Central Neuraxial Anatomy and Anesthetic Application (Central Neuraxial Blockade)

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Key Points

1. Neuraxial anesthesia can be used as a primary anesthetic, an adjunct anesthetic for intraoperative pain control in addition to general anesthesia or postoperative pain control for surgeries involving the abdomen, perineum, or lower extremities.
2. Absolute contraindications to neuraxial anesthesia include patient refusal, bleeding diathesis, elevated intracranial pressure (except pseudotumor cerebri), infection at site of injection, hypovolemia, and indeterminate neurologic disease.
3. Neuraxial anesthesia can be achieved by injection of local anesthetics (lidocaine, bupivicane, chloroprocaince, etc.) with or without additives into the intrathecal space (spinal) or the epidural space (epidural)
4. As a fetus, the spinal cord spans the entire length of the spine. The spinal cord ends at the L3 level in early childhood, and in adulthood the spinal cord extends from the foramen magnum to the L1-2 level.
5. Local anesthetics exert their effects at the level of the nerve root, producing numbess in a dematomal distribution.
6. Additives can be used to alter the length (epinephrine, clonidine) and onsest (sodium bicarbonate) of blockade.
7. Hypotension is the most common adverse effect of neuraxial anesthesia. It is caused by sympathetic blockade, which can decrease systemic venous resistance, venous return, and cardiac output. This sympathetic blockade extends 2 dermatomes above and below the sensory/motor blockade and is treated with crystalloid bolus and vasopressors.
8. Epidural hemtoma is the most feared complication of neuraxial anesthesia. Particular attention needs to be paid to the coagulation status and platelet functioning of the patient, including medications that may affect these functions. Treatment is surgical decompression and magnetic resonance imaging (MRI) should be obtained early so as not to delay surgery.
9. Post dural puncture headache (PDPH) is a relatively common adverse effect of neuraxial anesthesia. Risk factors include female sex, young age, pregnancy, and history of previous PDPH and the use of cutting-point, large-bore needles. Treatment includes adequate hydration, caffeine, analgesics, and, if warranted, epidural blood patch.
10. Many situations exist in which neuraxial anesthesia and anticoagulation would both be appropriate for a patient at the same time. The American Society of Regional Anesthesia (ASRA) guidelines exist as expert opinion to help guide the practitioner in risk benefit analysis and should be referenced whenever neuaxial anesthesia is considered on an anticoagulated patient.

2.1 Anatomy

2.1.1 The Vertebral Column

The vertebral column consists of the bony vertebral bodies, their posterior elements, and the intervertebral disks that form the boundaries of the vertebral canal in which lies the spinal cord and exiting nerve roots. The vertebral canal provides structural support to the body as well as protection for the spinal cord and nerve roots within the spine. The spine consists of 33 vertebrae from the base of the skull to the coccyx. There are 7 cervical, 12 thoracic, 5 lumbar, and 5 sacral vertebrae. The 5 sacral vertebrae are fused to form the sacrum, which is attached to the coccygeal vertebrae, or coccyx. A sagittal view of the spine reveals a double-C shape in which the cervical and lumbar regions exhibit a concave curvature (lordosis), and the thoracic region appears convex (kyphosis) (Fig. 2.1) [1] .

Although the shape of the anatomy of the spine varies at each level, a vertebra generally consists of a vertebral body connected to the vertebrae above and below it by intervertebral disks. At the thoracic and lumbar levels, the vertebral body is a large circular structure connected to a posterior vertebral arch [1]:

- The vertebral body is joined to 2 pedicles that course ventral to dorsal, which are each fused with a laterally extending transverse process.

Fig. 2.1 Sagittal view of the spine demonstrating lumbar and cervical lordosis and thoracic kyphosis. Note the spinous process angles, which change according to level of the spine (Reprinted with permission Ochsner Health Systems © 2016. All Rights Reserved)

- The laminar elements extend medially and dorsally and fuse posteriorly to form a single spinous process.
- The vertebral body, 2 pedicles, transverse processes, 2 laminae, and spinous process connect to form a hollow circle, which, when stacked with other vertebrae, form a cylinder that encases the spinal cord and its covering.
- While the vertebral bodies connect to each other by disks anteriorly, each vertebra connects posteriorly by facet joints. The facet joints are formed on each side by a superior articular process from the caudally located vertebra and an inferior articular process from the cephalad vertebra.
- Intervertebral foramina, or neural foramina, are lateral openings between cephalad and caudal vertebral pedicles through which the nerve roots leave the spinal cord and exit to each side (Fig. 2.2).

The cervical vertebrae differ from the thoracic and lumbar spine by the presence of bilateral transverse foramina, which contain the vertebral arteries as they pass superiorly through C6 and upward to the foramen magnum. The first cervical vertebrae, or the atlas, lacks a body but instead connects with the C2 vertebra, also called the axis. The atlas has a superiorly extending odontoid process, or dens, which essentially exists as the embryologic C1 body. The dens of C2 articulates with the posterior surface of the anterior arch of C1 [2]. The atlas and axis allow increased range of motion of the head and neck. The joint between the occipital bone and C1 forms the atlanto-occipital joint, which allows movement of the head, and the atlanto-axial joint between the atlas and axis allows for the twisting motion of the neck. The cervical spine also differs from the remaining vertebrae in that all the spinous processes, except for C7, are bifid. (Figs. 2.3 and 2.4).

The thoracic vertebrae are each connected to bilateral corresponding ribs. The spinous processes of the cervical and lumbar spine are shorter and appear to be in a more horizontal axis, allowing for a more direct trajectory during spinal and epidural needle placement (Fig. 2.5). The spinous processes of the midthoracic spine on the other hand are more caudally angulated, which requires a compensatory angulation when performing spinal and epidural needle placement. The interlaminar spaces are larger in the lumbar area than in the thoracic spine [3].

The 5 sacral vertebrae fuse prior to birth to form the sacrum:

- Each sacral vertebral level contains paired anterior and posterior intervertebral foramen from which the sacral nerve roots exit.

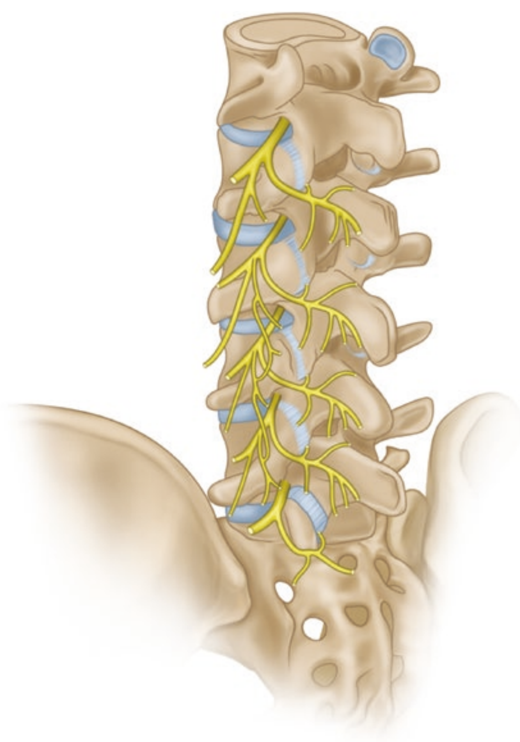


Fig. 2.2 Left oblique view of lumbar spine. Note the nerve roots exiting the neural foramen beneath the pedicles (Reprinted with permission Ochsner Health Systems © 2016. All Rights Reserved)

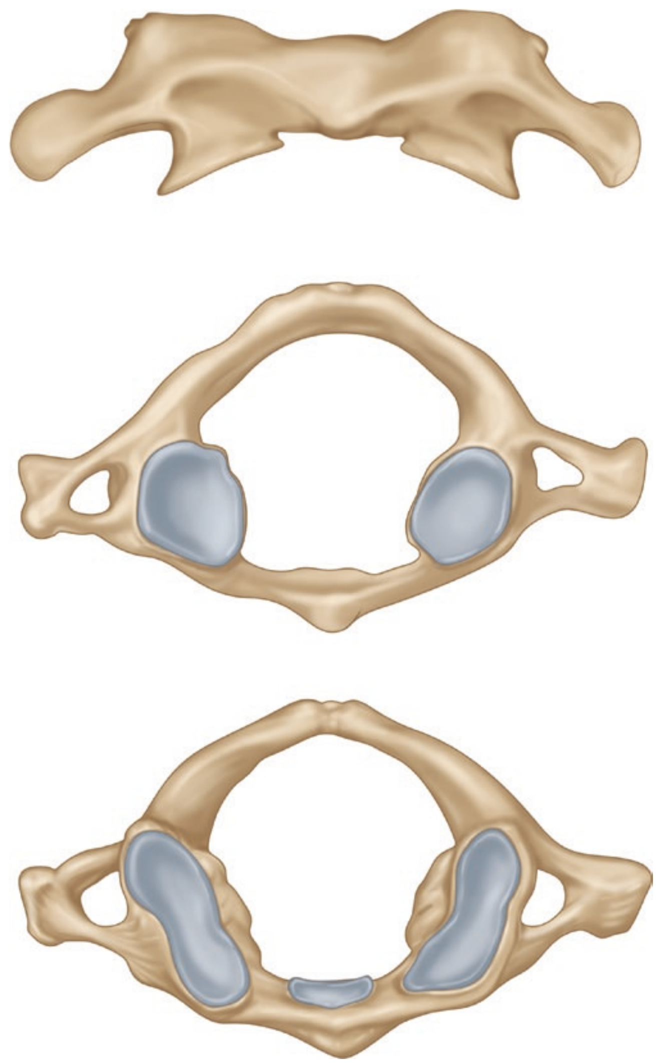


Fig. 2.3 C1 vertebra (atlas) with superior view, inferior view, and anterior view (Reprinted with permission Ochsner Health Systems © 2016. All Rights Reserved)

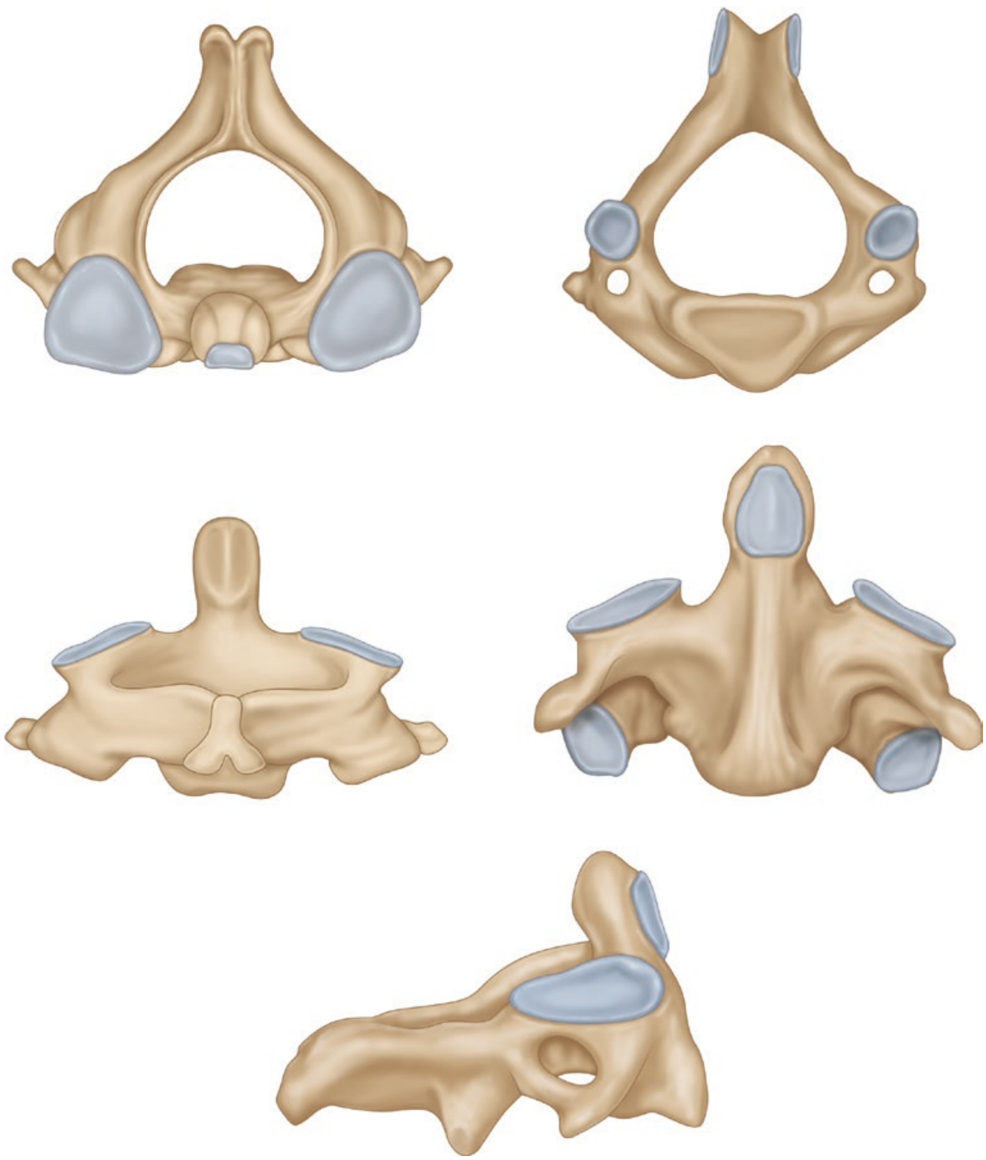


Fig. 2.4 C2 vertebra (axis) with views from multiple angles. Note the dens, which serves as the C1 body (Reprinted with permission Ochsner Health Systems © 2016. All Rights Reserved)

- The transverse and costal processes of S1 fuse to form the bilateral sacral ala, the wing-like lateral processes located superiorly at the base of the sacrum. The sacral alae articulate bilaterally with the ilium to form the sacroiliac joints.
- The sacrum also joins superiorly with the L5 vertebrae (via the L5/S1 intervertebral disk) and inferiorly with the coccyx (via the sacrococcygeal ligament).
- The sacrum contains a central canal, which is a continuation of the vertebral canal. The canal terminates at the sacral hiatus, a fissure located in the posterior sacrum where the laminae of the fifth vertebrae do not fuse.
- The sacral cornu, a landmark for caudal anesthesia, can be found here as bilateral projections on either side of the sacral hiatus [3].
- The filum terminale, the most caudal extension of the pia mater, extends to the sacral hiatus. Although the dural sac typically ends at the S2 level in adults, the epidural fat continues to the hiatus, which is what allows access to the epidural space at this level during caudal techniques [4, 5].

2.1.2 Ligaments

Several ligaments surround the vertebral column, and together with the paraspinous muscles, provide support and structure to the spine:

- The vertebral bodies and intervertebral disks are bound together anteriorly and posteriorly by the anterior and posterior spinal ligaments, respectively in a cephalad to caudal direction along the length of the cervical, thoracic, and lumbar spine.
- Dorsal to the vertebral canal, the ligamentum flavum is a thick layer of tissue connecting the lamina along the spinal column immediately posterior to the epidural

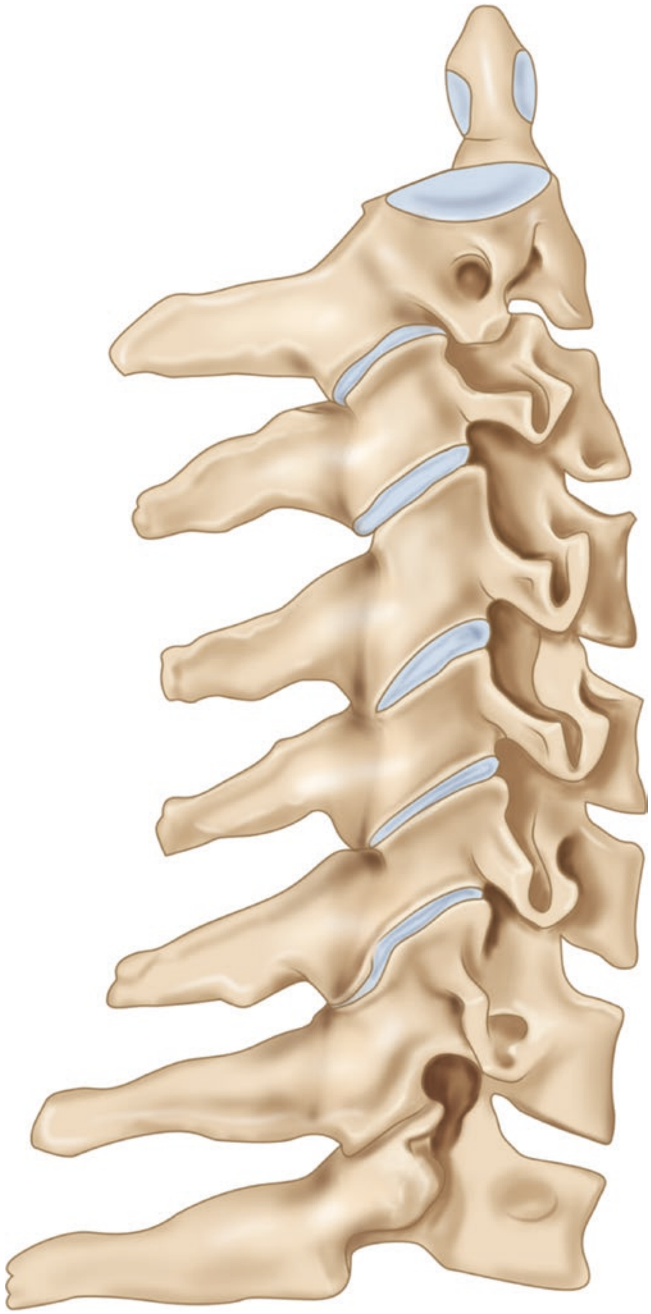


Fig. 2.5 The cervical spine spinous processes have a relatively horizontal angle (Reprinted with permission Ochsner Health Systems © 2016. All Rights Reserved)

space. When placing an epidural needle, this ligament is used as a landmark to help determine entrance to the epidural space. In some individuals the ligamentum flavum is absent, which can place the patient at a higher risk for unintended dural puncture.

- The interspinous ligament connects adjacent spinous processes, and the supraspinous ligament is the most superficially located ligament along the posterior surface of the spinous processes.
- Therefore, using a midline approach, the order of structures encountered during an epidural placement is skin, subcutaneous tissue, supraspinous ligament, interspinous ligament, ligamentum flavum, and, finally, epidural space.

2.1.3 Landmarks

When trying to locate the appropriate vertebral level in order to perform neuraxial anesthesia without the assistance of fluoroscopy, it is necessary to know surface landmarks:

- The C7 spinous process is the most prominent bony landmark in the base of the neck, whereas a line drawn between the lower edges of the scapulae denotes the T7 interspace. These 2 landmarks are useful for locating the desired interspaces for thoracic epidurals and paravertebral blocks [6].
- The most important landmarks for labor epidurals and spinal anesthesia are the iliac crests. A horizontal line drawn between the crests (Tuffier's line) generally will traverse the L4/5 interspace, which is below the spinal cord in most adults [6].
- Finally, the bilateral posterior superior iliac spines designate the level of the S2 vertebral body, which is the inferior border of the dural sac in adults [6].

2.1.4 The Spinal Cord

As a fetus, the spinal cord spans the entire length of the spine. As the infant ages, the spine lengthens at a faster rate compared to the growth of the spinal cord. As a result, the spinal cord ends at the L3 level in early childhood, and in adulthood the spinal cord extends from the foramen magnum to the L1-2 level.

As the spinal cord approaches L1 it tapers off into the conus medularis and eventually becomes the cauda equina, or "horse's tail," a bundle of nerve roots that float relatively freely in the cerebrospinal fluid (CSF) of the spinal canal. A spinal anesthetic performed below L1 would be in the territory of the cauda equina and decrease the potential for spinal cord trauma as the needle theoretically displaces the nerve roots to the side.

There are 31 pairs of spinal nerves (8 cervical, 12 thoracic, 5 lumbar, and 5 sacral). The nerve roots exit the spinal column through bilateral intervertebral foramen. In the cervical spine the nerve roots exit above their corresponding vertebral body. At the C7 body, the C7 root exits above and the C8 root exits below (between C7 and T1). Starting at T1, the nerve roots then exit below their respective vertebral bodies [2].

The dural sac, as well as the subarachnoid space, extends below the cauda equina to S2 in adults and S3 in children. The dura often continues to sheath the nerve roots as they exit the spinal canal into the intervertebral foramen. As such there is a risk of subdural or subarachnoid injection even when approaching from a caudal or transforaminal approach. Although the dura mater extends to S2, the pia mater continues as a thin strand of tissue to form the filum terminale, which connects the conus to the coccyx [4].

2.1.5 Meninges

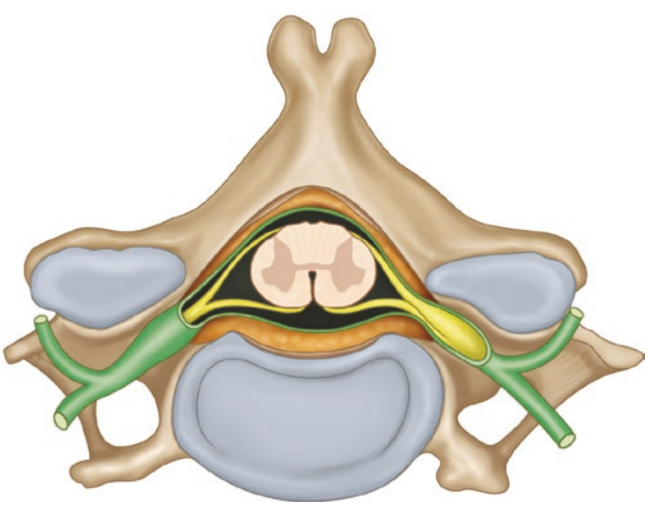
The meninges are the 3 layers of connective tissue surrounding the spinal cord composed of the outermost dura mater, the arachnoid mater, and the innermost pia mater. Superficial to these layers, the epidural space exists as a potential space between the dura mater and the ligamentum flavum. It contains fat, lymphatics, and blood vessels, and it is in this space that local anesthetic can be instilled for epidural anesthesia (◘ Fig. 2.6). The epidural space communicates freely with the adjacent paravertebral spaces by the intervertebral foramen. Closely adherent to the dura mater is the arachnoid mater. Beneath the arachnoid layer is the subarachnoid space, where cerebrospinal fluid is contained within the spinal column. The innermost layer is known as the pia mater, which is closely adherent with the spinal cord. The pia will extend laterally above T12 to form a dense triangular band between the dorsal and ventral roots known as the denticulate ligament [4]. Radiographic studies also suggest the presence of dorsal median connective tissue or septa within the epidural space, which may lead to an unintentional unilateral neuraxial anesthetic [7].

2.1.6 Cerebrospinal Fluid

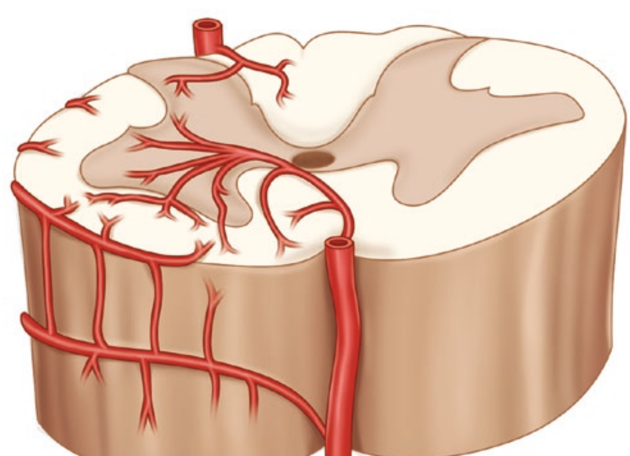
The major function of cerebrospinal fluid is to insulate and protect the brain and spinal nerves against trauma. It is found in cerebral ventricles and the subarachnoid space of the brain and spinal cord. It flows freely across the foramen magnum, allowing for introduction of local anesthetic to the brain in the event of a complete or high spinal. CSF is mostly formed in the choroid plexus of the cerebral ventricles. In adults, normal CSF production is 500 cc/day, yet total CSF volume is only about 150 cc secondary to continuous reabsorption into arachnoid granulations.

2.1.7 Blood Supply

The spinal cord is supplied by a single anterior spinal artery and 2 paired posterior arteries. The anterior spinal artery arises from the vertebral artery in the cervical region and supplies the anterior two-thirds (motor innervation) of the spinal cord. The posterior arteries are formed from the posterior inferior cerebellar arteries and cover the posterior one-third (sensory innervation) of the cord (◘ Fig. 2.7). Below the cervical level, the spinal cord also receives additional blood supply from segmental or radicular arteries, which feeds the anterior spinal artery in the thoracic and lumbar region. The anterior spinal artery receives variable contributions from these arteries and relies heavily on the large artery of Adamkiewicz or great radicular artery (GRA). The GRA typically branches off the aorta around T9-T12, but can be anywhere from T5-L5, and it is almost always on the left [2]. If this artery is damaged, a patient may present with bilateral lower extremity motor deficits from a process called anterior spinal artery syndrome. This syndrome occurs as a result of decreased spinal cord perfusion pressure, which is equal to mean arterial pressure (MAP) – spinal cord pressure. Anterior spinal artery syndrome, therefore, may occur secondary to either a decrease in MAP (hypotension, damaged GRA) or an increased spinal cord pressure (from a variety of factors including increased CSF pressure or mechanical pressure).



◘ **Fig. 2.6** Axial view of the spine reveals a cross-section of the spinal cord and exiting nerve roots, which lie between the anterior and posterior epidural space. The spinal nerve roots exit through the intervertebral foramen (Reprinted with permission Ochsner Health Systems © 2016. All Rights Reserved)



◘ **Fig. 2.7** Cross-section of the spinal cord with the midline anterior spinal anatomy and one of the 2 paired posterior spinal arteries on the left side (Reprinted with permission Ochsner Health Systems © 2016. All Rights Reserved)

The venous drainage from the spinal cord flows through the vertebral venous plexus. The plexus can be enlarged in situations that obstruct abdominal venous return, such as increased intra-abdominal pressure secondary to gravid uterus or tumors compressing the vena cava. This may result in an increased likelihood of intravascular injection during epidural anesthesia as well as increase the spread of local anesthetic by decreasing the volume of the epidural space.

2.2 Neuraxial Anesthesia

2.2.1 Preoperative Considerations

Indications

Neuraxial anesthesia may be indicated as the primary anesthetic for major or minor surgeries or as an adjunctive anesthetic for intraoperative pain control in addition to general anesthesia. It is most useful as the primary anesthetic in surgeries involving the abdomen, perineum, or lower extremities. Neuraxial anesthesia is also an option for thoracic and upper abdominal surgeries, although it may not be the optimal choice for a patient with respiratory insufficiency or during prolonged surgeries resulting in compromised respiratory function (such as pneumoperitoneum). This is related to the fact that these patients rely heavily on accessory muscles of inspiration, which are often weakened with high neuraxial anesthesia, despite minimal changes in tidal volume. In these situations, an epidural or spinal may be useful to supplement general anesthesia in providing postoperative pain relief. Continuous epidural anesthesia is also widely used in labor analgesia [6].

Contraindications

Absolute contraindications to neuraxial anesthesia include patient refusal, bleeding diathesis, elevated intracranial pressure (except pseudotumor cerebri), infection at site of injection, hypovolemia, and indeterminate neurologic disease [6].

Other disease processes are discussed as relative contraindications and clinical judgment should be used in these situations. Severe aortic or mitral stenosis or left ventricular outflow obstruction when combined with spinal or rapidly achieved epidural anesthesia may result in sudden, severe hypotension and possible cardiac ischemia. These effects are secondary to a sympathetic blockade, leading to vasodilation, venous pooling, and ultimately decreased preload. However, neuraxial anesthesia can be used safely with close monitoring, and when possible, a slowly dosed epidural would be preferred over spinal anesthesia to avoid the abrupt decline in blood pressure.

Sepsis or distant infections have been implicated in predisposing the patient to meningitis, epidural abscess, or central nervous system (CNS) infection via hematogenous spread following neuraxial anesthesia. While it is recommended to exercise caution in such patients, it is generally not contraindicated to perform a neuraxial block as it may actually be a better choice for some sick patients.

Chronic back pain or preexisting neurological deficits and paresthesia due to prior neurologic disease are generally not contraindications; however, prior symptoms or exacerbations of a disease state may mask or imitate side effects or complications associated with the procedure itself. Some practitioners would defer from performing neuraxial or regional anesthesia on such patients. It is, therefore, important to thoroughly interview and examine the patient and document reported findings prior to performing the neuraxial blockade. Also, in many patients with prior lumbar surgeries the ligamentum flavum may not be intact. Therefore, the provider should not rely on loss of resistance technique to find the epidural space and consideration should be made to enter at a level remote from previous surgery.

Previously, there were concerns that neuraxial anesthesia in a human immunodeficiency virus (HIV)-infected patient would hasten central nervous system manifestations of the disease. However, it is now understood that CNS involvement occurs early during the course of HIV infection and introduction of HIV into a previously virus-free CNS after is not a concern.

Preparation

Preparation for neuraxial anesthesia, like general anesthesia, should begin with a discussion with the patient and obtaining informed consent. The patient interview should include specific questions such as whether there is a history of anesthetic complications, prior difficult placement of epidural or spinal anesthesia, history of bleeding disorders or thrombocytopenia, whether the patient is taking any anticoagulant medications, and history of spine disorders (ie, scoliosis) or surgeries. The provider should then discuss the benefits and potential complications associated with neuraxial blockade. These include the rare but serious complications such as bleeding, infection, or temporary nerve damage, as well as more common but less severe risks such as post dural puncture headache and mild pain.

Location, Monitors, and Additional Equipment

Generally, a neuraxial blockade should only be performed in a facility with appropriate emergency equipment, medications, and personnel available in the event of an urgent situation requiring intubation or resuscitation. The procedure can be performed in an operating room or in an outside area with the above requirements. Patients should have frequent monitoring of blood pressure and pulse oximetry. Supplemental oxygen via nasal cannula or face mask with end tidal CO2 (EtCO2) monitoring is recommended if sedation is provided. Patients should have an adequately functioning intravenous line prior to the procedure. Although an ultrasound machine is typically unnecessary for neuraxial blockade, it may facilitate a difficult placement in a patient with poor surface landmarks, as discussed later in this chapter. Required practice for sterile technique includes hat, mask, and gloves.

Premedication and Sedation

Lumbar neuraxial anesthesia may be performed completely awake, with minimal sedation or under general anesthesia. Performing this block under general anesthesia, however, remains controversial. The reasoning is that the patient would be unable to verbalize pain or paresthesia during injection, symptoms that are associated with intraneural injection and postoperative neurological deficits. On the other hand, providing deep sedation or general anesthesia would reduce sudden patient movement, allowing for easier needle placement and less chance of nerve damage. Epidurals and spinals of the thoracic and particularly of the cervical spine should be placed in awake patients. The exception to this is the pediatric population, in which case neuraxial anesthesia is often performed under general anesthesia secondary to poor patient cooperation.

Pharmacological premedication, typically in the form of midazolam and fentanyl, is often beneficial prior to performing regional anesthesia. Premedication is avoided for labor epidurals, so it is essential to discuss expectations and verbally guide the patient through the procedure if desired. In situations where premedication is not used, patients should be provided with ample local anesthetic skin infiltration.

2.2.2 Patient Positioning

A patient can be positioned in either the sitting, prone, or lateral position for neuraxial anesthesia. Regardless of the type of position chosen, the goal is to flex the spine in order to draw apart the adjacent spinous processes and expand the interlaminar foramen.

Sitting

The sitting position is the most commonly encountered arrangement for spinal and epidural placement. In this position, the patient is curled forward, pressing the chin into the chest and the buttocks into the bed to form a C shape with the spine. This allows the spinous processes to be pressed closer to the skin where they are more easily palpated and also promotes the most expansion of the interlaminar space. The midline is also the most recognizable in the sitting position, which is of significant value in the obese population. This position is not ideal for a heavily sedated patient (Fig. 2.8) [6].

Fig. 2.8 Marks are made on the patient's skin at the midpoint of the probe's long and short sides. The needle insertion site should be the intersection of these 2 marks

Lateral Decubitus

This position is preferable in a patient under general anesthesia or in the elderly, sick population in which the patient is unable to sit upright without generous assistance. In the lateral decubitus position, the patient would lie on his or her side with the neck and knees flexed forward and pulled into the patient's chest.

Prone

The prone position is most often used for chronic pain procedures under the guidance of fluoroscopy. Rarely, the prone position is also used as the jackknife position for perineal procedures. In the prone position, the midline surface landmarks are not as easily appreciated. Because CSF pressure is lower than when the patient is upright, CSF aspiration is typically necessary to confirm subarachnoid injection as the CSF will not be free flowing.

2.2.3 Needles

Several different types of needles are available for spinal anesthesia, varying in overall size and the contour of their tips. In general, a smaller needle gauge decreases the incidence of post-dural puncture headaches (PDPH). The tapered pencil-point needles (Whitacre, Sprotte) are most commonly selected as their blunt tips are designed to ease the dural fibers apart versus cutting needles such as a Quincke. Pencil-point needles also produce a ragged-edged hole in the dura, which provokes a more robust inflammatory response. Both the cutting of less dural fibers and the increased inflammatory response are thought to contribute to a smaller CSF leak and subsequently a lower risk of PDPH. These needles contain a side port that allows for directed injection of local anesthetic. Since these pencil-tip needles require more force to push through the dura, a more pronounced popping sensation can be appreciated by the operator. The other basic type of needle is the open-ended beveled needle (Quincke). Such open-ended beveled needles cut through the dura, which is associated with more dural trauma and elevated risk of PDPH.

One recent cadaver study evaluated needle type (pencil point vs. cutting), needle gauge, and angle of dural puncture (30° vs. 90°) and found that a large-bore cutting needle was associated with a larger dual leak over 1 h than blunt-tip smaller bore needles. No correlation was found between dura leak and angle of puncture [8].

The most commonly used epidural needle is the blunt-tipped Tuohy needle, which is designed to push the dura outward and away rather than penetrate through it. This needle features a curved edge that gently directs the epidural catheter in the direction of the curve for optimal placement in the epidural space.

All needles contain a removable, smaller-gauged inner stylet, which occludes the center of the needle to prevent lodging of bone fragments or subcutaneous tissue, which if present can lead to a false sense of resistance and possibly result in dural puncture in epidural placement. Such an inner stylet also serves to prevent the transfer of epithelial cells and possible surface contaminants into the intrathecal space.

2.3 Spinal Anesthesia

2.3.1 Indications

Spinal anesthesia is commonly indicated for surgical procedures involving the mid to lower abdomen, perineum, and lower extremities. It is becoming more regularly encountered in orthopedic surgeries including total hip and knee replacements. Benefits of regional anesthesia over general anesthesia in this population include reduced postoperative pain, decreased opioid consumption, reduced incidence of pulmonary embolism and deep venous thrombosis, decreased hospital length of stay, and increased rehabilitation—although there is no consensus on whether it results in decreased morbidity and mortality [9, 10].

2.3.2 Contraindications

As previously mentioned, absolute contraindications for neuraxial anesthesia include patient refusal, bleeding diathesis, elevated intracranial pressure, infection at site of injection, severe hypovolemia, and indeterminate neurologic disease [11].

More specific to spinal anesthesia, the risk of sudden and severe hypotension following injection of local anesthetic into the intrathecal space is significantly more pronounced and immediate than in epidural anesthesia. This is likely due to the direct injection of local anesthetic into the CSF and the subsequent bathing of nerve roots. Spinal anesthesia is therefore contraindicated in many patients with hypovolemia and cardiac outflow obstructions such as aortic stenosis or hypertrophic obstructive cardiomyopathy (HOCM).

2.3.3 Technique

Midline Approach

For the midline approach, the patient is placed in the preferred position (can be in seated or lateral decubitus) and the spine is palpated to identify the midline and individual spinous processes. The interspinous spaces may be palpated as a depression between the bony spinous processes. Using the surface landmarks discussed earlier, the desired level can be identified by counting the number of spaces above or below these landmarks. Skin should then be cleaned with chlorhexidine or a similar solution, with subsequent application of a sterile fenestrated drape. A small-gauge needle such as a 25-gauge 1.5-in. needle is used to anesthetize the skin and subcutaneous tissue through the creation of a skin wheal with local anesthetic infiltration. This smaller needle also can be advanced deeper to act as a finder needle, identifying the superior and inferior borders of the space.

Next, an introducer needle such as an 18G 1.5-in. hollow-bore needle is placed into the space along the superior surface of the inferior spinous process. This thicker, shorter needle breaks the skin and assists in the guidance of the thin spinal needle. The spinal needle is then advanced through the introducer needle in slow, gradual movements in a slightly cephalad direction. The needle will easily pass through the subcutaneous tissue and then transverse the supraspinous and interspinous ligaments before encountering the thicker ligamentum flavum. The needle is further advanced until it penetrates the dura, which is accompanied by a characteristic popping sensation. Once the spinal needle is in the intrathecal space, the stylet is then removed to confirm the return of cerebrospinal fluid (CSF) into the hub of the needle (Fig. 2.9). If no fluid is apparent, the stylet should be replaced and the needle slowly advanced, again removing the stylet to check for return of fluid. With visible confirmation of CSF, a syringe containing local anesthetic is firmly attached to the needle. Aspiration of the syringe should reveal a swirl of clear CSF. The local anesthetic can then be slowly injected through the needle, reconfirming the correct location by a second aspiration near the end of the injection. Once complete, the needle and syringe are withdrawn and removed from the patient's back [11].

If the needle encounters bone superficially, the introducer and spinal needles should be slightly withdrawn and redirected either superiorly or inferiorly as it is likely contacting a neighboring spinous process. If the needle contacts bone at a deeper level, this likely indicates that the needle is not midline, so the needle should be withdrawn and redirected to the left or right of the previous location to avoid contacting the lamina. If the appearance of blood-tinged CSF is present on aspiration and

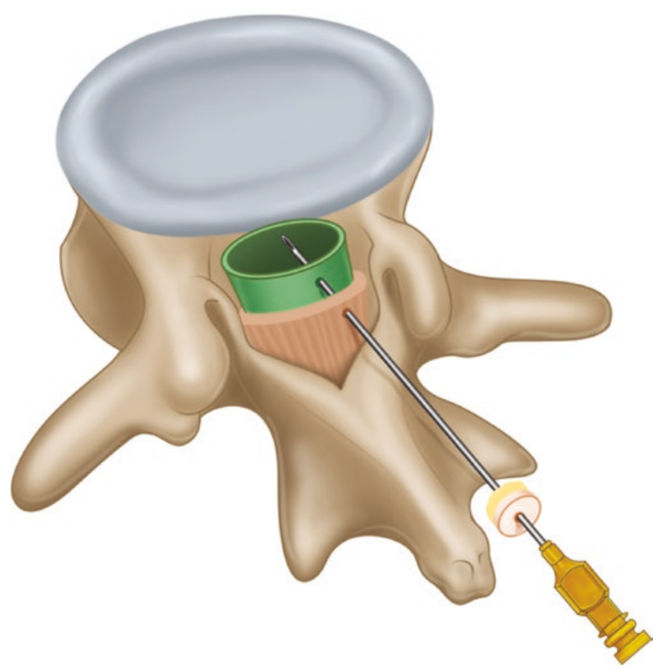


Fig. 2.9 View of spinal needle traversing the ligamentum flavum and dura mater (Reprinted with permission Ochsner Health Systems © 2016. All Rights Reserved)

does not clear immediately, the needle should be withdrawn and reinserted at a different interspace. Finally, if the patient reports transient paresthesia at any time (unilateral burning or shooting pain in buttocks, legs or perineum), local anesthetic should not be injected; instead, the operator should redirect the needle, as the paresthesia may indicate possible needle contact with a nerve or nerve root.

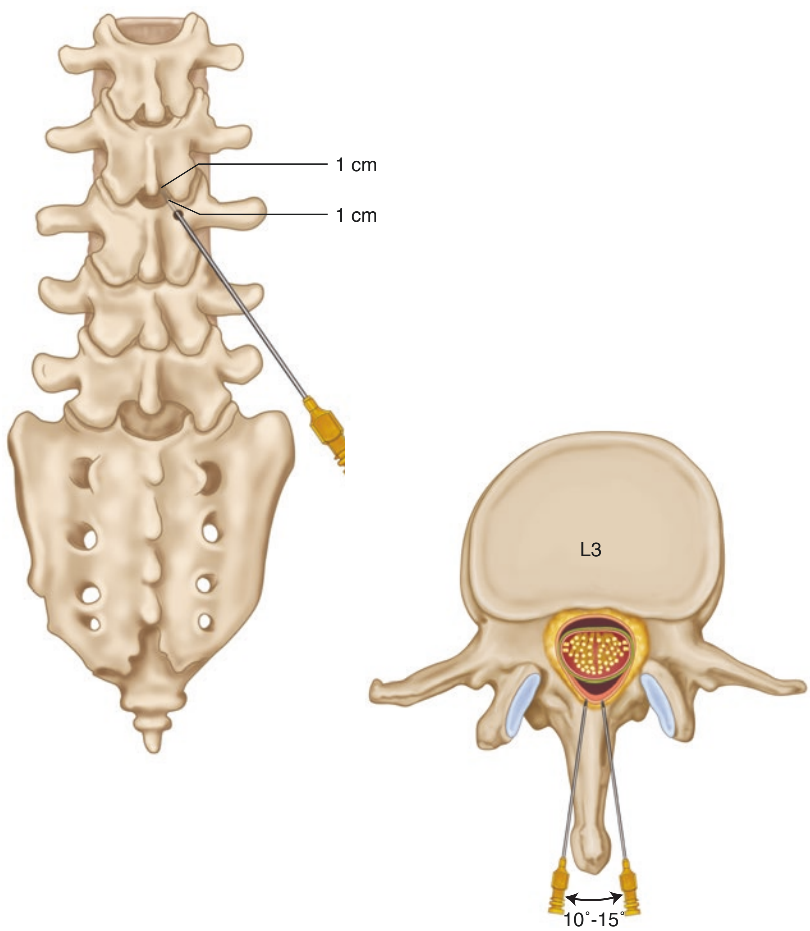
Paramedian Approach

Although the midline approach may be easier to perform for most patients, the paramedian approach can be selected if a neuraxial anesthetic is difficult to place because of a patient's spinal anatomy (e.g., severe spinal stenosis or prior spine surgery). This approach is also more commonly chosen for thoracic epidural placement given the angulated nature of the thoracic spinous processes. In this approach, the needle is inserted 1–2 cm lateral to the midline of the inferior surface of the superior spinous process and directly slightly medial and cephalad (◘ Fig. 2.10). The needle then passes through skin and subcutaneous tissue and directly encounters the ligamentum flavum, thus bypassing the medially located supraspinous and interspinous ligaments. If the needle contacts the lamina superficially, the needle should be redirected to walk off the bone in a cephalad direction. The operator should be mindful to avoid directing the needle too medially in this approach as it could potentially cross the midline [11].

2.3.4 Assessment of Neuraxial Blockade

Once injected, the local anesthetic bathes the nerve roots, blocking the small and unmyelinated nerve fibers (sympathetic, temperature/proprioception) first, followed by the large, myelinated fibers (sensory/motor). Since there is a differential in the density of neural blockade depending on the fiber type, the sympathetic blockade is typically at least 2 dermatomes levels higher than the sensory blockade, and the sensory blockade is 2 levels higher than the motor blockade.

The small C-type nerve fibers responsible for temperature change are the first to be affected, so one can test the adequacy of a spinal block within the first few minutes by wiping a wet alcohol pad over the patient's skin bilaterally. One can also test the adequacy of the sensory blockade by gently pricking the patient's skin with a blunt needle or the broken, sharp edge of a tongue depressor.



◘ **Fig. 2.10** Paramedian approach for spinal anesthesia uses an entry point 1 cm lateral and inferior to the superior spinous process and directed at a 15-degree angle medially and cephalad (Reprinted with permission Ochsner Health Systems © 2016. All Rights Reserved)

For intra-abdominal procedures, the minimum dermatome level should be approximately T4 (level of the nipples). For perineal, vaginal, and hip surgeries, a T10 level (at the umbilicus) should be adequate.

2.3.5 Pharmacokinetics and Pharmacodynamics of Spinal Anesthesia

The largest determinants of anesthetic spread include patient position during and immediately after injection and the dosage and baricity of the local anesthetic injected. A larger injected total *dose* (not volume or concentration alone) of local anesthetic will result in further spread in either direction [12]. The baricity of a local anesthetic basically refers to the relative density of the drug in relation to that of CSF. A hyperbaric drug is denser, and thus heavier, than CSF and will migrate in a direction consistent with gravity (ie, it will sink with gravity). A hypobaric solution is lighter than CSF and will spread in a direction opposite to gravity (rise against gravity). An isobaric anesthetic has the same density as CSF and will likely remain where it is injected [13]. For example, if a patient is injected with a solution while seated in an upright position, a hyperbaric solution will spread caudally, a hypobaric solution will spread cephalad, and an isobaric solution will remain at the site of injection. Dextrose is typically added to a solution to make it hyperbaric; whereas, fentanyl or sterile water added to a solution will make it hypobaric.

Patient positioning after injection will also determine spread [13]. If a patient is placed in Trendelenburg position, the anesthetic will travel cephalad, and if the patient is in reverse-Trendelenburg, the solution will travel caudally. This is not true for isobaric solutions, however, as gravity does not play a role in these cases.

When a hyperbaric solution is used for a thoracic neuraxial in a patient in the supine position, the injected drug will migrate to the most dependent region of the spine. The natural curvature of the spine dictates that the most posterior and dependent curvature of the thoracic spine occurs at the T4-T8 level, therefore producing an anesthetic level toward T4.

The spread and distribution of any spinal anesthetic is also highly dependent on the volume of CSF in the spinal column. In general, increased CSF volume is associated with decreased spread of local anesthesia, and decreased volume results in increased spread [13]. Patient factors affecting CSF volume include patient height (taller patients require more local anesthetic), intra-abdominal pressure including pregnancy or large intra-abdominal tumors, and individual anatomic variations of the spinal column. In the case of pregnancy, the thought is that the increased intra-abdominal pressure leads to engorgement of epidural veins, thereby decreasing CSF volume. Thus, parturients would require less anesthetic solution to achieve the same spread.

Some recent studies have indicated that obesity may prolong the effects of spinal anesthesia, possibly due to a reduction in CSF volume as a result of epidural fat or extradural vein distention, although controversy still exists regarding the effects of obesity on duration and spread of spinal anesthesia [14].

Age also may be an independent determinant in that the elderly have decreased CSF volume, possibly due to severe kyphosis, and require smaller doses of local anesthetic.

The height of the injection site and the direction of injection through the needle are also factors that may affect the level of anesthesia obtained.

Spinal Anesthetic Agents

One of the more commonly used local anesthetics for spinal anesthesia is hyperbaric 0.75% bupivacaine. This has a relatively slow onset of about 5–10 min with a prolonged duration of 90–120 min. The addition of epinephrine may modestly prolong the duration to 100–150 min. The typical dosage for hyperbaric bupivacaine is 8–10 mg for lower abdominal surgeries (up to T10 level), and 14–20 mg for a T4 level [14].

Other local anesthetics that are less commonly used include 5% lidocaine and 10% procaine (60–90 min), and 0.25–1% ropivacaine and 1% tetracaine (90–120 min). All solutions must be preservative-free to avoid neurotoxicity.

Years ago, lidocaine was the most commonly used local anesthetic for spinal anesthesia. However, in recent years it is typically avoided secondary to the concern for transient neurological symptoms (TNS) and cauda equina syndrome (CES) encountered more commonly with lidocaine. These syndromes are discussed in further detail later.

More specific details on mechanism of action and side effects of local anesthetics can be found in the pharmacology chapter on these agents.

Additives to Local Anesthetics

Vasoconstrictors (epinephrine 1:200,000), opioids (fentanyl), and alpha-2-adrenergic agonists (clonidine) are often added to the local anesthetic solution to prolong the duration and intensify the effect of a spinal anesthetic [6].

The addition of epinephrine or phenylephrine is thought to benefit in multiple ways. First, the vasoconstriction of nearby tissue limits the redistribution of local anesthetic away from the intended site of action, prolonging the duration of anesthetic by keeping the drug in contact with the nerve fibers. This vasoconstriction also prevents systemic reabsorption of local anesthetic, decreasing the incidence of local anesthetic systemic toxicity (LAST) [15]. And finally, the presence of epinephrine, if accidentally injected intravascularly, will alert the provider to the incorrect needle placement by the accompanying hypertension and tachycardia.

The effects of vasoconstrictors are not the same for all local anesthetics. This has the most apparent effect on tetracaine and the least significant effect on bupivacaine. The increased duration of action is more pronounced in anesthetics with shorter intrinsic duration as well as the degree of spinal cord vasodilation associated with the drug. For example, tetracaine is associated with the most vasodilation of spinal cord vasculature, and the addition of epinephrine to tetracaine has the most effect on prolongation of duration.

Opioids such as fentanyl and morphine also can be added to enhance surgical analgesia and improve postoperative pain without prolonging motor or sympathetic blockade. These opioids work at receptors located in the dorsal horn of the spinal cord. Fentanyl, a lipophilic agent, provides a more localized effect with a shorter onset and approximately 6-h duration of effect due to its rapid vascular uptake. Morphine, on the other hand, is hydrophilic, and provides roughly 6–24 h of analgesic effect.

Respiratory depression may be seen with the addition of opioids. With fentanyl, respiratory depression would occur early with the rostral spread of opioid in the CSF and immediate vascular uptake. On the contrary, respiratory depression with morphine often presents in a biphasic manner. It may first occur within 30 min due to vascular absorption, but it also may occur later (6–18 h) due to slow penetration of the brainstem with delayed rostral spread.

Pruritus and nausea are also common side effects associated with the addition of opioids. The treatment for pruritus consists of opioids antagonists or agonist/antagonists; however, given in large doses it may also reverse the analgesic effects [16].

2.4 Epidural Anesthesia

Epidural anesthesia is regional blockade of spinal nerves achieved by placing local anesthetics and sometimes adjuvants such as epinephrine or sodium bicarbonate into the epidural space surrounding the dural sac. The epidural space is the potential space between the ligmentum flavum posteriorly and the dura mater anteriorly and contains epidural fat and veins.

In contrast to the limited duration of spinal anesthesia, the duration of anesthetic blockade can be controlled by placing a catheter in the epidural space and providing a bolus and subsequent continuous infusion. Epidural anesthesia also can be utilized in conjunction with spinal anesthesia in a technique known as combined spinal epidural injection (CSE). A single shot technique without a catheter may be used, but generally this technique is used to deliver steroids to spinal nerves for the treatment of chronic pain, not as a regional anesthetic.

2.4.1 Indications

Epidural anesthesia can be used as a primary anesthetic for surgeries involving the abdomen and lower extremities and also for postoperative pain control in surgeries involving the thorax, abdomen, and lower extremities. It is particularly helpful when used in a patient who has comorbidities that may preclude or limit the use of general anesthesia. Lumbar epidural anesthesia is commonly used in the management of labor pain in the parturient. Thoracic epidural anesthesia is frequently used for postoperative pain control after surgery such as a thoracotomy. Pain management specialists can inject steroid around nerve roots for the treatment of radiculopathy and other chronic pain conditions along almost the entire length of the vertebral column [11].

2.4.2 Contraindications

Absolute contraindications to epidural anesthesia are similar to those in spinal anesthesia and include patient refusal, inability to remain still, or evidence of increased intracranial pressure. Some patients may not be able to maintain proper positioning or remain still throughout the procedure; this exposes the patient to greater risk of neurological complications such as spinal cord/nerve root trauma or inadvertent dural puncture. Relative contraindications to epidural anesthesia include coagulopathy, including iatrogenic coagulopathy secondary to anticoagulation, thrombocytopenia, local infection over the selected site, and hypovolemia. Risks, benefits and alternatives must be carefully considered when relative contraindications are present [11].

2.4.3 Technique

As in spinal anesthesia, there are 3 positions utilized in the delivery of epidural anesthesia: sitting, lateral, and prone. The most common position for lumbar and thoracic epidurals is the sitting position. The lateral position can be used if the patient cannot sit upright or if there is a contraindication to the sitting position. The prone position is used exclusively by pain management specialists in conjunction with fluoroscopy. With all positions except the prone position, the patient is asked to flex the spinal column, thereby increasing the space between the spinous processes and facilitating placement. In a similar fashion to spinal anesthesia, the patient's back is prepped and draped in a sterile fashion.

There are 4 approaches used in accessing the epidural space. Two of the approaches are interlaminar: midline and paramedian. The others are caudal and transforaminal—the latter being used for chronic pain management when selectivity is required for blocking one nerve root at a time. The 2 interlaminar approaches are described as follows since epidural catheters are commonly left in place using these approaches. The caudal and transforaminal approach will be discussed later.

Midline Approach

The midline approach is generally used for lumbar epidural placement. As discussed previously, a line connecting the bilateral iliac crests crosses the L4 vertebra and the spinous process can be palpated. Entering at L3/4 or L4/5 allows safe entry below the conus medullaris, which typically ends at the level of the L1 or L2 vertebral body in adults. The spinous processes are palpated to identify the intraspinous space. Once the space is identified, a skin wheal is made in the midline with local anesthetic. A 17 or 18 gauge epidural needle (most commonly a Tuohy needle) is then placed into the skin wheal and directed perpendicular to the coronal plane with a slight cephalad tilt and advanced until an increase in resistance is felt. This should indicate contact with the supraspinous ligament and continued advancement is made into the intraspinous ligament. At that point, the stylet is removed and the needle is advanced in an incremental or continuous fashion using the loss of resistance or hanging drop technique to identify the epidural space [6, 11].

Paramedian Approach

The paramedian approach is most often utilized with epidural placement in the thoracic spine as the spinous processes in this area are at a steeper angle in relation to the coronal plane making the midline approach difficult. As in the midline approach, the initial step is the identification of the spinous processes of the desired level. A skin wheal is then made about 1–2 cm lateral and 2 cm inferior to the midline of the desired level. The epidural needle is then inserted through the skin wheal and advanced medially and cephalad at an angle of 15–20° until lamina is contacted. The stylet is then removed and the needle is "walked off" the lamina medially and cephalad employing loss of resistance or hanging drop technique to identify the epidural space. When placing an epidural using the paramedian approach, the epidural needle penetrates the paraspinous muscles then enters the ligamentum flavum en route to the epidural space. While the supraspinous and interspinous ligaments are penetrated during a midline approach the epidural space, the paramedian approach is lateral to these ligaments [6, 11].

Catheter Placement and Test Dose

Once the epidural space has been identified, a catheter is advanced though the epidural needle. Typically, 3–5 cm is added to the depth of the epidural needle in order to leave the catheter in the epidural space. At this time, the catheter is aspirated in order to detect intrathecal or intravascular placement. If no CSF or blood is aspirated, which would indicate intrathecal or intravascular placement respectively, a test dose of lidocaine with epinephrine can be administered. Intravascular injection of the test dose may produce a metallic taste in the mouth secondary to the lidocaine and a rapid increase in heart rate secondary to the epinephrine. Sudden motor blockade of the lower extremities indicates an intrathecal injection of local anesthetic. While absence of these findings is not 100% sensitive for aberrant placement, the epidural catheter can now be used with reasonable confidence of correct placement.

Caudal Approach

In the caudal approach to epidural anesthesia, the sacral hiatus is the access point for the epidural space. This approach takes advantage of the fact that the epidural fat continues caudally through the sacral canal even beyond the distal-most point of the thecal sac, which generally terminates around S1-S3, depending on age. In children, the thecal sac ends around S3 and with increasing age moves proximally toward S1 and S2. The sacral hiatus is a natural defect of S5 dorsal midline and can be identified by palpating the 2 sacral cornu, which border the hiatus laterally and lie about 3–5 cm above the coccyx. The caudal epidural anesthesia technique is primarily used in pediatrics and pain management. Caudal epidural injection is used in pediatric anesthesia as part of an intraoperative anesthetic plan and postoperative pain control for urologic and lower extremity surgery such as inguinal hernia repair and hypospadias correction. In pain management, the caudal approach is used to deliver steroids to the sacral nerve roots and lumbar canal. A catheter also can be employed and threaded up to the lower lumbar vertebra in order to treat pain arising from the lumbar nerve roots. This is often done in the setting of prior surgery where accessing the lumbar epidural space with an interlaminar technique would be technically difficult or impossible due to a surgically absent ligamentum flavum. Caudal injection is performed with the patient in the prone position. After cleaning and draping in the usual fashion, the skin over the hiatus is anesthetized and a 22 gauge spinal needed is introduced through the sacrococcygeal ligament and advanced until it contacts the sacrum. It is then slightly withdrawn, the angle of entry flattened, and subsequently advanced. Flushing the needle with saline and observing for the absence of tissue swelling will confirm placement within the epidural space. If swelling is noted, this indicates that the needle lies posterior to the sacrococcygeal ligament and it must be redirected [6].

2.4.4 Pharmacokinetics and Pharmacodynamics of Epidural Anesthesia

The principle site of action for epidural anesthesia is the spinal nerve root. Local anesthetic instilled into the epidural fat then crosses the dural layer and affects impulse conduction. To a lesser extent, local anesthetics will diffuse into the subarachnoid space and exert some effect.

Three of the more common local anesthetics used in epidural anesthesia include **2-chloroprocaine**, **lidocaine**, and **bupivicane**. Duration of local anesthetic action in epidural anesthesia is not as important as in spinal anesthesia since use of a catheter allows continuous administration. In general terms, duration can be remembered by the 1-2-3 rule: 1 h for chloroprocaine, 2 h for lidocaine, and 3 h for bupivicane. Speed of onset mirrors duration with chloroprocaine having the fastest onset, lidocaine slightly longer, and bupivicane having the longest duration.

In addition to local anesthetics, several other medications can be added to the epidural space in order to modify the effects of the block. **Sodium bicarbonate** is often added to the local anesthetic and can decrease the time to onset of the block. Only the uncharged form of the local anesthetic penetrates the nerve fiber and blocks sodium conduction. However, with the addition of sodium bicarbonate, the pH is lowered and as the local anesthetics used in neuraxial anesthesia are weak bases, this forces more of the solution to the un-ionized form, thus leading to a greater fraction penetrating the nerve fiber and halting conduction. Sodium bicarbonate can be used with a variety of local anesthetics but is not added to bupivicane as it can precipitate at a high pH. Another example of an additive includes **epinephrine**, which can be added to local anesthetic to increase the duration of blockade. This occurs because the vasoconstricting effects of epinephrine limits absorption into the vasculature and thus delays metabolism of the drug. The addition of epinephrine extends the duration of chloroprocaine and lidocaine by about 50%. The decreased absorption also decreases the likelihood of local anesthetic systemic toxicity (LAST). **Clonidine** also can be injected into the epidural space as an adjuvant. As an α(alpha)2 agonist, clonidine increases the reuptake of norepinephrine at the pre- and post-synaptic terminal of the neuromuscular junction. This mimics the action of inhibitory neuro-pathways on pain signal transmission in the dorsal horn of the spinal column. Additionally, clonidine has been shown to inherently block transmission of pain signals in C and A delta fibers and cause local vasoconstriction, thereby reducing the washout of local anesthetic in the same manner as epinephrine [17].

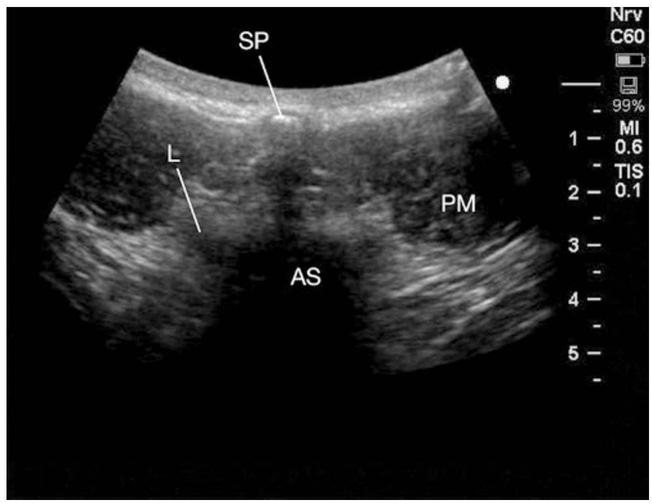
2.5 Combined Spinal Epidural

The combined spinal epidural (CSE) technique combines the rapid onset of spinal anesthesia with the ability to control duration of epidural anesthesia via an epidural catheter. Additionally, the dural puncture adds an element of reassurance that the catheter is, in fact, in the epidural space. Also, there is the theoretical benefit of a denser block as epidural medication migrates intrathecally though the dural puncture. A CSE is done in the same manner as an epidural injection, but after the epidural space is accessed, instead of immediately placing a catheter a spinal needle is advanced through the epidural needle until it penetrates the dura. CSF is aspirated to confirm placement and medication then can be injected into the intrathecal space. The spinal needle is withdrawn leaving the epidural needle in place and a catheter is placed through the needle into the epidural space.

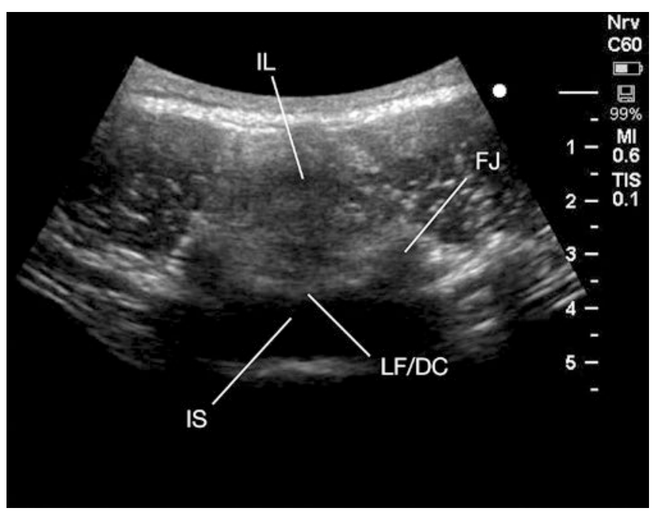
2.6 Ultrasound-Guided Neuraxial Procedures

Traditionally, landmarked-guided techniques are utilized in the delivery of spinal and epidural anesthesia. However, ultrasound guidance can aid in the ease and success of these procedures. It can be beneficial in all patients but there are specific situations where ultrasound guidance may be most helpful: patients with poorly identifiable surface landmarks, morbid obesity, lumbar spinal instrumentation, scoliosis, and ankylosing spondylitis. Advantages of ultrasound guidance include identifying correct vertebral level, identifying midline, identifying depth of various structures (spinous processes, lamina, epidural and subarachnoid spaces), identifying the optimal interspace and identifying anatomical abnormalities (scoliosis, prior laminectomy, and instrumentation). A low-frequency curvilinear ultrasound probe (2–5 MHz) is often used for better penetration to these deeper structures.

With the probe in a transverse plane (perpendicular to the vertebral column) on the approximate center of the patient's back, identify the dropout (acoustic shadow) of the spinous process with its characteristic acoustic outline (◘ Fig. 2.11). Slide the probe cephalad or caudal to obtain a transverse interspinous view (◘ Fig. 2.12). The acoustic shadow of the spinous process will give way to an echogenic interspinous ligament. A slight cephalad tilt of the probe may be necessary. The ligamentum flavum is visualized as a horizontal hyperechoic line running between the articular processes and facet joints. It is common to see a single hyperechoic line representing the ligamentum flavum/dura complex. Deep to this is the hypoechoic intrathecal space that appears gray or black due to its weaker spectral reflection. Once this view is obtained, a mark on the patient's skin can be made at the midpoint of the probe's long and short sides. The needle insertion site should be the intersection of these 2 marks (◘ Fig. 2.8). At this point, it is beneficial to freeze the image on the ultrasound image.



◘ **Fig. 2.11** Midline transverse probe placement: Spinous view. (*SP* spinous process, *AS* acoustic shadow behind spinous process and laminae, *PM* paraspinous muscle)



◘ **Fig. 2.12** Midline transverse probe placement: interspinous view. (*IL* interspinous ligament, *FJ* facet joint, *LF/DC* ligamentum flavum/dura complex, *IS* intrathecal space)

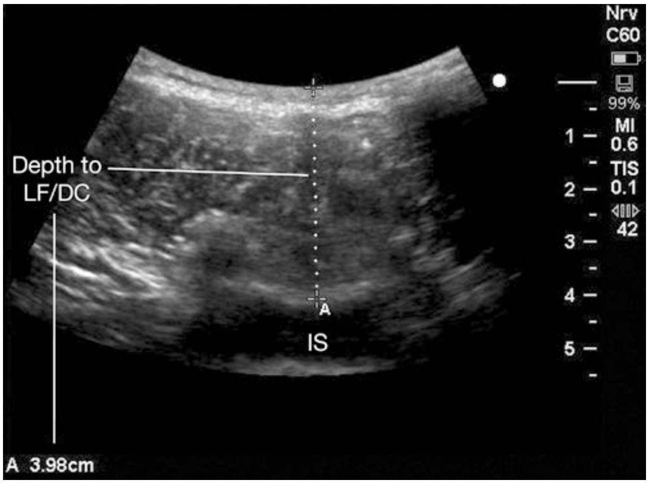


Fig. 2.13 The ultrasound machine's electronic caliper function measures the depth from skin to the ligamentum flavum to provide the expected depth of needle insertion. (*IS* intrathecal space, *LF/DC* ligamentum flavum/dura complex)

The ultrasound machine's electronic calipers can be used to measure the depth from skin to the ligamentum flavum to provide the expected depth of needle insertion (Fig. 2.13). The spinal or epidural needle should be inserted at the respective mark on the skin and the initial angle should attempt to reproduce the cephalad angulation used with the ultrasound probe needed to obtain the interspinous view. A loss of resistance to air or saline technique should still be employed for epidural procedures to confirm entry into the epidural space and to avoid dural puncture [18, 19].

2.7 Complications Associated with Neuraxial Anesthesia

2.7.1 Cardiovascular

Hypotension

Cardiovascular manifestations of neuraxial anesthesia are largely due to the blockade of small, unmyelinated sympathetic nerve roots. This sympathetic blockade usually extends 2 dermatomes above and below the sensory/motor blockade. Hypotension immediately following spinal anesthesia is a common side effect occurring as a result of sympathetic blockade, thereby decreasing systemic venous resistance and often decreasing venous return and cardiac output as well. The severity of hypotension is related to the level of the spinal block as well as degree of coexisting hypovolemia. Treatment involves restoring preload by placing the patient in slight Trendelenburg, providing intravenous (IV) fluids and vasopressors. Some practitioners will routinely administer 1 L of fluid as a preload before or during spinal or epidural anesthesia as prophylaxis against hypotension [20].

Bradycardia

Many patients experience modest bradycardia following a spinal, although rarely bradycardia can progress to asystole and cardiac arrest without appropriate treatment. The underlying cause for bradycardia is believed to result from a blockade of the T1-T4 cardio accelerator fibers. This may also occur as a result of the Bezold-Jarisch reflex in which bradycardia occurs in response to decreased venous return. Treatment for minor bradycardia and hypotension may begin with IV ephedrine; more severe, persistent bradycardia may be treated with atropine and/or epinephrine [11].

2.7.2 Respiratory

Dyspnea

While true hypoventilation can occur with epidural and spinal anesthesia if it extends into the thoracic and cervical regions, a much more common occurrence is the feeling of dyspnea secondary to loss of proprioception in the intercostal muscles [20].

2.7.3 Gastrointestinal and Genitourinary

Nausea

Nausea after spinal or epidural anesthesia is often caused by 1 of 2 mechanisms: hypotension and subsequent decreased cerebral perfusion. Once the hypotension is treated and cerebral perfusion pressure is restored, the nausea usually resolves. Alternatively, nausea can be caused by a predominance of parasympathetic tone. After spinal or epidural anesthesia produces sympathetic blockade, the patient is left with a predominance of parasympathetic tone and resulting nausea. Ondansetron or promethazine are good choices for treating nausea due to parasympathetic overstimulation [11].

Urinary Retention

S2-S4 nerve roots innervate the bladder. Blockade of these nerve roots inhibits the voiding reflex and sensation of a full bladder. Addition of opioids can also increase the incidence of urinary retention. Foley catheterization should be routinely used in the presence of spinal or epidural anesthesia.

2.7.4 Neurologic

Transient Neurologic Symptoms

Transient neurologic symptoms (TNS) is defined as pain in the back or buttocks that can radiate to the legs within a few hours of spinal anesthesia, which is not associated with any other neurologic dysfunction and resolves within 24 h. TNS has the greatest association with lidocaine but is also seen with other local anesthetics as well [21].

High Spinal Blockade

Exaggerated spread of local anesthetic secondary to the administration of a large or disproportionate dose of local or an unusual distribution secondary to patient anatomy may lead to a high or complete spinal blockade. The spread of local anesthetic into the cervical levels and sometimes even beyond the foramen magnum affecting the cranial nerves can lead to severe outcomes.

The patient likely will first complain of weakness and numbness of the upper extremities and nausea. Dyspnea may be a common side effect once the phrenic nerve (C3-C5) supplying the diaphragm is affected, in addition to the effects resulting from the loss of proprioception from the intercostal musculature. As the anesthetic continues to spread cephalad to surround the cranial nerves, the patient will experience severe hypovolemia and bradycardia, progressing to syncope and loss of consciousness. Respiratory insufficiency may develop as a result of ischemia to the ventilation centers of the brainstem secondary to hypovolemia and decreased perfusion.

Treatment for a high spinal consists of cardiopulmonary support. Hypotension can be treated with intravenous fluids and vasopressors plus placement of the patient in Trendelenburg positioning, which act to increase venous return and systemic venous resistance. The operator should not attempt to block further spread of anesthetic by placing the patient in head-up position for this reason. Support of the patient's airway is warranted once respiratory distress is present. Tracheal intubation and mechanical ventilation are often necessary, particularly in patients at increased risk for aspiration [11, 20].

Failed Spinal

Occasionally a spinal anesthetic may not provide adequate analgesia and anesthesia even though the technique appeared seemingly successful. This may result from subdural injection (injection into the potential space between the dura and arachnoid layers instead of the subarachnoid layer), incomplete penetration of the needle opening into the intrathecal space resulting in only partial injection, or movement of the needle during injection. Failure rate is often related to the level of experience of the provider.

Post-Dural Puncture Headache

Puncture of the dura during spinal anesthetic, lumbar puncture, or an epidural wet tap can result in a post-dural puncture headache (PDPH). The proposed mechanism for this headache is a direct result of CSF loss through the open dural puncture site faster than the rate of CSF production, leading to a downward displacement of the brain and stretching of supporting structures (meninges, tentorium, and cranial nerves). Traction and tension on the blood vessels may also contribute to pain. There have been case reports, especially in young patients, of cerebral hemorrhage after dural puncture secondary to this tension. Factors that increase the likelihood of PDPH include: female sex, young age, pregnancy, and history of previous PDPH and the use of cutting-point, large-bore needles [8, 20].

Symptoms often present 12–48 h following the procedure, although occasionally symptoms can appear as early as immediately post-procedure or sometimes as long as several weeks later. The hallmark presentation is a positional headache, which intensifies when the patient is in an upright posture and is relieved while lying flat. The headache is typically bilateral, frontal, or occipital (sometimes extending to the neck) and described as a throbbing or constant pain. It is commonly associated with nausea and photophobia.

Treatment is typically conservative with caffeine, analgesics (nonsteroidal anti-inflammatory drugs, acetaminophen, opioids), rest and supine positioning, and fluids. Caffeine acts as a vasoconstrictor to decrease dilation and traction of intracranial vasculature. Caffeine, as well as fluid resuscitation, aids to increase CSF production. Recumbent positioning helps to prevent further loss of CSF through the dural defect.

If the headache persists after conservative treatment, the patient may be offered an epidural blood patch, which is typically very effective, offering immediate results. This procedure involves removing roughly 20 ml of autologous blood and reinjecting it into the epidural space at or below the level of the dural puncture. This is believed to work by sealing the dural puncture to prevent further leakage of CSF.

Nerve Root/Spinal Cord Trauma or Compression

Nerve root or spinal cord trauma can occur during needle or catheter placement. Usually this results in transient paresthesias that resolve immediately either spontaneously or with removal of the needle or catheter. Some paresthesias may be associated with postoperative neurologic problems but most of these problems resolve spontaneously.

It is of paramount importance while performing spinal or epidural anesthesia never to inject in the presence of a paresthesia. Should the needle/catheter be located within an area of restricted spread (thus causing increased pressure on nearby nerve roots or spinal cord), the spinal cord or nerve root the damage may be much more severe.

Epidural Hematoma

An epidural hematoma can cause spinal cord compression resulting in severe neurological deficits and paralysis. Epidural hematomas may be caused by rupture of the veins of the epidural venous plexus. Clinically significant epidural hematomas occur at a rate of 1:150,000 epidural procedures and 1:220,000 for spinal procedures. The majority of these have occurred in the presence of anticoagulation or intrinsic defects of coagulation. Thus, neuraxial anesthesia is relatively contraindicated in patients on anticoagulation, a known coagulation defect, thrombocytopenia (less than 60 K), and severe platelet dysfunction. An epidural hematoma can present at the time of the procedure but also has been known to present on catheter removal. Symptoms of an epidural hematoma include back pain, motor deficits, and bowel or bladder incontinence. Treatment consists of surgical decompression so urgent MRI is indicated as not to delay surgery. In the setting of a spinal hematoma, surgical decompression of the hematoma in less than 8 h from the onset of symptoms is crucial to provide the best long-term neurological outcome [22, 23].

Epidural Abscess

Epidural abscesses can also cause significant spinal cord compression in a similar fashion to epidural hematomas. The presentation of an epidural abscess can occur as early

2

as 5 days after spinal or epidural anesthesia but presentation can be delayed up to several weeks. An epidural abscess can be a complication of spinal or epidural anesthesia, neurosurgical procedures or can occur spontaneously in the absence of a neuraxial procedure. Those occurring in the absence of recent procedures are thought to be secondary to systemic infection seeding the epidural space. Symptoms of an epidural abscess include fever, chills, back pain, increased with percussion, radicular pain, bowel and bladder dysfunction, and paralysis. Elevated white blood cell (WBC) count also can be seen. Urgent MRI or computed tomography (CT) is indicated as definitive treatment consists of surgical decompression. Additionally, antimicrobial antibiotics with particular attention to covering for *Staphylococcus aureus* and *Staphylococcus epidermidis* should be initiated [24].

2.8 American Society of Regional Anesthesia Guidelines

The American Society of Regional Anesthesia (ASRA) has developed guidelines to assist the practitioner in making decisions concerning regional and neuraxial anesthesia in patients on anticoagulation. ◘ Table 2.1 consist of the recom-

◘ **Table 2.1** Guidelines for regional anesthesia

Drug	Amount of time drug must be discontinued before procedure	Amount of time medication must be delayed after procedure	Catheter removal	Time interval between removing catheter and restarting medication
Apixaban Eliquis	3 days	6 h	3 days	6 h
Aspirin	No restrictions	No restrictions	No restrictions	No restrictions
Clopidogrel Plavix	7 days If within 5–7 must show normal PLT function	Avoid If within 5–7 must show normal PLT function	Avoid If within 5–7 must show normal PLT function	No Recommendation
Dibigatran Pradaxa	5 days	6 h	5 days	6 h
Enoxaparin Lovenox (BID DVT Prophylactic dosing)	10–12 h	12 h post op	Before dosing of LMH	4 h after catheter removal if >12 since surgery
Enoxaparin Lovenox (Treatment dosing)	24 h	No recommendation Catheters should be removed before dosing	No recommendation Catheters should be removed before dosing	No recommendation
Heparin (SQ Bid dosing)	Hold for 4 h(ideally 6 h) If on heparin >4 days check PLT CT	Immediately	Hold for 4 h (ideally 6 h) If on heparin >4 days check PLT CT	Immediately
Rivaroxaban Xarelto	3 days	6 h	3 days	6 h
Warfarin Coumadin	4–5 days + Normal INR For 1st dose 24 h before surgery or if second dose then check INR	No delay If catheter left in place 1. Low dose 2. Daily INR 3. Routine neuro checks 4. Minimize sensory and motor block 5. INR 1.5 or less for removal	INR < 1.5 remove & neuro checks × 24 h 1.5 ≤ 3.0 Assess all medication that alter coagulation and remove with caution continue neuro checks until INR stabilizes at therapeutic level >3.0 hold or reduce warfarin do not pull Therapeutic INR No recommendation	No recommendation

PLT platelet, *BID* twice daily, *DVT* deep vein thrombosis, *LMH* low molecular weight heparin, *SQ* subcutaneous, *INR* international normalized ratio mendations for regional anesthesia and Table 2.2 covers the recommendations for neuraxial procedures. Many situations exist in which neuraxial anesthesia and anticoagulation would both be appropriate for a patient at the same time; the most common scenario would be deep vein thrombosis (DVT) prophylaxis in a postoperative patient. These guidelines are consensus opinions by experts in the fields of anticoagulation and neuraxial anesthesia. They also represent a thorough review of case reports and the literature surrounding epidural hematomas since they are such rare events, they do not lend themselves to study by randomized control trial. Thus, this is the strongest level of evidence available to guide practitioners. The ASRA guidelines for regional anesthesia list 2 items for each drug: how long of a period a patient should abstain from an anticoagulant before receiving neuraxial anesthesia and how long after removal one should avoid anticoagulants. The guidelines for neuraxial anesthesia risk stratify procedures into low, medium, and high risk and advise the practitioner on durations for which the drug should be held before and restarted after the procedure. High risk procedures include invasive procedures such as spinal cord stimulator (SCS) trial, intrathecal pump placement, and vertebroplasty. Intermediate risk procedures include epidural steroid injections and sympathetic blockade. Low risk procedures include sacroiliac (SI) joint injections and peripheral nerve blocks. Tables 2.1, 2.2, and 2.3 summarize these guidelines [25, 26].

Table 2.2 Neuraaxial and pain guidelines

High-risk	Intermediate-risk	Low-risk
SCS trial Intrathecal catheter and pump placement Vertebroplasty, Kyphoplasty, Epiduroscopy and Epidural decompression	Interlaminar and transforminal ESI Facet MBNB and RFA Paravertebral nerve block Intradiscal procedures Sympathetic blocks Peripheral nerve stimulation trial and implant Pocket revision IPG/ITP placement	Peripheral nerve blocks Peripheral joint and musculoskeletal injections Trigger point injections including piriformis SI joint Sacral lateral branch blocks

Patients with high risk for bleeding (multiple anticoagulants, old age, history of bleeding or bleeding tendency, advanced liver or renal disease) undergoing low or intermediate risk procedures should be elevated to the next higher stratification
SCS spinal cord stimulator, *ESI* epidural steroid injection, *MBNB* medial branch nerve block, *RFA* radiofrequency ablation, *IPG/ITP* internal pulse generator/intrathecal pump,*SI* sacroiliac

Table 2.3 Guidelines advising how long patients should stop taking their medications before the procedure and when to restart after the procedure

Drug	When to stop			When to restart
	High risk	Intermediate risk	Low risk	
Acetylsalicylic acid (ASA)	Primary prophylaxis 6 days Secondary prophylaxis shared assessment and risk stratification	Shared assessment and risk stratification	no	24 h
Nonsteroidal Anti-Inflammatory Drugs (NSAIDs)				
NSAIDs	5 half-lives	No (consider stopping for certain procedures such as cervical epidural steroid injection [ESI])	No	24 h
Diclofenac Ketorolac Ibuprofen	1 day			
Etodolac Indomethacin	2 days			
Naproxen Meloxicam	4 days			

(continued)

2

Table 2.3 (continued)

Drug	When to stop			When to restart
	High risk	Intermediate risk	Low risk	
Nabumetone	6 days			
Oxaprozin Piroxicam	10 days			
Phosphodiesterase inhibitors				
Cilostazol	2 days	No	No	24 h
Dipyridamole	2 days	No	No	
ASA combinations	Follow ASA recommendations	Shared assessment and risk stratification		
Anticoagulants				
Coumadin	5 days Normal INR	5 days Normal INR	No Shared assessment and risk stratification	24 h
Acenocoumarol	3 days Normal international normalized ratio (INR)	3 days Normal INR	No Shared assessment and risk stratification	24 h
IV heparin	4 h	4 h	4 h	2 h (if moderate or high risk and involved bleeding the 24 h)
SQ heparin (BID & TID)	8–10 h	8–10 h	8–10 h	2 h
Low molecular weight heparin (LMWH) prophylactic	12 h	12 h	12 h	4 h (low risk) 12–24 h medium to high risk
LMWH therapeutic	24 h	24 h	24 h	4 h (low risk) 12–24 h medium to high risk
Fibrinolytic agents	48 h	48 h	48 h	48 h
Fondaparinux	4 days	4 days	Shared assessment and risk stratification	24 h
New anticoagulants				
Dabigatran	4–5 days (6 days with impaired renal function)	4–5 days (6 days with impaired renal function)	Shared assessment and risk stratification	24 h
Rivaroxaban	3 days	3 days	Shared assessment and risk stratification	24 h
Apixaban	3–5 days	3–5 days	Shared assessment and risk stratification	24 h
Glycoprotein IIb/IIIa inhibitors				
Abciximab	2–5 days	2–5 days	2–5 days	8–12 h
Eptifibatide	8–24 h	8–24 h	8–24 h	8–12 h
Tirofiban	8–24 h	8–24 h	8–24 h	8–12 h

IV intravenous, *SQ* subcutaneous, *BID* twice daily, *TID* three times a day

2.9 Questions and Answers

Questions (Choose the Most Appropriate Answer)

1. In an adult with no history of spinal canal abnormalities, at which vertebral level does the dural sac generally terminate?
   A. L2
   B. S2
   C. T12
   D. S4
2. In a neonate, the spinal cord extends to which vertebral level?
   A. L1
   B. T12
   C. S3
   D. L3
3. What is the order of spinal ligaments in relation to the epidural space when moving from superficial to deep?
   A. Skin > supraspinous ligament > intraspinous ligament > ligamentum flavum > epidural space
   B. Skin > intraspinous ligament > supraspinous ligament > ligamentum flavum > epidural space
   C. Skin > supraspinous ligament > ligamentum flavum > intraspinous ligament > epidural space
   D. Skin > ligamentum flavum > intraspinous ligament > supraspinous ligament > epidural space
4. Which statement regarding the blood supply of the spinal cord is most true?
   A. The spinal cord is supplied by 1 anterior spinal artery and 2 paired posterior arteries.
   B. The anterior spinal artery supplies the anterior spinal cord, the area responsible for sensory innervation.
   C. The artery of Adamkiewicz or Great Radicular Artery generally is found on the right side and supplies the anterior spinal artery in the upper thoracic region.
   D. There are 3 posterior arteries that supply the spinal cord and account for two-thirds of the blood supply to the cord.
5. Which statement regarding spinal vertebral anatomy is most true?
   A. There are 7 cervical spinal nerves and each one exits the neural foramen and each exits below their corresponding vertebral body.
   B. A lateral view of the spine reveals a double-C shape in which the cervical and lumbar regions exhibit a convex curvature (kyphosis) and the thoracic region appears concave (lordosis).
   C. The covering of the spinal cord is composed of the outermost dura mater, then the pia mater, and the innermost arachnoid mater.
   D. The C7 spinous process is the most prominent bony landmark in the base of the neck and a line drawn between the lower edges of the scapulae denotes the T7 interspace.
6. Which of the following is NOT a likely contraindication to the placement of an epidural catheter for the purpose of postoperative analgesia?
   A. Infection at the insertion site
   B. Platelet count of 45,000
   C. Enoxaparin 1 mg/kg administered 12 h prior to placement
   D. Human immunodeficiency virus (HIV) infection
   E. Elevated intracranial pressure
7. Which of the following symptoms are NOT consistent with a post-dural puncture headache?
   A. Tinnitis
   B. Diplopia
   C. Worse in a recumbent position
   D. Nausea
   E. Photophobia
8. When placing an epidural utilizing the paramedian approach, which of the following ligaments is traversed?
   A. Supraspinous ligament
   B. Interspinous ligament
   C. Ligamentum flavum
   D. Costotransverse ligament
   E. A, B, and C only
   F. All of the above
9. A 62-year-old male underwent right thoracotomy and lung lobectomy. An epidural catheter was placed in the T4-5 interspace. He is receiving epidural analgesia via a continuous infusion of ropivacaine 0.1% with fentanyl 5 mcg/ml running at a rate of 8 ml/h. On postoperative day 2, he develops weakness in the lower extremities and associated sensory deficits. Which of the following is an appropriate next action?
   A. Reassure the patient and re-evaluate the next morning
   B. Change the local anesthetic to bupivacaine
   C. Reduce the rate of infusion to 6 ml/h.
   D. Remove the opioid from the infusion
   E. Obtain magnetic resonance imaging
10. Based on the American Society of Regional Anesthesia and Pain Medicine (ASRA) guidelines, in which of the following scenarios would you proceed with the placement of an epidural catheter?
    A. Patient on enoxaparin 1.5 mg/kg daily and the last dose was 12 h ago
    B. Patient whose last dose of dabigatran was 48 h ago
    C. Patient who last took clopidogrel 5 days ago
    D. Patient last took warfarin 4 days ago and the current international normalized ratio (INR) is 1.2

Answers

1. **B.** S2. In children, the dural sac terminates at S3 and regresses to lie around S2 in adults. The epidural fat continues caudally to S4 and can be accessed via the sacral hiatus for use in caudal epidural anesthesia. When performing caudal anesthesia, care must be

taken not to advance the needle tip up to S3 in children to avoid intrathecal injection.

2. **D**. L3. When a child is born, the conus medullaris extends to about the L3 level and with age regresses to the level of about the L1 level in an adult. Thus, a spinal or epidural anesthesia approach is much safer at L4/5 or L5/S1 because this avoids approaching at the level of the cord. The cauda equina exists at the L4/5 and L5/S1 level but these nerves will generally move to the side with gentle pressure of a spinal needle.
3. **A**. Skin > supraspinous ligament > intraspinous ligament > ligamentum flavum > epidural space. When approaching in a midline trajectory for spinal or epidural anesthesia, 3 separate ligaments will be encountered when moving from superficial to deep. After passing through the skin and subcutaneous tissue, the first increase in resistance will be the supraspinous ligament, which runs vertically to connect the posterior-most portions of the spinous processes. This resistance continues through the intraspinous ligament, which connects the inferior portion of the spinous process body with the superior portion of the spinous process of the vertebral level below and also traverses anteriorly from the outermost portion of the spinous process to the lamina. Finally, lying along the anterior surface of the lamina is the ligamentum flavum. It is shaped like a V with the apex pointing posteriorly and it runs the length of the spine from the cervical to lumbar region. After a spinal or epidural needle passes through this ligament, an abrupt loss of resistance may be encountered indicating entrance into the epidural space and may continue into the dural sac.
4. **A**. The spinal cord is supplied by 1 anterior spinal artery and 2 paired posterior arteries. The anterior spinal artery arises from the vertebral artery and supplies the anterior two-thirds (motor innervation) of the spinal cord whereas the posterior one-third of the cord is supplied by the 2 posterior arteries and this territory is responsible for sensory innervation. The anterior spinal artery can receive contribution from the large artery of Adamkiewicz or great radicular artery (GRA). The GRA typically branches off the aorta around T9-T12 but can be anywhere from T5-L5 and a majority of the time arises on the left side. The GRA can contribute considerable arterial flow to the lumbar region anterior spinal artery, so if injured will result in motor loss such as lower extremity weakness and bowel and bladder incontinence, but sensory innervation being posterior may remain intact. The anterior spinal artery arises from the vertebral artery whereas the 2 posterior arteries arise from the posterior inferior cerebellar arteries.
5. **D**. The C7 spinous process is the most prominent bony landmark in the base of the neck and a line drawn between the lower edges of the scapulae denotes the T7 interspace. A horizontal line drawn across the bilateral iliac crest will generally lie in the region of L4/5. These are useful landmarks in determining epidural placement and paravertebral blocks. There are 31 pairs of spinal nerves (8 cervical, 12 thoracic, 5 lumbar, and 5 sacral). The nerve roots exit the spinal column through the bilateral intervertebral foramen. In the cervical spine the nerve roots exit above their corresponding vertebral body. At the C7 body, the C7 root exits above and the C8 root exits below (between C7 and T1). Starting at T1 the nerve roots then exit below their respective vertebral bodies. The cervical and lumbar regions exhibit a concave or lordotic curvature and the thoracic region appears convex (kyphosis). The meninges are the 3 layers of connective tissue surrounding the spinal cord composed of the outermost dura mater, the arachnoid mater, and the innermost pia mater. Beginning most superficially, the epidural space exists as a potential space between the dura mater and the ligamentum flavum.
6. **D**. In addition to patient refusal, there are several relative contraindications and the provider must weigh the risk versus benefit for the patient. Infection at or near the insertion site can increased the risk of meningitis. Significant coagulopathy, thrombocytopenia, or recent administration of anticoagulatant drug can increase the risk of spinal hematoma. Enoxaparin dosed 1 mg/kg every 12 h or 1.5 mg/kg daily require being held for 24 h prior to placement of a neuraxial block. Patients with increased intracranial pressure can be predisposed to brainstem herniation in the event of a dural puncture and large volumes injected into the epidural space can further increase intracranial pressure. Previously, there were concerns that neuraxial anesthesia in an HIV-infected patient would hasten central nervous system (CNS) manifestations of the disease. However, it is now understood that CNS involvement occurs early during the course of HIV infection and introduction of HIV virus into a previously virus-free CNS after is not a concern.
7. **C**. Patients with a post-dural puncture headache typically present with a fronto-occipital headache that radiates to the neck. Associated symptoms often include neck stiffness, tinnitus, photophobia, diplopia, and nausea. The headache is often postural in nature and is worse in the upright position and improves in the horizontal or supine position.
8. **C**. When placing an epidural using the paramedian approach, the epidural needle penetrates the paraspinous muscles then enters the ligamentim flavum en route to the epidural space. While the supraspinous and interspinous ligaments are penetrated during a midline approach to the epidural space, the paramedian approach is lateral to these ligaments. The costotransverse ligament connects the rib to the transverse process of the vertebrae and is not encountered during epidural placement.

9. **E**. A spinal hematoma is a potentially devastating complication following neuraxial **anesthesia**, most commonly presenting with numbness and/or weakness of the lower extremities. Epidural analgesia with local anesthetics can potentially cloud the clinical presentation, but any unexpected neurologic deficits must be taken seriously. A high thoracic epidural is unlikely to cause lower extremity symptoms and thus immediate action must be taken. Changing the local anesthetic or removing the opioid would not improve this scenario. A small change in the infusion rate would not be expected to make a significant difference. The epidural infusion should be immediately stopped and the patient should be regularly monitored for resolution of his lower extremity deficits, and the provider should have a high index of suspicion for other causes of this new neurological deficit. Prompt consultation with neurosurgery and obtaining an MRI to diagnose an epidural hematoma is very important. In the setting of a spinal hematoma, surgical decompression of the hematoma in less than 8 h from the onset of symptoms is crucial to provide the best long-term neurological outcome.
10. **D**. A spinal hematoma is a potentially devastating complication following neuraxial **anesthesia**, and patients with pre-existing coagulopathy or patients using medications that impact coagulation or platelet function are at increased risk. The American Society of Regional Anesthesia and Pain Medicine (ASRA) provides practice guidelines/recommendations that summarize evidence-based reviews of regional anesthesia in patients receiving antithrombotic or thrombolytic therapy. According to ASRA guidelines: for patients receiving enoxaparin 1.5 mg/kg daily, neuraxial block should be delayed for at least 24 h after the last dose; the last dose of dabigatran should be 5 days prior to neuraxial block; the last dose of clopidogrel should be 7 days prior to neuraxial block. Warfarin should be stopped 4–5 days in advance and INR within the normal reference range should be confirmed prior to the neuraxial block.

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