171 Iatrogenic Deformities of the Spine

Alan P. Moelleken, M.D., Ziya L. Gokaslan, M.D., Paul R. Cooper, M.D.

Iatrogenic spinal deformity refers to abnormalities of alignment resulting from treatment instituted by a physician or a surgeon. This definition does not necessarily indicate that adverse results are caused by improper management or a faulty surgical technique (77). Nevertheless, an unsatisfactory outcome is related to the operative or nonoperative treatment. This chapter discusses the iatrogenic conditions of the cervical, thoracic, and lumbar spine (Table 171.1), with emphasis on prevention of these deformities and treatment when they do occur.

IATROGENIC DEFORMITY OF THE CERVICAL SPINE

Biomechanical Considerations

From a mechanical standpoint, the cervical spine should be viewed as two anatomically different motion segments. These include the upper cervical spine, or occipito-atlanto-axial (O-A-A) complex, and the lower cervical spine, or C3–T1.

The stability of the O-A-A joint is provided primarily by ligaments, with relatively minor contributions from bony articulations and joint capsules. The axis is connected to the C2–C3 bodies caudally by means of the tectorial membrane, which is the cephalad continuation of the posterior longitudinal ligament, and to the occiput rostrally. The atlas is connected to the occiput by means of the anterior and posterior atlanto-occipital membranes, which respectively connect the anterior and posterior arches of the atlas to the occiput. The axis is connected to the occiput by the alar and apical ligaments. The alar ligaments have two portions: the occipitoalar portion, which runs between the dens and the occipital condyles, and the atlantoalar portion, which connects the dens to the lateral masses of C1. The apical ligament connects the tip of the dens to the foramen magnum but provides only minimal mechanical strength. The transverse ligament holds the dens to the anterior atlas and provides most of the stability for this segment. Atlanto-occipital stability is primarily maintained by the tectorial membrane and the alar ligaments. The rest of the ligamentous structures are not sufficient to maintain stability.

From a mechanical viewpoint, the lower cervical spine can be viewed as a lordotic column with articulating segments. Each segment has a central fulcrum at the facet joints. Anteriorly, the fulcrum is supported by the vertebral bodies and discs. The posterior ligamentous complex (interspinous ligaments, facet ligaments, and ligamentum flavum) and the paraspinal muscles provide the support. Posterior structures attach to the spinous processes and the laminae, and these structures function much like tension wires. Gravity normally exerts a flexion force on the cervical spine, and posterior structures counteract this flexion.

In the upper cervical spine, the deformities are usually the result of bony erosion or ligament failure. Similarly, in the lower cervical spine, the deformities can occur after removal of the anterior supporting column or the posterior stabilizing complex or by alteration of the facet joints.

Deformities of the Cervical Spine following Laminectomy

Although the advent of anterior cervical decompression and fusion in the mid-1950s diminished the need for posterior decompression for certain pathological conditions, multilevel cervical laminectomy for decompression of neural structures is still widely used. Spinal deformities following one-level laminectomy or multilevel hemilaminectomies are uncommon. However, multilevel total laminectomies are associated with an unusually high incidence of insta-

Table 171.1.
Classification of Common Types of Iatrogenic Instability

Thoracic Spine
1. Decompressive laminectomy with wide decompression
2. Disc excision
   a. Anterior approach
   b. Posterior approach
3. Trauma followed by further surgical destabilization
4. Tumor or infection with further surgical destabilization

Lumbar and Thoracolumbar Spine
1. Decompression
   a. No preoperative spondylolisthesis
   b. Preoperative spondylolisthesis
      1. Degenerative
      2. Isthmic
   c. Decompression with discectomy
2. Disc excision
   a. Routine
   b. Far lateral
3. Tumor or infection with further surgical destabilization
4. Trauma followed by further surgical destabilization
5. Spinal fusion
   a. Level above or below the fusion
   b. Pseudarthrosis
   c. Acquired spondylolisthesis

bility and deformity in the immature skeleton (8, 15, 103). Almost half of all pediatric patients with spinal cord tumors develop postlaminectomy kyphosis (58). Interestingly, the same operation, although performed commonly, only rarely results in deformity in the adult patient. Because the growing spine responds differently to removal of the posterior elements than the adult spine does, deformity after laminectomy is discussed separately for children and adults.

Iatrogenic Cervical Deformity after Laminectomy in Children

In children, a high percentage of cervical laminectomies are performed for the management of spinal cord tumors. The most common deformity following multilevel laminectomy in children is kyphosis, although scoliosis and rotatory deformities can also occur (104).

The true incidence of postlaminectomy kyphosis is difficult to determine because many conditions that require this operation may also cause spinal deformities (76). Nevertheless, in a study by Yosuoka et al. (116, 117), all patients with conditions that could cause spinal deformities were excluded, and these investigators found that the patient's age and the site of the laminectomy were the major determining factors in the development of postlaminectomy kyphosis (Fig. 171.1). Only patients who were younger than 18 years developed kyphosis. In addition, kyphosis was found in all the younger patients who underwent cervical laminectomy, whereas only 36% of the patients who underwent thoracic laminectomy, and none of the patients who had lumbar laminectomy, developed this deformity. The patient's sex, the number of laminae removed, and the patient's neurological condition after laminectomy were not predictive of the development of postoperative deformities (116).

Progression of the deformity is difficult to predict. Kyphosis may progress rapidly during the adolescent growth spurt or may develop slowly for years. It may or may not be associated with spinal cord compression or scoliosis (59, 65). Because deformity of the cervical spine can develop as late as 6 years after the surgical procedure, long-term follow-up is important so that the physician can identify the occurrence of this condition (37, 116).

In children, three sets of circumstances may lead to the development of kyphotic deformity after laminectomy: Instability can occur following facetectomy, wedging of the vertebral bodies may develop because of abnormal compressive forces on the immature growing spine, and hypermobility between the vertebral bodies may lead to gradual rounding of the spine (76). The last two mechanisms are seen only in children and probably account for the fact that this deformity is relatively uncommon in adult patients (116).

The importance of the facet joints for spinal stability has been well recognized and demonstrated in both animal and cadaver experiments (67, 72, 73, 102). Facet injury can cause spinal instability with vertebral body subluxation in adults and children, even those who do not undergo laminectomy or facetectomy. Therefore, during laminectomy, as much of the facet joints as possible should be preserved (77).

The removal of the posterior supporting structures as a result of laminectomy results in shortening of the posterior moment arm with respect to the central fulcrum, or facet joints; this shortened moment arm allows more weight to be transmitted anteriorly. The stronger compressive force anteriorly inhibits cartilage growth and ossification of the anterior aspect of the vertebral body, compared with the posterior aspect of the vertebral body and the remainder of the vertebral column, which are still growing. This situation leads to gradual vertebral body wedging and a short and angular kyphotic deformity (77). This mechanism of deformity requires a growing spine and can occur only in children.

Gradual rounding of the cervical spine results from the hypermobility of the motion segments. Because the plane of the facet joints is more horizontal in children and assumes a more vertical orientation only with maturity, and because the ligaments and capsular tissues are more viscoelastic in this age group, children are particularly susceptible to this deformity. Removal of the posterior supporting structures causes the load to shift more anteriorly. Stretching of the ligamentous structures with time leads to gradual rounding of the spine or sometimes subluxation of the vertebral bodies extending both rostrally and caudally beyond the actual levels of the multilevel laminec-

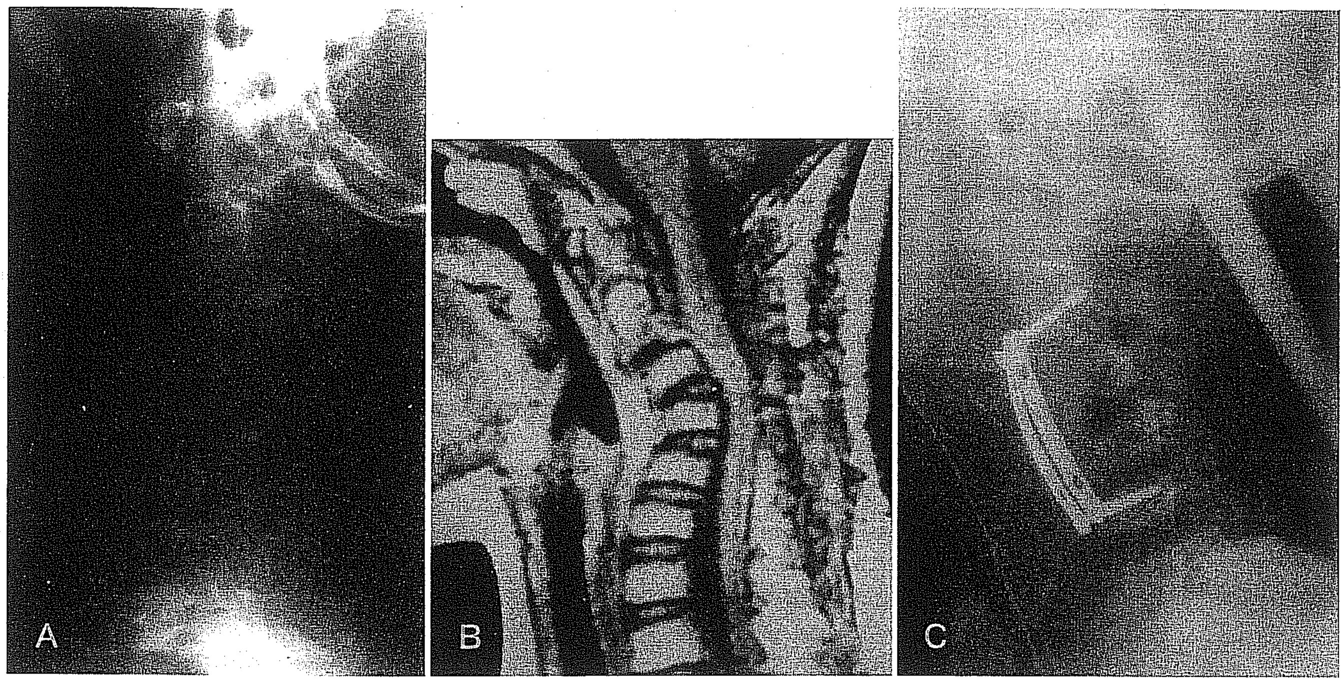

Figure 171.1. (*A*) Lateral cervical spine x-ray of an 8-year-old boy who underwent decompressive laminectomy at the C2–C4 level for a compressive extradural granuloma. The kyphotic deformity is most severe at the C3–C4 level. (*B*) Sagittal magnetic resonance image (MRI) shows spinal cord compression from the kyphosis, which is maximal at the C3–C4 level. (*C*) Immediate postoperative x-ray following C3–C4 vertebrectomy and anterior cervical fusion from C2 to C5 with anterior cervical plating. Because of the patient's size, two small reconstruction plates were placed parallel from C2 to C5.

tomy. If the vertebral bodies are still immature, wedging may also occur (77).

Because treatment of postlaminectomy kyphosis is difficult and technically demanding, prevention is the most important element of the management plan. Bracing has been proposed to prevent deformity following laminectomy (98, 101). However, no convincing, well-controlled, prospective studies exist to support the efficacy of this modality as either a preventive or a therapeutic measure. Because this deformity is a common sequela of laminectomy in children, some investigators recommend prophylactic fusion of the remaining structures (facet joints and transverse processes) (77). The halo vest can be used to achieve immobilization if the cervical laminectomy and fusion are carried out during the same operation. If fusion was not feasible at the completion of the laminectomy, close observation is necessary and should include serial lateral x-rays of the spine that are obtained while the patient is in the standing position. In certain circumstances, prophylactic anterior fusion has been recommended after laminectomy (114).

Laminoplasty has been proposed to prevent postoperative deformity after spinal surgery (67, 79, 97, 101). This procedure involves removal of the laminae and the spinous processes at each level, as one unit, by dividing them near the facets bilaterally. At the completion of the operation and prior to closure, this unit is reinserted and sutured in place. The effectiveness of this procedure in preventing the deformity has not yet been established, but the pathophysiology of the development of deformity supports the rationale behind the operation. Possibly, the procedure minimizes or prevents deformity by causing fusion to take place between the adjacent posterior elements that have been replaced.

Once the deformity is established, bracing is of no value for correction of the kyphosis. In young children, early intervention, involving correction of the deformity and spinal fusion, is recommended as soon as the deformity is recognized (77). Preoperative traction may be used in an attempt to reduce the deformity. Anterior fusion with strut grafting is usually the procedure of choice (77).

Iatrogenic Cervical Deformity after Laminectomy in Adults

In adults, the primary indication for laminectomy is degenerative disease of the cervical spine. Unlike children, adults rarely have progressive kyphotic deformity of the cervical spine following laminectomy (45, 86, 95). When kyphotic deformity does occur, violation of the facet joints is implicated (110).

In a biomechanical model in which Panjabi et al. (73) sequentially removed the posterior supporting structures of the cervical spine, increasing instability occurred with flexion loads. The most significant loss of stability occurred after removal of the posterior articular processes; this finding indicates the importance of these structures in resisting the kyphotic forces in the presence of an intact anterior column. In addition, with the removal of posterior structures and the stripping of the paraspinal muscles, laminectomy causes shortening of the moment arm posterior to the central fulcrum (facet joints); this shortened moment arm results in a mechanical disadvantage in counteracting the flexion and kyphotic forces. Furthermore, as the kyphotic deformity increases, the moment arm anterior to the fulcrum becomes longer; this lengthened moment arm provides a mechanical advantage for progression and worsening of the kyphotic deformity (109).

Although laminectomy has been used to treat degenerative conditions of the cervical spine for many years, most studies either have failed to specifically address the development of late spinal deformity as a complication of this procedure or have not analyzed a sufficient number of patients to reliably assess this problem. After studying small numbers of patients, Scoville (95) claimed that laminectomy and bilateral facetectomies could be performed safely without the risk of anterior dislocation in older patients. However, Herkowitz (41) reported 12 patients who developed kyphotic deformity following cervical laminectomy and partial bilateral facetectomies. Mikawa et al. (64) reported 64 patients who underwent multilevel cervical laminectomies for the treatment of cervical spondylosis and ossification of the posterior longitudinal ligament (OPLL). Eleven percent of the patients who underwent laminectomy for OPLL developed kyphosis, whereas none of the patients treated for spondylosis developed this deformity. On the basis of this study, these investigators suggested that patients with cervical spondylosis have inherent spinal instability due to degenerative changes of the anterior spinal column.

Deformity is uncommon in adults, and prevention is the most important aspect of the management plan. During surgery, extensive bone removal should be avoided whenever possible, and facet joints and their capsular ligaments should be preserved. In the authors' experience, patients who have preexisting kyphosis or loss of the lordotic curvature of the cervical spine are more likely to develop a progressive kyphotic deformity following laminectomy. If laminectomy cannot be avoided for such patients, posterior fusion should be performed at the time of posterior decompression.

Treatment of an established or a progressive kyphotic deformity is a different situation and presents the surgeon with more difficult management options than prevention of deformity. With an established deformity, not only must solid arthrodesis of the unstable motion segments be achieved, but ideally the deformity should be corrected at the same time (Fig. 171.2).

A period of skeletal traction using Gardner-Wells tongs or a halo vest is recommended to achieve maximal correction prior to surgery. Unfortunately, many kyphotic deformities are relatively rigid and demon-

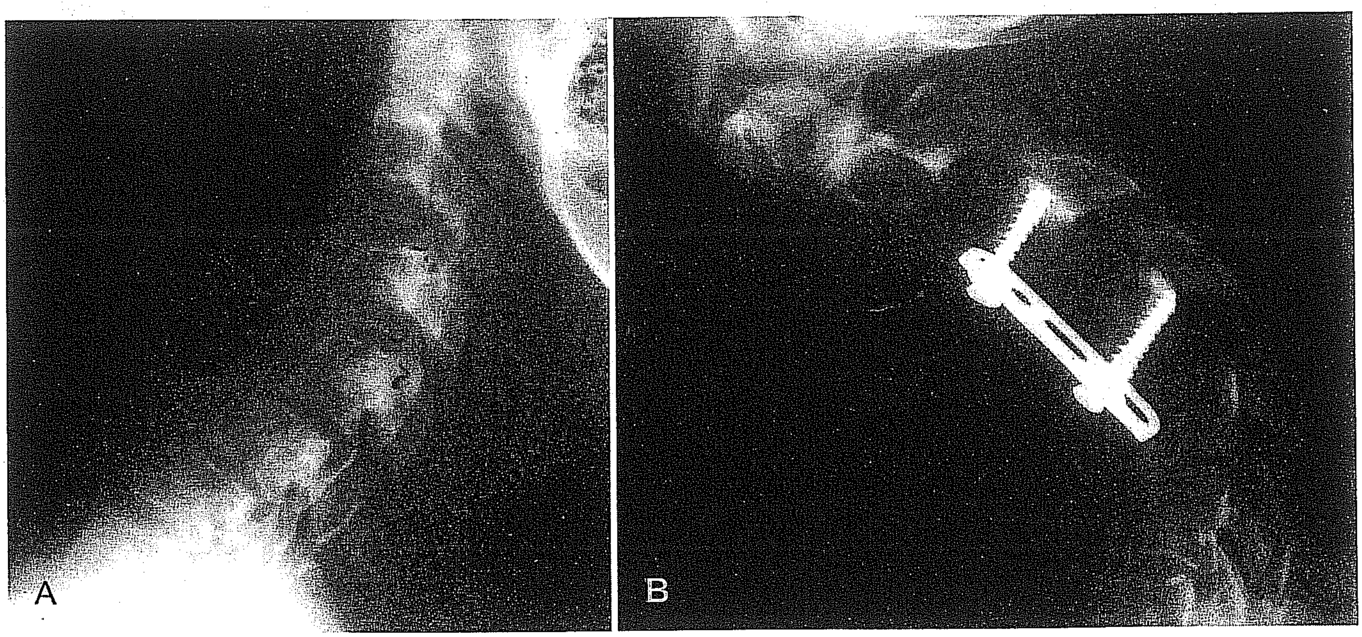

Figure 171.2. (*A*) Lateral cervical spine x-ray of a 35-year-old man who underwent C2–C5 laminectomy for resection of a cervical ependymoma. Despite total resection of the tumor, he developed progressive myelopathy several years after his initial operation as a result of subluxation at the C3–C4 level with spinal cord compression. (*B*) The deformity corrected easily in traction, and anterior cervical fusion and plating were performed at the C3–C4 level. However, the patient subsequently developed instability at the C4–C5 level, the level below the fusion and plating.

strate only minimal correction with preoperative traction.

In patients with preexisting kyphotic deformities of the cervical spine, an anterior approach is generally most appropriate. Such an approach allows the surgeon to perform vertebrectomy to decompress the spinal cord and to correct the deformity by distracting and extending the spine. The anterior column may be reconstructed, and this correction can be maintained with a bone graft placed in compression.

Several anterior fusion techniques have been developed for stabilization of the cervical spine (5, 16, 99, 100). However, the interbody fusion techniques described by Smith and Robinson (100) and by Cloward (16) are unsuitable for the treatment of kyphotic deformities because vertebrectomies at one or more levels must be performed to decompress the spinal cord and allow correction of the deformity. The fusion method reported by Bailey and Badgley (5) consists of a median corpectomy at a single level or multiple levels, followed by a strut graft of appropriate length. Although this method may be satisfactory for achieving cervical fusion, it may result in inadequate decompression of the spinal cord at the apex of the kyphosis. The authors of this chapter prefer a wide vertebrectomy (18–20 mm) to ensure adequate decompression.

Either fibula or iliac crest may be used for reconstruction and grafting. Iliac crest is easily harvested and usually fuses rapidly. It is ideal for a one- or two-level vertebrectomy. However, when three vertebrae have been resected, obtaining a piece of iliac crest that is long enough and of appropriate shape is sometimes difficult. If iliac crest is unsuitable, fibula (either allograft or autograft) may be used. Fibula is composed primarily of cortical bone and can better resist compressive forces without fracturing (7, 111). However, it is considerably harder than the adjacent vertebral bodies. Therefore, it may telescope into the cancellous bone of the adjacent vertebrae with loss of correction of the kyphotic deformity.

Graft dislodgment is a serious complication that becomes more likely with longer grafts spanning multiple motion segments. A number of techniques of graft insertion have been described. One requires undercutting the vertebrae adjacent to the graft so that when it is inserted it lies entirely within the prepared trough. With this technique, the cervical spine is usually extended during insertion. However, because of the shape and positioning of the graft, posterior dislodgment may occur (7). In another technique, only a portion of the graft is inserted (111). Extension is not required to achieve insertion, and the risk of posterior dislodgment into the spinal canal is minimal. However, when the notched technique is used, the superior or inferior vertebral body still may fracture.

The advent of anterior cervical plates has made these notching techniques mostly irrelevant (14, 66). The authors now impact the graft without notching the adjacent vertebrae and routinely secure the vertebrae immediately above and below the graft with a plate and screws, as shown in Figures 171.1 and 171.2. Using this technique, the authors have not had a single case of graft dislodgment.

Although the procedure of choice for the treatment of established kyphotic deformity is anterior cortical grafting, various posterior fusion techniques following laminectomy have been described. Although a posterior approach may be used to fuse a kyphotic deformity, such an approach generally is unsuccessful. Even if posterior instrumentation is used, the kyphotic deformity frequently progresses. Moreover, correction of a fixed deformity from a posterior approach is generally impossible.

The posterior approach may be used prophylactically to prevent the development of deformity at the time of laminectomy. However, after a laminectomy, typically a minimal amount of bone is left for fusion. In addition, because the bone graft is placed under tension, not compression, nonunion occurs more commonly than with an anterior approach. Robinson and Southwick (85) described a technique of facet wiring in which the wires are passed through the facet joints and the iliac struts are tied down against the posterior surface of the articulating processes. Callahan et al. (13) described a modification of this technique and reported a high fusion rate, even in delayed cases. The use of a bone graft without the simultaneous placement of internal fixation does not produce immediate stability; thus, pseudarthrosis or progression of kyphosis may occur until fusion takes place.

The authors of this chapter believe that the standard treatment for internal fixation of the cervical spine from a posterior approach involves placement of lateral mass plates, as first described by Roy-Camille et al. (88). Because the screws that secure the plate are screwed into the lateral mass, this method is ideal for patients who have undergone laminectomy. Fusion may be achieved by curetting the articular cartilage from the facet joint and packing the joint with bone taken from the laminectomy. Additional bone may be placed over the lateral masses. The fixation provided by these devices for patients who do not have preexisting kyphotic deformity is so good that the patients may be managed postoperatively in a Philadelphia Cervical Collar or a similar orthosis until fusion occurs.

Postirradiation Spinal Deformity in Children

The epiphyseal endplates of the vertebral bodies grow axially by endochondral ossification. Epiphyseal cartilage is a radiosensitive tissue, and radiation, in sufficient concentrations, can prevent normal endochondral maturation (4, 80). The degree of growth inhibition is related to the child's age and the radiation dosage. The younger the child and the larger the radiation dosage, the worse the ultimate deformity (50, 69, 90, 107). An accumulated dose of 1000 rad does not produce detectable inhibition of vertebral growth (69, 82). In a young child, a temporary or an inhibiting effect on growth may occur from an intermediate dose (1000–2000 rad). Permanent inhibition of epiphyseal growth is seen with the administration of 2000 to 3000 rad or more (69, 82, 90), and a dose of 5000 rad almost always causes bone necrosis (51). The most severe changes are seen in children who are younger than 2 years.

Irradiation of immature vertebrae results in a smaller-than-normal vertebral body with almost no angular spinal deformity. For example, whole abdominal radiation affects the entire vertebral endplate and results in reduction of longitudinal height. Although the patient's standing height is only moderately affected, the patient's sitting height is markedly shorter.

Irradiation of only a portion of the vertebral body inhibits growth of that portion; this growth inhibition promotes axial spinal deformity as the remainder of the vertebra grows. This differential amount of radiation exposure in a given vertebral body is the main factor determining the ultimate deformity. When the radiation involves a lateral portion of the vertebral body, maximum inhibition of vertebral growth plate and loss of height occur laterally; thus, scoliosis results, with concavity toward the side of the radiation. Similarly, when growth of the anterior portion of the vertebral growth plate is inhibited by radiation, kyphosis occurs (6, 8, 82). In addition to vertebral body distortion, radiation-related soft tissue changes, fibrosis contractures, and rib and iliac hypoplasia may contribute to the ultimate spinal deformity.

Postirradiation spinal deformity progresses more rapidly during the adolescent growth period; when growth gradually ceases, progression of the deformity diminishes and eventually stabilizes (77). Most information regarding the effect of radiation on the growing spine has been gathered from studies of children who received radiotherapy for intra-abdominal neoplasms such as Wilms' tumors and neuroblastomas. Nevertheless, the general principles also apply to cervical spinal deformities following radiation therapy.

All children who receive radiation to the neck, for any reason, should be observed closely for the development of spinal deformity. Although initial vertebral changes occur 6 months to 2 years after radiotherapy, the deformity may not manifest until years after the initial exposure (90). Whereas mild deformities may be managed with a cervical orthosis, progression requires spinal fusion, almost always from an anterior approach, and usually internal fixation.

For patients with severe or long-standing cervical deformities who may have severe soft tissue contractures, preoperative traction may be of value. Because the bone stock is poor in many of these patients, fusion occurs more slowly and pseudarthrosis is common. Postoperative immobilization should be used for a longer period than that required by patients with deformities unrelated to radiation (8). The indications for combined anterior and posterior fusion and instrumentation have not been completely defined for adults or children. However, for patients with severe cervical kyphotic deformities, the authors routinely supplement anterior fusion and instrumentation with posterior instrumentation to minimize the risk of losing correction because of graft compression or instrumentation failure. Supplemental use of the halo vest should be considered because such use increases the chances of successful correction and fusion in these severe cases.

Iatrogenic Deformities Following Cervical Trauma

Atlantoaxial Rotatory Subluxation

Patients with atlantoaxial rotatory subluxation usually present with the typical "cock-robin" position as a result of the torticollis (74). In children, the possible etiologic factors of such subluxation include infection of the pharynx or the upper neck, trauma, and certain surgical procedures, such as repair of cleft lip and palate, as well as removal of certain orthotic devices and body casts (27, 63, 115). If the symptoms are minor, children with this lesion may go unrecognized. Delayed diagnosis and inadequate immobilization initially may result in late fixed rotatory deformity of the C1–C2 joint.

If the transverse ligament is intact and the dens can act as a pivot, the rotation will be within 35% and the deformity will generally correct with traction (27). This is usually the case when the subluxation is associated with an upper respiratory tract infection or with minor trauma, the most common form of pediatric rotatory atlantoaxial subluxation (27). However, when the transverse ligament is disrupted, the arch of the atlas may displace forward, and this displacement compromises the spinal canal. In this situation, the rotation may exceed 40%, and the alar and accessory ligaments usually are disrupted as well. Transverse ligament disruption most commonly results from severe trauma to this region and usually requires reduction and derotation. In addition, internal fixation and fusion of C1–C2 are essential (63).

Odontoid Fractures

Odontoid fractures, especially type II fractures, may be associated with nonunion and instability. Certain risk factors for nonunion should be recognized: type

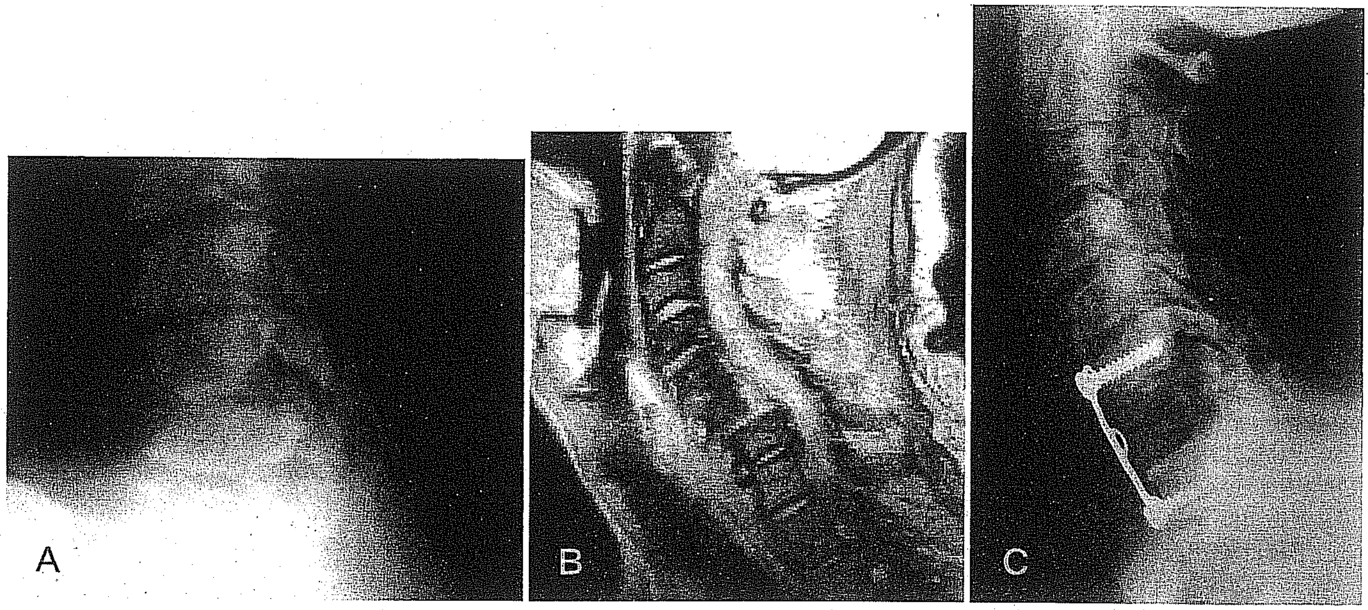

Figure 171.3. (*A*) Lateral cervical spine x-ray taken 1 year after an automobile accident. The immediate posttrauma x-rays were reportedly normal. The patient presented with progressive myelopathy. (*B*) Lateral MRI shows spinal cord compression at the upper aspect of the body of C7. (*C*) Lateral cervical spine x-ray following C7 vertebrectomy, C6–T1 bone grafting, and placement of an anterior cervical plate. The patient's myelopathy resolved dramatically.

II fractures in patients older than 50 years, posteriorly displaced fractures, fractures immobilized longer than 2 weeks after trauma, and fractures with more than 4 mm of residual subluxation. If any of these risk factors is present, early C1–C2 fusion is preferred to external immobilization with the halo vest (17, 23, 94). In addition, the presence of any preexisting pathological condition of this region, such as Down syndrome, rheumatoid arthritis, or neoplastic involvement, dictates early fusion, since nonunion rate is high. Ligamentous injury of the C1–C2 articulation, which will not heal with external immobilization, also requires fusion.

Subaxial Deformities

Chronic fixed-facet deformities occur as a result of unrecognized subluxations that are not reduced shortly after injury, failure of nonoperative treatment, or unsuccessful operative fixation. In certain patients with ligamentous injury, good alignment may be achieved initially, but resubluxation that is either unrecognized or treated inadequately may ensue; the result is a progressive deformity that eventually becomes fixed (Fig. 171.3). In such cases, restoration of alignment and normal lordosis is difficult regardless of which operative procedure is used. Roy-Camille et al. (58) recommend a corpectomy in which the posterior and superior portion of the vertebral body is resected, to decompress the spinal cord, and a bone graft is placed. Savini et al. (93) similarly suggest anterior decompression and stabilization for dislocations that measure less than one third of the sagittal diameter of the vertebral body. For more severe cases, anterior release and fusion followed by posterior reduction and stabilization with lateral mass plates is recommended.

Compression-burst fractures of the cervical spine with associated ligamentous injury may also result in late flexion deformity if managed nonoperatively. Although patients with associated ligamentous injury represent a minority of patients, early recognition of the ligamentous injury is important in choosing between operative stabilization and external immobilization (18).

Appropriate case selection is critical when the physician is considering external immobilization as the definitive mode of treatment; inappropriate selection can result in late deformities of the cervical spine. Use of the halo vest for injuries involving the posterior ligamentous complex usually results in healing that is insufficient to withstand the normal physiologic load (111). Therefore, late and progressive angulation may occur as a result of incomplete healing. The presence of injury to these ligaments should be considered an indication for operative stabilization (9).

IATROGENIC INSTABILITY OF THE THORACIC AND LUMBAR SPINE

To appreciate how surgery can destabilize the thoracic and lumbar spine, it is necessary to understand not only the factors determining spinal stability, but also the anatomic features and biomechanics of the thoracic and lumbar spine. Although a number of definitions of spinal instability have been proposed (68, 78), White and Panjabi's concept is both simple and inclusive (109). They define clinical instability as "the loss of the ability of the spine under physiologic loads to maintain relationships between vertebrae in such a way that there is neither damage to the cord or nerve roots and, in addition, no development of incapacitating linear or angular deformities or pain from structural changes" (p. 192).

Anatomy and Biomechanics

Thoracic and Thoracolumbar Spine

The mechanism of postoperative instability of the thoracic and thoracolumbar spine is dissimilar from that of the lumbar spine because of differences in anatomic components and biomechanics. Compared with the lumbar spine, the thoracic and thoracolumbar spine is stiffer and less mobile. The attachments of the ribs to the adjacent vertebral bodies through the costotransverse and radiate ligaments are important stabilizers. Anteriorly, the ribs attach to the sternum, which further stabilizes and limits the range of motion. As in the lumbar spine, the facets and capsules are the major posterior stabilizing structures.

Biomechanical studies have shown that when all the posterior elements are cut, the motion segment remains stable in flexion until the costovertebral articulation is destroyed. Because the vertebral bodies and discs are wedged and this wedging produces the normal kyphosis, this region is more unstable in flexion than in extension.

Flexion and extension become freer in the lower thoracic region. The last few thoracic vertebrae are transitional with respect to the surfaces of the articular facets. These facets begin to turn more toward the sagittal plane and tend to limit rotation and permit more extension.

Lumbar Spine

The normal lumbar nonrotatory rigidity of the lumbar spine results predominantly from the orientation of the facets. The facet joints at the L5–S1 level are oriented more in the frontal plane, whereas higher in the lumbar spine, they are oriented more in the sagittal plane. However, a range of facet joint configurations can be seen at the L4–L5 level. A more sagittal facet joint orientation has been implicated as the cause of degenerative spondylolisthesis (35). The oblique orientation of the facets at the L4–L5 level renders this area more susceptible to subluxation.

The synovial articulations at the lumbosacral junction are unique. The presence of the strong iliolumbar ligaments likely restricts much rotational and translational motion. The most essential function of the synovial L5–S1 articulations involves their role as buttresses against the forward and downward displacement of the fifth lumbar vertebra in relation to the sacrum.

Because of the lordosis in the lower lumbar spine, the shear force increases more caudally and is maximal at the L5–S1 level. The posterior elements resist this shear. In the lower joints, the shear load is supported by the facet joints and the disc. The thick, wedge-shaped, fifth lumbar disc tends to give way to the shearing vector that the lumbosacral angularity produces, and spondylolisthesis results. This situation most frequently results from a deficiency in the lamina that fails to anchor the fifth vertebral body to the sacrum and allows its forward displacement.

However, degenerative spondylolisthesis most commonly occurs at the L4–L5 level and not at the L5–S1 level, presumably because of the restraining effects of the iliolumbar ligaments on the L5 vertebral body and transverse processes. Such restraint allows relatively more motion and subluxation at the L4–L5 level (56).

Thoracic Spine: Causes of Iatrogenic Instability

Instability after Laminectomy with Wide Decompression

When deformity occurs after a multilevel laminectomy, it is usually a generalized kyphosis, occasionally with a concomitant scoliosis, which is usually minor. The risk of deformity increases as the number of laminectomized levels increases; the severity of the deformity is directly related to the extent of facet resection. However, if the facets are preserved, the length of the laminectomy does not increase the chance of deformity. When even one facet is saved, deformity progresses slowly. For this reason, the surgeon should always save one facet and try to save most of both whenever possible. If both facets at one level are destroyed, a fusion should be performed at the time of the decompression. Because of the large amount of remaining growth, the skeletally immature patient (especially younger than 2 years) has the most risk of developing deformity.

Instability Following Thoracic Disc Excision

The surgical treatment of thoracic disc disease may result in instability regardless of whether the disc is removed through a thoracotomy, the posterolateral approach, or a costotransversectomy. The transthoracic approach with complete discectomy and partial corpectomy of adjacent vertebral bodies provides excellent visualization and safe decompression for central or paracentral disc herniation. Unfortunately, the cost of this visualization is a high likelihood of instability (105). Fusion is indicated when stability is compromised by the decompression or when Scheuermann's kyphosis (defined as excessive thoracic kyphosis with a Cobb angle of more than 45 degrees and wedging of 5 degrees or more of at least three adjacent apical vertebrae, as well as vertebral endplate irregularities) is present (11). When only a small amount of bone and disc is excised, fusion generally is unnecessary (11, 26, 75, 91), but some authorities believe that fusion is mandatory with complete discectomy (11).

The authors of this chapter believe that with discectomy without bone removal, fusion is unnecessary. However, when bone is removed from the vertebral bodies adjacent to the herniated disc, bone grafting can prevent instability and deformity. If a prior laminectomy was performed, additional stabilization must be provided. Stabilization may be done posteriorly as advocated by Bohlman and Zdeblick (11) or with the use of an interbody bone graft and anterior instrumentation.

Lateral thoracic disc herniations may be approached by costotransversectomy (extrapleural removal of bone from the transverse process, rib, pedicle, and vertebral body to gain access to the disc fragment) or by a posterolateral technique (laminectomy, medial facetectomy, excision of the transverse process with removal of the pedicle) (20). In these cases, the risk of producing instability in the thoracic spine, even with bilateral facetectomy, is slight.

Trauma Followed by Further Destabilization from Laminectomy

Instability can result from an anterior compression fracture when a laminectomy removes the posterior supporting elements (83, 85, 89). For this reason, and because the anterior fragment is reached with difficulty and with considerable risk to the spinal cord, laminectomy is rarely indicated for the management of thoracic trauma (28). If a laminectomy is performed on such patients, surgical stabilization with internal fixation and arthrodesis must be performed or a kyphotic deformity will result. Posttraumatic kyphosis of more than 40 degrees is usually associated with a progressive deformity and should be treated with appropriate posterior instrumentation before further progression occurs (10).

When decompressing or stabilizing an injury involving the anterior and middle columns of the spine, the authors prefer an anterior approach with anterior stabilization. If the posterior column is also involved, the authors also use posterior instrumentation. The authors prefer an anterior approach prior to the posterior procedure because several cases of progressive neurological injury have occurred when the posterior procedure was followed by an anterior decompression and fusion. During the anterior approach with bone grafting, anterior instrumentation is used.

Tumor or Infection with Further Surgical Destabilization

Resection of intact posterior elements during decompression in the face of destruction of the vertebral bodies by tumor or infection may promote instability. Anterior decompression may further increase the degree of instability. Although an unstable spine destroyed by tumor may reconstitute and restabilize with temporary bracing if the tumor is sensitive to radiation or chemotherapy, such restabilization occurs uncommonly (19, 24).

Kostuik et al. (53), Cooper et al. (19), and Errico and Cooper (24) recommend vertebral body replacement with polymethyl methacrylate for metastatic disease when the patient's life expectancy is less than 1 year; they recommend bone grafting in patients with longer life expectancies. When the disease is solely anterior or is associated with significant kyphosis, an anterior approach should be used. If disease is also present posteriorly with three-column involvement, as defined by Denis (21), a laminectomy should be performed to decompress the tumor, and patients should be stabilized posteriorly.

If the anterior and middle columns above T11 are involved, the spine will be stable if the posterior column is not involved; vertebral body replacement without instrumentation is sufficient to restore stability. If all three vertebral columns are involved, supplemental instrumentation is required. Because the thoracic spine below T11 and the lumbar spine lack the fixation provided by the rib cage, supplemental instrumentation can help prevent extension that could lead to graft extrusion (48, 53, 62).

Special Considerations Pertaining to Thoracic Laminectomy in Pediatric Patients

Because of the large amount of remaining growth following laminectomy, deformity is much more likely to develop in the pediatric patient. The ideal treatment is to fuse posteriorly, usually without instrumentation, at the time of surgery. Bracing with orthoses such as the Milwaukee brace may also be effective, although surgery is indicated if the deformity progresses despite bracing. When deformity occurs, a posterior fusion without correction of the deformity may halt progression. However, severe deformities may require correction by means of both an anterior approach and a posterior approach.

Thoracolumbar Junction: Causes of Iatrogenic Deformity

Because the thoracic cage does not provide stabilization in the lower thoracic spine, this area of the spine behaves more like the lumbar spine than like the thoracic spine. In addition, the stress at the junction of the spine stabilized by the thoracic cage and the nonstabilized area often increases instability at the thoracolumbar junction. Therefore, the considerations discussed in the following section also apply to the thoracolumbar junction.

Lumbar Spine: Causes of Iatrogenic Instability

The spinal surgeon frequently encounters iatrogenic lumbar instability. Because of the lack of ribs and their supporting structures in the lumbar spine, this area is often more susceptible to instability than the thoracic spine is. Usually, the amount of instability that is created relates to the amount of the facets that is removed during a laminectomy. Laminectomy in a patient with a biomechanically normal spine, even at multiple levels, does not destabilize the spine if the facets are left intact.

Instability Following Decompression

Instability Following Decompression for Lumbar Stenosis without Preoperative Spondylolisthesis

The development of spondylolisthesis after decompression increases with the extent of facet removal. Some authorities favor extensive laminectomy in the decompression for spinal stenosis (47, 54, 55, 112), whereas others advocate limited laminectomy (46, 57, 96, 106).

Although conflicting opinions are evident in the literature, several reports of biomechanical and clinical studies now argue for saving at least 50% of each facet whenever possible during decompression (3). The surgeon can remove a total of one facet (either one entire facet or one half of each facet at a given level) without destabilizing the spine. If facet removal of more than 50% is necessary, fusion should be performed at the time of laminectomy.

Fusion is also indicated when significant scoliosis (>35 degrees with a flexible curve) is present, when decompression is performed at the apex of a curve, or when lateral olisthesis is present at the site of decompression (32). Recently, investigators have noted that the potential for developing postoperative spondylolisthesis is related more to the preoperative facet orientation than to the presence of a preoperative slip or the extent of decompression; patients with a more sagittal facet orientation are more likely to have postoperative slippage (84).

Instability Following Decompression for Degenerative Spondylolisthesis

Degenerative spondylolisthesis is often an unstable condition and progresses at an average rate of 2 mm per 4 years, even without surgical destabilization (70, 92). Studies have documented the tendency of the slippage to progress in patients who undergo decompression for lumbar stenosis and have degenerative spondylolisthesis (Fig. 171.4) (54). The likelihood of postoperative progression of degenerative spondylolisthesis is related to the preoperative extent of the deformity, the patient's age, the presence or absence of stabilizing osteophytes, whether or not the disc is excised, and the extent of facet removal (84, 113).

Because of poor clinical results with progression of the slip following facet removal, most authorities now advocate preserving as much facet as possible (29, 46, 57, 81, 87). The authors of this chapter and other investigators believe that excision should be limited to one-third of each facet (81). If the decompression requires further resection of each facet, the authors

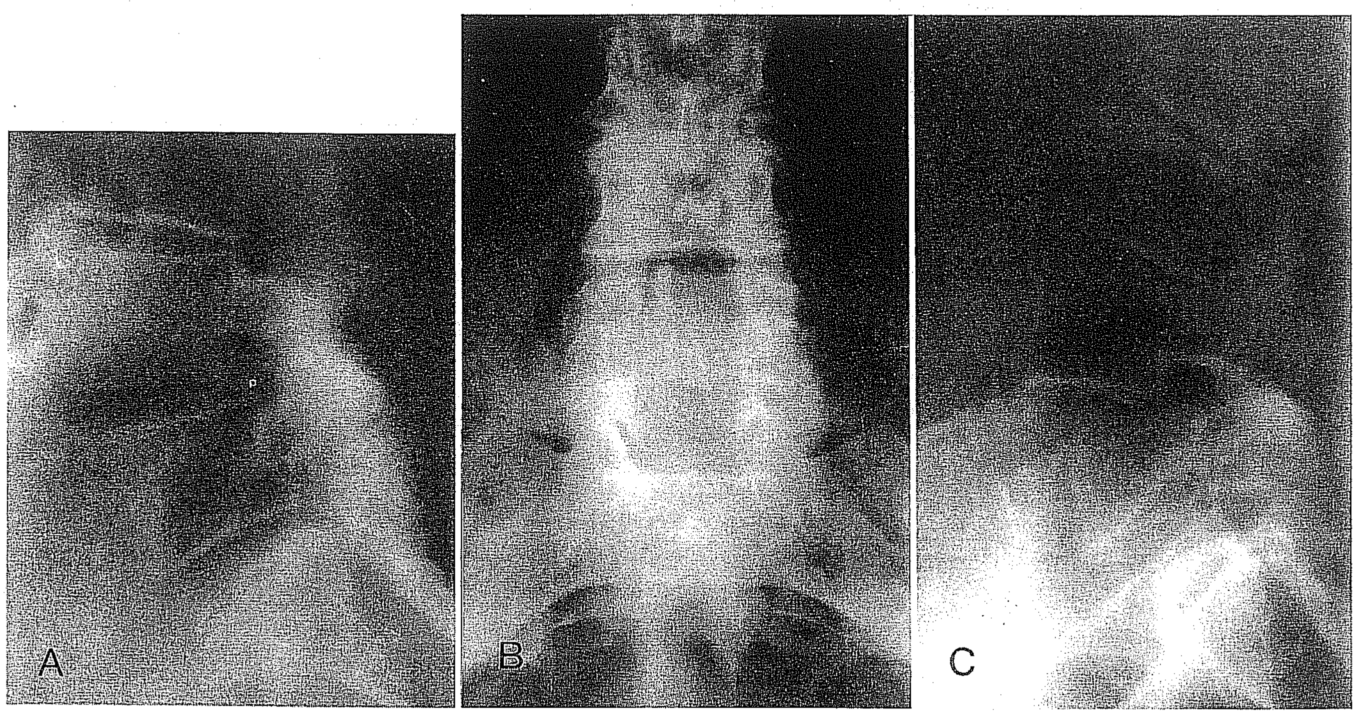

Figure 171.4. A patient with spinal stenosis and slight degenerative spondylolisthesis of the L4–L5 level underwent decompression without fusion. (*A*) Preoperative lateral x-ray shows a slight slip. (*B*) Postoperative anteroposterior x-ray of the lumbar spine shows bilateral laminectomy and partial facetectomy of L4–L5. (*C*) Postoperative progression of the spondylolisthesis is seen on the lateral lumbar x-ray.

also perform fusion to minimize further postoperative slippage.

Indications for Fusion Following Decompression for Degenerative Spondylolisthesis. Although some authorities advocate decompression without fusion for patients with spinal stenosis and preexisting degenerative spondylolisthesis, other investigators argue for concomitant fusion at the time of decompression (12, 25, 39, 57, 61, 70).

The first prospective study of fusion was reported by Herkowitz and Kurz (42), who demonstrated significantly improved results in patients who underwent an accompanying L4–L5 intertransverse floating fusion, compared with patients undergoing decompression only for degenerative lumbar spondylolisthesis. During an average follow-up of 3 years, the slip increased in 96% of patients who did not undergo fusion and in only 28% of those who underwent fusion. Recently, Grobler et al. (35) recommended that the surgeon analyze the facet joint configuration on a case-by-case basis before deciding whether to fuse. These investigators also found that the presence of preoperative spondylolisthesis did not affect outcome (34).

In light of the reports in the literature and personal experience, the authors of this chapter recommend posterolateral fusion for all patients undergoing decompression for spinal stenosis with degenerative spondylolisthesis. Normally, only the involved levels must be fused; for most patients with an L4–L5 degenerative slip, the fusion need not be extended to the L5–S1 level because this level is usually stabilized by bony abnormalities or marked disc degeneration (29).

Additional controversy concerns the necessity for instrumentation when fusion is performed. Some investigators recommend routine instrumentation (38, 49); others do not (42). Still other authorities advocate instrumentation only for selected patients (22). Two recent prospective studies yielded clinical results that were better for patients who underwent fusion and instrumentation with pedicle screw devices than for patients who underwent fusion alone (60, 118). This finding is not surprising in view of recent biomechanical studies demonstrating that pedicle screws are superior to other devices or to no device (2, 36) and that pedicle screw constructs permit the surgeon to spare additional motion segments while providing superior stability (36).

On the basis of these data, the authors now advocate fusion with pedicle screw fixation for patients with degenerative spondylolisthesis who undergo decompression for lumbar stenosis. If osteoporotic bone is present, posterolateral fusion without instrumentation is used. For patients who have had failed posterior surgical fusion procedures with deficient posterior elements, an anterior interbody fusion may be appropriate.

Instability Following Decompression for Isthmic Spondylolisthesis

In contrast to degenerative spondylolisthesis, isthmic spondylolisthesis most commonly occurs at the L5–S1 level and is the result of a bilateral pars interarticularis defect of L5. Some investigators believe that removal of the loose L5 posterior element (Gill procedure) without fusion increases instability (71, 112). In the older patient with a narrowed L5–S1 disc space, Wiltse et al. (112) believe that further slippage is less likely to occur. For this reason, they recommend fusion only for patients younger than 50 years. The authors of this chapter routinely perform posterolateral fusion during decompression for isthmic spondylolisthesis with pedicle screw fixation, unless osteoporotic bone is present.

Instability Following Laminectomy and Discectomy

Special consideration should be given to decompression and laminectomy when combined with discectomy because this combination is more likely to result in instability. The authors routinely perform fusion following discectomy and decompression with extensive bilateral facetectomy (removal of >50% of each facet), even in patients without a preoperative slip.

Instability Following Disc Excision

Routine Discectomy

Ten or more years after routine discectomy, 3% of patients require stabilization as a second procedure for low-back pain (31). Because of this low rate of long-term instability, the authors do not recommend fusion at the time of routine discectomy.

Far-Lateral Discectomy

Controversy exists regarding the amount of facet that may be removed without creating instability when a far-lateral discectomy is performed. Some authorities advocate a complete facetectomy because of the improved visualization of the disc fragment (33, 40, 54), whereas others recommend a limited facetectomy to prevent instability (1, 43, 44).

The authors attempt to save a portion of the facet whenever possible, if doing so does not compromise the decompression. If a complete facetectomy is done, the patient should be observed. If postoperative instability occurs and becomes symptomatic, fusion of the involved level is indicated.

Tumor or Infection with Surgical Destabilization

Because of the lack of rib-cage stabilization below the T11 level, anterior stabilization with instrumentation at these levels should accompany decompression and structural grafting.

Figure 171.5. A 60-year-old patient developed instability at the L3–L4 level 2 years after undergoing an L4–S1 floating fusion for instability at the L4–S1 levels. (*A*) Lateral x-ray of the lumbar spine taken in flexion. (*B*) Lateral x-ray of the lumbar spine taken in extension.

Post-traumatic Instability Secondary to Laminectomy

Treatment of postlaminectomy instability after trauma to the lumbar and thoracolumbar spine is similar to that after trauma to the thoracic spine. Caudal to T11, bone grafting should be accompanied by instrumentation. In the lumbar spine, however, pedicle screw fixation, rather than hooks and rods, can be used. This type of fixation preserves more motion segments than can be preserved with hook/rod constructs.

Instability Following Spinal Fusion

Instability above or below a Fused Segment

Fusion of a spinal level increases motion and shear stresses above and below the level of a solid fusion, and instability can develop with time (Fig. 171.5). After L4–L5 fusion, the appearance of instability at L3–L4 is uncommon. However, patients with L5–S1 fusions are much more likely to develop instability at the L4–L5 level. If unstable levels are not incorporated into a fusion, existing instability can worsen following surgery because of the increased stress. If instability does develop with time, appropriate levels should be fused when they become symptomatic.

Instability Resulting from Fusion Failure

The risk of instability from fusion failure increases with extensive facetectomy, discectomy, and multilevel fusions.

In the surgical treatment of pseudarthroses, either an anterior fusion (52) or a posterior fusion can be performed (108, 118). Recently, Zdeblick (118) published the results of a prospective, randomized study of lumbar fusions. He noted a 20% fusion rate for the treatment of pseudarthrosis with fusion alone and a 100% fusion rate for posterior instrumentation with either a pedicle screw/plate or a pedicle screw/rod construct.

The authors' experience has been similar. Therefore, posterior fusion with transpedicular instrumentation is recommended for symptomatic patients with pseudarthroses. For patients who had pedicle screws inserted previously, an anterior interbody fusion, with or without a staged posterior fusion, is used.

Acquired Spondylolisthesis

Acquired spondylolisthesis is present in 1% of patients who have undergone prior midline fusion and appears to be due to a fatigue fracture or excessive decortication of the pars (30, 31). Treatment for these patients is similar to that for patients with pseudarthroses.

SUMMARY

Iatrogenic instability can often be prevented by recognizing a potentially unstable condition preoperatively and avoiding further destabilization. If instability is present or is created intraoperatively, a stabilizing procedure often can improve the patient's outcome.

Recent techniques, which are rapidly evolving, give the surgeon a variety of options to use to prevent and treat this devastating problem.

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