12 Monitoring Procedures of the Spine

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Introduction

The vertebral column is an extremely complex structure, and surgical procedures involving the cervical, thoracic, and lumbar levels pose a risk to the neural elements. Although the overall incidence of a major neurologic complication such as paraplegia is low, advances in intraoperative neurophysiological monitoring (IOM) techniques have made multimodality monitoring an effective approach for preventing iatrogenic injury to the nervous system during spinal surgery.

Mixed nerve somatosensory evoked potentials (SSEPs) and transcranial motor evoked potentials (Tc-MEPs) are the IOM modalities most often used to monitor the spinal cord. Upper limb SSEP monitoring can also help prevent peri-surgical complications such as ulnar neuropathy and brachial plexopathy. However, these modalities have not been proven highly sensitive to detecting spinal nerve root injury, although there is some evidence supporting the sensitivity of Tc-MEPs for impending nerve root injury. Therefore, the addition of electromyography (EMG) and triggered EMG can be used to monitor the spinal nerve roots.

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Spinal Anatomy

The spine is composed of 33 interlocking bones, surrounded by ligaments and muscles, that provide the main support for the trunk and protect the spinal cord (Fig. 12.1). The 7 cervical, 12 thoracic, and 5 lumbar vertebrae are each separated by fibrocartilaginous discs that act as shock absorbers and allow the neck and back to move in multiple directions. Additionally, five fused vertebrae form the sacrum, and four coccygeal bones form the tailbone or coccyx.

Each vertebra has critical functional parts. The vertebral body is the weight-bearing portion of the vertebra and is located anterior to the vertebral canal. Posterior to the vertebral body are bony projections that form the vertebral arch: bilateral pedicles, lamina, transverse processes, and facet joints and a single posterior spinous process (Fig. 12.2). The vertebral canal contains the spinal cord or cauda equina, fat, ligaments, and blood vessels. Under each pedicle, spinal nerves exit the spinal cord and pass through the intervertebral foramen to branch out to the body. Surgeons often remove the lamina of the posterior vertebral arch to access and decompress the spinal cord or spinal nerves to treat spinal stenosis, tumors, or herniated discs.

The spinal cord extends from the foramen magnum to around spinal level L1. At L1, the terminal portion of the spinal cord is called the conus medullaris. From the conus, a bundle of

S. F. Davis, A. D. Kaye (eds.), *Principles of Neurophysiological Assessment, Mapping, and Monitoring*, https://doi.org/10.1007/978-3-030-22400-4_12

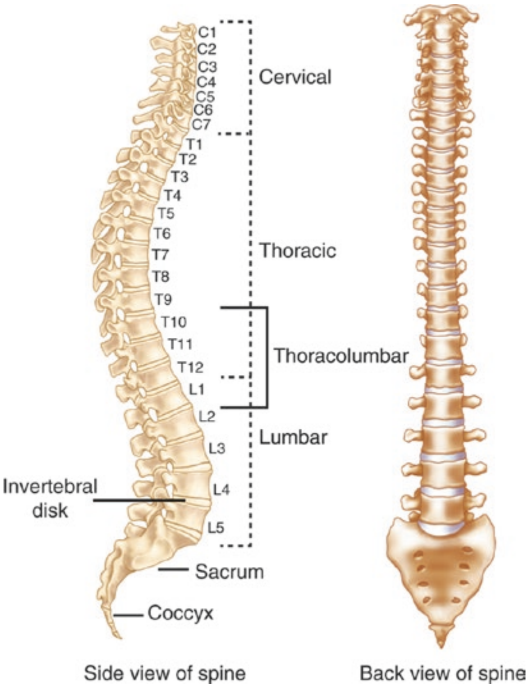

Fig. 12.1 Lateral view (left) and posterior view (right) of the spine. The cervical, thoracic, and lumbar vertebrae are separated by a cartilaginous disc that provides cushioning and allows for movement. The sacral and coccygeal vertebrae are already fused

spinal nerves called the cauda equina further extend down to their respective vertebral level where they exit the spinal column.

Thirty-one pairs of spinal nerves emerge from the spinal cord (Fig. 12.3). There are 8 cervical spinal nerves, 12 thoracic nerves, 5 lumbar nerves, 5 sacral nerves, and 1 coccygeal nerve. Each spinal nerve is composed of motor and sensory fibers that pass through an intervertebral foramen between adjacent vertebrae. Cervical and thoracic spinal nerve roots exit laterally from the vertebral canal between adjacent pedicles, while lumbosacral roots extend downward as part of the cauda equina before exiting through foramina below the spinal cord. Nerve roots can be injured during surgery by electrocautery, drilling, retraction, or misplaced hardware.

Procedures of the Cervical Spine

The main function of the cervical spine is to support the head and allow it to move. The first cervical vertebra (C1), sometimes called the atlas, is a bony ring (not a true vertebral body) that

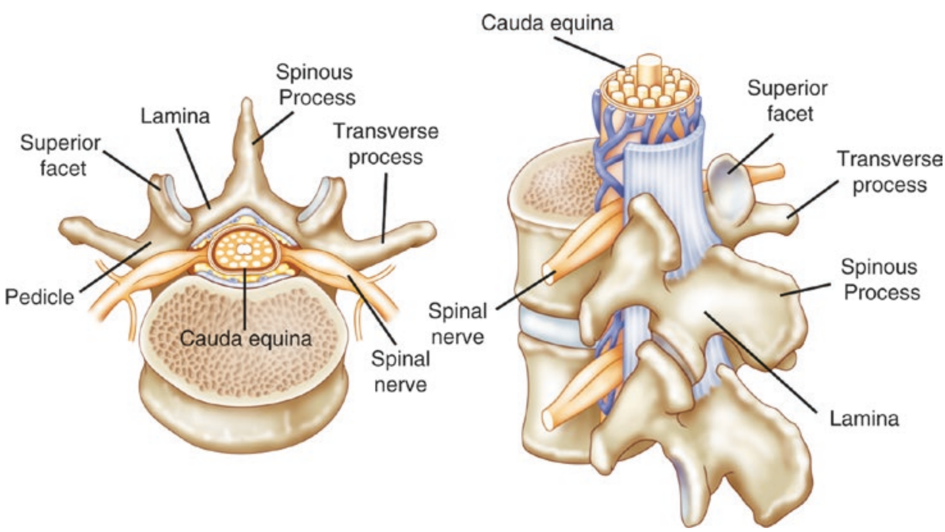

Fig. 12.2 Superior view of a vertebra showing the location of the critical functional parts relative to the spinal canal. The vertebral arch protects the spinal cord and exiting nerve roots and is formed from bilateral pedicles, lamina, transverse processes, and facet joints and a single posterior spinous process

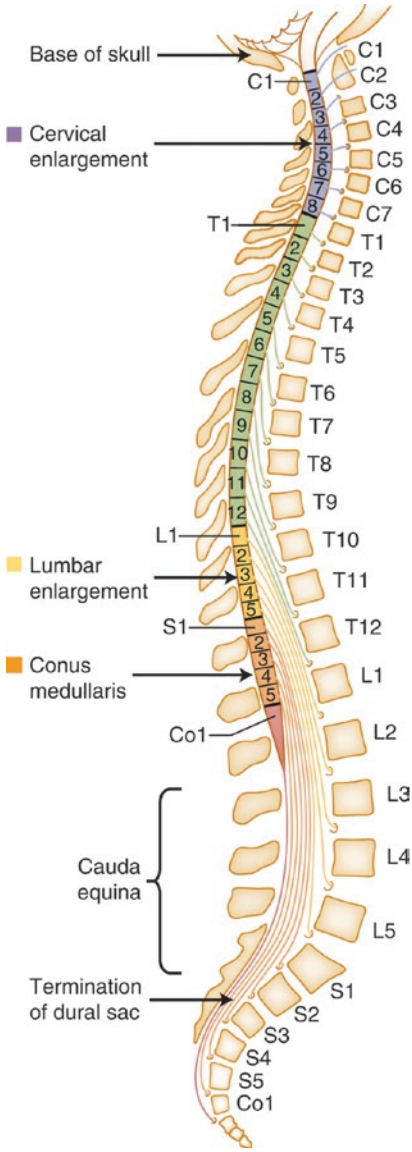

Fig. 12.3 Thirty-one pairs of spinal nerve roots branch off the spinal cord. Cervical and thoracic spinal nerve roots exit laterally from the spinal canal between adjacent pedicles, while lumbosacral roots extend downward as part of the cauda equina before exiting through foramina below the spinal cord

connects directly to the skull. Together with the C2 vertebra, or axis, these two vertebral joints attach the skull to the spine and allow for a range of movement in all directions. The remaining C3–C7 vertebrae form the lordotic curve of the neck. Also specific to the cervical vertebrae is the presence of transverse foramina that enclose and protect the vertebral arteries.

Cervical spine surgery is generally performed to treat nerve impingements (radiculopathy), spinal cord compression (myelopathy), or spinal instability that is causing pain and weakness. Common cervical procedures include anterior cervical discectomy and fusion (ACDF), posterior cervical fusion (PCF), and cervical corpectomy. Risks during surgery include but are not limited to cord contusion, motor loss or weakness, peripheral nerve injury, or vascular compromise.

Injury to the C5 nerve root is the most common injury from cervical surgery and can result in pain, paresis, or paralysis of the shoulder. Other nerve roots are subject to postoperative palsy, but most complications occur at C5 due to its shorter length and more obtuse angle of exit from the foramen [1, 2]. The C5 nerve root is the only nerve supply to the deltoid muscle of the shoulder, so injury to the nerve root leads to an obvious weakness of this muscle and difficulty raising the arm to the side [2]. The potential for C5 palsies can be detected by using EMG and Tc-MEP monitoring during spinal surgery with specific focus on the deltoid and biceps brachii muscles. Brachial plexopathy resulting from positional or traction-induced injury may mimic C5 palsy [3]. Many surgeons maintain downward traction on the shoulders during a cervical surgery. Injury to the brachial plexus may result from this traction and can be detected by monitoring SSEPs during the procedure.

Anterior Cervical Discectomy and Fusion

ACDF is a procedure often performed to remove a herniated or degenerative disc. Narrowing of the vertebral canal, a condition called spinal stenosis, can cause chronic pain, numbness, and muscle weakness in both upper and lower extremities. Bone spurs can also develop resulting in foraminal stenosis thus compressing the exiting spinal nerves.

The surgical approach during an ACDF is from the anterior, or front, of the neck. An anterior approach allows the surgeon access to the disc space without disturbing the spinal cord, spinal nerves, and posterior neck musculature. An incision is made and midline structures and musculature are retracted to expose the vertebral bodies and disc space. Bone and disc fragments are removed in order to decompress the spinal cord and nerve roots. After the disc space is cleaned out, an implant (often made of bone, metal or a biopolymer like PEEK) is placed between the vertebral bodies and secured with a metal plate and screws. The ultimate goal of the surgery is to create a bony fusion between the adjacent vertebrae with the metal hardware simply acting as a cast, stabilizing the spine until fusion occurs (Fig. 12.4).

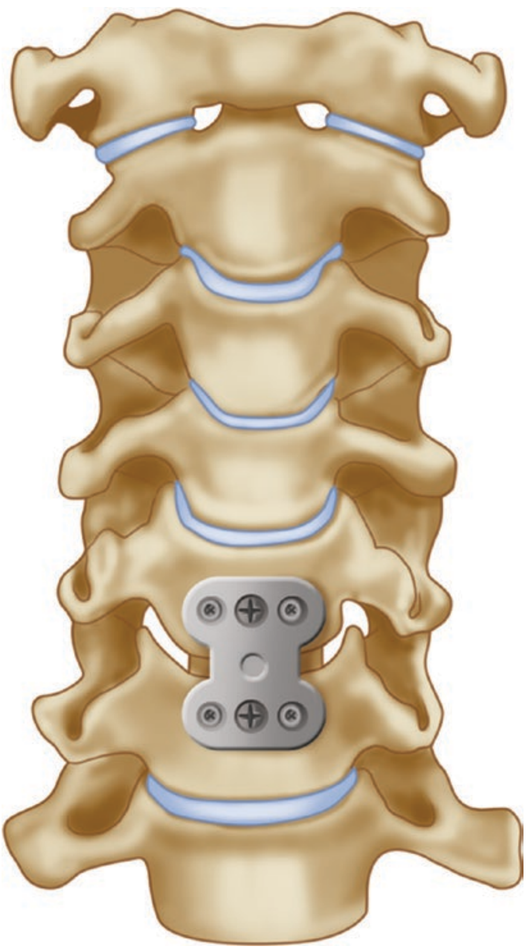

Fig. 12.4 Example of a metal plate and screws placed over the bone graft during ACDF surgery

A common complication in anterior cervical surgery is vocal cord paralysis resulting from an injury to the recurrent laryngeal nerve (RLN). Patients with RLN palsy may experience hoarseness, develop a cough, or lose their voice completely and it may take several months for the nerve to recover [4, 5]. EMG monitoring using a special endotracheal tube has been shown to be useful in detecting injury to the RLN. Monitoring the RLN is discussed in detail in Chap. 16 of this book.

Multimodality monitoring for anterior cervical fusions should include upper and lower SSEPs and Tc-MEPs to monitor spinal cord function, as well as EMG from the myotomes at risk to provide protection for the nerve roots. Positional injury may also be detected with upper extremity SSEP monitoring.

Posterior Cervical Fusion

If spinal stenosis cannot be relieved by an anterior approach, or if the patient's spine is not stable enough before or after an anterior approach, the surgeon may opt for a posterior cervical laminectomy and fusion (PCF). The object of this procedure is the decompression of the neural elements and stabilization of the cervical spine. Posterior fusions are also performed for instability of the cervical spine resulting from trauma or a degenerative pathology.

For PCF surgery, the patient is placed in a prone position (on their abdomen) with the head made immobile by placing it in a special frame called a Mayfield (Fig. 12.5). The head is held in the Mayfield with pins. After the incision is made in the back of the neck, the surgeon will then dissect down through the subcutaneous tissues to the fascia overlying the spinous processes. Retractors are inserted to hold the muscle away from the spine, and the surgeon will begin to remove the lamina and other bony elements in order to decompress the spinal cord and nerve roots.

Various types of instrumentation are used to posteriorly fuse the cervical spine. Wiring can be used to stabilize the upper cervical vertebral seg-

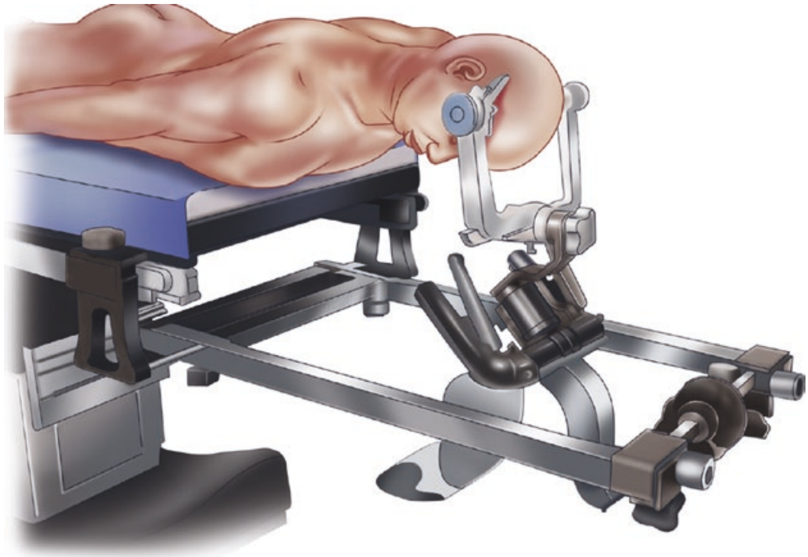

Fig. 12.5 Drawing of a patient positioned for a posterior cervical fusion using a Mayfield head frame

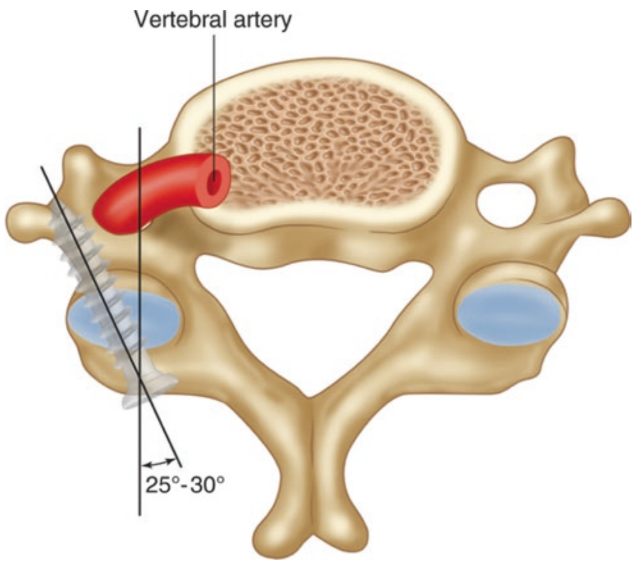

Fig. 12.6 Placement of lateral mass screws in a cervical vertebra

ments (C1 and C2). Cervical vertebrae have anatomical structures not found elsewhere in the spine called the lateral masses, which are more amenable for screw placement than cervical pedicles. Placement of lateral mass screws and rods provides equal or greater biomechanical stability when compared to anterior plating or interspinous wiring techniques [6] (Fig. 12.6). Placement of lateral mass screws does not depend on the integrity of the laminae, pedicle, or spinous processes to achieve fixation as is the case of cervical wiring and pedicle screws. The limitations of lateral mass fixation include risk of injury to the adjacent nerve roots, vertebral arteries, or facet joint [6, 7].

Similar to ACDFs, multimodality monitoring using SSEPs and Tc-MEPs to monitor the spinal cord and EMGs to monitor the nerve roots is the preferred monitoring plan for PCF.

Cervical Corpectomy

When the cervical disease involves more than just a single disc space, it may be necessary to remove part of the vertebral body and adjacent discs in a procedure called a corpectomy. This can be necessary for multilevel stenosis, tumor removal, or vertebral infection. The approach is similar to that of an ACDF. Once a majority of the affected vertebral bodies and disc material have been removed, a graft—typically shaped bone or a stackable cage—is fitted to support the anterior vertebral column (Fig. 12.7). The cervical spine is further stabilized with a metal plate and screws similar to that used in an ACDF. If the spine appears unstable after the anterior corpectomy, a PCF may be necessary to provide long-term stability. Recommended IOM is similar to that of an ACDF [8].

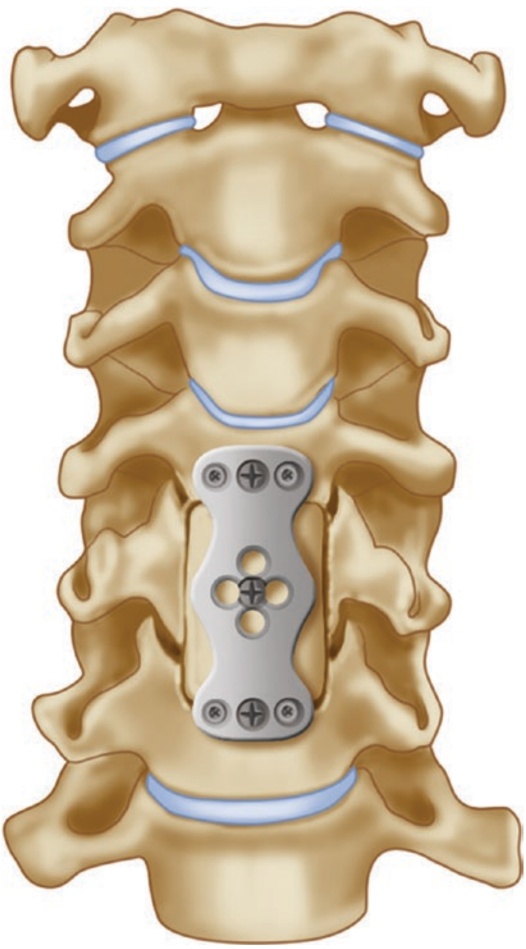

Fig. 12.7 Following removal of the vertebral body, a wedge-shaped bone graft is inserted into the space created by the corpectomy and is stabilized using a screw and plate system similar to an ACDF

Procedures of the Thoracic Spine

The thoracic vertebrae—T1 through T12—attach to the posterior rib cage. Due to the presence of the ribs and position of the spinous processes, the thoracic spine is stiff and motion is limited. This immobility can put strain on the adjacent cervical or lumbar spine, making the areas from C6 to T2 and T11 to L2 especially susceptible to injury. Commonly trauma or metastatic lesions are the cause of thoracic spine surgery. Thoracic laminectomy, corpectomy, and fusion are performed similarly to other levels. Burst fractures (discussed below) are often seen in the lower thoracic segments. Commonly monitored procedures of the thoracic spine are for correction of scoliosis and spinal deformity.

Surgery for Scoliosis Correction

Scoliosis describes an abnormal, lateral, curvature of the spine. The two most common forms of scoliosis are neuromuscular and idiopathic (also called adolescent). Neuromuscular scoliosis is usually caused by a deterioration of the facet joints and occurs most commonly in people over 65. Surgery is often performed to reduce pain. Older patients may have osteoporosis and may require many levels of instrumentation to achieve a complete fusion. Idiopathic, or adolescent scoliosis, is seen in children and teenagers and is often discovered during routine doctor's exams. It is necessary to prevent the curvature from progressing as the child ages. If the curve measures <20°, surgeons often choose to brace the spine or continue to observe the progression of the curvature. Surgery for adolescents with scoliosis is only recommended when the curvature is >45° and continuing to progress [9]. A high degree of curvature may put the patient at risk for cardiopulmonary compromise as the curve of the spine rotates the chest and decreases the vital capacity (ability to breathe).

Scoliosis correction procedures are extensive and may require both an anterior and posterior approach in severe cases. Correcting the scoliosis involves applying different forces to the spine including distraction and rotation. These maneuvers place the spinal cord at risk for either direct injury or regional ischemic injury as blood vessels become compressed.

Posterior fusion for scoliosis correction involves a long incision and exposure through the posterior musculature to access the bony elements of the spine. Instruments such as hooks and screws are attached to the vertebrae and serve as anchors for long rods that straighten and hold the spine in the correct position (Fig. 12.8). Bone graft is then added along the spine to facilitate a permanent fusion. An "anterior release" may be necessary prior to posterior instrumentation for patients with a severe deformity. This procedure is typically done with a lateral approach where the intervertebral discs are removed from the front to allow for more spinal movement and to encourage bony growth once the spinal curvature is corrected.

For corrections that are mainly needed at the thoracolumbar junction (T12–L1), the surgery can be performed via an anterior approach. The discs are removed to loosen up the spine, screws are placed in the vertebral bodies, and rods are used to reduce the curvature. An anterior technique has minimal blood loss and muscle damage compared to a posterior or anterior–posterior procedure. Additionally, not as many lumbar segments need to be fused thereby preserving some motion segments reducing the risk for future back pain. The anterior approach can only be done on thoracolumbar curves and most idiopathic scoliotic curves involve the thoracic spine.

Multimodality spinal cord monitoring using SSEPs and MEPs has become a standard of care for scoliosis surgery. SSEPs may also help prevent postoperative neuropathy or plexopathy as these procedures can be quite lengthy [3, 10, 11]. Injury to the thoracic spinal cord can produce abrupt bilateral or unilateral leg MEP loss and/or a decrease in lower extremity SSEP amplitude [12], and the surgeon can be immediately notified. While thoracic levels T2–T7 are not amenable to EMG monitoring, lower thoracic and lumbar levels can utilize free-running EMGs to reduce risk to spinal nerve roots. The anal sphincter should also be monitored when instrumenting at thoracolumbar levels due to the presence of the conus medullaris and risk to the extending cauda equina.

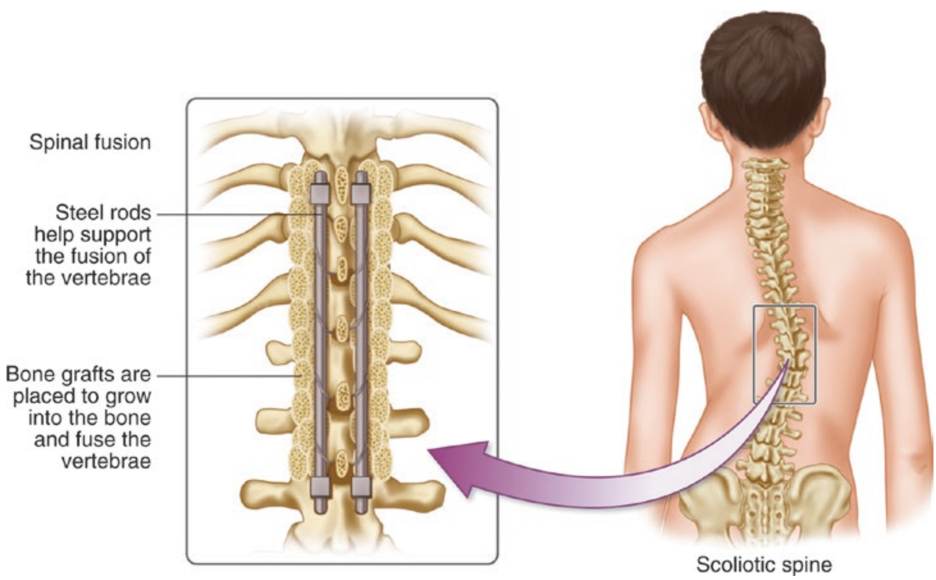

Fig. 12.8 On the *right* is an example of scoliosis. Notice the curvature creates an asymmetry that is visible in the stance of the patient. On the *left* is a corrected curve being held in place with rods. Bone graft is in place to facilitate bony fusion

Thoracolumbar Trauma

Trauma to the spine indicates that an injury has occurred to any or all of the following components: bony elements, ligamentous (soft) tissues, and neurological structures. While injury does not always indicate the need for surgical intervention, mechanical instability and potential neurological injury are two concerns for spinal traumas. Instability is usually the result of a fracture in one of the major bony components (vertebral body, pedicles, lamina) of a vertebra. An unstable fracture may not allow the spine to withstand normal load-bearing activities without further risk of a neurologic injury. Classification methods for thoracolumbar fractures are based upon the mechanism of failure and the column of the spine affected. The spine is viewed as having three columns when viewed laterally. There is an anterior, middle, and posterior column [13] with the middle column the most important for stability (Fig. 12.9). Trauma to the spinal column can result in compression (burst) fractures, anterior and posterior element injuries with distraction, and anterior and posterior injuries with rotation [14]. Burst fractures can be highly unstable and generally occur when a violent compressive load results in failure of both the anterior and middle spinal columns. This severe compression of the vertebral body may be associated with extrusion of bony fragments into the vertebral canal putting at risk the spinal cord and cauda equina (Fig. 12.10). Burst fractures can be treated by a procedure known as kyphoplasty. Guided by fluoroscopy, a needle is inserted into the vertebral body then a balloon is inflated to restore height, thereby creating a space where bone cement can be injected to stabilize the fracture. Multimodality monitoring for trauma surgery of the spine can help reduce further injury to the neural elements as well as possibly providing information on the functional neurological status of the trauma patient that has just arrived to surgery from the ER.

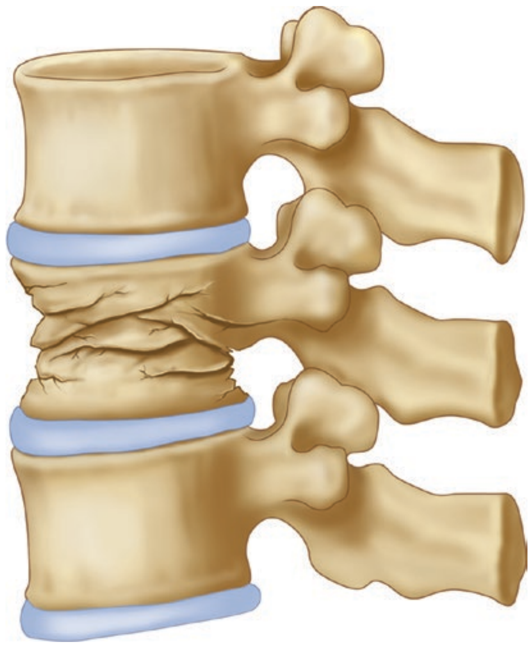

Fig. 12.10 An example of a burst fracture viewed laterally

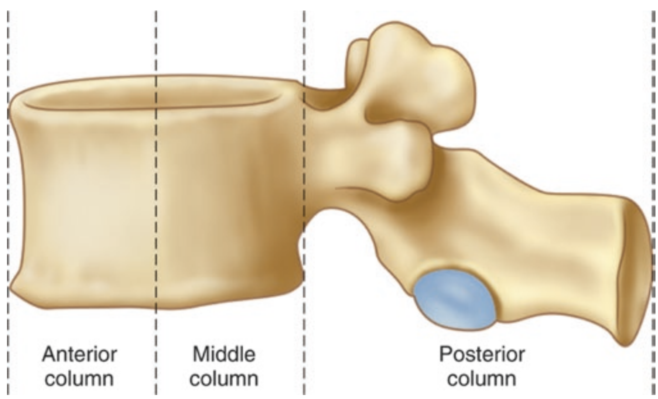

Fig. 12.9 The spine is viewed as having three columns when viewed laterally. The *middle column* is the most important for stability and load bearing

Procedures of the Lumbosacral Spine

The lumbar spine—L1 through L5—supports the weight of the body. The vertebral bodies are much larger in order to absorb the stress of lifting and carrying. Below the lumbar region, the sacrum connects the spine to the hipbones. Below the sacrum, the coccyx completes the spine and provides attachment for ligaments and muscles of the pelvic floor. Common spine-related conditions that can cause lower back and lower extremity discomfort include disc herniation, degenerative disc disease, spondylolisthesis, spinal stenosis, and sacroiliac joint dysfunction. Minimally invasive (MIS) procedures such as a microdiscectomy or laminectomy may be able to relieve pain caused by central or foraminal stenosis. In the most serious cases, when the condition does not respond to conservative therapies such as physical therapy or pain management, a spinal fusion may be necessary to strengthen the spine and prevent motion in the vertebral segment(s) causing pain.

Below vertebral level L1, the vertebral canal contains the cauda equina. The cauda equina contains the lower lumbar and sacral spinal nerves traveling toward the appropriate level where they exit and innervate the lower extremity. Nerve roots can be injured during lumbosacral surgery by retraction, compression, electrocautery, drilling, or misplaced hardware. One of the most common postoperative deficits is foot drop caused by injury to the L5 nerve root. Other postoperative deficits can include numbness, weakness, and bowel or bladder dysfunction. SSEPs are not sensitive to detecting nerve root injuries; therefore free-running and triggered EMG along with Tc-MEP are the primary modalities most often used to monitor nerve root function. Depending on patient anatomy and the lumbar levels requiring fusion, there are different approaches to the spine that are utilized during surgery including posterior, anterior, and lateral approaches.

Posterior Lumbar Interbody Fusion

During a posterior lumbar interbody fusion (PLIF), the spine is accessed through an incision in the midline of the back and the large erector spinae muscles are retracted. Once the proper spinal levels are exposed, a laminectomy and often a discectomy are performed with the goal of decompressing the neural elements. If a discectomy is to be performed, it is followed by placement of a cage in the disc space (typically made of bone or synthetic material) that restores height to the disc space and assists in bone growth. Bone graft is added to provide a matrix for additional bone growth. The level is stabilized using pedicle screws and rods while fusion takes place (Fig. 12.11).

The monitoring plan for a PLIF consists of upper and lower SSEPs to monitor the spinal cord and for positional injury [3, 10, 11]. Although the surgery is not at the level where the spinal cord is present, the addition of SSEPs can still be useful in detecting ischemia as a result of hemodynamic changes.

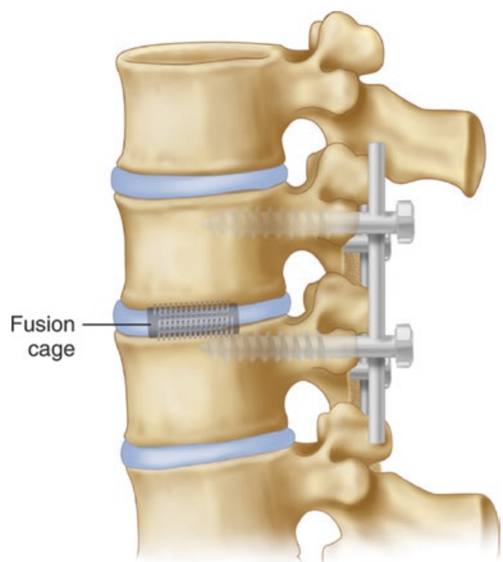

Fig. 12.11 The result of posterior lumbar interbody fusion. Following a laminectomy and discectomy, a bone graft was placed in the disc space. Screws and rods were inserted to stabilize the spine until the bony fusion is complete

Spontaneous EMG for nerve root monitoring is typically recorded continuously during surgery, so it is very important for anesthesia to not administer any neuromuscular blockade after intubation. Activity is recorded from myotomes corresponding to the nerve roots at risk, and irritation resulting in "train firing" or "neurotonic discharge" should be immediately reported to the surgeon. In addition to free-running EMG, stimulus-triggered EMG has become a standard technique used during pedicle screw insertion. Triggered EMG relies on the concept that intact cortical bone should electrically insulate a properly placed pedicle screw from the adjacent nerve root. By stimulating the pedicle screw directly using a monopolar probe, a properly placed screw should not elicit any muscle response below a stimulus of 10 mA. With a medial pedicle breach, either directly by the screw or from a crack in the pedicle wall, electrical stimulation will activate adjacent nerve roots, evoking compound muscle action potential (CMAP) responses in muscles from the appropriate myotomes at a stimulus <7 mA [15–17]. Some types of pedicle screws, such as those coated with hydroxyapatite, have an extremely high electrical resistance and cannot accurately or safely be stimulated [18]. In these cases, stimulating the pilot hole or tap (instrument) prior to placement of these screws is recommended. Patients with advanced osteoporosis may have lower than expected impedances and may trigger false-positive responses. Alternatively, patients with chronically compressed nerve roots may require a much higher stimulus intensity to evoke a CMAP response. The surgeon may also wish to stimulate a nerve root directly using t-EMG for identification or to test function.

Anterior Lumbar Interbody Fusion

An alternative to the PLIF is an anterior lumbar interbody fusion (ALIF). For this procedure, the spine is accessed through an abdominal incision more commonly on the left side. This retroperitoneal approach allows access to the spine without disturbing abdominal structures. The anterior approach gives better access to the disc space so more disc material can be removed and a larger spinal implant can be used. With an ALIF, there is minimal damage to the large stabilizing spinal muscles and the spinal nerves remain largely undisturbed. The procedure is performed in close proximity to the major blood vessels (aorta, iliac artery, vena cava, and iliac vein) that supply the legs [19, 20]. Vascular surgeons often assist in retracting the blood vessels during exposure for these procedures (Fig. 12.12). Lower extremity SSEPs are performed while retractors are in place to monitor for vascular compromise.

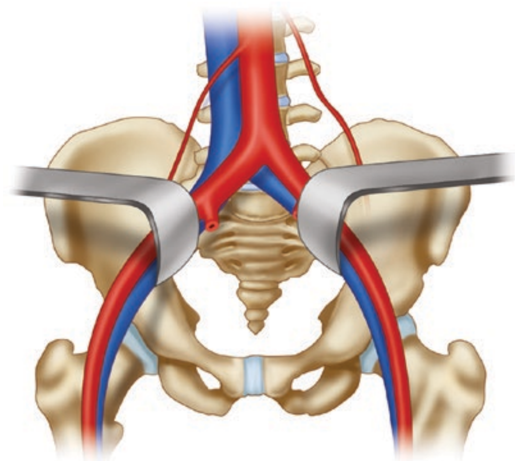

Fig. 12.12 Retraction of major blood vessels is required for access to the vertebral bodies and disc space during an ALIF

Minimally Invasive and Lateral Approaches to the Lumbar Spine

MIS approaches to spine surgery are designed to offer decompression and fusion through a smaller incision resulting in reduced tissue damage, blood loss, less postoperative discomfort, and a quicker recovery time. Procedures such as a microdiscectomy or laminectomy can be done

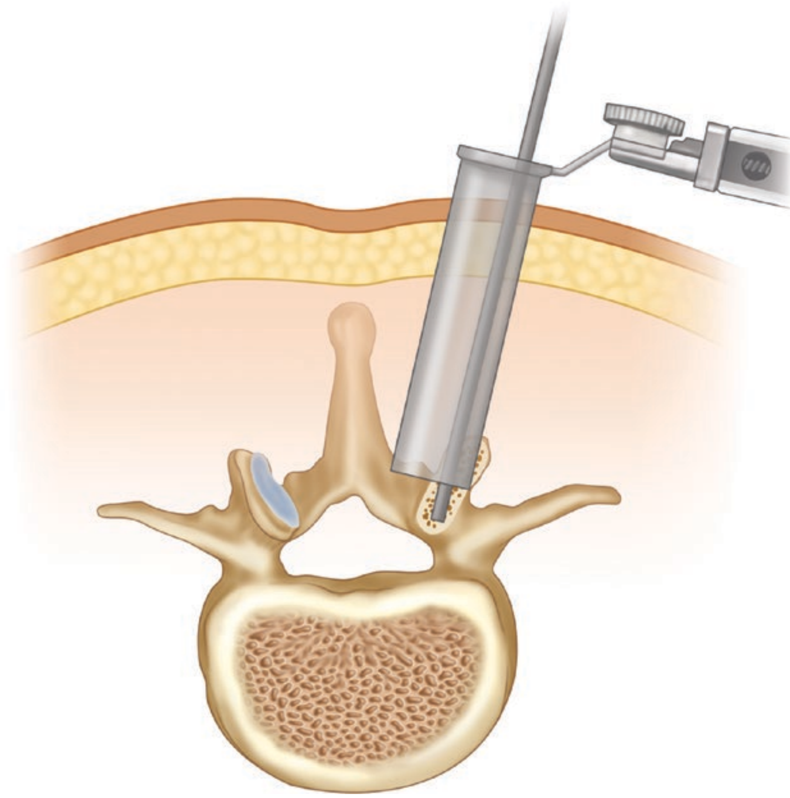

Fig. 12.13 Minimally invasive approaches to spinal surgery involve the use of tubular dilators for access

through a very small incision and the insertion of tubular dilators to enlarge the space (Fig. 12.13). IOM can be valuable to the surgeon during these procedures because the incision is small and the spine is not largely exposed, making anatomical landmarks challenging to identify [21].

A lateral approach to perform a spinal fusion is considered a minimally invasive surgery (or MIS) procedure [22]. Instead of a long posterior or anterior incision, the surgeon makes one or more smaller incisions on the patient's side and uses a dilator/retractor system to expose and visualize the spine. A lateral approach does not require major organs or blood vessels to be moved. Once the spine is exposed, a standard discectomy is performed and a large cage is implanted in the disc space. A lateral plate or posterior instrumentation may be used to further secure the implant and stabilize the spine.

To access the disc space, the surgeon must navigate through the large psoas muscle and in close proximity to nerves of the lumbosacral plexus (Fig. 12.14). Free-running and triggered EMGs are critical during lateral approaches as these modalities can help identify the location of nerves in the lumbar plexus during exposure and retractor placement. Upon placement of the retractor, the surgeon may wish to further verify the absence of neural tissue with an electrically stimulated monopolar probe. A more recent approach, the oblique lateral interbody fusion (OLIF), is another lateral approach that gives surgeon lateral access but allows them to avoid the psoas and the iliac crest [23].

While not as routinely used as EMGs during lateral procedures, lower extremity SSEPs can be utilized to monitor the nerves of the lumbar plexus, and both upper and lower extremity SSEPs can be used to monitor positional effects.

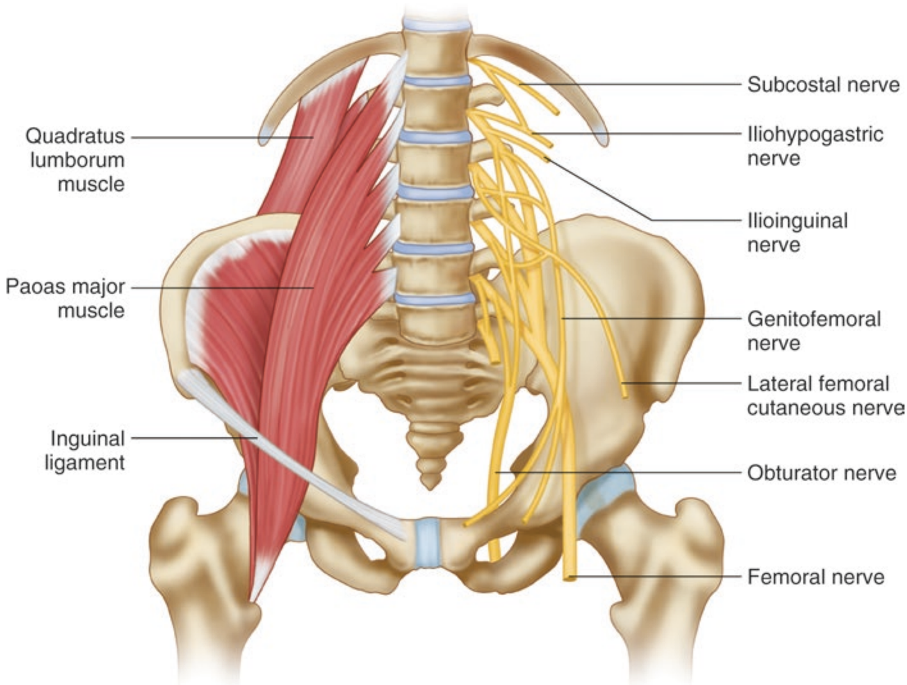

Fig. 12.14 The transpsoas approach to lateral access spine surgery puts elements of the lumbar plexus at risk

Conclusion

Spine surgery places at risk the spinal cord, nerve roots, nerve plexuses, and peripheral nerves. A multimodality approach to intraoperative monitoring utilizing SSEPs, Tc-MEPs, and EMGs can provide real-time feedback to the surgical team and reduce the risk of permanent neurologic injury.

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