Thoracic and Lumbar Spinal Anatomy 38

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Abstract

Degenerative arthropathy, trauma and congenital anomalies, as well as focal abnormalities such as facet overgrowth and disk herniations render each patient unique, and these abnormalities can impact surgical approach. The goal of this chapter is to discuss anatomic considerations that impact surgical planning and to provide a framework for thinking about patient-specific anatomy when approaching the thoracic and lumbar spines.

Keywords

Thoracic spine · Lumbar spine · Degenerative arthropathy · Intraoperative localization

Thoracic Spine

The thoracic spine is composed of 12 rib-bearing vertebrae, separated by intervertebral disks and connected posteriorly by the interspinous ligament (Fig. 1). Each thoracic vertebra has a body, a spinous process, and superior and inferior articulating facets in addition to inferior, superior, and transverse costal facets to articulate with the head of the rib. The pedicles of thoracic spinal vertebrae vary in size, with T1 pedicles being narrow and subsequent pedicles increasing in width approaching the thoracolumbar junction (Fig. 2).

The angulation of the thoracic pedicles further changes, with more caudally oriented trajectories

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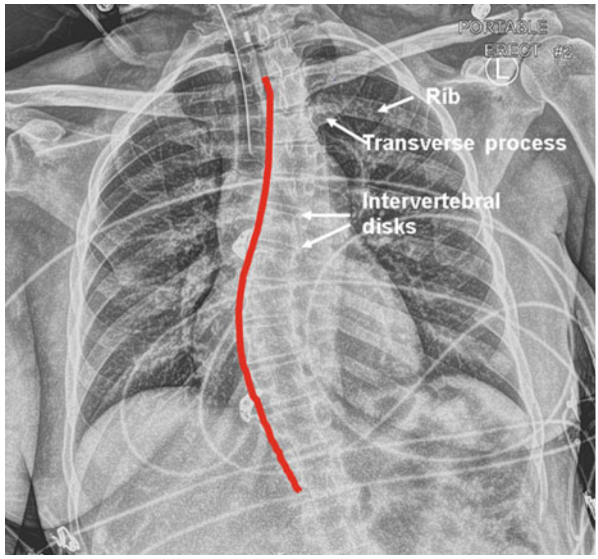

Fig. 1 Anterior-posterior x-ray of the thoracic spine demonstrating coronal scoliosis in the thoracic spine. Ribs, intervertebral disks, and bodies are shown. The red line indicates the lateral aspect of the vertebral bodies

in the upper thoracic spine. Thoracic instrumentation can be challenging due to this variability, and navigation or fluoroscopy-based techniques can assist in planning thoracic pedicle screw trajectories.

The thoracic spine is more rigid than the cervical or lumbar spine, as it is fixed to the sternum via the ribs, limiting the range of motion in the thoracic spine. The cervicothoracic junction and thoracolumbar junctions are more mobile points of transition and are thus more likely to succumb to traumatic pathology. Degenerative pathologies of thoracic spine include sagittal kyphotic deformity, typically secondary to progressive compression fractures, and coronal scoliosis (Fig. 1). Adolescent scoliosis is a common childhood disorder affecting thoracic spine alignment, and in adult patients, iatrogenic or degenerative scoliosis with coronal curvature may affect thoracic spine alignment.

Common traumatic thoracic pathologies include disk herniations and fractures. Thoracic disk herniations may occur with minimal trauma, and over time these disk herniations may become calcified (Oppenlander et al. 2016). If a thoracic disk herniation is noted on magnetic resonance imaging (MRI), computed tomography (CT) can be useful to identify the degree of calcification prior to surgical planning. If a thoracic disk is calcified and causing cord compression and neurological deficit, a transpedicular approach may be required to safely access and drill down the calcified component (Fig. 3).

In older patients with osteoporosis, falls are a common cause of compression fractures in the thoracic spine. Thoracic compression fractures may also be seen in patients with metastatic cancer involving the vertebral bodies. Pain with axial loading (i.e., standing) is a common symptom in thoracic compression fractures. Patients may develop myelopathy from cord compression following fracture or severe, radicular chest pain along the chest wall from neuroforaminal narrowing. Due to the overall stability of the thoracic spine, severe thoracic spine fractures require high velocities such as motor vehicle accidents. If the thoracic spinal column is fractured and displaced, there will likely be associated rib and sternal fractures. Spinal cord transection, although rare, can happen with these types of injures. Patients with diffuse idiopathic skeletal hyperostosis (DISH) or ankylosing spondylitis (Rustagi et al. 2017) are more likely to experience thoracic spine fractures with low velocity accidents (Fig. 4).

Intraoperative localization in the thoracic spine can be challenging if the lesion is not readily identifiable on standard radiographic studies or

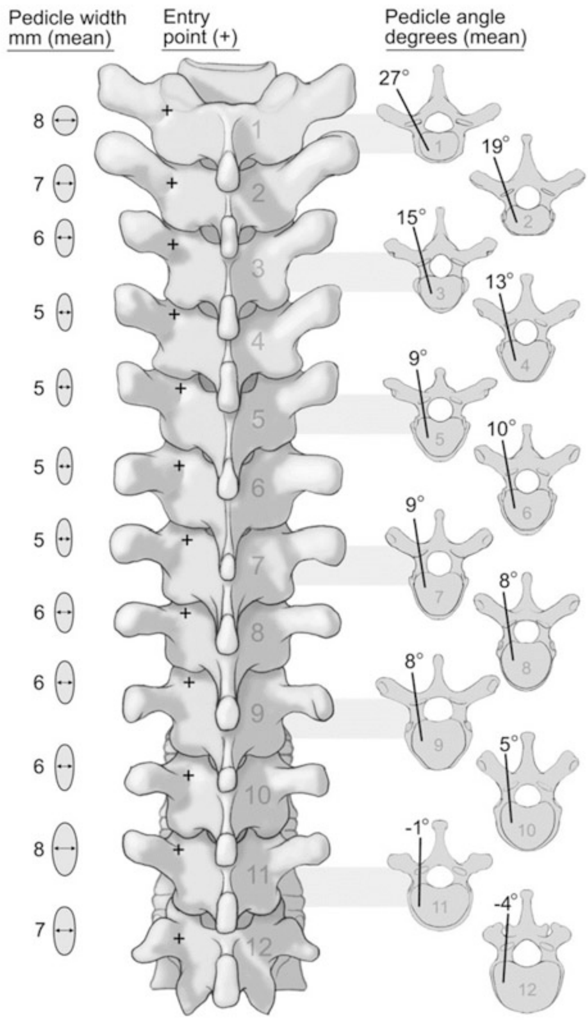

Fig. 2 Illustration showing some morphometric characteristics of the thoracic vertebrae from T1 to T12. The widths of the isthmus of the transverse pedicle are listed on the left. The pedicle entry points (+) and their relationship to the transverse process, laminae, and facets are shown in the center. The transverse pedicle angles are listed on the right. (Reprinted with permission from Hartl et al. 2004, Technique of thoracic pedicle screw fixation for trauma, *Operative Techniques in Neurosurgery*)

fluoroscopy. Unlike cervical and lumbar spine localization, there is no distinct body (i.e., sacral endplate or dens) available as a reference for counting. Preoperative thoracic and lumbar x-rays may be helpful to determine the true number of ribbed and non-ribbed vertebrae. This may help to correlate with the MRI if the patient has a transitional S1 that may be lumbarized or hypoplastic or an abnormal number of ribbed vertebrae.

Preoperative CT or MRI scans for localization may be obtained prior to surgery incorporating a reference body (i.e., sacral endplate, dens, or other identifiable structure). A radiologist can provide labeling of the localization scan to confirm the precise thoracic body affected. This allows congenital anomalies, such as sacralized lumbar vertebrae, or an abnormal number of rib-bearing vertebrae to be identified. These studies can be correlated with preoperative plain films to reduce the likelihood of wrong-level surgery.

Intraoperative anterior-posterior and lateral fluoroscopic images may be taken to localize the surgical level. Live intraoperative fluoroscopy may also be used for level confirmation, typically by counting up from the sacrum. Intraoperative 3-D imaging, if available, may also help to provide more definitive surgical localization. Prior instrumentation, kyphoplasty cement, or unique fractures may further help to confirm the target level.

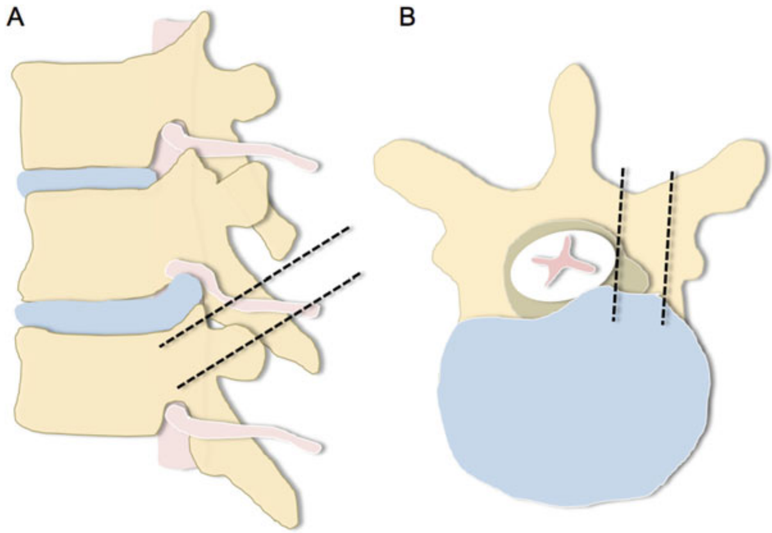

Fig. 3 Transpedicular approach for resection of calcified thoracic disk. (**a**) Lateral view of herniated thoracic disk causing deformation of exiting nerve root. Black lines indicate transpedicular approach to the calcified thoracic disk. (**b**) Axial diagram depicting approach to calcified thoracic disk

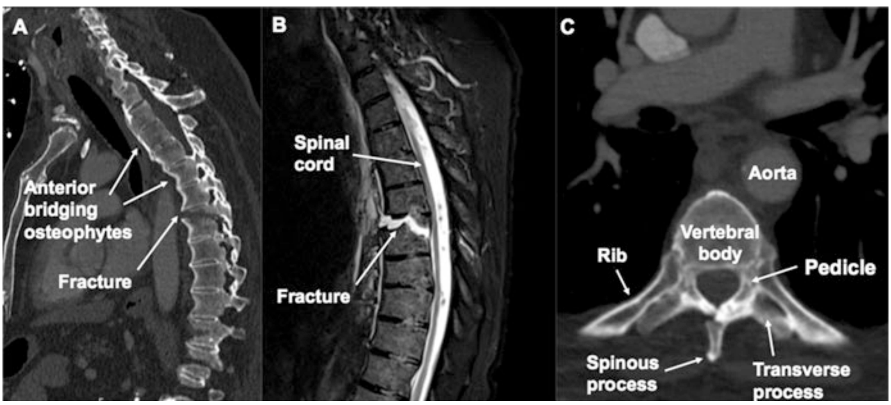

Fig. 4 T8 fracture extending though vertebral body, pedicle, and spinous process in a patient with ankylosing spondylitis. (**a**) Sagittal CT scan demonstrating anterior bridging osteophytes consistent with ankylosing spondylitis and fracture line extending through the T8 vertebral body, pedicle, and spinous process. (**b**) Sagittal T2-weighted fat-suppressed MRI demonstrating T2 hyperintensity along fracture line. The spinal cord can be seen draped ventrally along the posterior aspect of the vertebral bodies. (**c**) Axial CT scan through mid-thoracic vertebra demonstrating relationship of the rib, spinous process, transverse process, and pedicle

It is important to note that technical and patient factors (obesity, surgical position, non-radiolucent OR tables, and others) may interfere with the correct interpretation of these studies. In these instances, consultation with a radiologist should be undertaken.

Direct anterior approaches to the thoracic spine are uncommon, as the aorta and vena cava abut the ventral aspect of the thoracic vertebrae and the lungs and other key structures obstruct direct access (Fig. 5). En bloc resection of thoracic spinal tumors or metastatic pathology may merit anterior approaches (Xu et al. 2009), and these surgeries are often conducted with a cardiothoracic access surgeon. Anterolateral approaches to the thoracic spine include costotransversectomy with removal of the transverse costal facet and rib head for access to the lateral vertebral body and the lateral extracavitary approach, which removes portions of the rib head lateral to the transverse process for greater access to the vertebral body. Careful coordination is necessary when planning

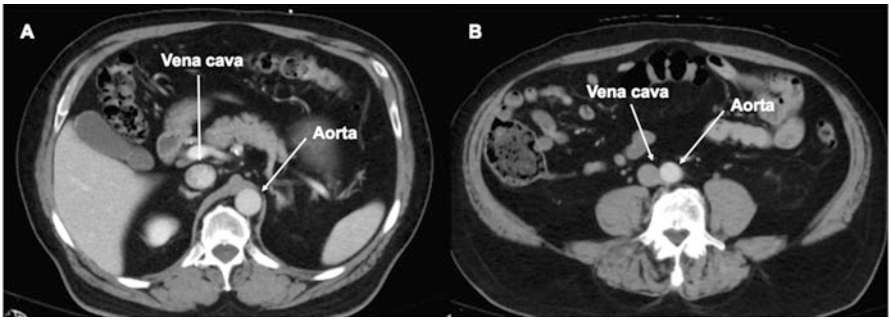

Fig. 5 Sagittal CT scan through (**a**) T12 and (**b**) L3 levels illustrating the relationship of the aorta to the thoracic and lumbar spines

an anterior thoracic approach, as the patient may be intubated with a dual-lumen endotracheal tube. This allows the anesthesiologist to selectively hold respirations in the lung adjacent to the surgical field, facilitating access to the vertebral body. Injury to the lung pleura puts patients at an increased risk of pulmonary complications in some studies, and a chest tube may be electively placed to reflate the lung and prevent pneumothorax or large pleural effusions after anterior thoracic spine approaches. Other treatments such as the application of talc powder or mechanical abrasion of the pleural surfaces to promote pleural adhesion may also be considered. Minimally invasive and endoscopic techniques have also been described to reduce complications for anterior spinal surgeries (Borm et al. 2004).

Posterior and posterolateral approaches to the thoracic spine provide limited access to the posterior vertebral body for debulking of metastatic tumors and decompression of fracture fragments. Following laminectomy, unilateral or bilateral pedicles can be resected via careful drilling to access the ventral vertebral body. In the thoracic spine below T2, nerve roots do not provide significant motor contributions, and these roots may be sacrificed lateral to the dorsal root ganglion to further expand the exposure and improve access to the ventral disk space. Nerve root avulsion or compression should be avoided as this may result in postoperative radicular pain.

For calcified disk herniations, pedicle resection can be an effective way to access the disk space. If the pedicle is sacrificed for access, unilateral or bilateral posterior fusion may be required to limit segmental motion and collapse. Posterior fusion of the thoracic spine typically involves placement of pedicle screws, and preoperative evaluation should take into account pedicle length and width. Medialized screws in the thoracic spine result in cord compression, while lateralized screw trajectories can incorporate rib or injure thoracic viscera. Intraoperative navigation is a useful tool to decide optimal screw trajectory.

Bullet Points

- Ventral disk herniations in the thoracic spine may be calcified.
- Thoracic spine localization requires careful preoperative planning.
- Unilateral nerve roots T2-12 can be sacrificed to improve surgical exposure in posterior and posterolateral approaches.

Lumbar Spine

The lumbar spine is composed of five vertebrae in lordotic alignment, joined by intervertebral disks and posteriorly via facet joints (Fig. 6). Lumbar vertebrae are composed of a body, two pedicles, two transverse processes, and a superior and inferior articulating facet. The transverse processes project laterally and may become fractured during an assault or trauma, leading to musculoskeletal discomfort. There is no load-bearing function of

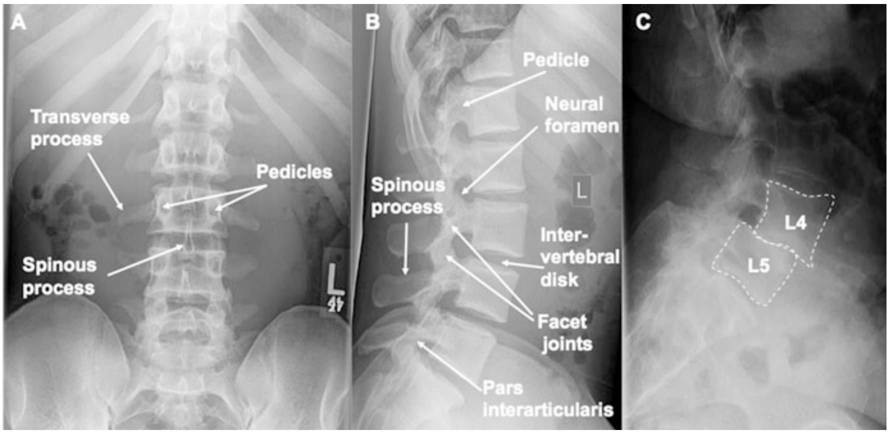

Fig. 6 (**a**) AP and (**b**) lateral x-rays of the lumbar spine illustrating the transverse process, pedicles, spinous process, facet joints, and neural foramen of the lumbar spine. (**c**) Lateral x-ray of the lumbar spine of a different patient, illustrating spondylolisthesis of L4 on L5. The vertebral bodies are outlined with dotted white lines

the transverse processes, and these do not need to be repaired in the case of fracture. The iliopsoas muscle attaches at the transverse processes along the lumbar spine and inserts on the trochanter of the femur. During posterior instrumented fusion, the transverse processes may serve as a surface to encourage fusion. The midportion of the transverse process, as determined in a superior-inferior direction, generally correlates with the midpoint of the lumbar pedicle (again as determined in the superior-inferior axial plane). This landmark can be used to help localize the starting point for pedicle probe or drill insertion.

Intraoperative localization for lumbar spine surgery is typically achieved with lateral radiographs, and the levels are identified by counting from the L5 to S1 disk space. In some patients the fifth lumbar vertebrae may be sacralized, meaning its orientation mimics a typical S1 caudal orientation. This anatomic variant should be identified prior to surgery, as it affects intraoperative localization. Spina bifida occulta may be recognized in patients undergoing evaluation for other spinal issues, and laminar defects may be identified prior to surgery. Another congenital anomaly in the lumbar spine is a pars defect. In this variant, the pars interarticularis (the bony bridge between the superior and inferior articulating facets) fails to develop. The pars interarticularis resists the vector of anterolisthesis, and when the pars is compromised, patients may be at increased risk of developing progressive spondylolisthesis (Fig. 6).

Many patients with lumbar stenosis experience worsening of symptoms with axial loading and ambulation. In contrast, MRI and CT images are traditionally acquired in a supine position. Standing, 36-in. x-rays with neutral leg position (i.e., no compensatory knee bend) provide a more accurate illustration of a patient's global alignment. Spinopelvic parameters can help surgeons to establish how much correction is needed if a lumbar fusion surgery is planned (Celestre et al. 2018). Among these measurements, pelvic incidence and lumbar lordosis are particularly relevant to lumbar spinal anatomy. Lumbar lordosis is measured by the angle between the lower T12 endplate and S1 endplates (Fig. 7).

The pelvic incidence is measured as the angle between a line drawn perpendicular to the center of the S1 endplate and a second line from the center of the S1 endplate to the center of the femoral heads. A patient's lumbar lordosis should be comparable (within 10°) to their pelvic incidence; otherwise an iatrogenic "flat-back" deformity of the lumbar spine may occur.

Common lumbar pathologies include lumbar stenosis, facet arthropathy, spondylolisthesis, and disk herniations (Issack et al. 2012). The posterior facets are prone to degenerative arthritis from

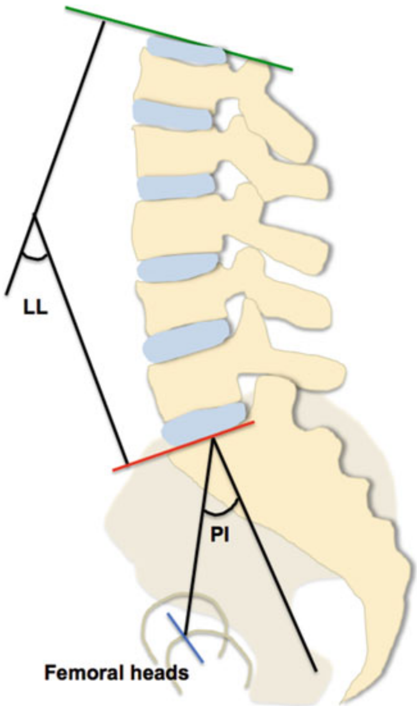

Fig. 7 Pelvic incidence (PI) and lumbar lordosis (LL). The green line indicates the interior endplate of T12 and the superior endplate of S1 (red line). Pelvic incidence is depicted as the angle subtended from the perpendicular line to the S1 endplate and the midpoint of a line drawn (blue) between the femoral heads

repeated abnormal motion, leading to facet overgrowth and synovial cyst formation (Fig. 8). These arthritic changes can compress the spinal canal and contribute to lumbar stenosis. Patients will manifest with radicular symptoms or lumbar claudication in cases of severe stenosis. In cases of spondylolisthesis (Fig. 8), subadjacent vertebral bodies may angle away from the surgeon, complicating the initial dissection. If facet overgrowth is suspected, removal of facet osteophytes may be necessary to identify the anatomic laminar edge.

Posterior approaches to the lumbar spine include laminectomy, hemilaminectomy with discectomy, and instrumented lumbar fusion. Hemilaminectomy is appropriate for patients with unilateral symptoms and a focal disk herniation; however, if the disk herniation is large or central (Fig. 9), a full laminectomy may be completed. If decompression without fusion is planned, the surgeon should avoid manipulation of the facet joint, as removal of the bone may disrupt facet integrity and lead to progressive instability. When fusion is planned, removal of facet overgrowth via rongeur or drilling can improve the surgical exposure and help to identify the laminar edge.

Anterior approaches to the lumbar spine are typically achieved with the help of an access general surgeon or vascular surgeon. The anterior lumbar interbody fusion (ALIF) involves removal of the intervertebral disk, placement of a disk replacement, and securing the disk replacement with an anterior plate and screws (Phan et al. 2017). This approach is complicated by the presence of the lumbosacral plexus (L5-S1) and the iliac bifurcation (L4-5). Anterior approaches may be utilized for patients with failed posterior fusion or in patients with severe deformity requiring anterior and posterior instrumentation to facilitate strength and reduce the risk of failure. Anterior lumbar approaches can be challenging in obese patients if the abdominal girth exceeds the length of surgical instruments. Further, retrograde ejaculation is a reported complication in men at a rate of 7.4–9.8% following manipulation of the lumbosacral plexus in ALIFs, thus compromising male fertility (Lindley et al. 2012).

Bullet Points

- Lumbar degenerative arthropathy can obscure the laminar edge on initial dissection.
- Sacralized lumbar vertebra can complicate intraoperative localization.
- Anterior lumbar fusions may be challenging in obese patients and carry the risk of retrograde ejaculation in male patients.

Conclusion

Careful patient examination and review of available preoperative imaging is crucial for success in spine surgery. CT scans provide key information regarding calcifications, and MRI scans are necessary to identify disk herniations. Prior to

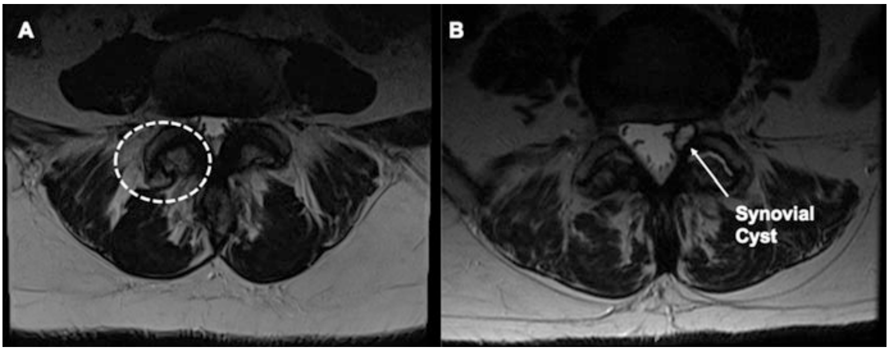

Fig. 8 Axial T2-weighted MRIs of the lumbar spine demonstrating (**a**) spine facet arthropathy with osteophytes noted at the superior and inferior articulating facets. (**b**) Synovial cyst with impingement of spinal canal

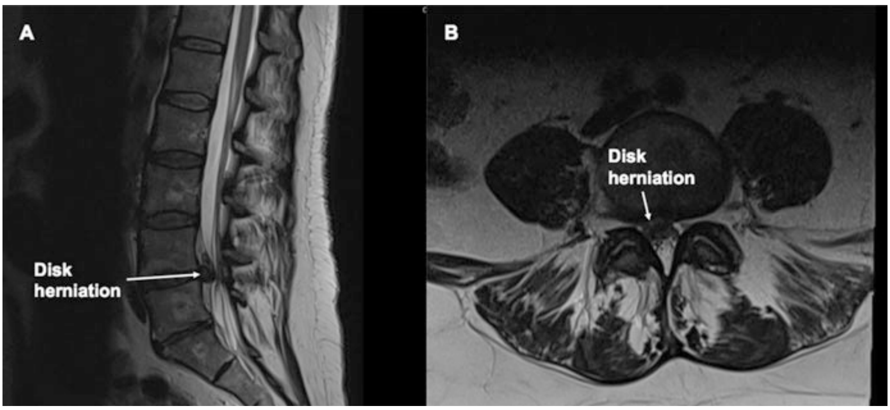

Fig. 9 Right-sided disk herniation causing compression of spinal canal and cauda equina nerve roots. (**a**) Sagittal T2-weighted MRI demonstrating compression of spinal canal and nerve roots. Swelling of nerve roots is noted caudal to the disk herniation. Heterogeneous T2 signal abnormality can be seen within the vertebral bodies of adjacent spinal levels

entering the operating suite, technical aspects of the surgery should be decided, including the type of surgical instrumentation if indication. Patient anatomical anomalies, such as sacralized vertebrae, abnormal rib-bearing vertebrae, osteophytes, and overgrown facets, should also be reviewed in detail. Upright or standing radiographs can complete the picture, as they may highlight loss of lordosis or spondylolisthesis. While knowledge of general spinal anatomy is crucial to form the foundation of spine surgery, patient-specific details must be considered to ensure the optimal outcome.

References

Borm W, Hubner F, Haffke T, Richter HP, Kast E, Rath SA (2004) Approach-related complications of transthoracic spinal reconstruction procedures. Zentralbl Neurochir 65:1–6

Celestre PC, Dimar JR 2nd, Glassman SD (2018) Spinopelvic parameters: lumbar lordosis, pelvic incidence, pelvic tilt, and sacral slope: what does a spine surgeon need to know to plan a lumbar deformity correction? Neurosurg Clin N Am 29:323–329

Issack PS, Cunningham ME, Pumberger M, Hughes AP, Cammisa FP Jr (2012) Degenerative lumbar spinal stenosis: evaluation and management. J Am Acad Orthop Surg 20:527–535

Lindley EM, McBeth ZL, Henry SE, Cooley R, Burger EL, Cain CM, Patel VV (2012) Retrograde ejaculation after anterior lumbar spine surgery. Spine (Phila Pa 1976) 37:1785–1789

Oppenlander ME, Clark JC, Kalyvas J, Dickman CA (2016) Indications and techniques for spinal instrumentation in thoracic disk surgery. Clin Spine Surg 29:E99–e106

Phan K, Lackey A, Chang N, Ho YT, Abi-Hanna D, Kerferd J, Maharaj MM, Parker RM, Malham GM, Mobbs RJ (2017) Anterior lumbar interbody fusion (ALIF) as an option for recurrent disc herniations: a systematic review and meta-analysis. J Spine Surg 3:587–595

Rustagi T, Drazin D, Oner C, York J, Schroeder GD, Vaccaro AR, Oskouian RJ, Chapman JR (2017) Fractures in spinal ankylosing disorders: a narrative review of disease and injury types, treatment techniques, and outcomes. J Orthop Trauma 31(Suppl 4): S57–S74

Xu R, Garces-Ambrossi GL, McGirt MJ, Witham TF, Wolinsky JP, Bydon A, Gokaslan ZL, Sciubba DM (2009) Thoracic vertebrectomy and spinal reconstruction via anterior, posterior, or combined approaches: clinical outcomes in 91 consecutive patients with metastatic spinal tumors. J Neurosurg Spine 11:272–284