CHAPTER 14

The Adult Spine

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THE CERVICAL SPINE

Special Anatomic Considerations

The surgical anatomy of the cervical spine is divided into that of the craniocervical junction and the subaxial cervical spine (Fig. 14-1). The first includes the occiput (C0), atlas (C1) and axis (C2) vertebrae. The atlas vertebra has the form of a ring, with two lateral articular masses that articulate with the occipital condyles cephalad and with the superior facets of the axis caudad. The atlas and axis provide 40 percent of the total rotation of the cervical spine. This occurs around the odontoid process (dens).

The stability between C1 and C2 depends on the lateral-mass facet-joint capsules and on the transverse ligament of the atlas, which prevents anteroposterior (AP) translation of the dens. Pathology that can potentially damage this ligament includes trauma and inflammatory pannus, as that from rheumatoid arthritis (Fig. 14-2). Instability of C1–C2 may be repaired by a C1–C2 fusion. Advanced arthritis may also erode the articular surfaces of C0–C1 and C1–C2. As a consequence, the axis migrates closer to the foramen magnum and the dens may intrude into the cranium. If this basilar invagination is reducible with traction, the patient is operated under skeletal traction and the occiput is fixed or fused in the reduced position to the cervical spine (craniocervical fusion). Nevertheless, if the dens cannot be reduced or there are other conditions that occupy the anterior spinal canal and displace the brainstem, this may be decompressed anteriorly via transoral exposure.

The subaxial cervical spine consists of five vertebrae linked by five joints at each level: the intervertebral disk (a symphysis), two facet joints, and two uncinate processes. These joints provide significant range of motion and also protect the neural elements. This area may be approached for fusion and/or decompression from both the anterior and posterior aspects of the neck.

Anterior decompression includes anterior diskectomy or corpectomy and fusion. Posterior decompression may be by laminectomy or laminoplasty. In general, posterior decompression is preferred for multilevel disease with a lordotic cervical spine. The anterior approach to the subaxial cervical spine is a standard, widely used procedure. The approach takes advantage of the anatomic planes of the neck and requires only minimal soft tissue disruption.

Patient Profile

A wide array of patients may present, including young and healthy patients who have suffered an injury as well as elderly patients with long-standing spinal cord dysfunction secondary to myelopathy. A spine affected by rheumatoid arthritis requires special attention and is discussed later (see also Chap. 8). Multiple other comorbidities may be present in the elderly group. Finally, there are also those who have suffered spinal cord injury, whose management deserves special consideration.

Common Comorbidities

Comorbidities and, therefore, the indications for the procedure may vary significantly. Most frequently, patients who require fusion for injuries or for cervical disk disease are young and present without comorbidities. Patients with cervical spondylotic myelopathy, on the other hand, are frequently in their sixth or seventh decade of life and present with one or more comorbidities as well as long-term spinal cord dysfunction. Patients suffering from rheumatoid arthritis and subsequent atlantoaxial instability frequently
present with multiple medical problems, including those associated with chronic steroid therapy.

**Spinal Cord Injury**

The loss of sympathetic tone produces generalized vasodilatation below the level of the injury. The intravascular volume is expanded, which leads to hypotension. Additionally, there is an increase in vagal tone due to sympatholysis, resulting in bradycardia, which reduces cardiac output and further adds to the reduction of systemic blood pressure. Fluid management is therefore crucial. Too aggressive attempts to treat neurogenic shock solely by the administration of fluids may cause fluid overload and pulmonary edema. Furthermore, some patients may have concomitantly suffered pulmonary contusion. The resultant hypoxia not only worsens the effects of oligemia but may also contribute to the progression of secondary injury of the spinal cord. Optimal oxygenation is mandatory, and anticholinergic drugs such as atropine may be used to counteract bradycardia. Careful administration of vasopressors is indicated to control vasomotor disturbances, and great care must be taken to identify and treat other associated injuries, such as liver and spleen lacerations, which may be masked by the spinal cord injury. If the injury is above the level of C4, respiratory function may be compromised owing to involvement of the phrenic nerve, and assisted ventilation may be required after surgery. Additionally, gastroparesis and immobility increase the risk of aspiration pneumonia. Nasogastric tubes are therefore essential.

**Positioning on the Operating Table**

Positioning may directly influence surgical exposure and fusion alignment. Correct positioning is also necessitated to preserve neurologic function. Once the patient is anesthetized, there are no warning signs of maneuvers that might be damaging to the cervical spinal cord. This is especially important in cases of instability and cervical canal stenosis. General precautions include moving the patient in a rigid cervical orthosis at all times and head-to-trunk immobilization during transfers.

**Positioning for Anterior Surgical Exposure**

For anterior cervical exposure, the neck should lie in a neutral or slightly extended position. This is achieved by placing a roll under the scapulae. Care must be taken in positioning an elderly patient with a stenotic spinal canal. Gardner-Wells tongs may be used to assist in positioning and also to help in immobilizing the head and neck. The shoulders may be taped down distally to facilitate fluoroscopic visualization of the cervicothoracic junction. The arms are carefully padded and wrapped to the sides. If autologous bone is required for grafting, the anterior iliac crest may be prepared. A horseshoe or Mayfield head rest is padded with a soft roll, adapted,
and secured. After the anesthesiologist has secured the airway, the surgeon should hold the patient’s head and gently extend the neck slightly. Most of this extension should involve the occipitocervical junction. Once adequate positioning has been obtained, the head rest is secured and, if necessary, a head halter or tong traction applied. Finally, the head of the bed is slightly elevated to decrease venous bleeding. The knees can be raised to prevent the patient from sliding down during the operation and to protect the sciatic nerve from traction injury.

**Positioning for Posterior Cervical Exposure**

For posterior cervical exposure, the neck must be aligned close to neutral, with some degree of forward thrust of the head. If instability is caused by flexion, care must be taken not to increase traumatic deformity. When occipitocervical and/or atlantoaxial fixation is planned, flexion of the head creates space for exposure and instrumentation by maximizing the distance between the occiput and the posterior arches of the atlas and axis. A horseshoe or Mayfield head rest is recommended. In occipitocervical fixation the head should be aligned in a functional position at the time the implants are fixed.

For both anterior and posterior procedures, the arms are carefully positioned next to the body, with elbows, wrists, and hands well padded. Wrist straps may be used for traction, especially for lower cervical or cervicothoracic fusions. In this situation, lateral fluoroscopy may be very difficult because the shoulders may obstruct the x-rays; therefore downward traction of the shoulders may be needed.

Potential complications due to positioning include nerve trauma at the ulnar tunnel, at the carpal tunnel, or in the axillae. In the lower extremities, the most common nerve compression syndromes associated with positioning include femorocutaneous and peroneal nerve palsies. The orbits should also be free of any external compression.

**Authors’ Surgical Technique**

**Anterior Cervical Decompression and Fusion (ACDF)**

The anterior exposure to the cervical spine has been widely used since its original description in 1958. As described, this approach is useful for single- or multiple-level discectomy and cervical corpectomy. The removal of a vertebral body is useful in trauma where the thecal sac is invaded by a fragmented vertebral body or as an alternative to multiple-level discectomy and interbody fusions, where the pseudarthrosis (nonunion) rate increases in proportion to the number of levels of attempted fusion.

Magnification is recommended, and the skin is incised horizontally, starting from the midline and extending laterally. The surface landmarks for the incision are the hyoid at C3, the thyroid cartilage at C4–C5, and the cricoid cartilage at C6. A longitudinal incision following the anteromedial border of the sternocleidomastoid muscle is indicated for the treatment of multilevel surgery, as for two or more vertebrae. With a properly placed horizontal incision, up to three discectomies may be performed. If multiple corpectomies are planned, a longitudinal incision is preferred.

Following incision, the platysma muscle is divided longitudinally, strap and sternocleidomastoid muscles are identified, and the superficial layer of fascia is divided (Fig. 14-3). The pretracheal fascia is exposed, and the strap muscles are divided longitudinally to identify the medial border of the carotid sheath. The omohyoid muscle may be transected if more extensive exposure is required. The strap muscles, trachea, and esophagus are retracted medially, and the prevertebral fascia is exposed. A needle is used to mark the appropriate disk space, and AP and lateral fluoroscopy is used to confirm the appropriate level, and the midline.

Once the appropriate disk space is confirmed, the prevertebral fascia and longi colli muscles are dissected and Cloward-type retractor blades are placed with the distal lips lying deep in these muscles. All static retractors cause pressure on the soft tissues, including the airway, carotid artery, and internal jugular vein; this pressure should therefore be relieved at regular intervals. It may be advantageous to reduce the endotracheal cuff pressure to avoid mucosal ischemia.
The disk is then removed, as are anterior osteophytes. To visualize the posterior annulus and spinal canal, the vertebrae are distracted with a Cloward distractor or Caspar spreader. Microsurgical curettes, Kerrison rongeurs, and a nerve hook are used to complete the diskectomy and examine the spinal canal for evidence of any compressing elements. If disk material is suspected to be lying posterior to the posterior longitudinal ligament (PLL), this is removed, avoiding pressure on the dura. Free disk fragments are removed with a pituitary rongeur.

After decompression, arthrodesis is done by positioning a graft between the endplates. The distractor system is removed, and fluoroscopy is used to confirm correct placement. A low-profile titanium plate may also be added for increased stability (Fig. 14-4).

If two adjacent disks have been removed, a Leksell rongeur is used to create a trough in the vertebral body. The remainder of the vertebral body is then burred down to the posterior cortex, which is finally removed with curettes and a Kerrison rongeur. The lateral margins of the corpectomy must always be limited to the projection of the uncovertebral processes in order to protect the vertebral arteries.

The muscles are repositioned and the platysma and subcutaneous tissue layer and skin sutured. The patient’s neck is stabilized with a cervical orthosis.

**Posterior Cervical Decompression and Fusion**

After prone positioning of the patient and surgical preparation, a vertical incision is made from the superior occipital protuberance to the prominent spinous process of C7. Epinephrine (1:500,000) may be used to help with hemostasis. After dissection of the subcutaneous tissue layer, the trapezius fascia and paraspinal muscles are dissected from the tip of the spinous processes, extending laterally to the lateral aspect of the articular processes. Dissection beyond the facet joints or articular processes may result in denervation of the muscles and may also threaten the vertebral artery. Intraoperative x-rays or fluoroscopy are used to confirm the correct anatomic site. Decompression procedures—including foraminotomy, laminectomy, and laminoplasty—are carried out through this exposure (Fig. 14-5). In laminoplasty, the posterior arch is hinged open to increase the AP diameter of the spinal canal, thus maintaining the integrity of the posterior tension band. Laminectomy also allows decompression of the thecal sac, but this may compromise the stability of the spine. Foraminotomy allows access to decompress a single nerve root without compromising spinal stability.
Screws may be placed into the lateral articular processes. The technique described by Magerl is the most popular owing to its many biomechanical advantages and because it protects the neurovascular structures, though not completely. This is so especially during drilling, which is targeted cranially from 30 to 40 degrees, following the direction of the superior articular surface and laterally 25 to 30 degrees to avoid the vertebral artery. The screws are connected to plates or rods, providing rigid fixation of the segments with disordered motion.

The articular surfaces and the lateral processes are prepared for arthrodesis with a high-speed burr so as to provide decorticated bone for bone graft only. Finally, the wound is closed in three layers and a cervical orthosis applied.

Occipitocervical Fusion
With the patient in the prone position, a midline incision is made from the caudal aspect of the occiput to the C3 spinous process. The deep dissection is kept as close to the midline as possible, although the median raphe or ligamentum nuchae may follow a tortuous course, making it difficult to remain in an avascular plane for the dissection. The ligamentous attachments of the C2 spinous process are identified and subperiosteally elevated. The exposure extends no further than the medial one-third of the facet joint between C2 and C3. The midline of the occiput is exposed subperiostially. The posterior tubercle of C1 is palpated and subperiosteal dissection performed. Excessive pressure on the posterior arch of C1 can cause accidental penetration of the atlantooccipital membrane, which may injure underlying structures. The dura can be especially vulnerable in cases of C1–C2 instability. The vertebral artery and vein are vulnerable beyond a point 15 mm from the midline as the artery courses from a slightly posterior foramen transversarium of C1 in a posteromedial direction to enter the foramen magnum, just cephalad of the ring of C1. If the atlantooccipital membrane is accidentally penetrated proximally to the superior border of the ring of C1, the vertebral artery lies more medial, where it may be vulnerable. Arterial bleeding in this location may have disastrous consequences. Additional care must be taken when these structures are being dissected in rotatory dislocations of C1–C2, because the vertebral artery is stretched across the joint where C1 is dislocated anteriorly.

After dissection, instrumentation is started by inserting 4.5- to 5.25-mm screws into each side of the occiput, avoiding penetration of the skull. Cerebrospinal fluid (CSF) may leak, but this stops once the screw is placed. Ideally, three screws per side are placed.

Transarticular C1–C2 screws are then placed starting at the midline of the caudal aspect of the inferior facet of C2, aiming toward the lateral mass of C1 through the C1–C2 joint. This procedure is fluoroscopically guided and provides reliable fixation of this joint. Additionally, a sublaminar wire loop is passed under the posterior arch of C1 and anchored under the spinous process of C2. The free ends are used to hold an H-shaped bicortical autograft from the base of the occiput to the posterior arch of C2. The wires are tied, firmly fixing the graft, and the transarticular screws are connected through a rod to the occipital screws. The wound is then closed in three layers and a cervicothoracic orthosis (CTO) is applied.

Anesthetic Considerations

Spinal Cord Monitoring
Spinal cord monitoring is widely used during cervical and thoracic spinal procedures. Intraoperative neurophysiologic monitoring of the spinal cord has proven beneficial in minimizing the risks of neural injury during surgery.

The Wakeup Test
Traditionally, the wakeup test (WUT) has been considered the “gold standard” that provides a “snapshot” of the neurologic situation. This test is performed after instrumentation, decompression, and correction of the deformity have been completed. It consists of decreasing the anesthesia, typically by administering an infusion of remifentanil or alfentanil with propofol or inhalational anesthesia to the point where the patient is able to follow verbal commands. The patient must be fully reversed from any neuromuscular blocking agents and is first asked to squeeze the anesthesiologist’s hand to indicate his or her ability to respond and then to move the feet and toes. If hand movement occurs but foot movement does not, the surgeon will undo corrective procedures or remove implants invading the spinal canal in order to reassess the situation. Removal or modification of instrumentation within 3 h after the onset of a neurologic deficit may significantly decrease permanent damage. Spinal cord perfusion and oxygenation must be optimized. High doses of steroids can be used to prevent the progression of secondary injury to the spinal cord, but this is controversial.

Because inhalational anesthetics make timing of the wakeup test very difficult, opioids like remifentanil with nitrous oxide and propofol or ketamine are anesthetic agents of choice. Risks involved with the wakeup test include accidental extubation, dislodgment of instrumentation, injury, bronchospasm, recall of intraoperative events, and psychological trauma, air embolism, and cardiac ischemia. Success and safety are therefore very dependent on informing the patient properly beforehand. Midazolam is also helpful in causing anterograde amnesia.

Somatosensory Evoked Potentials
Somatosensory evoked potentials (SSEPs) allow for continuous assessment of spinal cord function, primarily the
function of the sensory system. The negative predictive value of SSEPs is reported to be 99.93 percent, and this assessment is started immediately after the induction of anesthesia. A peripheral nerve, usually the posterior tibial nerve at the ankle, is stimulated, and cortical potentials are recorded with surface electrodes. Early positive potentials after stimulation are recorded at 31 ms (P31), followed by a small negative potential at 35 ms (N35) and subsequent sizable positive potentials at 40 ms (P40). The P31 potential arises from the brainstem and is more consistent and resistant to anesthetic agents than P40, which is a cortical response. An increase in latency and decrease in amplitude may be observed at clinically used concentrations of inhalation anesthetic agents. This decreases the specificity and sensitivity of the monitoring. This false-positive response is dose-dependent. It has been determined that 0.5 MAC of halothane or 1.0 MAC of isoflurane, sevoflurane, or enflurane combined with 50% nitrous oxide will provide adequate sensitivity and specificity of the monitoring. Data for desflurane are not available. Additionally, stable spinal cord blood flow and oxygenation provide more consistent responses. This requires normal temperature and blood pressure as well as optimal oxygenation, hematocrit, and glucose.

**Motor Evoked Potentials**

Motor evoked potentials (MEPs) are motor responses of the limb muscles obtained by transcranial electrical stimulation or by magnetic pulse stimulation of the motor cortex. A brief muscle response is recorded in the lower extremities. This tests the pathways of the motor neurons. Transcranial electrical stimulation requires the application of high voltage and may be painful to the conscious patient. Magnetic stimulation is not painful but requires a sizable coil and cable that is extremely sensitive to positional changes, making its use during surgery impractical. Electrical stimulation thus seems more practical for intraoperative monitoring. MEPs are also very sensitive to anesthetic agents. Halogenated inhalational agents must be avoided. Nitrous oxide also interferes with MEP recordings and may be used as an adjunct to propofol anesthesia with a concentration below 50%. Neuromuscular blockade makes this type of monitoring of spinal cord function impossible, but neuromuscular blockade to one to two Twitches of the train-of-four nerve stimulator monitor may be permissible. It is important to discuss the problem with neurophysiologists before neuromuscular blocking agents are used.

**Postoperative Analgesia**

Anterior cervical exposure requires little dissection; tissue disruption and postoperative pain are therefore limited and little analgesia is required. Most commonly, the pharynx and larynx are edematous and inflamed, causing dysphagia. This requires alimentation with cool fluids as well as mashed and semisolid foods until symptoms subside. If bone was removed from the iliac crest for grafting, this commonly becomes the main source of pain.

Pain following posterior cervical exposure requires more analgesia because tissue disruption is greater than with anterior exposure. The patient with spinal cord injury also suffers from pain at the operative site and may also have other complex regional pain or neuropathic pain syndromes that necessitate intensive management.

**Associated Medication**

Antibiotic prophylaxis is similar to that in other musculoskeletal procedures where implants are used. Modern guidelines for using prophylactic antibiotics are outlined in Chap. 4.

A further consideration is the use of steroids. A patient admitted with a spinal cord injury will have received high-dose steroid therapy. This usually includes 30 mg/kg of methylprednisolone (Solu-Medrol) as a bolus diluted in normal saline and infused over 30 min. Thirty minutes after this bolus has been completed, a continuous infusion of methylprednisolone at 5.4 mg/kg/h is initiated for 24 or 48 h. Although this protocol is currently considered the standard of care in most emergency department settings, its use remains a matter of controversy. Not only has its usefulness been questioned but it has also been pointed out that high-dose steroids may increase perioperative morbidity, particularly surgical-site infection, pneumonia, and gastrointestinal hemorrhage. Finally, existing studies lack control for surgical interventions, stratification of the patient population, and the use of summed motor scores and functional assessment of improvement in motor function. Mortality after hospitalization for spinal cord injury currently reaches approximately 7 percent in the first year; this is attributed mainly to multiple trauma and respiratory and infectious complications. Mortality is directly proportional to the level of injury and the patient’s age. Although not proved by evidence in the clinical literature, the timing of surgical intervention may be a key factor determining neurologic outcome. There is wide support for early surgical intervention and early rehabilitation. Improved nursing care and attempts to reduce systemic complications seem to be among the most important factors that reduce mortality and improve neurologic outcome.

**Physical Therapy Goals and Requirements in the Postoperative Period**

Reconstruction procedures of the cervical spine often provide enough stability to allow the patient to begin rehabilitation. If there is doubt about stability or bone quality, a
cervical orthosis must be used to protect the bone-implant interface. Upper extremity loading is restricted until fusion is achieved. Exposure to potential trauma is also avoided, including participating in sport—especially contact sport, use of all-terrain vehicles, horseback riding, etc.

For patients with anterior cervical decompression and fusion, out-of-bed activities are encouraged on the day of surgery, and patients are usually discharged from the hospital after 1 or 2 days. Generally one or two visits by the physical therapist and occupational therapist are sufficient to provide instructions on care and independence in daily activities. Patients subject to more extensive posterior procedures may require an additional day of hospitalization for pain control.

In cases of spinal cord injury, the reconstruction of the spine should be stable enough to allow for all rehabilitation procedures, including pulmonary rehabilitation, orthostatic rehabilitation, the acquisition of transfer skills, and self-care.

**Special Intra- and Postoperative Surgical Requirements**

**The Unstable Cervical Spine**

There is currently no consensus on the definition of clinical instability of the spine. It has been defined as the loss of the capacity of the spine to support physiologic loads while still maintaining a harmonious relationship between the vertebrae in such a way that there is neither initial nor subsequent damage to the spinal cord or the development of incapacitating deformity or pain. A checklist that facilitates its clinical application has also accompanied this definition. The checklist also includes images that reveal destruction of the bony architecture, the presence of neural deficit, anticipated dangerous loading, spinal canal narrowing, and static/dynamic (flexion-extension) radiographic signs ($\geq 3.5$ mm of subluxation or more than 11 degrees of focal kyphosis). For the patient who undergoes general anesthesia, the most important predictor of paralysis is the space available for the cord (SAC). The SAC is the distance between the posterior cortex of the vertebral body and the spinolaminar line. In a cohort of 49 patients with rheumatoid arthritis who underwent joint arthroplasty, almost 50 percent presented criteria for instability with subaxial subluxation of the cervical spine $\geq 3$ mm; nevertheless, only 8 percent presented with SAC $\leq 13$ mm.

At the level of the atlantoaxial complex, the SAC is significantly greater than that in the subaxial cervical spine. The “rule of thirds” describes the relationship between the dens and the spinal cord inside the ring of the atlas. The dens and the thecal sac occupy one-third each, leaving a safety margin of a third of the anteroposterior diameter of the spinal canal. The relationship between C1 and C2 is maintained by its lateral masses and by the transverse ligament of the atlas. If the distance between the anterior margin of the dens and the posterior margin of the ring of the atlas (atlanto-dens interval) exceeds 4 mm, then most likely the transverse ligament is incompetent. Nevertheless, a SAC $\leq 13$ mm is a major clinical predictor of spinal cord injury. The posterior atlanto-dens interval (PADI) represents the SAC at the level of the atlas and has a negative predictive value of 94 percent for the development of paralysis if the measurement exceeds 14 mm. The PADI is especially useful in determining risks for chronic atlantoaxial instability, such as rheumatoid arthritis and Down’s syndrome. Other conditions include the presence of a hypoplastic dens, os odontoideum, rheumatoid arthritis, or a pseudoarthrosis of the dens.

In cases of cervical instability, the unconscious patient is at particular risk. Fiberoptic endoscopically assisted intubation of the patient is preferable. The patient is turned and transferred to the operating table with a rigid cervical orthosis in position. Sometimes surgeons prefer to place the patient in the prone position before general anesthesia is induced. This allows for neurologic assessment after positioning. Common causes of cervical instability include trauma and destructive lesions caused by infection or malignant tumor growth.

**Cervical Stenosis**

The patient with a narrowed cervical spinal canal may be at particular risk of developing central cord syndrome if the neck is extended. The normal sagittal diameter of the spinal canal in the subaxial cervical spine is approximately 17 to 18 mm in healthy people, and the spinal cord diameter is approximately 10 mm in this same region. Cervical stenosis is defined as an anteroposterior spinal canal diameter $\leq 13$ mm by a Torg (Pavlov) ratio of less than 0.8. This ratio is the size of the spinal canal relative to the anteroposterior dimensions of the vertebral body. A Torg ratio of less than 80 percent represents a risk factor for the development of myelopathy in patients with cervical spondylosis.

The dimensions of the spinal canal change with flexion-extension movements. When the neck is extended, the spinal cord may be compressed between the posterior vertebral bodies’ osteophytes projecting from the posterior lip of the inferior endplate and the superior border of the lamina of the vertebra immediately below, resulting in a central cord syndrome. Flexion, on the other hand, results in tension forces on the spinal cord, and concomitant compression of the ventral spinal cord against endplate osteophytes and disk material. Furthermore, during extension, the cervical cord shortens and its cross-sectional area increases. Simultaneously, the ligamentum flavum bulges inward to further reduce the SAC and compress the spinal cord. Neck extension poses the greatest risk of cord injury because the SAC is narrowed with simultaneous
expansion of the cervical cord. Neutral alignment of the neck must thus be maintained at all times, since that position provides the largest SAC.

Patients with a significant risk of spinal cord compression and ischemia, due either to traumatic instability or stenosis, should be stabilized before anesthesia induction. This is possible only for anterior cervical exposure with the patient supine. Fiberoptic assisted intubation in awake patients is mandatory to prevent manipulation of the neck. When awake, the patient is able to provide feedback, and continuous neurologic assessment is possible. If anesthesia must be induced before positioning the patient, as for posterior cervical exposure, it is important to position the patient with a rigid cervical orthosis constantly in place.

**Complications**

**Neurologic Injury**

Injury to the spinal cord is probably the most feared complication associated with spinal procedures. The Cervical Spine Research Society has surveyed 5356 cases and has reported an incidence of 1.04 percent neurologic complications, with 0.2 to 0.4 percent of these being spinal cord injuries. The figure was lower for anterior procedures than for posterior procedures. Intraoperative management as well as the principles of prevention have been described earlier.

**Vascular Complications**

Although ACDF involves minimal blood loss, the approach involves displacing the carotid sheath and all its contents. Although injury to the carotid artery is extremely rare, bradycardia may result from a vasovagal response caused by retraction of the carotid sheath. Other structures that may bleed during and after surgery are the thyroid vessels as well as the superficial jugular vein.

Vertebral artery laceration is rare, with a reported incidence of 0.5 percent. These injuries usually occur during cervical corpectomy. Anatomic variants of the trajectory of this artery and excessive lateral resection of the vertebral body are the key factors. The vertebral artery is approximately 5 mm from where a decompression is performed at the C6 level and is situated in the posterior quarter of the vertebral body, allowing a very narrow margin of safety when the lateral nerve roots are being decompressed.

Control of bleeding from vertebral artery laceration is difficult. Ligation may result in cerebellar infarction with cranial nerve palsies, transient dysphagia and dysarthria, persistent posterior fossa circulatory insufficiency, vocal cord paralysis, and quadriplegia. A report on 100 patients with vertebral artery ligation gave a mortality of 12 percent, secondary to brainstem ischemia.

**Postoperative Visual Loss**

This devastating complication of spinal surgery has frequently been reported in the literature on anesthesia in orthopedics and neurosurgery with an incidence of approximately 0.2 percent. In an attempt to identify risk factors and preventive measures, the American Society of Anesthesiologists developed the “postoperative visual loss (POVL) registry” in June 1999 and had registered 79 cases by the end of summer 2003. Although this does not represent the true occurrence of this problem, this registry revealed some interesting facts. First, ischemic optic neuropathy (ION) was by far the most common cause of visual loss. Second, the most common procedures associated with POVL were spine surgery (54 percent) followed by cardiac surgery (10 percent). Third, most of the spinal cases involved prolonged prone positioning (median 8 h) and large blood losses (median 2.3 L). Age does not seem to matter. Some cases occurred in young, healthy patients with 3 h prone time and minimal blood loss. Nevertheless, the incidence does seem to increase dramatically for prone times ≥ 25 h. Venous congestion may be important, in association with hypotension and anemia.

Finally, of the spine surgery cases in the prone position that developed POVL, 77 percent had their heads positioned with a foam support and 18 percent with Mayfield tongs.

**Other Complications**

Horner’s syndrome may occur because of an injury to the cervical sympathetic plexus. This plexus lies within the longi colli muscles and can be injured by dissection or excessive pressure from a retractor blade. The syndrome may be temporary or permanent.

The recurrent laryngeal nerve may be damaged, causing hoarseness and vocal cord paralysis. The hoarseness is usually temporary, but cases have been reported in which the vocal cords were permanently paralyzed. Care must be taken when considering a second procedure with contralateral exposure. Visual inspection of the vocal cords is recommended before surgical intervention.

Laceration of the dura is uncommon during cervical spinal surgery. If it does occur, repair should be attempted. Possible complications include dural-cutaneous fistula, secondary Arnold-Chiari phenomenon, and cranial nerve dysfunction. The thecal sac may be lacerated as a result of a traumatic injury or may be damaged during ossification of posterior longitudinal ligament (OPLL) surgery.

Postoperative dysphagia is a common yet underreported problem, which may last up to a year. This complication has been reported in up to 50 percent of patients 1 month after surgery and in 12 percent of patients after 1 year. The dysphagia is commonly mechanical but may also be accompanied by odynophagia, breathing difficulties in 18 percent, and pneumonia.
during the early postoperative period. Patients with gastroesophageal reflux disorder are more likely to experience breathing difficulties in the postoperative period. The etiology of dysphagia is not completely understood. During the procedure, inadvertent perforation of the esophagus may occur. This is a very serious complication, including the development of osteomyelitis, abscess formation, and mediastinitis. The incidence of this complication has been reported to be between 0.2 and 0.9 percent of all anterior cervical exposures, and one-third of these injuries occur during surgery. Promuding graft, hardware, or cement, which may erode the esophagus in the postoperative period, accounts for the other two-thirds. Early recognition and immediate management are vitally important.

In the postoperative period, the most urgent complication is acute respiratory distress due to cervical hematoma. Careful intraoperative hemostasis as well as a postoperative drain deep to the aponeurosis help to prevent this problem. Immediate treatment includes orotracheal intubation. A cricothyroidotomy may be lifesaving, along with immediate drainage of the hematoma. If the patient has been subjected to prolonged surgery, especially in the prone position, edema may develop around the neck and compromise the upper airway. Steroid therapy may be useful in coping with this complication.

Finally, although extremely uncommon, a hematoma of the spinal canal may develop. This will lead to progressive neurologic deterioration. This situation also requires immediate exploration. The diagnosis is confirmed by magnetic resonance imaging (MRI) or computed tomography (CT) myelography.

► THE THORACIC SPINE

Indications and Special Anatomic Considerations

The thoracic spine provides structural support, limited motion, and protection of the neural elements. The stability and rigidity of this part of the spine partially depends on its relationship with the rib cage through the costovertebral and costotransverse joints. Injury to the heads of the ribs is an indirect sign of significant torsional stress on the spine and must not be overlooked. In addition, the close relationship with the mediastinum and lungs must warn of potential injuries to these structures, especially when there is evidence of translational or shearing forces that have acted on the thoracic spine.

Posterior surgery to the thoracic spine includes that for the correction of deformities, stabilization after trauma or tumor resection, and decompression of the thoracic spinal cord. Anterior surgery is most commonly undertaken for decompression of the thoracic spinal cord from trauma, tumor, infection, or degenerative pathology such as thoracic disk herniation. Anterior surgery also plays an increasing role in the correction of deformities, alone or combined with a posterior procedure. More detail on the correction of deformities in the pediatric population is given in Chap. 14.

Patient Profile

The patient profile ranges from the healthy young adult with a deformity or a herniated disk to the chronically ill patient with an infection or tumor.

It must be always kept in mind that the enormous energy required to injure the thoracic spine may have damaged other organs or systems. With lung contusions, prone positioning of the patient may potentially disrupt pulmonary blood flow and cause ventilation/perfusion mismatch.

Similar considerations apply to patients with spinal cord injury, such as those described in the discussion of the cervical spine, above. In thoracolumbar trauma, the patient with paralysis is even more likely to have occult abdominal or thoracic trauma, which must be thoroughly evaluated.

Common Comorbidities

For the anterior exposure to the thoracic or thoracolumbar spine, a thoracotomy is required. This exposure significantly decreases the values of pulmonary function tests (PFTs) for up to 2 years. Patients with previous lung disease must be carefully evaluated, and planning for the postoperative period is mandatory. Ventilatory assistance may be required after surgery. In patients with injuries to the thoracolumbar spine, pulmonary contusion may be relevant in deciding on the timing and laterality of the surgical exposure. Spinal instability will not allow adequate mobilization of the patient, and it may be impossible to achieve adequate pulmonary function. Gas exchange can be further compromised by single-lung ventilation during spinal surgery, and the surgical team must decide whether the patient will be able to tolerate one-lung ventilation for several hours.

Positioning on the Operating Table

Posterior Approach to the Thoracic Spine

This exposure requires prone positioning. Most surgeons prefer to use a four- or five-post frame. The face is positioned on contoured foam, taking care to prevent pressure and congestion around the eyes. Some devices with a mirror allow continuous observation of orotracheal tube placement. Care should also be taken to avoid compression of the abdomen, since this increases venous congestion and intraoperative bleeding from venous epidural sinuses. Decompression of the abdomen and inferior vena cava reduces epidural blood flow, which allows better visualization of structures in
the spinal canal. If the fusion is carried into the lumbar spine, preservation of the sagittal alignment is essential. This is further discussed below, under positioning for lumbosacral fusion exposures.

The superior posts should be positioned under the patient’s rib cage, while the inferior posts should be positioned underneath the anterior iliac spine. For heavier patients, a transverse post across the superior chest, two posts on the inferior rib cage, and two posts on the iliac crests are used. The legs are supported with pillows. Care should be taken to prevent excessive pressure on the breasts in female patients.

The arms are positioned with 90 degrees or more of flexion of the elbows and 90 degrees or less abduction of the shoulders. The arms rest on well-padded boards, and special care is taken to avoid pressure on the ulnar grooves and the wrists. The axillae must also be protected against compression.

Prone positioning checklist:
No pressure on eyes to ensure normal retinal blood flow
Endotracheal tube unobstructed
Head not lower than heart to prevent cerebral congestion and decreased cerebral blood flow
Neck not extended but neutral
Abdomen free to prevent venous congestion, increased bleeding, and epidural venous congestion
Breasts not compressed
Male genitals free and not compressed
Urinary catheter free and not compressed or obstructed
Legs supported; femoral nerves free from compression
Shoulders abducted 90 degrees or less
Elbows flexed 90 degrees or less
Ulnar nerves free and not compressed
Median nerves at wrists free of compression; wrists neutral
Ventilation bilateral and normal
Intravenous and arterial lines free and unobstructed

**Anterolateral Approach to the Thoracic Spine**
This exposure requires lateral positioning, usually on the patient’s right side. The left-sided exposure is the most convenient, especially for the lower thoracic spine and thoracolumbar junction. Retracting the right hemidiaphragm may be difficult. The spleen is smaller and therefore easier to retract than the liver. In addition, the vena cava (on the right side) can be lacerated more easily than the aorta. Because of its pulsation, the aorta is easier to locate on the left side (Fig. 14-6). This is especially important when resection includes soft tissue mass extension from tumor or infection. Nevertheless, there are conditions when a left-sided exposure will not be convenient, as in the correction of scoliosis with a right-sided curve. If the operation involves the upper thoracic spine (T1–T4), it is convenient to approach the spine from the right side so as to avoid the aortic arch. If the vertebral bodies are small, as in small people, spinal implants may be relatively prominent and the aortic wall may be eroded by the pulsations of the artery against them. The right arm is abducted and flexed as far cephalad as possible to allow mobilization of the scapula anteriorly and superiorly. Since left-sided exposures are more frequent, the following description considers the patient lying on his or her right side.

Figure 14-6. Left-sided thoracotomy exposure. The lung has been retracted anteriorly, and the dome of the left hemidiaphragm is observed.
padding. Foam padding is also placed underneath the right leg from the hip down to the foot. The head is supported with pillows or foam, maintaining neutral alignment of the neck. The trunk is supported on the sternum and the back by padded supporting attachments or by a beanbag. The pelvis is supported by adhesive tape or straps over the left greater trochanter, which is always protected by foam padding. In procedures involving decompression of the spinal canal or instrumentation of the spine, stable positioning is important for surgical orientation and intraoperative imaging. The right arm is supported by a foam-padded arm board with the shoulder at 90 degrees of extension and the left is extended on top of this, separated by pillows or other soft padding. Special supporting devices for the upper arm are available. Some surgeons prefer to flex the table at the patient’s waist in order to increase the space between the ribs. Tilting the table into a reverse Trendelenburg position facilitates retraction of the hemidiaphragm by displacing the abdominal viscera caudally. This position also facilitates venous drainage and decreases surgical bleeding from the epidural venous sinuses or obstruction of vision by them.

Authors’ Surgical Technique

Posterior Spinal Fusion and Instrumentation

After a standard midline incision of the skin and subcutaneous tissues, the thoracic fascia and paraspinal musculature are dissected in a subperiosteal manner with a bovie cautery and a Cobb elevator. After the skin incision, 1:500,000 epinephrine may be used to provide hemostasis. Stripping of the muscles subperiosteally prevents muscle tearing and excessive bleeding. Self-retaining retractors are inserted, and tissue ischemia is avoided by intermittently decreasing the pressure. The facet joint capsules are stripped and the cartilage removed with the use of a high-speed burr and curettes. Care is taken to avoid injury to the facet joints that are not to be included in the fusion. Intraoperative x-ray or fluoroscopy is convenient at this point to confirm the levels to be operated on. To prepare the spine for fusion, the transverse processes and laminae are also decorticated with the use of a high-speed burr.

Instrumentation consists of sublaminar hooks, pedicle screws, and rods. Hooks are placed either facing in a caudal direction and anchored over the superior border of the lamina or facing in a cephalad direction and anchored under the inferior border of the lamina. To place each hook, the ligamentum flavum is removed from its attachment with a curette; once the spinal canal is visualized, a Kerrison rongeur is used to square off the anchoring point on the lamina. Hooks of different sizes and angulations are available and are determined by the orientation and dimensions of the lamina and spinal canal. The hooks will occupy a portion of the posterior spinal canal. The number of hooks and the pattern of placement are planned before surgery and depend on the corrective maneuvers that are deemed necessary. Once all hooks have been positioned, they are connected with rods, and compression or distraction forces are applied as appropriate. These forces may significantly modify the contours and dimensions of the spinal canal.

The bone graft is placed laterally, over the decorticated transverse process and along the lateral aspect of the lamina and decorticated pars interarticularis region as well as on the facet joints. Finally, the wound is closed in three layers.

Thoracoabdominal Approach for Corpectomy and Reconstruction

Injuries to the thoracolumbar spine frequently occur at the thoracolumbar junction (T10–L2). Corpectomies of these transitional segments or instrumentation for deformity correction requires thoracoabdominal exposure. This starts with a skin incision placed over the 10th rib (Fig. 14-7). If the approach involves higher levels, the rib chosen is at the level of the affected vertebral body or one level higher. For the upper thoracic spine (T1–T4),
the arm is placed as far cephalad as possible so as to mobilize the scapula anteriorly and superiorly.

The musculature is divided in line with the rib and includes the latissimus dorsi and external oblique (Fig. 14-8). The rib is dissected subperiosteally and is cut from the costochondral junction anteriorly and as far posterior as possible. After removal of the rib, the abdominal muscles are transected with a bovie cautery, in line with the skin incision. The posterior aspect of the approach should not reach the midline. The costochondral cartilage is divided longitudinally, exposing the retroperitoneal space.

The peritoneum is dissected bluntly from the abdominal wall and from the undersurface of the diaphragm and forced distally toward the side opposing the approach. The chest cavity is opened along the rib bed by longitudinal division of the parietal pleura. Wet laparotomy sponges are placed on the borders of the thoracotomy, and a rib spreader is placed to allow for better visualization. The lung is retracted with a sponge-covered malleable (Fig. 14-6). At this point, the spine is identified and the posterior parietal pleura are incised in line with the midline of the vertebral bodies. Dissection is started over the intervertebral disks because they are easy to identify. Next, the segmental vessels are identified in the midline of the vertebral bodies. These vessels are elevated with a dissector and ligated or clipped and successively cut. If these vessels are cut too near the aorta, there is a risk of bleeding from an orifice in the aorta. On the other hand, if they are cut too near the foraminae, blood flow to the spinal cord may be compromised. The midthoracic spinal cord has the least abundant blood supply and the narrowest bony confines. The anterior spinal artery is smaller in diameter and in 85 percent of the cases depends mainly on a single accompanying radiculomedullary artery that arises somewhere from T9 through L2 (artery of Adamkiewicz). The segmental arteries contribute to the anterior medullary artery through the anterior radicular branch. Collateral circulation is usually present in close proximity to the foramen and includes anastomoses at the same foraminial level distal to the ligated segmental artery or by radicular arteries originating from adjacent segmental vessels. This critical zone of the spinal cord may predispose the patient to an ischemic insult to the cord after ligation of the segmental vessels, especially if cut too short from these anastomoses. Some surgeons favor temporary ligation and evaluation of the SSEPs. In our experience, ligation of the segmental vessels in the midportion of the vertebral body has proven to be a safe procedure. After ligation, the mediastinal structures are easily displaced and a malleable retractor is placed for protection during the procedure.

The diaphragm can be circumferentially transected approximately 2 cm from the chest wall insertion. If it is sectioned too peripherally, reconstruction may be very difficult; if too medially, hemostasis may be difficult and the phrenic innervation may be compromised. Different or alternate colored marking sutures are placed, which will enable appropriate reconstruction at the end of the procedure. If the dissection continues distally into the upper lumbar spine, the psoas muscle should be cautiously dissected off the anterior surface of the lumbar vertebral bodies, or the lumbar plexus may be injured.

For the upper thoracic spine, the skin incision surrounds the inferior and medial aspects of the scapular wing. The trapezius muscle is dissected along the skin incision, and latissimus dorsi muscles are dissected as far caudally as possible. When the rib cage is encountered, the dissection continues as described above.

When the exposure has been completed, the intervertebral disks are excised, starting with an incision in the annulus fibrosus. The nucleus pulposus is removed with curettes and pituitary rongeurs. If anterior release is necessary for mobilization of the spine, the annulus and the anterior longitudinal ligament must be circumferentially excised. Angled curettes and Kerrison rongeurs are used for this purpose. The surgeon's fingertips should be able to circumferentially palpate the disk, including the contralateral side of the exposure. A small portion of the posterior annulus and posterior longitudinal ligament are left intact. After the discectomy has been completed, endplates are freed of all cartilage with ring curettes to prepare them for fusion.

If the purpose of discectomy is that of spinal canal decompression, the rib head is removed by the use of...
osteotomes and a Kerrison rongeur, allowing access to and view of the spinal canal. Extruded disk material may be removed by this route. If the purpose of the surgery is a corpectomy to decompress the spinal canal from bone fragments, the ipsilateral pedicle may also be removed, with great caution to protect the emerging segmental nerve. The vertebral body, including the ipsilateral cortex, is excised with osteotomes, a high-speed burr, curettes, and pituitary rongeurs. The anterior and contralateral cortices are preserved for protection of the mediastinal structures. When the vertebral body has been cavitated, the retropulsed bone is removed in a posteroanterior direction, away from the thecal sac. The procedure is completed when the dura is free of all compressing elements.

Finally, for the reconstruction of the spine, an interbody strut graft is measured and placed between the adjacent endplates. A wide variety of materials may be used, including autograft, allograft fibula or humerus, titanium-mesh or carbon-fiber cages, according to the surgeon’s preference. After reconstruction, a titanium plate is secured to the adjacent vertebral bodies with bicortical screws, which are placed under fluoroscopic guidance.

When the decompression and reconstruction of the spine have been completed, the diaphragm is reconstructed with a running, nonabsorbable suture. Incomplete reconstruction of the diaphragm may lead to the development of a hernia. The pleura may be closed with running suture. Many times, due to the presence of the implants, this is not possible. Revision procedures show evidence of complete epithelial coverage 2 weeks after a pleural defect occurs. Some surgeons feel that insistence on sealing a pleural defect may actually carry the mediastinal structures closer to the metallic implants. The chest is thoroughly lavaged and the lungs are allowed to reexpand. Careful inspection for air leakage or injuries to the visceral pleura is carried out. One or two chest tubes are left in the chest cavity, and the chest is closed. First, the ribs are approximated with a nonabsorbable threaded interrupted suture. The intercostal muscles and the parietal pleura are then closed with a running suture and similarly the latissimus dorsi on a separate plane.

**Costotransversectomy Approach**

This is a posterior extrapleural approach that allows access to the lateral aspect of the vertebral bodies (Fig. 14-9). The positioning of the patient is similar to that for posterior spinal fusion. The incision may be in the midline or just lateral to the midline over the costotransverse junction. After dissection of the skin and subcutaneous tissues, the costotransverse joint is approached through the erector spinae muscles. The base of the rib and the transverse process are removed. Great care is taken to avoid disrupting the parietal pleura. If this were likely to occur, the patient would have to be warned that a chest tube might be required in the postoperative period. The spinal canal and the dura are approached by laminectomy and by removal of the ipsilateral pedicle. Great care is taken with the neurovascular bundle exiting caudal to the pedicle. The spinal cord is safely decompressed, with optimal visualization. Compressing elements on the midline, such as a central disk protrusion or OPLL, may not be accessible by this approach. This approach is not suitable for placement of a

![Figure 14-9. Costotransversectomy approach. After resection of the ipsilateral pedicle, the spinal cord may be decompressed through a posterior approach to the thoracic spine.](image-url)
structural interbody graft. The anterolateral approach is preferred for these cases (Fig. 14-10).

**Anesthetic Considerations**

Spinal cord monitoring is preferred for most operations on the thoracic spine. Anesthetic recommendations are similar to those described for cervical spinal procedures.

Measures to prevent iatrogenic spinal cord injury are similar to those described for cervical spinal procedures. In particular, hypotensive anesthesia is to be avoided, especially when the anatomy of the spinal canal is significantly altered or when the thecal sac is manipulated. Similar considerations apply to anterior procedures when the segmental vessels are ligated.

**Blood Loss and the Quality of the Surgical Field**

Bleeding due to surgery to the spine is mainly from venous epidural sinuses. Arterial or capillary bleeding plays no role or a very small role during spinal surgery. It is therefore important to keep the venous pressure as low as possible while still maintaining cardiac filling and cardiac output. It is of no value to decrease the arterial pressure. Furthermore, measures that decrease the cardiac output, and therefore increase the central venous pressure, should be avoided. This includes the popular yet senseless practice of reducing the arterial blood pressure with beta-blocking agents. This will only serve to increase the bleeding from venous sinuses and worsen the surgical field.

Apart from keeping the blood volume optimal and adequately positioning the patient, keeping pressure off the abdomen, venous dilators like trinitroglycerin will further help to decrease bleeding. If the central venous pressure is abnormally high, it may even be necessary to administer small doses of furosemide. A central venous pressure lower than that of the surgical field will cause air to be sucked into the venous system, with resulting air embolism. Although this is rare, it may be the cause of an otherwise inexplicable state of hemodynamic instability. It is therefore essential to monitor the central venous pressure and keep it approximately at the same level as the main surgical activity.

**Analgesia**

When anterior exposure to the thoracic spine is used, intercostal block with 0.25% bupivacaine at the time of closure is recommended. Epidural block above and below the level of surgery provides excellent analgesia, and so does thoracic paravertebral block. These two procedures provide short-term analgesia and help with pulmonary rehabilitation and ventilation. Recovery of ventilatory mechanics is fundamental for functional recovery and in avoiding pulmonary complications. Pain management must be optimized, and we insist on the frequent use of an incentive spirometer.

Patients who do not receive epidural or paravertebral block usually require intravenous morphine or hydromorphone patient-controlled analgesia (PCA) for the first 24 to 36 h. Thereafter they are managed with oral opioids such as oxycodone.

**Associated Medication**

Patients with spinal cord injury may be receiving high doses of steroids. Steroids may also be given when monitoring indicates possible damage to the spinal cord during the operation.

Treatment with prophylactic antibiotics is started 1 h before the operation and repeated every 6 h during the procedure. Thereafter, antibiotics are continued until all indwelling catheters have been removed, including chest tubes and the urinary catheter.
Physical Therapy Goals and Requirements in the Postoperative Period

Patients undergoing surgery for deformity usually have very stable constructs and require very little if any external immobilization. Out-of-bed activities are encouraged, with assistance, on the first day after surgery. These patients can walk or sit on a recliner as tolerated. Age obviously has an enormous influence on the speed of recovery. If there has been any anterior surgery, respiratory therapy is started immediately. This includes use of an incentive spirometer. Upright posture is encouraged because of its benefits for pulmonary toilette. Chest tubes are removed on the second to third days after surgery, and patients with either anterior and/or posterior fusions are discharged within 5 to 7 days. Physical therapy goals include independent walking (may be aided by a walker), transfers, personal hygiene, and some stair steps. If these goals are not met within the first week, patients are transferred to a rehabilitation facility for 2 to 4 weeks, especially elderly patients.

The reconstruction of the spine should be stable enough to allow all necessary rehabilitation procedures, including pulmonary rehabilitation, and the acquisition of transfer skills and self-care.

Special Intra- and Postoperative Surgical Requirements

Lung retraction is probably one of the most important considerations during anterior surgery to the thoracic spine. In open thoracotomy, handheld malleable retractor may collapse the lung sufficiently. Nevertheless, we are increasingly performing anterior operations on the thoracic spine through video-assisted thoracoscopic spinal surgery (VATSS). The exposure is minimal, requiring three or four 15- to 20-mm portals to perform a corpectomy. The success of this procedure depends largely on adequate lung deflation. This is obtained either by use of a double-lumen endotracheal tube or a bronchial blocker. The double-lumen tube tends to be obstructed by mucous plugs due to its smaller diameter. The patient may develop inadequate gas exchange during the procedure, requiring reexpansion of the lung and fiberoptic inspection and lavage of the lumens of the tube. The bronchial blocker also provides adequate lung collapse, but it may require repositioning during the procedure.

Common Problems (Pre-, Intra- and Postoperative)

Vascular Injuries

The proximity of the greater vessels obviously makes a vascular injury possible. In the thoracic spine, most intraoperative problems may be caused by inappropriate handling and ligation of the segmental vessels. Careful dissection and respect for anatomic landmarks is the best way to prevent damage to these vessels.

Spinal Cord Injury

Although it is very uncommon, spinal cord injury is among the most devastating complications of spinal surgery. In a large single-center case series, including adult and pediatric deformity cases, a 0.37 percent incidence of major neurologic complications was reported. All these patients underwent combined anterior and posterior exposure, they all had ligation of segmental vessels, and they were all subject to intraoperative controlled hypotension.

Although most surgeons now prefer to use spinal cord monitoring, some surgeons have described false-negative results. The mechanisms of injury are multifactorial and include those related to the anatomic configuration of the spinal canal, the placement of spinal instrumentation, and adequate perfusion of the spinal cord. The first of these mechanisms is most commonly associated with the correction of deformity and realignment of the spinal canal, while the second may have to do with the space occupied by instrumentation, including laminar hooks or misplaced pedicle screws.

Spinal cord injury may also occur in the immediate postoperative period because of the development of an expanding epidural hematoma. This problem must be addressed immediately and includes surgical evacuation of the hematoma and management of coagulopathies. Patients who have received multiple transfusions and suffer from dilutional decrease in coagulation factors may benefit from transfusion of fresh frozen plasma and platelets. In spite of all immediate efforts, damage may be permanent.

Dural Laceration

This complication may occur as a result of trauma or secondary to aggressive decompression of the thecal sac. In particular, patients with OPPL may have an ossified dura, which may leave a dural defect at the time of removal. In the chest, this creates a particular problem due to the negative intrathoracic pressure. A dural-pleural fistula creates a strong gradient for the leakage of spinal fluid. This gradient may force the spinal cord into the defect and may even produce a herniation of the cord. The patient will then develop further signs and symptoms of myelopathy. The consequences of spinal fluid leakage are discussed in the section on the lumbar spine, below.

Pulmonary Complications

Atelectasis is very common, but aggressive respiratory therapy in the early postoperative period is effective in preventing it. If this is not aggressively done, atelectasis may lead to pneumonia. Other complications include hemothorax, pneumothorax, and chylothorax.
Diaphragmatic rupture and the formation of a hernia are extremely rare complications and may be avoided by proper reconstruction of the divided diaphragm.

**THE LUMBAR SPINE**

**Indications and Special Anatomic Considerations**

In contrast to the rigid thoracic spine, the lumbar spine makes motion of the trunk possible while also providing structural support to approximately 60 percent of the body weight as well as protection to the neural structures. The conus medullaris lies somewhere between the T12–L1 and the L1–L2 disk spaces. The cauda equina floats within the spinal fluid contained by a thecal sac.

The vast majority of degenerative conditions—including disk herniation, spondylolisthesis, and osteoarthritis—occur in the last two or three disk spaces.

**Patient Profile**

An increasing number of elderly people seek surgical care for symptoms of spinal stenosis. This is explained by increase in life expectancy and increased functional demands. Advanced age is accompanied not only by comorbid conditions but also by a decreased physiologic reserve. Attention to detail is important for patient safety and early recovery. Fluid volume management, oxygen transport, perfusion, and metabolic control constitute the most important elements. Continuous evaluation of hemoglobin, gas exchange, and lactic acid are recommended during prolonged surgery.

**Common Comorbidities**

Multiple comorbidities are frequently seen in elderly patients who undergo lumbar decompression with or without fusion. Diabetes, high blood pressure, coronary artery disease, and chronic obstructive pulmonary disease (COPD) are common in this age group.

**Positioning on the Operating Table**

**Posterior Approach to the Lumbar Spine**

The posterior approach requires prone positioning. Patients who do not need fusion, such as microdiscectomy or laminectomy for decompression of a stenotic spine, may be positioned in the semireclined position under the anterior iliac spine. The patient’s back should be parallel to the floor; knees and hips are flexed slightly past 90 degrees. Many surgeons prefer the prone position on a flat table with a Wilson frame. Care must be taken to avoid compression of the abdomen. Decompression of the abdomen and inferior vena cava helps to reduce epidural blood flow, allowing better visualization (see “Blood Loss and the Quality of the Surgical Field,” above). Additionally, if the spine remains in lordosis, the interlaminar space is closed down and an unnecessary amount of laminectomy will be required to expose the disk.

For lumbar fusion procedures, the most important function of positioning is to preserve the sagittal contours of the lumbosacral spine. A radiolucent four-poster frame or similar device is recommended, and padding should be added to maintain the hips fully extended. This position preserves normal lordosis, thus avoiding flat-back deformity. The superior posters should be positioned under the patient’s rib cage and the inferior ones under the anterior iliac spine.

The arms are positioned with 90 degrees of flexion at the elbows and less than 90 degrees of abduction at the shoulders. The arms rest on well-padded arm boards and are taken to avoid pressure on the ulnar grooves and wrists. Care is also taken at the superior posts, which must not exert pressure on the axillae. In women, pressure on the breasts must be minimized. In heavier patients, we prefer a five- or six-post configuration instead of four to allow better distribution of the weight. The male genitals should also be free of pressure. (See “Prone positioning checklist” on page 164.)

**Anterolateral Retroperitoneal Exposure of the Lumbar Spine**

These approaches require lateral positioning. The positioning is similar to that required for the anterior exposure of the thoracic spine and is adequate for anterolateral retroperitoneal exposure of the lumbar spine as well as for transpleural retroperitoneal (thoracoabdominal) exposure of the thoracolumbar junction. The patient is placed in a lateral decubitus position with the side to be operated on facing up. Since left-sided exposures are more frequent, the following description considers the patient to be lying on his or her right side.

The patient is transferred from the preanesthesia cart to the operating table in a supine position and then turned 90 degrees. An axillary roll is placed to prevent circulatory obstruction to the right arm. Our preference is for silicone padding. Foam padding is also placed underneath the right leg from the hip down to the foot. Pressure on the peroneal nerve on the right side must be avoided. The head is supported with pillows or foam, taking care to maintain the alignment of the neck. The chest cage is supported on the sternum and the back by pads and adhesive tape or by a beanbag. The pelvis is supported by adhesive tape over the greater trochanter, which is always protected by foam padding.

In procedures involving decompression of the spinal canal or instrumentation of the spine, stable positioning is essential.
for surgical orientation and intraoperative imaging. Finally, the right arm is supported by a foam-padded arm board with the shoulder at 90 degree extension and the left is extended on top of this, separated by pillows or other soft padding. Some surgeons prefer to break the table at the patient’s waist in order to increase the space between the inferior rib border and the ilium. This is particularly beneficial for the lower lumbar spine.

**Anterior Trans- or Retroperitoneal Exposure of the Lumbar Spine**

The exposure to the two or three lower lumbar segments requires supine positioning with hyperextension of the lumbosacral junction. This is obtained by placing foam padding underneath the lumbar region. The table is then tilted into the Trendelenburg position. This helps to displace the abdominal contents cephalad, facilitating the exposure. Owing to the necessary mobilization of the iliac vessels, some authors recommend pulse oximeters in both the upper and lower extremities.

**Authors’ Surgical Technique**

**Lumbar Microdiscectomy**

The level of the disk to be removed is confirmed with fluoroscopy. A 1-in. midline skin incision is then made (Fig. 14-11). After dissection of the skin and subcutaneous tissues, the dorsal lumbar fascia and paraspinal musculature are dissected in a subperiosteal manner from the tip of the spinous process all the way lateral to the corresponding facet joint. A Taylor retractor is placed lateral to this joint, and the ligamentum flavum is released with a small angled curette from the inferior and superior borders of the adjacent laminae as well as from the medial edge of the superior facet. A Kerrison rongeur is used to remove several millimeters of the cephalad lamina and 2 to 3 mm of the medial border of the inferior facet. The ligamentum flavum is then removed in a piecemeal manner. The medial border of the superior facet is visualized and removed with a Kerrison rongeur. A nerve root retractor is used to displace the dural sac and the emerging nerve root toward the midline of the spinal canal. Epidural veins are usually encountered, and these are coagulated with a bipolar cautery. This allows optimal visualization of the disk and the herniation. The extruded disk fragments are now removed with a pituitary rongeur. If the extrusion is subligamentous, the posterior longitudinal ligament is incised with a knife in a horizontal manner. Following this, the spinal canal is thoroughly explored with a 4-mm Murphy ball-tipped probe to determine whether there are any residual disk fragments or any other compressing elements on the dural sac or emerging nerve root.

This procedure may be carried out under microscopic or loupe magnification. There are certainly advantages to the use of a microscope, but their consideration is beyond the scope of this chapter.

When the procedure is complete, 40 mg of Depo-Medrol is deposited on the interlaminar space and the wound is closed in three layers. After closure, the skin is injected with 0.25% bupivacaine.

**Lumbar Decompression**

Laminectomy has become the standard procedure for surgical decompression in lumbar spinal stenosis. A midline skin incision is made. After dissection of the subcutaneous tissues, the dorsal lumbar fascia and paraspinal musculature are dissected in a subperiosteal manner, from the tip of the spinous processes all the way lateral to the corresponding facet joints (or transverse processes if fusion is going to be done). After thorough hemostasis, the inferior half of the superior spinous process as well as the superior half of the inferior spinous process and all intermediate spinous processes are removed with a rongeur. The laminae are thinned down with a Leksell rongeur or a high-speed burr. A Kerrison rongeur is then used to remove the remainder of the laminae and ligamentum flavum in a caudad-to-cephalad direction (Fig. 14-12A). The dural sac is now centrally decompressed and can be manipulated to allow access to the lateral recesses or subarticular areas of the spinal canal. A partial medial facetectomy is performed by undercutting with a 45-degree Kerrison rongeur all the way lateral to the medial wall of the pedicles (Fig. 14-12B). The nerve roots are identified and followed into the corresponding foramina with an overlying Kerrison rongeur removing all overlying spurs (Fig. 14-12C). A 4-mm Murphy ball-tip probe is used...
Figure 14-12. Lumbar decompression. After posterior exposure of the spine, the spinous process is cut and a curette or small Cobb is used to dissect the ligamentum flavum from the undersurface of the lamina. A. A Kerrison ronguer is used to undercut the hypertrophic facet joints and ligamentum flavum. B. The emerging nerve roots are freed of any compressing elements all the way toward the foramina. C. Completed lumbar decompression.
to determine whether decompression is adequate. Closure is similar to that for microdiscectomy.

**Anterior Lumbar Interbody Fusion**

This procedure is indicated mainly for the caudal lumbar disks, namely L5–S1, L4–L5, and/or L3–L4. The approach to this area of the lumbar spine must allow the surgeon to see the disks facing the midline, and it requires either a retro- or transperitoneal exposure. The first choice should be retroperitoneal exposure, especially in male patients. Our second choice is the transperitoneal exposure, but we prefer it for obese patients, revision exposures, and for patients in whom the abdominal retroperitoneum or pelvis have been exposed previously.

An infraumbilical vertical incision is extended proximally to the pubis. The rectus fascia is opened longitudinally with the incision; the rectus abdominis muscle is then retracted laterally, exposing the posterior rectus fascia. This is done to avoid damage to the segmental (T6–T12) innervation of the rectus. The arcuate line is identified. The preperitoneal space is encountered, and the peritoneum is dissected away from the posterior rectus sheath before incising the sheath. Great care is taken to avoid injury to the inferior epigastric vessels. The exposure continues by dissection of the retroperitoneal space. The peritoneum is mobilized from medial to lateral by gentle digital dissection. Once the psoas muscles are reached, the peritoneal sac is protected with wet laparotomy sponges and retractors are placed. Care must be taken with the ureter on the side of the dissection.

In the transperitoneal approach, the peritoneum is incised in line with the rectus sheath. The bowels are packed cephalad to expose the posterior peritoneum, which is also incised in a longitudinal manner, exposing the great vessels and the lumbar spine.

The next part of the dissection consists of mobilizing the greater vessels to allow for the orthopaedic procedure (Fig. 14-13). The aorta and vena cava usually bifurcate at the height of the L4-L5 intervertebral disk, but higher or lower bifurcations are not infrequent. We recommend a thorough preoperative assessment of the vascular anatomy with MR angiography (MRA) as well as planning the direction in which the greater vessels are to be mobilized. The parasympathetic plexus (hypogastric) is distributed as a diffuse plexus that courses around the aorta and head distal from the bifurcation in the presacral area. Great care is taken in protecting this plexus, so as to avoid the complication of retrograde ejaculation. The middle sacral artery and/or lower segmental vessels and ascending lumbar vein are ligated at the level and side of mobilization. The psoas muscles mark the lateral limits of the dissection. The ureters may occasionally be visible and must be retracted with the peritoneum.

The lower lumbar disks should be directly visible at this point. Retractor blades are then placed on a table-mounted retractor system, including vascular retractors. Some systems anchor with pins into the vertebral bodies. The orthopaedic procedure consists of removal of the anterior annulus and anterior longitudinal ligament, complete removal of the nucleus pulposus, and preparation of the endplates with curettes and osteotomes. Fusion is achieved by implanting a femoral ring allograft or cage with bone graft. This approach is also optimal for total disk replacement or disk arthroplasty.

**Instrumented Posterior Lumbar Fusion**

After a standard midline dissection of the skin and subcutaneous tissues, the lumbar fascia is dissected in a subperiosteal manner with a bovie cautery and a Cobb elevator. After the skin incision, 1:500,000 epinephrine may be used for hemostasis. This dissection is advanced from the tip of the spinous process all the way lateral to the tip of the transverse processes. Stripping the muscles subperiosteally prevents tearing of the muscles and excessive bleeding. The superior and inferior segments are sequentially stripped, depending on the levels to be fused. Self-retaining retractors are then placed, but prolonged pressure on the
paravertebral musculature is avoided by freeing the pressure intermittently to prevent necrosis. The intervening facet joint capsules are stripped and the cartilage is removed with a high-speed burr and curettes. Great care is taken to avoid damage to the facet joints that will not be fused. Some bleeding may occur, especially during the dissection of the pars interarticularis, where the superior articular artery may be damaged. Bipolar cautery is recommended to avoid injury to the exiting nerve root.

To prepare the spine for fusion, the facet joints are stripped of their capsules and articular cartilage and the transverse processes and laminae are decorticated with the use of a high-speed burr. The ala of the sacrum is also decorticated if needed (Fig. 14-14).

Instrumentation consists of pedicle screws and rods. Landmarks for placing pedicle screws in the lumbar spine include the midline of the transverse process and the lateral cortex of the pars interarticularis. A Leksell rongeur or a high-speed burr is used to decorticate the entry position. A pedicle opener or “gearshift” is then used to perforate the pedicle, and a ball-tipped pedicle probe is used to palpate the inner walls of the trajectory of the screw hole. An appropriately sized tap is next used, and finally the screw is inserted. The structures at risk during the insertion of pedicle screws include the dural sac medially, the exiting nerve root medial and caudal to the pedicle, and the greater vessels anteriorly. These vessels lie anterior to the vertebral bodies above L3 or L4 and caudal to L4; the bifurcating common iliac arteries and veins take a more lateral position, directly anterior to the pedicles. For the placement of sacral (S1) pedicle screws, bicortical purchase is strongly recommended. The internal and external iliac artery and vein lie laterally along the sacral ala, and any penetration of the anterior cortex must be done with extreme caution. In the anterior midline of the sacrum, the middle sacral artery may also be injured.

In longer surgical incisions, we use a medium-sized drain between the fascia and the skin. The wound is closed in three layers.

TRANSFORAMINAL LUMBAR INTERBODY FUSION (TLIF)
As an additional step in posterior lumbar fusion, an interbody device or cage may also be placed. The major reasons for doing this are to restore sagittal contours, strengthen the load-bearing characteristics of the construct, and increase the chances of obtaining a successful fusion. The inferior articular process is removed with an osteotome and the superior articular process is then removed in a piecemeal manner with a Kerrison rongeur. This allows access to the intervertebral disk. The dural sac lies medially, underneath the ligamentum flavum, and the exiting nerve root is on the superolateral aspect of the foraminotomy. Both the thecal sac and emerging nerve root are protected with retractors. Annulotomy is performed with a knife blade, and the disk is completely removed with disk shavers, pituitary rongeurs, and sharp curettes. The cartilage endplates are removed as well to prepare the adjacent vertebrae for interbody fusion. The anterior interbody space (posterior to the anterior annulus) is packed with bone graft; an interbody device is placed between both endplates and filled with bone graft as well. Fluoroscopy is used to assess correct placement of the cage.

Posterior Iliac Crest Bone Graft
Morcellized corticocancellous autograft may be obtained by the same skin incision used for a lumbopelvic fixation or by a separate incision. If the spinal fusion extends into the sacrum, the subcutaneous tissue layer is undermined and the posterior iliac crest approached through a separate fascial incision that stretches approximately 4 cm from the posterior superior iliac spine (PSIS), in an anterior direction. The gluteal musculature is dissected in a subperiosteal manner and a Taylor retractor is placed in the depth of the wound under direct vision. Great care is taken not to use any sharp instruments in the sciatic notch. The Taylor retractor or a sharp Cobb may not only injure the

Figure 14-14. Preparation for pedicle screws. The transverse process, lamina, and facets have been decorticated.
sciatic nerve but also lacerate the superior gluteal artery, in which case bleeding will be very difficult to control. Alternatively, a vertical incision may be made 4 cm lateral to the PSIS. After dissection of the skin and subcutaneous tissues, the procedure is as described above.

The graft is obtained by removing the lateral cortex of the ilium with the use of osteotomes. The cancellous bone is then obtained by exposing the cortex of the ilium with gouges and curettes. Care is taken to avoid penetrating the inner cortex of the ilium and potentially damaging the sacroiliac joint or ilioinguinal nerve (Fig. 14-15). When sufficient bone graft has been removed, surface bleeding of the bone is controlled by bone wax and Gelfoam. The aponeurosis is then closed with a running suture. Wound drains are usually not necessary.

Anesthetic Considerations

Microdiskectomy is usually performed under general anesthesia, but it may also be performed under epidural or local anesthesia. Advantages of epidural anesthesia include shorter recovery room time, faster return of alertness, absence of postoperative nausea and vomiting, and superior postoperative pain management. Additionally, there can be less intraoperative bleeding due to decreased venous pressure (see “Blood Loss and the Quality of the Surgical Field,” above). Disadvantages of epidural anesthesia include hypotension, difficulty in obtaining an airway in case of an adverse intraoperative emergency and the fact that the patient may move the upper body during the procedure. The patient may also be uncomfortable during the surgery. Furthermore, the volume of the anesthetic may further compromise severely diminished canal dimensions due to a large disk extrusion. Epidural anesthetics may also increase urinary retention, requiring an overnight hospital stay. Laminectomy for decompression and posterior spinal fusion requires general anesthesia, mostly due to the length of the procedure. For these procedures, as in thoracic spinal fusion, control of the surgical field and reduction of intraoperative bleeding are important anesthetic considerations (see the discussion of thoracic spinal fusion, above).

Analgesia

After microdiskectomy, patients may be discharged on the same day or after a 23-h hospitalization regimen. They are mobilized within a few hours and may require only mild enteral analgesics, since this surgery is generally not painful. More extensive procedures, including laminectomy or lumbar fusion, require longer hospital stays and more intensive pain control. It is recommended that the patient become mobile on the day after surgery. Intrathecal morphine (0.004 mg/kg, or 0.3 mg for the average patient, injected by the surgeon before closing the wound) or epidural analgesia (the catheter placed by the surgeon prior to closure of the wound) have been shown to be very effective analgesic measures.

Associated Medication

Most elderly patients with degenerative conditions of the lumbar spine also have one or more comorbid conditions that require specific management.

Prophylactic antibiotics are used for all spinal procedures. Because the intervertebral disk is poorly vascularized, it is more vulnerable to a disk-space infection (diskitis). In general, this occurs with an incidence of 1 percent for lumbar diskectomy; but this figure doubles in diabetic patients. For all implant procedures, antibiotics are continued until all indwelling catheters have been removed. (See Chap. 3 for antimicrobial prophylaxis and Chap. 4 for thromboprophylaxis.)

Physical Therapy Goals and Requirements in the Postoperative Period

Patients who underwent microdiskectomy are encouraged to resume their activities in a short time. Ambulation and physical therapy are initiated on the same afternoon after
Special Intra- and Postoperative Surgical Requirements

Neuromuscular blockade is helpful for surgery to the lower lumbar spine, especially in obese or very muscular patients; it may be very difficult to obtain adequate access to this area. Completely paralyzed paravertebral musculature is easier to retract laterally and allows for better visualization. Nevertheless, thereafter, complete recovery of neuromuscular function in order to monitor electromyographic (EMG) activity should be achieved for spontaneous as well as for stimulus-evoked modalities. This is discussed further in the next section.

Common Problems (Pre-, Intra- and Postoperative)

Complications of Iliac Bone Graft Harvesting

Donor-site problems have a reported incidence of 8 to 39 percent and range from minor wound problems to severe, persistent donor-site pain, neurovascular injury, and even loss of pelvic stability. The most common problem is that of pain, which can be severe within the first 6 months but tends to diminish thereafter. Other complications that may have direct intraoperative implications include herniation through the ilium, lateral femoral cutaneous nerve injury (meralgia paresthetica), and injury to the superior cluneal nerves or ilioinguinal nerve.

The superior gluteal artery may be injured by dissection with a sharp instrument or by retraction over the sciatic notch. Bleeding is extremely difficult to control, and owing to its anatomic location, repair or ligation is not only difficult but may cause other complications, including sciatic nerve injury and injury to the ureter or iliac vessels. In our opinion, the best way to deal with this problem includes tamponade by direct pressure and endovascular repair or selective embolization.

The stability of the sacroiliac joint may be damaged by removing excessive amounts of the inner cortex of the posterior ilium as well as by damage to the sacroiliac ligaments. Pelvic instability and pain are the long-term consequences of such damage. In patients with persistent sacroiliac joint pain after graft harvesting, there is a high prevalence of inner cortical disruption of the ilium.

Problems with Pedicle Screw Placement

As previously mentioned, soft tissue structures may be harmed by misplaced pedicle screws. A review of the literature reveals that in cadaver studies, experienced surgeons breech the cortex of the pedicle 5.5 to 31.3 percent of the time; in clinical studies, between 28.1 and 39.9 percent of pedicle screws are misplaced. Nevertheless, only 1.6 to 5 percent of clinical series present with irritation or injury to the adjacent nerve roots. Current methods to avoid this problem include pedicle probing, visualization of axial landmarks by fluoroscopy, image-guided navigation systems, neuromonitoring with stimulus-evoked EMGs, and sensory evoked potentials. The latter have had limited success because they are not sensitive enough to detect individual nerve root dysfunction. Evoked EMG has become an increasingly popular technique to confirm correct pedicle screw placement in the lumbar and sacral spine. The intact pedicle cortex insulates the adjacent nerve root from the stimulating current, and relatively high levels of energy are required to stimulate it, while the stimulation threshold is lower after a cortical breach in the pedicle. Electrodes are placed in muscle groups whose nerve roots are at risk from misplaced screws. Because EMG monitoring is strongly influenced by paralysis from pharmacologic agents and chronic nerve compression, neuromuscular blockade is reversed after exposure is completed.

Vascular Injury

A serious complication of anterior spinal surgery is laceration of the greater vessels, with significant blood loss. These injuries occur very rarely, but they do have disastrous consequences. The reported mortality of operative injury to a major vessel has ranged up to 50 percent. If the patient survives, blood supply to the spinal cord may also be affected. Although the incidence of these injuries
is extremely low; it could be underestimated, because the clinical manifestations may be extremely variable. Sometimes the effects are readily apparent early on, but they may also manifest in the long term, as is the case of arteriovenous fistulas or pseudoneuromysium in the retroperitoneal space.

During anterior exposure of the lower lumbar spine, direct pressure on the iliac artery may promote arterial occlusion, especially in patients with risk factors for thrombosis (obesity, smoking, hypotensive anesthesia, prolonged retraction time, and history of thrombosis). Great care is taken with patients who have demonstrated arteriounous plaques.

**Deep Venous Thrombosis and Pulmonary Embolism**

The incidence of deep venous thrombosis as revealed by ultrason has been reported in 0.6 to 2 percent and by venographic studies in 10.8 to 17.7 percent of patients subjected to spinal surgery (see Chap. 4). The occurrence is higher for lumbar spinal surgery (26.5 percent) than for cervical spinal surgery (5.6 percent), and the prevalence of proximal deep venous thrombosis is 0.9 percent. Fatal pulmonary embolisms have been described in many case reports, but the exact incidence is not yet clear. Risks factors include lengthy procedures, prone positioning, prolonged recumence after surgery, and motor paralysis of the lower extremities, as is the case for patients with spinal cord injuries. One particular reason that may explain a higher incidence in lumbar surgery may be the use of Hall-Reston type frames with direct pressure on the iliac region, thus increasing venous stasis in the lower legs. The same holds true for prolonged retraction of the iliac vessels during anterior exposure to the lower lumbar spine.

Several methods to prevent these complications have been attempted; nevertheless, there is no clear consensus on the optimal regimen. Both pharmacologic and mechanical methods have been shown to reduce this risk. Pharmacologic prophylaxis is not a well-accepted method for reducing this risk, because it may increase the risk of formation of an epidural hematoma with potentially catastrophic neurologic damage. For this reason, most surgeons prefer mechanical prophylaxis. Venographic studies show that most of the thrombi are in the calves, and they may occur proximally only occasionally. The effects of mechanical methods to prevent thrombosis have not been clearly demonstrated in spinal surgery (see Chap. 4).

**Dural Lacerations**

In spite of meticulous surgical technique, dural lacerations sometimes cannot be prevented during lumbar spinal surgery, particularly in cases of spinal stenosis and previous laminectomies. The reported incidence is 4.6 percent in patients subjected to laminectomy for lumbar stenosis, 9.8 percent if the surgery is revision, and 1.8 percent in disk surgery. Some authors have reported even higher numbers for patients with lumbar stenosis, possibly as a consequence of an atrophic dura. It is noteworthy that accidental durotomy constitutes the second most frequent cause for malpractice claims in lumbar spinal surgery.

The manifestations of intracranial hypotension may be quite dramatic, with cranial nerve dysfunction, tonsillar herniation, cerebellar hemorrhage, brainstem compression, and respiratory arrest. More commonly, patients present with orthostatically induced headaches, vertigo, or a subarachnoid-cutaneous fistula. This may potentially cause and signal meningitis. Repair is warranted. The etiology of cerebellar hemorrhage has been ascribed to reduced intracranial CSF pressure, which increases the difference between intravascular pressure and CSF pressure. Alternatively, extensive CSF loss causes downward displacement of the cerebellum and stretching of the superior vermian veins. Other nontraumatic risk factors include hypertension, coagulation disorders including anticoagulant therapy, and vascular malformations.

When dural laceration is diagnosed, it must be repaired. The exposed nerve roots are protected with a cottonoid, the laminectomy is made adequate, and the dura is sutured with running monofilament, nonabsorbable 5–0 suture. Care is taken to avoid catching the nerve roots into the suture. The repair is then tested for leakage by applying a Valsalva maneuver. Fibrin glue is used to cover the repair at the end of the procedure. The patient is left in flat bed rest for the subsequent days, which lowers the intrathecal pressure and thus promotes healing of the dura.

If CSF drainage continues after surgery, Trendelenburg positioning or a blood patch may be attempted. The placement of an intrathecal lumbar drain may also facilitate healing. Prophylactic antibiotics are used, and the height of the drain receptacle is adjusted to obtain 50 to 100 mL of CSF per 8-h shift over 4 days. Alternatively, the patient may be returned to the operating room for repair.

**APPENDIX**

**Common Surgical Procedures**

**Fusion:** Surgical arthodesis allowing permanent immobilization of a joint by inducing bone growth across the joint space. For example, in the subaxial cervical spine, two adjacent vertebral bodies have five joints, allowing for motion between them. This includes the intervertebral disk, the facet joints (one on each side) and the uncovertebral processes. In an anterior procedure, an interbody
structural load-bearing bone graft is placed between the vertebral endplates to allow bone growth between the vertebral bodies. In a posterior procedure, the facet joint surfaces are partially destroyed, and the lateral masses are bridged together by morcellized cancellous bone graft.

**Anterior cervical decompression and fusion (ACDF):** Anterior approach to the cervical spine, removal of the intervertebral disk and interbody fusion.

**Corpectomy:** Surgical excision of the vertebral body, including the two adjacent intervertebral disks. This procedure is intended for decompression of the spinal canal and for reconstructive purposes. The spine is then reconstructed with a structural bone graft and plate instrumentation.

**Anterior instrumentation:** Placement of anterior plate to increase stability and to promote fusion.

**Laminectomy:** Removal of the laminae and spinous process to increase the AP dimensions of the spinal canal, thus relieving pressure on the thecal sac.

**Laminoplasty:** This procedure is intended to increase the AP diameter of the spinal canal while preserving the posterior tension band, thus avoiding iatrogenic deformity (kyphosis). There are several different techniques, but the posterior arch is interrupted on one side of the spine and hinged on the opposite side, producing an open-door effect. As the laminae are splayed, the cord migrates posteriorly and the pressure is reduced.

**Posterior cervical lateral-mass instrumentation:** Screws are positioned in the articular processes and are subsequently interconnected by plates or rods.

**Posterior wire fixation:** Multiple techniques include the passage of wires or titanium cables through the spinous processes or facets so as to reproduce stability on motion segments that have become unstable.

**Craniocervical fusion:** Surgical arthrodesis between the occiput and the cervical spine. This is achieved by inserting a structural bone graft, which spans the base of the occiput, posterior to the opisthion, and down to the posterior arch of C1 and C2. Several techniques have been described, but probably the most widely used includes occipital plates anchored with screws connected through rods to the lateral processes of the subaxial cervical spine and the pars interarticularis of C2.

**Transarticular C1–C2 screws:** Screws are driven from the inferior articular process of the axis through the C1–C2 joint into the lateral mass of the atlas, as described by Magerl. This allows for C1–C2 fusion procedures.

**Gallie or Brooks wiring technique:** These techniques for C1–C2 arthrodesis consist of sublami-}

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**Dens screws:** Anterior exposure is required at the height of the C4 vertebral body so as to obtain adequate angulation for the insertion of screws through the anteroinferior corner of the body of the axis and into the dens. This procedure is indicated for dens fractures with a risk factor for nonunion.

**Transoral decompression:** This approach allows for removal of ventrally situated bony abnormalities causing cervicomedullary compression from the base of the clivus to the body of the axis. The approach is through the soft palate and posterior wall of the pharynx. After excision of the anterior arch of the atlas, the dens is fully viewed and may be completely removed.

**Anterior release:** The thoracic or thoracolumbar spine is approached anteriorly to removing the intervertebral disks. This allows for increased flexibility of the spine and provides enhanced deformity correction. The endplates are curetted free of cartilage and bone graft is packed in between in order to obtain interbody fusion.

**Thoracolumbar corpectomy:** Complete or subtotal removal of a vertebral body in the thoracic spine, including the two adjacent disks, with the purpose of decompressing the spinal cord and/or reconstructing the anterior column. The void is filled with a structural bone graft or a cage device packed with morcellized bone.

**Anterior instrumentation:** Placement of anterior plate or rod-screw construct to obtain increased stability and promote fusion. In scoliosis surgery, anterior instrumentation may be used to correct the curvature, avoiding a posterior procedure after anterior release.

**VATSS (video-assisted thoracoscopic spinal surgery):** Endoscopic or mini-open thoracotomy allows access to the anterior thoracic spine for most standard procedures, including anterior release, corpectomy, spinal cord decompression, and anterior instrumentation.
Costotransversectomy: A posterior extrapleural approach to the anterior and middle column of the spine, including the vertebral body and ipsilateral pedicle. This allows for adequate decompression of the spinal canal. It also allows for partial reconstruction of the anterior column.

Microdiskectomy: The spinal canal is approached through the interlaminar space, with a very small laminotomy (hemi-, semilaminectomy), with the purpose of removing an extruded disk fragment.

Lumbar decompression: This procedure is intended for the treatment of lumbar spinal stenosis. The spinal canal is approached through wide laminectomies, with the purpose of removing osteophytes, and other hypertrophic structures that produce pressure over the thecal sac.

Posterior lumbar fusion: Surgical arthrodesis is obtained by decorticating the intervening facet joint as well as the transverse processes. Morcelled bone is placed in the intertransverse process area, providing a scaffold for vascular ingrowth and bone formation.

Anterior lumbar interbody fusion (ALIF): Surgical arthrodesis is obtained by placing a structural graft or device between the vertebral bodies through an anterior exposure. The endplates are prepared by curetting them free of cartilage. If a cage is used, it is filled with bone graft to allow for the formation of a bone bridge.

Posterior lumbar interbody fusion (PLIF) and transforming lumbar interbody fusion (TLIF): Surgical arthrodesis is obtained by placing a structural graft or device between the vertebral bodies through a posterior exposure. If the approach to the disk includes a laminectomy and displacement of the thecal sac, this is defined as a PLIF. If the approach is through a foraminotomy, this is defined as a TLIF.

Circumferential spinal fusion (‘‘360-degree fusion’’): Surgical arthrodesis including both posterior intertransverse process fusion and anterior lumbar interbody fusion.

‘‘270’’ fusion: An anterior lumbar fusion is complemented by the implantation of posterior instrumentation without arthrodesis. This has become increasingly popular with the advent of percutaneous posterior spinal instrumentation.

SUGGESTED FURTHER READING


