>
<td>LongC</td>
<td>longissimus cervicis muscle</td>
</tr>
<tr>
<td>MS</td>
<td>middle scalene muscle</td>
</tr>
<tr>
<td>Multifid</td>
<td>multifidis muscle</td>
</tr>
<tr>
<td>PS</td>
<td>posterior scalene muscle</td>
</tr>
<tr>
<td>RhMinor</td>
<td>rhomboid minor muscle</td>
</tr>
<tr>
<td>SCM</td>
<td>sternocleidomastoid muscle</td>
</tr>
<tr>
<td>SemiC</td>
<td>semispinalis cervicis muscle</td>
</tr>
<tr>
<td>SemiCerv</td>
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<tr>
<td>SpinC</td>
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</tr>
<tr>
<td>SplenCap</td>
<td>splenius capitis muscle</td>
</tr>
<tr>
<td>SplenC</td>
<td>splenius cervicis muscle</td>
</tr>
<tr>
<td>Trap</td>
<td>trapezius</td>
</tr>
</tbody>
</table>

*The iliocostalis, longissimus, and spinalis muscles are frequently referred to collectively as the erector spinae muscles.

**The semispinalis (capitis, cervicis, dorsi), multifidus, rotatores (cervicis, thoracis, lumbarum), interspinales, and intertransversarii muscles may be referred to as the transversospinal muscles. These muscles function to extend and rotate the spine.
The iliocostalis, longissimus, and spinalis muscles are frequently referred to collectively as the erector spinae muscles. 

The semispinalis (capitis, cervicis, dorsi), multifidus, rotatores (cervicis, thoracis, lumborum), interspinales, and intertransversarii muscles may be referred to as the transversospinal muscles. These muscles function to extend and rotate the spine.
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**KEY**

- **AS**: anterior scalene muscle
- **IlioC**: iliocostalis cervicis muscle
- **LCap**: longus capitis muscle
- **LColi**: longus colli muscle
- **LevS**: levator scapulae muscle
- **LN**: ligamentum nuchae
- **LongC**: longissimus cervicis muscle
- **MS**: middle scalene muscle
- **Multifid**: multifidus muscle
- **PS**: posterior scalene muscle
- **RhMinor**: rhomboid minor muscle
- **SCM**: sternocleidomastoid muscle
- **SemiC**: semispinalis capitis muscle
- **SemiCerv**: semispinalis cervicis muscle
- **SplenC**: splenius cervicis muscle
- **SplenCap**: splenius capitis muscle
- **Trap**: trapezius

*The iliocostalis, longissimus, and spinalis muscles are frequently referred to collectively as the erector spinae muscles.*

**The semispinalis (capitis, cervicis, dorsi), multifidus, rotatores (cervicis, thoracis, lumborum), interspinales, and intertransversarii muscles may be referred to as the transversospinal muscles. These muscles function to extend and rotate the spine.*
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