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Anatomy of lumbar puncture and epidural analgesia

CHAPTER 35

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CORE PROCEDURES

- Epidural injections: commonplace in obstetrical anaesthesia, as well as in the treatment of radiculitis throughout the spine
- Epidural catheterization: permits continuous administration of an anaesthetic agent
- Lumbar puncture: single injection of local anaesthetic into the subarachnoid space via lumbar puncture offers excellent surgical anaesthesia for abdominal, pelvic and lower-extremity procedures

The epidural space is the potential space that lies outside the dura and is the outermost part of the vertebral (spinal) canal. Its upper limit is the foramen magnum, and its lower limit is the sacrococcygeal membrane. The dura encloses the arachnoid mater, subarachnoid space, cerebrospinal fluid (CSF) and spinal cord, and ends at approximately S2. The subdural space is the potential space between the dura and arachnoid mater (**Fig. 35.1**). It does not connect with the subarachnoid space but continues for a short distance along the cranial and spinal nerves. Accidental subdural catheterization may occur during epidural injections; injection of fluid into the subdural space may damage the cord either by direct toxic effects or by compression of the vasculature. The subarachnoid space contains the CSF in continuity around the brain and spinal cord. CSF is created in the choroid plexus and mainly absorbed in the arachnoid granulations, with a normal specific gravity of 1.004–1.006. The total volume of CSF in the normal adult is approximately 150 ml and is produced 25 ml per hour.[1,2]

CLINICAL ANATOMY OF THE EPIDURAL SPACE

The posterior epidural space is widest in the upper thoracic region (7.5 mm), narrowing to 4.1 mm at the T11–T12 region, and 4–7 mm in the lumbar region.[3] It takes 1.5–2 ml of local anaesthetic to block a spinal segment in the epidural space but far less (0.3 ml) for a similar block in the subarachnoid space.[4]

Both the shape and size of the epidural space are dictated by the shape and size of the vertebral canal and the position of the dural sac. The space freely communicates with the paravertebral space via intervertebral foramina. The epidural space can be separated into cervical, thoracic, lumbar and sacral epidural regions. In the cervical epidural space, the spinal and periosteal layers of dura fuse at the foramen magnum, preventing intracranial extension.[5] The lumbar epidural space extends from the lower margin of the L1 vertebra to the upper margin of S1. A line drawn between the iliac crests (intercristal line) across the back usually denotes the L4–5 interspace in adults and the L5–S1 level in infants. The sacral epidural space extends from the upper margin of S1 to the sacrococcygeal membrane. The space is bounded anteriorly by the posterior longitudinal ligament, vertebral bodies and intervertebral discs; the pedicles and intervertebral foramina form the lateral boundaries, and the ligamenta flava and vertebral laminae form the posterior boundary. The ligamentum flavum forms the anterior covering of the diarthrodial zygapophysial joint; haptic recognition of the ligamentum flavum is critical in successful cannulation of the epidural space (see Fig. 35.1).

Contents of the epidural space

The epidural space contains fat, lymphatics, arteries, connective tissue, spinal nerve roots and an extensive venous plexus. Epidural fat is the dominant constituent of the posterior spinal epidural space. It buffers the pulsatile movements of the dural sac; protects nerves; facilitates the movement of the dural sac over the periosteum of the spinal column during flexion and extension; and creates a reservoir for lipophilic substances.[6] The fat is largely distributed along the dorsal margin of the space. The clinical significance of the epidural fat distribution is related to the pharmacokinetics of drugs injected into the epidural space: changes in fat content and distribution associated with different diseases may alter the absorption and distribution of drugs injected into the epidural space.

The internal vertebral venous plexus within the epidural space is thought to be involved in traumatic tap during needle placement.[7] The plexus consists of four interconnecting longitudinal vessels, two anterior and two posterior, which receive a large contribution from the posterior aspect of each vertebral body via the basivertebral vein (**Fig. 35.2A**).[8] Anterior and posterior external vertebral venous plexuses anastomose freely and are most developed in the cervical region. Anterior external plexuses are anterior to the vertebral bodies, communicate with basivertebral and intervertebral veins, and receive tributaries from vertebral bodies. Posterior external plexuses lie posterior to the vertebral laminae and around spinous, transverse and articular processes. They anastomose with the internal plexuses and join the vertebral, posterior intercostal and lumbar veins.[9] The basivertebral veins are paired, valveless veins that drain the pars spongiosa of the vertebral bodies into the internal and external vertebral venous plexuses. In each segment, they emerge horizontally from foramina in the vertebral bodies. Posteriorly, they drain into the transverse branches of the anterior internal vertebral plexuses. Anteriorly, they drain directly into the anterior external vertebral venous plexus.[10] These veins are predominantly in the anterolateral part of the epidural space; they connect deep pelvic veins draining the bladder, prostate and rectum to the internal vertebral venous plexus. Sparse lymphatics concentrated along the dural roots and the valveless venous system contribute to the haematogenous spread of infection or malignancy to the epidural space. Obstruction of the inferior vena cava, pregnancy or intra-abdominal tumours can cause distension of the venous plexus, leading to increased risk of trauma during needle or catheter placement in the epidural space. Spinal arteries entering each intervertebral foramen form an anterior and posterior spinal arterial arcade; these arteries arise from the vertebral arteries and the thoracic and lumbar aorta, and anastomose with the anterior spinal artery (**Fig. 35.2B**). The arteries in the lumbar epidural space are branches of the iliolumbar arteries, and because they are placed laterally in the space, they typically escape trauma during an epidural puncture.

Innervation of the vertebral column and its associated soft tissues is derived from the spinal nerves where they branch, in and just beyond the intervertebral foramina. There is an input from the sympathetic system either via grey rami communicantes or directly from thoracic sympathetic ganglia. The branches of the spinal nerve concerned are the dorsal ramus and the recurrent meningeal or sinuvertebral nerves (usually more than one at each level). The anterior dura is heavily innervated, whereas the posterior dura is sparsely innervated.[11]

Anchoring meningovertebral ligaments divide the epidural space into anterior, lateral and posterior compartments.[6] Fibrous bands of connective tissue in the anterior epidural space, Hofmann ligaments, connect the anterior dural sac to the posterior longitudinal ligament (PLL) and may play a supportive role in anchoring the dural sac to the bony vertebral canal (**Fig. 35.3**). The greatest numbers of ligaments have been observed in the lower thoracic spine.[12]

Identification of the epidural space

Identification of the epidural space is of critical importance and accuracy of needle placement determines the success of epidural analgesia. The epidural needle, as inserted in the midline, pierces the skin and traverses successively the supraspinous ligament, interspinous ligament and ligamentum flavum (**Fig. 35.4**; see Fig. 35.1). The depth of the epidural space can be variable, particularly in an obese patient. Ravi[13] correlated the distance from the skin to the epidural space based on body mass index (BMI). In most patients, this distance is in the range of 3–6 cm.

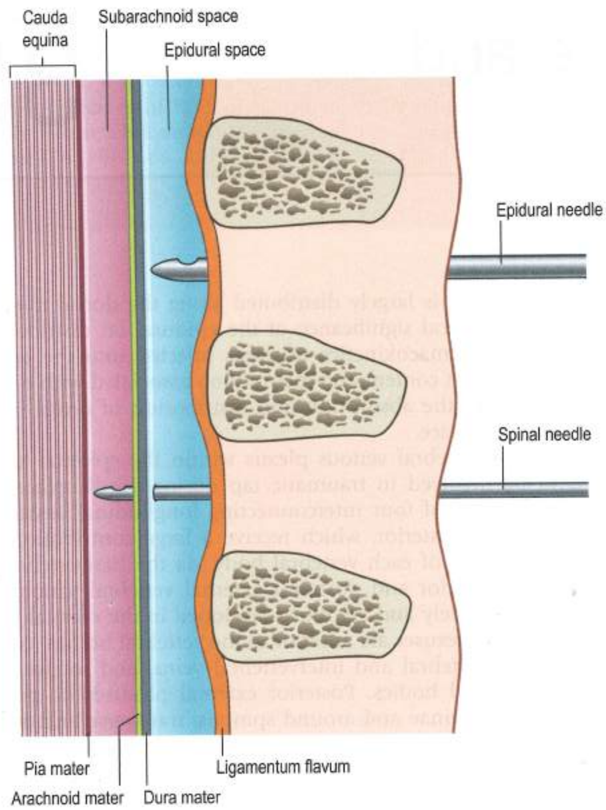


Fig. 35.1 A sagittal section through the layers of the posterior vertebral (spinal) canal. Note the larger gauge epidural needle with a rounded tip located in the epidural space, deep to the ligamentum flavum. The smaller gauge spinal needle with a sharp tip is located in the subarachnoid space, deep to the dura mater and arachnoid mater.

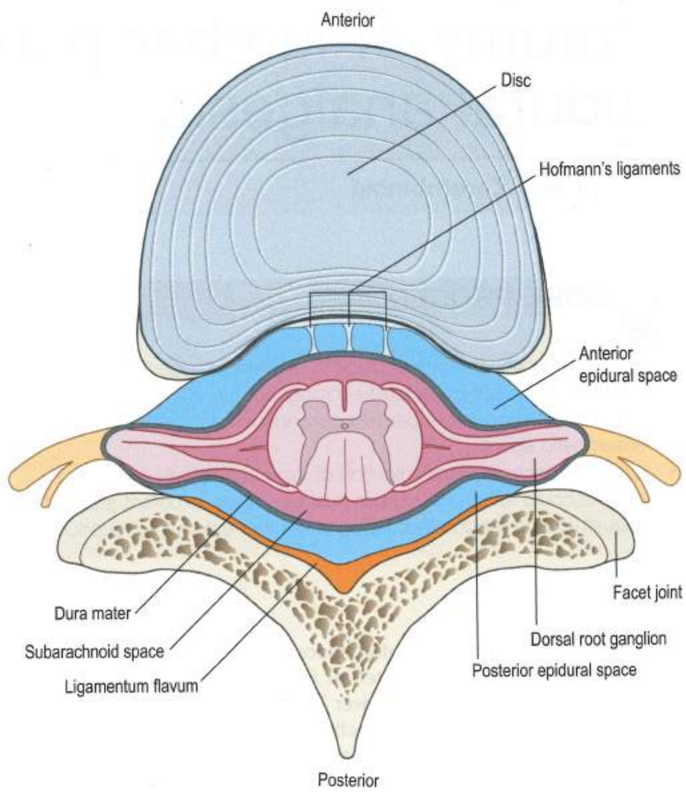


Fig. 35.3 A transverse section showing the contents of a typical vertebral (spinal) canal. Key: Blue, epidural space; orange, ligamentum flavum; pink, subarachnoid space.

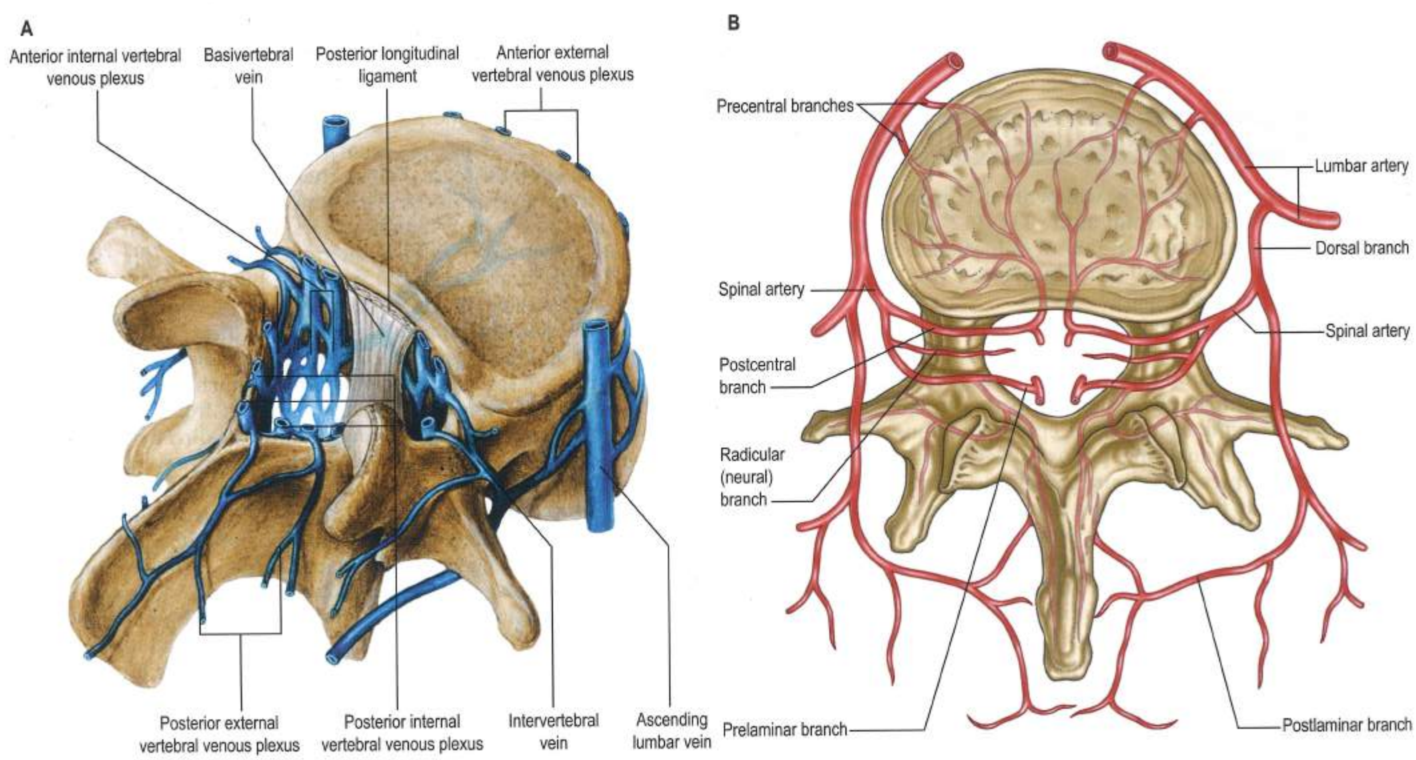
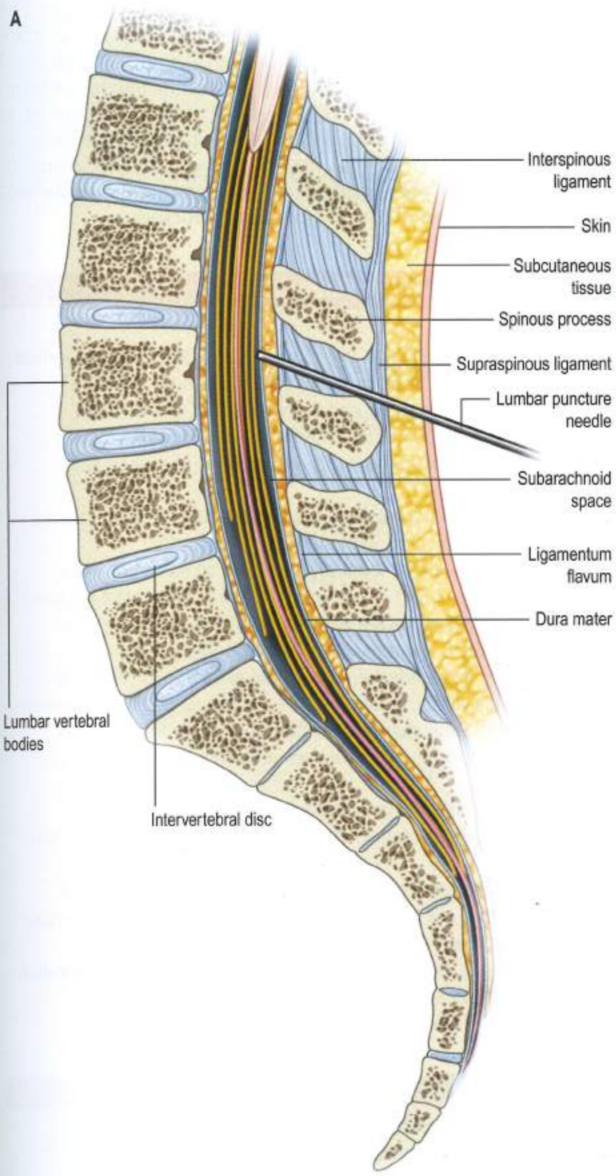


Fig. 35.2 A, The venous drainage of the vertebral column. Note that the basivertebral vein is shown beneath (that is, anterior to) the posterior longitudinal ligament. **B,** The arterial supply to the vertebrae and the contents of the vertebral canal, showing the branching pattern of the lumbar segmental arteries. (A, With permission from J. Waschke, F. Paulsen (eds), Sobotta Atlas of Human Anatomy, fifteenth ed., Elsevier, Urban and Fischer. Copyright 2013. B, From S. Standring (ed.), Gray's Anatomy, forty-first ed. © Elsevier, 2016, Fig. 43.20A.)

Methods of identification of the epidural space

Traditional methods of locating the epidural space depend on the negative pressure exhibited during introduction of an epidural needle into the space. The conventional method employs a loss of resistance (LOR) technique with the use of either air or saline. This technique uses continuous or intermittent pressure on the piston of an epidural glass or plastic syringe; the LOR is noted when it becomes possible to inject easily through the syringe attached to the epidural needle, allowing the piston to move easily within the barrel of the syringe (**Videos 35.1 and 35.2**). This technique works because the ligamentum flavum is dense and injection into it is difficult. Rarely, LOR to air has been



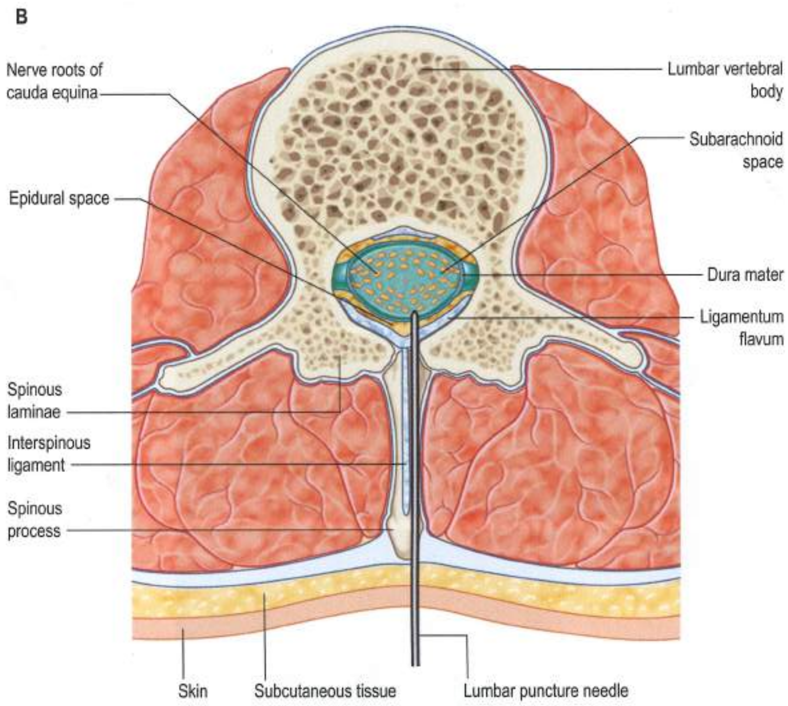


Fig. 35.4 **A**, A sagittal section of lumbar and sacral vertebrae illustrating the course of a lumbar puncture needle through (in order) the skin, subcutaneous tissue, supraspinous ligament, interspinous ligament between the spinous processes, ligamentum flavum and dura mater, into the subarachnoid space between the nerve roots of the cauda equina. **B**, A horizontal section of a lumbar vertebra illustrating the course of a lumbar puncture needle through (in order) skin, subcutaneous tissue, between the spinous processes and laminae, ligamentum flavum, epidural space and dura mater, into the subarachnoid space and between the nerve roots of the cauda equina. (With permission from J.M. Boon, P.H. Abrahams, J.H. Meiring et al., Lumbar puncture: anatomical review of a clinical skill, Clin. Anat. 17 (2004) 544–53.)

linked to paraplegia[14] and pneumocephalus,[15] while LOR to saline has been associated with dilution of injected local anaesthetic.[16] Other techniques have been described.[17–21] Ultrasound can predict skin to epidural depth[22] and correlates with MRI identification of the epidural space.[23] On MRI with T1 sequencing, the epidural space is seen as a bright signal displayed by epidural fat. A generous epidural space as seen on MRI with T1 sequencing may translate to ease of cannulation (**Fig. 35.5**).

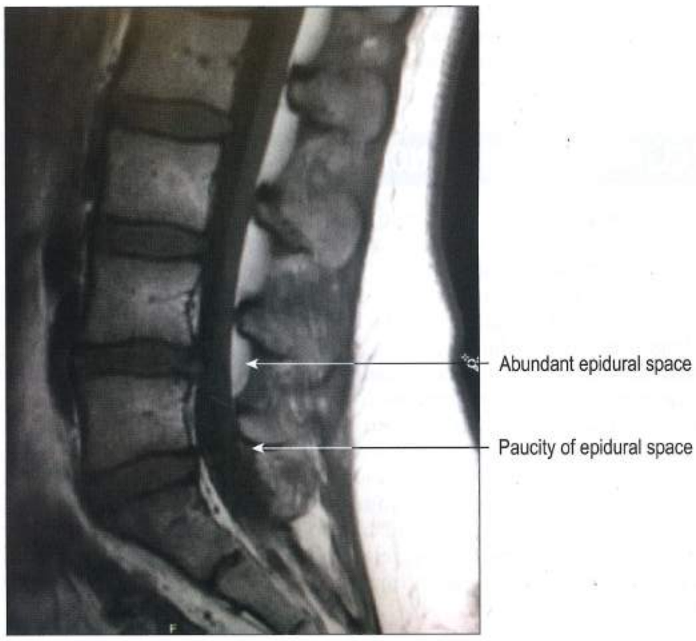


Fig. 35.5 MRI with T1 sequencing of the sagittal lumbar spine.

Technical considerations

Initial contact with the lamina before entry into the epidural space provides depth control, which is crucial for safety, especially in the cervicothoracic canal. Lateral and contralateral oblique images provide a measure of depth to enhance safety[24]; contralateral oblique images should delineate the spinolaminar line clearly and define accurate depth control. The importance of their use was highlighted by the observation that incomplete midline fusion of the ligamentum flavum can be seen in 67% of patients at C6–7 and C7–T1 levels.[25] Safe cervical interlaminar epidural placement is aided by contralateral oblique fluoroscopic views.[26] In the lumbar spine, contralateral oblique imaging will confirm needle placement when combined with anteroposterior images and has been shown to be especially useful when target landmarks are unclear in the lateral view: for example, in obesity, severe osteoporosis or atypical anatomy.[27] Air at the time of LOR is clearly visible in contralateral images and facilitates reliable epidural cannulation without the use of contrast agent[28–30] (**Fig. 35.6**).

Pathology affecting epidural entry

Congenital abnormalities that cause difficulties in epidural cannulation include achondroplasia, congenital adolescent scoliosis and spina

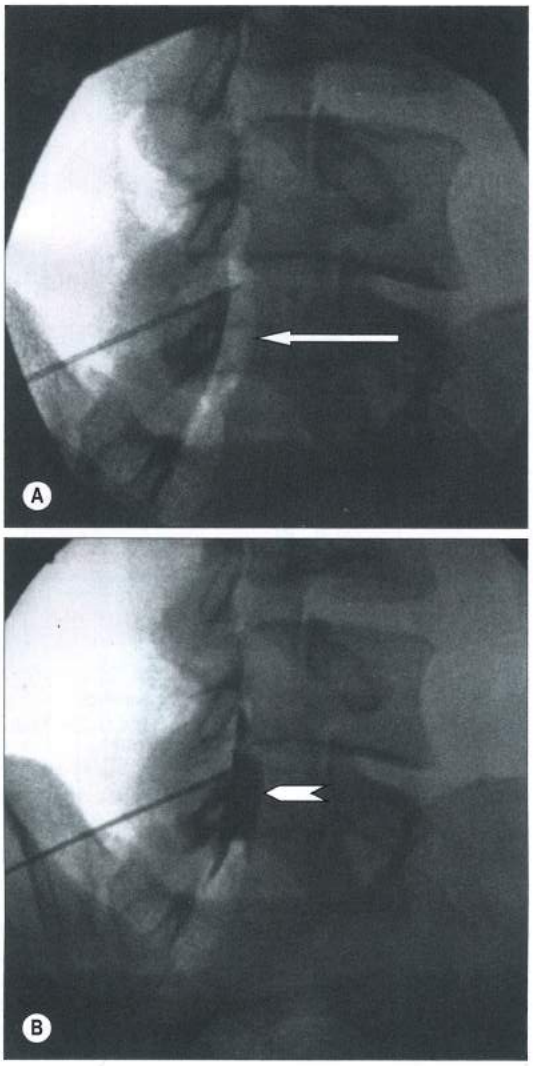


Fig. 35.6 A, A contralateral oblique fluoroscopy image of air in the epidural space (long arrow). **B**, Contrast dye in the epidural space (short arrow).

bifida. Acquired abnormalities include ligamentum flavum hypertrophy, foraminal stenosis and disc herniation. Examination of MRI preoperatively may help predict any procedural challenges and avoid complications.

CLINICAL IMPORTANCE OF THE EPIDURAL SPACE

The close proximity of the epidural space to neural structures means that lesions involving the space may present with symptoms of myelopathy or radiculopathy. MRI is the primary imaging modality to assess pathologies of the epidural space; clinical assessment and laboratory and imaging findings help the clinician to form a specific diagnosis. The epidural space is a focus for the purpose of inducing anaesthesia and analgesia. Injection into this space can be by single injection, whereas catheterization permits intermittent or continuous injection, including patient-controlled epidural analgesia (PCEA). Epidural injection of corticosteroids is commonly used to manage radicular pain caused by nerve irritation[31]; steroids placed in the epidural space have a potent anti-inflammatory action and can decrease pain and improve function. Administration of local anaesthetics into the epidural space provides pain relief during labour, abdominal surgery and lower-extremity surgery. Implanted delivery systems may be used to manage cancer pain.

CLINICAL IMPORTANCE OF THE SUBARACHNOID SPACE

MRI is the primary initial imaging modality to assess the subarachnoid space. Single injection is the most common modality used for drug administration. Local anaesthesia administration offers excellent surgical anaesthesia for the abdomen, pelvis and lower extremities. The sensorimotor block produced by injecting into the subarachnoid space requires smaller doses of local anaesthetics, which means that local anaesthetic toxicity is rarely a concern. Subarachnoid narcotic administration is helpful for postoperative pain relief, as well as serving as a test for those patients being considered for an intrathecal narcotic pump. Conditions that result in increased abdominal pressure or engorgement of epidural veins, such as pregnancy, ascites and abdominal tumours, will increase the height of spinal blockade.

Tips and Anatomical Hazards

Meticulous technique is critical in avoiding hazards, such as inadvertent dural puncture, which can lead to spinal headache and places the spinal cord at risk with cervicothoracic approaches. Identification of laminar depth, recognition of landmarks on imaging, and haptic feedback during needle placement are critical skills to ensure safe practice.

Complications such as epidural abscess and epidural haematoma are uncommon but are associated with significant morbidity.

In intrathecal administration of local anaesthetic, an extremely high anaesthetic level to C2–3 can result in phrenic and intercostal muscle paresis, hypoxia and hypercarbia. An anaesthetic level of T1–4 can result in bradycardia and decreased myocardial contractility.

The sympathectomy associated with a spinal anaesthetic produces hypotension primarily due to dilation of the venous capacitance vessels and decreased peripheral vascular resistance. Clearly, the ability to provide respiratory support, vasopressors and intravenous fluids is critical.

Contraindications for epidural or subarachnoid injection include hypovolaemia, coagulation disturbances, stenotic valvular disease and bacteraemia.

Spinal headache is reduced by using a small-gauge needle; spinal needles shaped with a pencil point may offer a smaller rent in the dura with a reduced incidence of postdural puncture headache.[32,33]

Spinal anaesthesia has been associated with symptomatic deterioration in patients with multiple sclerosis.[34]

Bonus eBook content

Video 35.1 Anatomy of lumbar puncture and epidural analgesia.
Video 35.2 Anatomy of lumbar puncture and epidural analgesia: lumbar puncture needle.

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