CHAPTER 13

Other Anatomic Disorders of the Spine

Spondylolisthesis

Spondylolisthesis is defined as the forward slippage of one vertebra on its adjacent caudal segment. The term is derived from the Greek words for vertebra and to slip or slide. Spondylolisthesis has been recognized since the late eighteenth century, when it was first described by obstetricians as a barrier to the passage of the fetus through the birth canal.[55]

Spondylolisthesis is one of the most variable conditions affecting the pediatric spine. The severity of its clinical presentation ranges from a coincidental radiographic finding in asymptomatic patients to a disabling deformity that produces severe postural and gait disturbances, pain, and neurologic impairment affecting the lower extremities, bowel, and bladder. Just as the presenting symptoms can vary, so does the radiographic severity of the slip, which ranges from a few millimeters of anterior displacement to complete dislocation of L5 anteriorly over the sacrum (termed *spondyloptosis*). There is much continued controversy over the surgical treatment alternatives in severe cases. Because of the complexity of treatment, it has become important to have a classification system to help define the pathology and natural history of the various forms of spondylolisthesis to direct the treatment of this condition.

CLASSIFICATION

Neugebauer first divided spondylolisthesis into congenital or acquired types in 1880.[85] Capener followed, separating patients with spondylolisthesis into two groups: cases in which there is fracture of the pars interarticularis (termed *spondylolysis*) and the slippage of the vertebra occurs through the fracture and cases in which the pars is not fractured but elongated and the abnormal anatomy of the spine allows for forward slip.[19] This principle has led to the commonly used classification described by Wiltse and colleagues.[136] They divided spondylolisthesis into five types based on the radiographic findings and age at presentation:

Type I: Dysplastic (also known as congenital or developmental). This type is characterized by an anatomic predisposition to slip because of abnormalities in the L5–S1 articulation. There may be an intact pars interarticularis or elongation of the pars to allow forward slippage. Lysis of the pars may be present because of the abnormal stresses that the congenital vertebral malformations of the facet joint place on it.

Type II: Isthmic (also known as spondylolytic). This form is characterized by a stress fracture through the pars interarticularis, with forward slippage occurring through the fracture so that the posterior elements of the fractured vertebra are left in situ.

Type III: Degenerative. This type presents in adulthood and is associated with segmental intervertebral instability.

Type IV: Posttraumatic. This form is characterized by an acute fracture following an episode of trauma resulting in forward slippage of the caudal vertebra by displacement of the fracture site.

Type V: Pathologic. This type is characterized by attenuation of the pars from a generalized or localized bony pathologic process. Examples include osteogenesis imperfecta, osteopetrosis, or connective tissue diseases such as Ehlers-Danlos syndrome.

The discussion in this chapter is limited to Wiltse types I and II.

Marchetti and Bartolozzi have further modified the Wiltse classification.[76] They subdivide type I slips into a high dysplastic spondylolisthesis that results in lumbosacral kyphosis and a low dysplastic type where the slip is purely translational, the vertebral endplates remain relatively parallel, and there is no associated kyphotic deformity. The differentiation of these two types has implications for the potential for slip progression, the risk of neurologic involvement, the choices for surgical treatment, and sometimes the rate of healing following surgical fusion.[28]

Dysplastic Spondylolisthesis (Wiltse type I). The dysplastic form of spondylolisthesis occurs only at the L5–S1 level and is due to a primary congenital dysplasia of the L5–S1 facet joints (Fig. 13–1). Its congenital nature is supported by the fact that it is most often associated with spina bifida occulta of L5 and/or S1. The anatomic incompetence of this facet joint allows the slipping (listhesis) to begin. Without

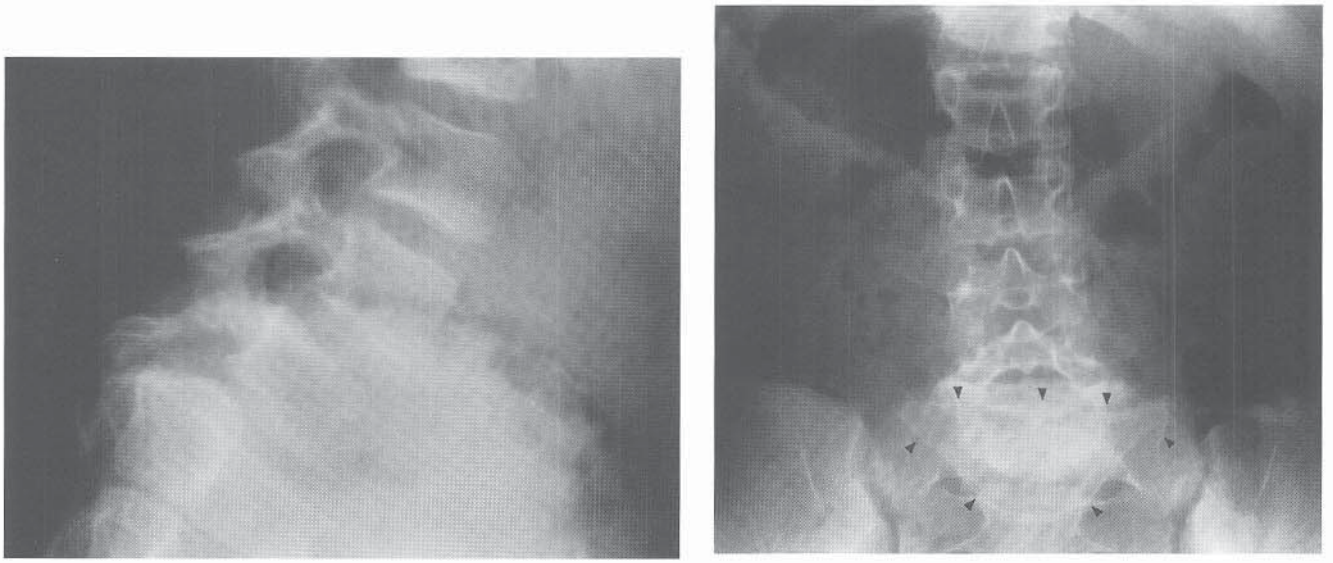

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FIGURE 13–1 **A,** Dysplastic spondylolisthesis. The L5–S1 facet is congenitally dysplastic. Listhesis has occurred in conjunction with subluxation of the L5–S1 facets. This patient presented in neurologic crisis from severe listhesis without a pars elongation or defect. **B,** When the L5 body is displaced well forward of the sacrum, it is projected on an AP radiograph as an upside-down "Napoleon's hat."

lysis or elongation of the pars, such forward vertebral slipping beyond 25 percent would almost certainly produce neurologic deficit as the posterior neural arch impinges on the dura. In the absence of a pars defect, the dural constriction may produce symptoms in childhood. Frequently the patients remain asymptomatic until early adolescence and the prepubertal growth spurt, when they present with severe leg pain and hamstring spasm resulting in gait disturbances, with or without back pain.[24,76,81,86]

In some cases, a pars defect is found along with the congenitally abnormal L5–S1 articulation, differentiating this form from the type II slip, where the L5–S1 articulation is anatomically normal but a stress fracture occurs in the pars and the slip migrates by displacement of the stress fracture. When there is an isthmic defect in a dysplastic slip, or when elongation of the pars is sufficient not to constrict the cauda equina, the displacement can become quite severe without neurologic sequellae, since the dural sac is not impinged by the posterior elements.

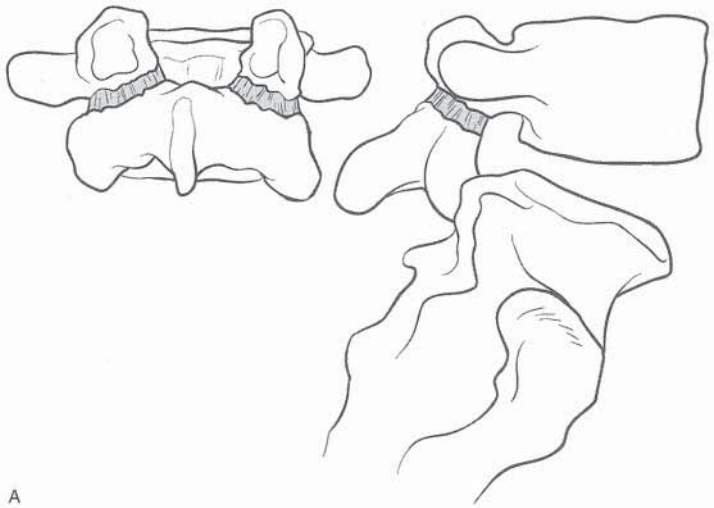
Dysplastic spondylolisthesis is reported to be more common in females and has an increased incidence in first-degree relatives of patients, suggesting a genetic etiology that results in the congenitally incompetent facet.[24]

Isthmic Spondylolisthesis (Wiltse type II). The isthmic type of spondylolisthesis is a more common and a more benign form that rarely produces significant neurologic findings or gait disturbance (Fig. 13–2). The incidence of the pars stress fracture, or spondylolysis, has been reported to be 4.4 percent at age 6 years and 6 percent at age 18 years, indicating that stress fractures of the pars interarticularis are fairly common.[40] Spondylolysis is most prevalent at L5, accounting for 87 percent of all stress fractures, followed by lysis at L4 (10 percent) and L3 (3 percent).[99] There is a familial tendency toward isthmic spondylolisthesis[40,121,133,138] and a racial predisposition to stress fracture: the incidence is low in the black population and extremely high in the Eskimo population.[35,121,127] It has been estimated that the incidence of isthmic spondylolisthesis stabilizes in adulthood, during which the degenerative type of spondylolisthesis predominates.

Mechanical causes have been described in the production of pars defects. The pars region is the weakest area of the neural arch, making it susceptible to fatigue fracture.[23] Histologic analysis of fetal and stillborn vertebrae have identified uneven trabecular bone formation and cortical irregularity of the pars interarticularis in the lower lumbar vertebrae as a result of irregularities in the development of the ossific nucleus.[102] This histologic peculiarity may act as a stress riser in lower lumbar vertebrae.

Pars defects have not been observed in newborns or nonambulatory patients, and pars lysis or elongation does not occur in primates that do not have upright bipedal gait.[137] The presence of lumbar lordosis, which is unique to humans, is thought to be necessary for spondylolisthesis to occur. Both flexion and extension forces have been implicated in the production of these stress fractures.[31,39] The increased incidence of isthmic spondylolytic defects in athletes who perform repetitive lumbar hyperextension (e.g., gymnasts,[61] football linemen,[112] pole vaulters, cricket bowlers[30]) confirms that a repetitive hyperextension activity is a leading cause of the L5 stress fracture. Spondylolisthesis occurs more frequently if L5 has short transverse processes and is high riding relative to the iliac crest. This susceptibility to spondylolisthesis may occur because the L5 vertebral body is hypermobile when it is not anchored deeply in the pelvis with strong ligaments attached to longer transverse processes.[39,80,87]

An isthmic spondylolysis in an adolescent can progress to a listhesis as a result of shear forces present during upright gait. An anterior force on L5 is produced, increasing as the



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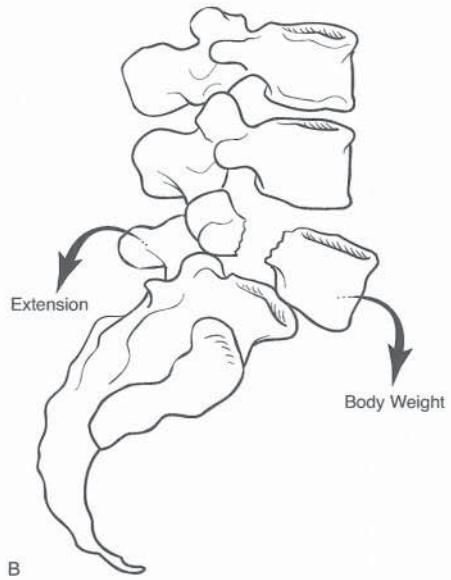

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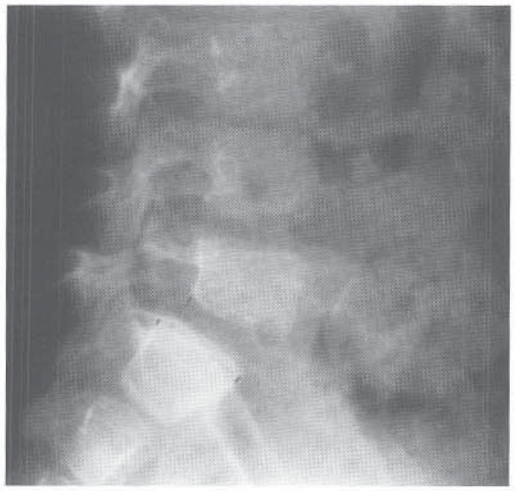

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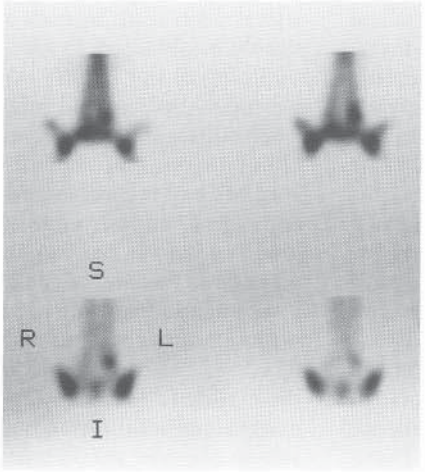

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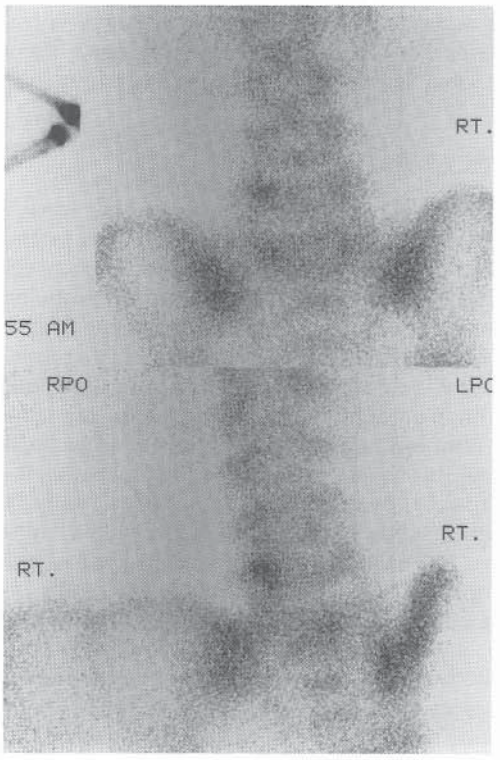

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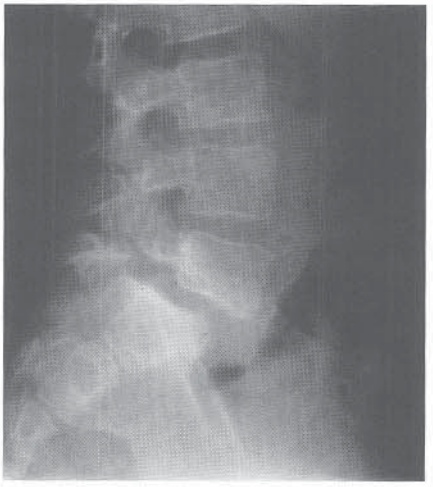

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FIGURE 13–2 **A,** Isthmic spondylolysis, beginning as a stress fracture of the pars. **B,** Progression of the anterior translation of L5 due to mechanical forces (axis of body weight and extension produced by posterior musculature) in a growing child. **C,** Lateral radiograph in a 4-year-old child with back pain. There is a pars defect and 13 percent listhesis. **D,** Bone scan demonstrating unilateral "hot" lysis on the left. **E,** SPECT scan demonstrating same active lysis. **F,** Although orthotic management eliminated the symptoms, the listhesis increased to 29 percent over 4 years. Observation continues.

spine is flexed. The posterior muscle attachments that act on the laminae and spinous process hold this part of the neural arch in place and thus tend to separate or distract the spondylolysis further. With strong anterior deflection forces, a slip between the sacral apophysis and end-plate may also rarely occur, allowing anterior translation and rotation of the slipping vertebra.[103] Thus, an isthmic spondylolysis in a growing child can progress to a significant spondylolisthesis, even in the absence of congenital dysplasia of the lumbosacral facets.

Other Types of Spondylolisthesis. Degenerative spondylolisthesis, which occurs in adults, will not be discussed in this chapter. Similarly, traumatic spondylolisthesis, a rare condition resulting from significant spinal trauma, is more appropriately discussed under the management of spinal injuries. Pathologic spondylolisthesis is treated in the same fashion as a nonpathologic spondylolisthesis of the same grade and severity,[77] with the treating surgeon realizing that the underlying bone pathology may make pseudarthrosis more likely and treatment failure more frequent.

CLINICAL PRESENTATION

The age at presentation is probably the most important determinant of symptoms and the need for treatment. Both dysplastic and isthmic spondylolisthesis can show up in childhood and adolescence, with the dysplastic type usually becoming evident at an earlier age (owing to greater instability of the lumbosacral junction, which results in lower extremity neurologic symptoms). Children may present without pain but with deformity and gait abnormalities from lumbosacral instability as the only neurological signs.[81] Asymptomatic spondylolyses are common and, if symptomatic, usually manifest with low back pain only. This is not surprising considering that the lysis produced by stress fracture in, for example, the adolescent gymnast produces no slippage and hence no neurologic risk. Pain may radiate to the buttocks and posterior thighs from mechanical instability, and it is usually aggravated by flexion and extension activities. Mechanical low back pain symptoms are always a cause for suspicion in a child or adolescent and mandate radiography, especially in a susceptible athlete or dancer.

Physical examination of the spine may actually be normal in spondylolysis or a low-grade (less than 50 percent) listhesis. If a spondylolisthesis is present, a palpable step-off at the lumbosacral junction may be present, and back pain may be elicited by standing hyperextension stress. As the degree of listhesis increases, more obvious physical findings can be appreciated, including a postural disturbance of flexed hips and knees combined with sacral prominence posteriorly and hyperlordosis proximal to the slip. Hamstring tightness, thought to be due to lumbosacral instability and subsequent rotation of the sacrum into a more vertical position rather than to actual nerve root or dural impingement,[81] may cause a distorted gait owing to the individual's inability to take a normal stride. The individual may also have to walk on tiptoes because of the flexed hip and knee positions (Fig. 13–3). In a severe disturbance, the individual may actually walk sideways in a bizarre fashion because the hamstrings are so tight that no forward stride can be taken at all. Straight-leg raising with the patient supine on an examining table may be dramatically limited. Because of the vertical position of the sacrum and pelvis, a backward pelvic tilt and an abdominal crease may be obvious cosmetic complaints, with the prominence of the sacrum posteriorly producing the so-called "heart-shaped" buttocks. Because of hamstring tightness, forward bending will probably be limited in such a circumstance, and an olisthetic scoliosis producing marked spinal decompensation with hyperlordosis can be observed (Fig. 13–3). This type of scoliosis is often rigid, having been produced by the irritative phenomenon of the slip, and is a measure of how severe the spondylolisthetic crisis has become.

Neurologic evaluation of the lower extremities may uncover an actual L5 or S1 root weakness. This may include a motor weakness or the loss of an ankle jerk reflex. Bowel and bladder function must be evaluated by history, including questions about incontinence but also about decreased frequency of urination, for example. Sacral sensation and rectal tone are important evaluations of cauda equina function. Any patient who is to undergo surgical treatment must have these functions evaluated preoperatively.[27,108] If the patient reports infrequent urination, bladder capacity should be determined by cystometrography and urologic consultation.

RADIOGRAPHIC FINDINGS

The diagnosis of a spondylolysis or listhesis is made from a single *standing* spot lateral radiograph of the lumbosacral junction (Fig. 13–4). A standing radiograph is emphasized, to measure both displacement and the true angulation of the lumbosacral junction if present.[74] Although other radiographic features have been described, it is the degree of translational displacement and the amount of lumbosacral kyphosis, as measured by the slip angle, that determine the course of treatment.

A unilateral pars defect may be difficult to see on a single lateral plain film. In such an instance, oblique radiographs should be obtained. Proper positioning is confirmed by easy outlining of the "Scotty dog" head and neck (the articular processes superior and inferior, and the pars in between) at levels adjacent to the level of interest (Fig. 13–4B). The oblique views may show the defect, elongation, or sclerosis suggestive of a chronic stress reaction. A defect that is wide and has a smooth edge suggests a longstanding chronic lesion, whereas an irregular edge suggests a more acute process. If the clinical situation suggests acuteness, such as a recent injury producing back pain, then a bone scan or single-photon emission computed tomograph (SPECT) may be "hot," confirming an acute lesion (see Fig. 13–2). In these recent "fractures," an attempt to heal the lesion by external immobilization is justified. CT is occasionally necessary to diagnose occult pars lesions that cannot be visualized on plain films (Figs. 13–4D to F). Thin, 1.5-mm sections are recommended to observe the lysis. CT scans with three-dimensional reconstruction can be useful in a severe dysplastic spondylolisthesis in a preoperative evaluation to characterize the pathologic anatomy more precisely.

Disk herniation in association with spondylolisthesis has been reported in as many as 25 percent of cases at the next level above the slip, and in 15 percent at the level of the listhesis itself.[30] Magnetic resonance imaging (MRI) may

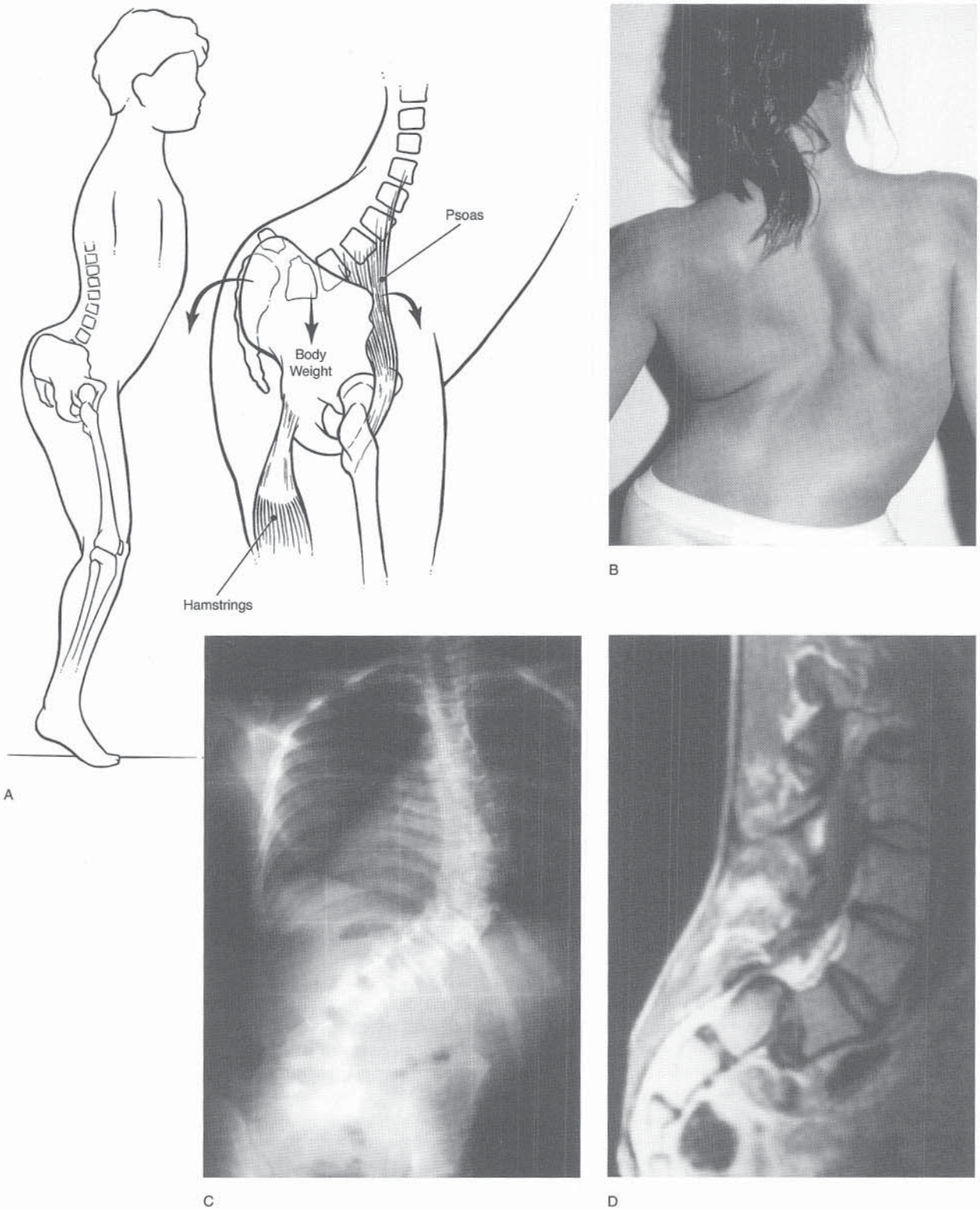


FIGURE 13–3 **A,** Postural disturbances—hyperlordosis, hip and knee flexion, equinus—from severe spondylolisthesis. The hamstrings exacerbate the flexion rotation of the pelvis, producing a vertical sacrum, while the psoas flexes the spine, displacing L5 forward. **B** to **D,** Olisthetic scoliosis with hyperlordosis in a 12-year-old girl with nearly 100 percent listhesis as seen on MRI. The scoliosis is characterized by a severe trunkal shift without concomitant rotation or vertical wedging.

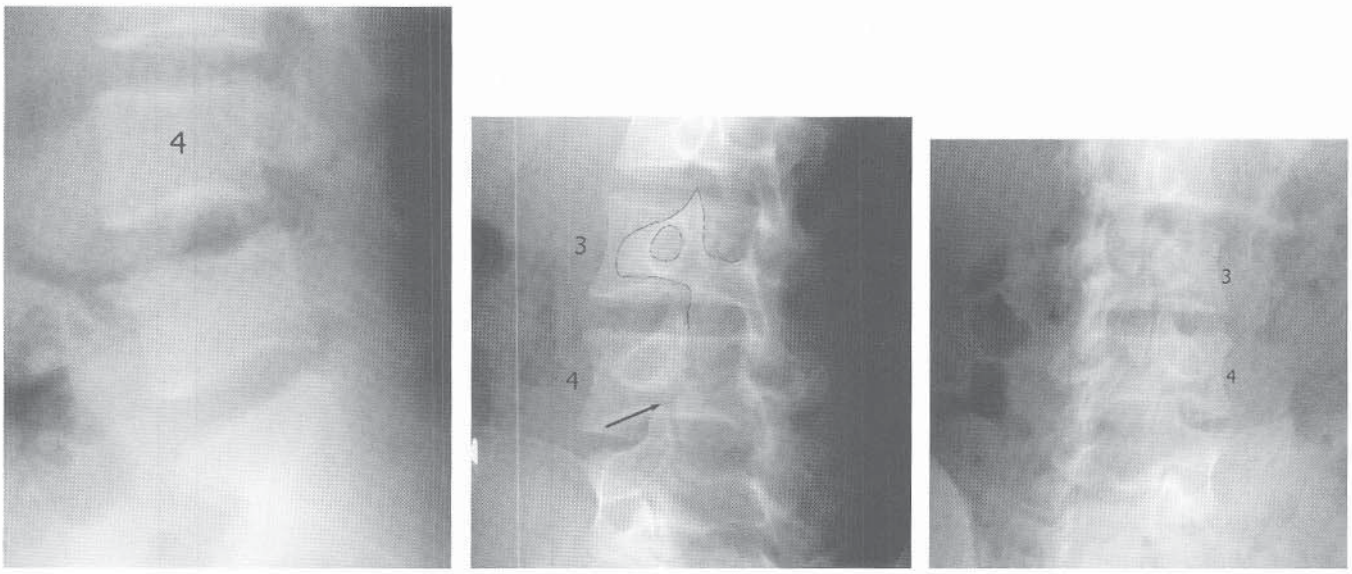


FIGURE 13–4 **A,** Standing spot lateral radiograph showing a defect in L4 pars. **B,** Oblique radiograph. The intact "neck" of the scotty dog at L3 is compared to the defect in the pars of L4. **C,** Contralateral oblique radiograph obtained at the same level. Stress fractures are equivocally seen at L3 and L4.

therefore clarify the clinical picture in the patient with L5 radicular symptoms and minimal listhesis, or in the patient with radicular symptoms not correlating with the level of the slippage. MRI is also useful to rule out other causes of lumbosacral dysfunction, such as tumor or infection, and may also demonstrate a slipped vertebral apophysis if present.

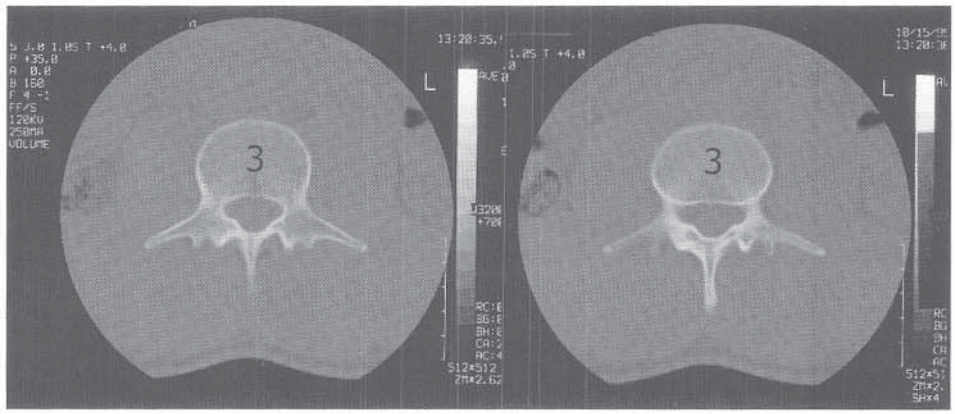
The radiographic parameters of deformity in spondylolisthesis help to define the severity of the condition and the need for treatment. The degree of anterior translation—the displacement of L5 on S1—is measured by the method of Taillard (Fig. 13–5A),[122] or it can be described by the classic Meyerding grades (Fig. 13–5B).[80] The lumbosacral kyphosis, or sagittal rotation, is measured by the slip angle (Fig. 13–5C). It is important to construct the slip angle from the tangential line of the *upper* end-plate of L5, because the lower end-plate of L5, the site originally described by Boxall,[10] is almost always deformed and rounded by the process of slipping, and furthermore often cannot be identified on a postoperative radiograph when fusion has occurred either spontaneously or surgically. The cephalad end-plate of L5 is consistently present and undeformed and thus should be used for this measurement. The body of L5 may become trapezoidal in shape, a response to impression by the dome of the sacrum, and such distortion points to a more severe deformity. The sacrum may be rotated toward a vertical position, which is described by the sacral inclination, the angle between a vertical line and the same line paralleling the posterior edge of the proximal sacrum used to measure the slip angle (Fig. 13–5C). Of course, besides an appreciation of the deformity, the standing lateral radiograph must be carefully inspected in a case of spondylolisthesis to determine whether the pars interarticularis is elongated or actually fractured (see Figs. 13–1A and 13–2A).

Because of the lumbosacral kyphosis, a standing or even supine anteroposterior (AP) radiograph of the sacrum will be difficult to interpret because of the superimposition of L5 and the sacrum ("Napoleon's hat" sign) (see Fig. 13–1B). To eliminate this superimposition, to evaluate spina bifida occulta, and, most important, to evaluate the quality of the postoperative fusion mass accurately, a Ferguson view of the sacrum is recommended. The Ferguson view is an outlet view of the pelvis and thus shows the L5 and S1 bodies in their true AP position.[72]

PROGNOSIS AND NATURAL HISTORY

Once the diagnosis of spondylolisthesis or spondylolysis has been made, the risk of progression is the most important determinant of treatment. The age of the patient probably ranks foremost in determining whether observation, nonoperative management, or immediate surgical stabilization is appropriate. The younger the patient and the greater is the growth potential, the greater is the risk that progression of the deformity will occur. The adolescent growth spurt continues to be the main period of risk, as significant progression of either translation or kyphotic deformity is uncommon after maturity in a mild (less than 50 percent slip) deformity.[104] Other indicators of prognosis include repeated episodes of symptomatic pain, hamstring spasm, and a postural deformity or gait disturbance. These symptoms suggest displacement and instability that is unlikely to respond long term to a nonoperative course.

Radiographically, the presence of a dysplastic listhesis is very significant. Patients with dysplastic L5–S1 facets must be followed closely for progression in the unusual circumstance in which the diagnosis is made before significant deformity and symptoms have developed. Such findings as a dome-shaped and vertical sacrum, a trapezoidal L5, and a kyphotic slip angle are all indicators of a high-grade dysplastic deformity that is more likely progress.[10,76] On the other hand, a sclerotic buttress on the anterior edge of the



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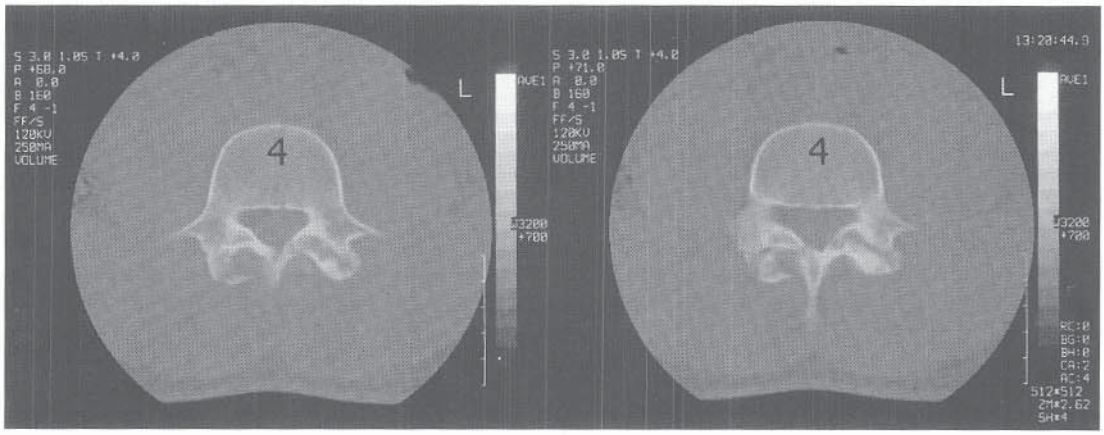

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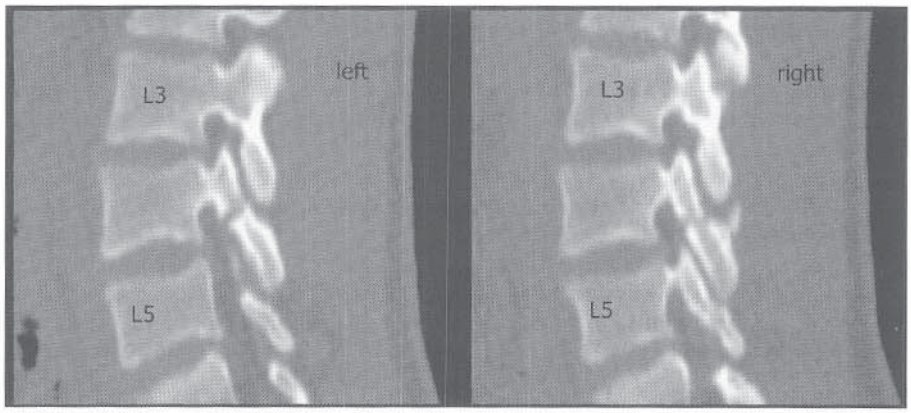

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FIGURE 13–4 *Continued.* **D** and **E,** To confirm the pars defect(s), CT scans of both levels were obtained. L3 is normal, while L4 clearly has bilateral pars reactions indicating stress fractures. **F,** A sagittal reconstructed image clearly demonstrating an L4 lesion and normal L3 pars.

sacrum suggests a more stable L5–S1 articulation with an element of spontaneous ankylosis, a much less sinister radiographic finding. Similarly, isthmic listhesis (acquired) without dysplastic changes should progress little.

The natural history of *untreated* spondylolisthesis is fairly satisfactory, although patients often have impairment. Harris and Weinstein in an 18-year (average) follow-up of untreated spondylolisthesis greater than 50 percent noted only mild symptoms in the majority of patients, although 36 percent reported an influence on their job choice and 45 percent avoided heavy lifting.[51] Most noted some limitation in recreational activities. Only mild progression of the listhesis occurred, and symptoms were significant in only one of 11 patients. In lower-grade slips (<30 percent), progression is unexpected unless the patient is immature,[7] and even then progression occurs rarely in isthmic (acquired) defects.[42] Conservative treatment of low-grade slips has been reported to yield the same results as operative treatment,[43,110] and in general progression of listhesis is mild and has no correlation with later symptoms on long-term follow-up. Thus, *prophylactic* treatment of the lower-grade spondylolisthesis to avoid later progression of slip does not, in general,

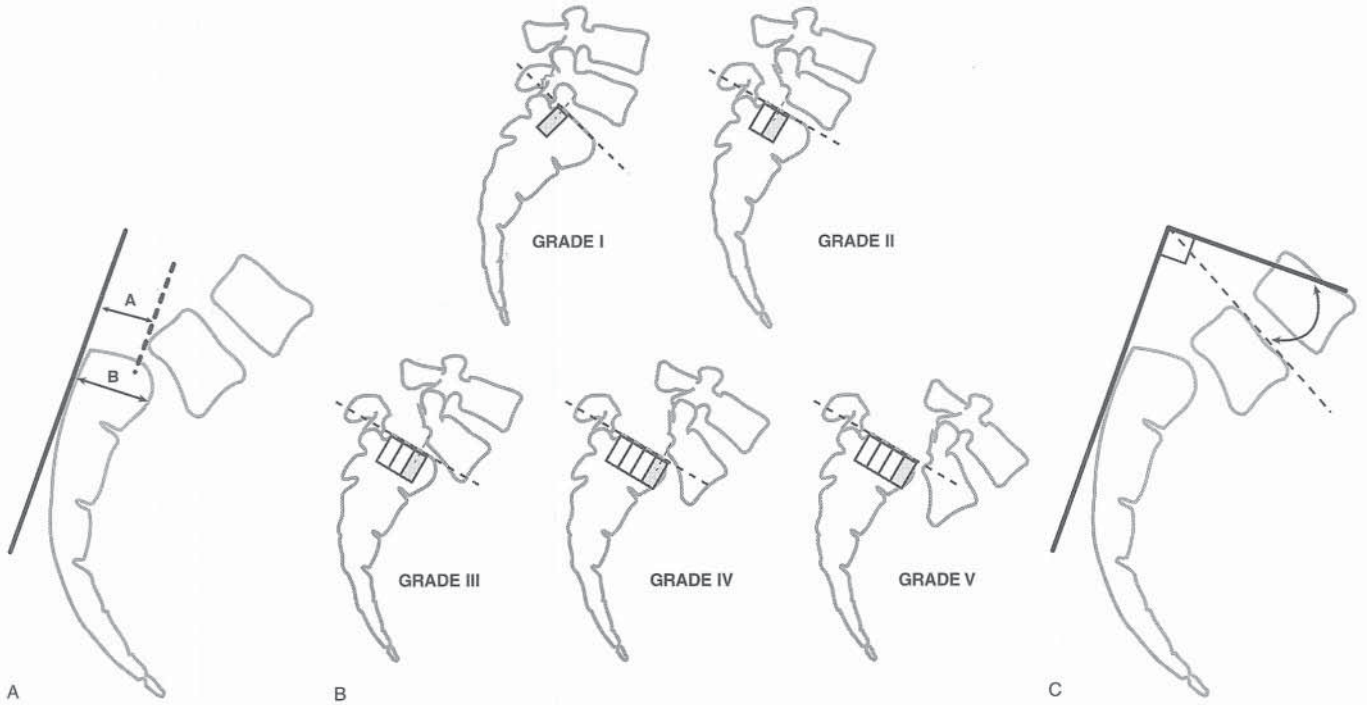


FIGURE 13–5 **A,** The percentage of forward slip *A/B*, described by Taillard. **B,** Meyerding grades I–IV. The degree of spondylolisthesis is determined by dividing the sacral body into four segments. Grade V is a complete spondyloptosis. **C,** The slip angle measured from the *superior* border of L5 and a line drawn perpendicular to the posterior edge of the sacrum.

appear to be justified, especially when a low incidence of progression is expected.[42,104] While patients with spondylolisthesis may have disk degeneration and other low back impairment as adults,[104,111] such problems do not appear to be due to progression of the deformity, which in some series is not altered by the presence of a fusion in situ. The data on the effectiveness of surgical treatment in preventing long-term progression are confounded by the fact that technically questionable posterior fusions were performed in many of the patients in whom longer follow-up was available. The controversy surrounding the need for more aggressive treatment in higher-grade spondylolisthesis, such as circumferential fusion and/or reduction of the listhesis, stems from the either favorable or unfavorable interpretation of the long-term studies of natural history and of the results of in situ posterior fusion.[10,17,43,60,111]

TREATMENT

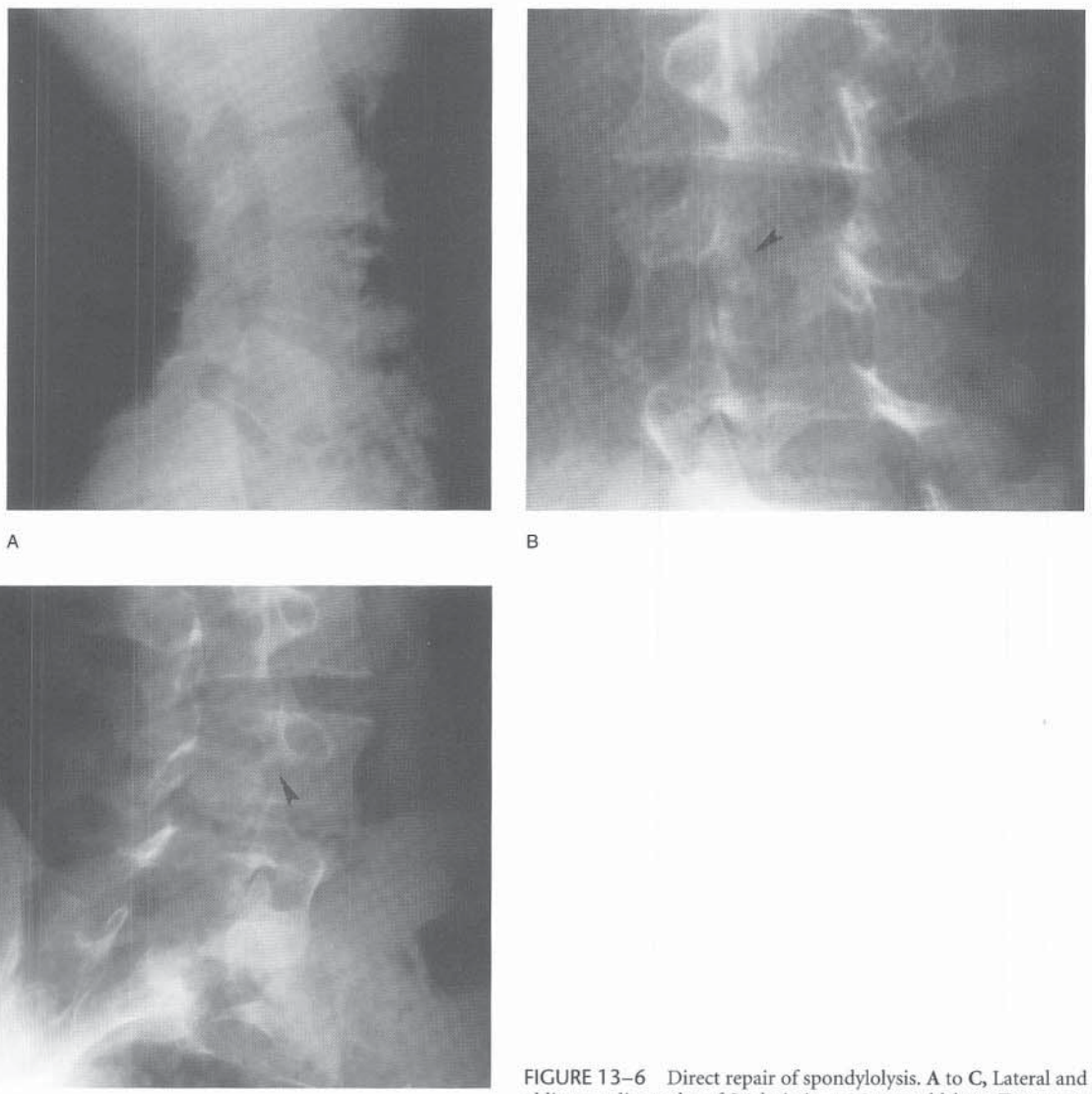
Spondylolysis. The symptomatic patient with spondylolysis without listhesis requires treatment for transient mechanical low back pain. A large number of patients will be asymptomatic, with a history of antecedent trauma in the past or with the diagnosis having been made coincidentally during investigation for other problems (e.g., scoliosis). An asymptomatic patient needs no treatment and, if more than 10 years old, probably needs no follow-up either to check for progression to a listhesis. No restrictions on activity are necessary, but if the patient is younger than 10 years the possibility of progression should be raised and the patient counseled to return for reevaluation should symptoms occur. It has been our experience that patients with spondylolysis or minimal listhesis who are asymptomatic do not need regular follow-up to check for progression, because progression of deformity will uniformly be accompanied by the onset of symptoms.

In the patient with symptomatic spondylolysis, the level of treatment may depend on the determination of whether the stress fracture is acute or relatively chronic. As mentioned earlier, routine radionucleotide scintigraphy or SPECT may be useful to determine the chronicity of the lytic defect, and if the bone scan is "hot" (Fig. 13–2), immobilization of the lumbosacral junction with a TLSO brace or a cast may be attempted in an effort to heal a lytic defect. With recent attention to the early diagnosis of so-called stress injuries of the pars, thought to be a prodromal event occurring before plain radiographs show an actual lysis, SPECT has proved to be the most sensitive diagnostic test for presumed impending spondylolysis. Rest and immobilization appear to prevent progression to a pars defect if instituted on discovery of a hot SPECT scan but prior to actual radiographic lysis.[2] On the other hand, documentation of healing of an acute spondylolytic *defect* by this technique is lacking, and it is our impression that such defects rarely heal solidly with nonoperative external immobilization. But, in the patient with severe back pain, external immobilization for a period of 3 to 6 months may be the most effective way to resolve symptoms. Curtailing inciting activities is probably the main issue in patients with symptoms related to athletics. Although abdominal and back-strengthening exercises are often prescribed, most adolescent athletes are already in excellent physical condition, and abdominal and back musculature-strengthening exercises are superfluous. The mainstays of treatment—rest, avoidance

of inciting activities, use of anti-inflammatory pain medicines, and use of a brace in an extreme situation—usually allow an acute symptomatic spondylolysis to resolve.[6,95,120]

Once the patient is asymptomatic, a full return to all activities without restriction is permitted. Follow-up is unnecessary unless symptoms recur. Should symptoms recur after return to a higher level of activity, two treatment options must be discussed with the patient: abandonment of the activity that produces symptoms, or possible surgical treatment, either to repair the lytic defect or to eliminate movement at the spondylolytic segment with a one-level fusion.

Direct repair of the lytic defect is indicated when nonoperative measures do not prevent the recurrence of symptoms on return to activity. The obvious advantage of direct repair is that it obviates fusion, and theoretically would produce less morbidity in the short and long term. Prerequisite to defect repair is ensuring that disk herniation or other pathology (osteoid osteoma, apophyseal avulsion) is not present.[15,128] Several methods of direct pars repair have been reported, including screw fixation[15,92] across the defect, compression wiring[89] between the transverse process and the spinous process (Fig. 13–6A),[14,62,128] and combinations of pedicle screw and laminar hook constructs.[53,65,83,126] Radiographic union can be achieved in 80 to 90 percent of patients with appropriate indications, with 80 percent good or excellent clinical results.[14,16,92] The direct repair of the pars is probably best suited to a lytic defect of L4 or above, as limited L5–S1 fusion for an L5 defect carries little morbidity or loss of motion. Repair of a spondylolytic defect may be destined to fail clinically if there is any preoperative evidence of disk degeneration at this level; thus, MRI evaluation of the involved disk is mandatory prior to performing a spondylolytic repair at this level. Direct repair is also more likely to succeed in the patient under 30 years of age.[14,53,128] The advantage of a wiring technique is that the implant takes up little space, and thus the pars defect may be thoroughly curetted and debrided and the lamina, transverse process, and spinous process thoroughly decorticated prior to bone grafting the defect and tightening the com-



A B C

FIGURE 13–6 Direct repair of spondylolysis. **A** to **C**, Lateral and oblique radiographs of L4 lysis in a 16-year-old boy. Treatment was by compression wiring and bone grafting.

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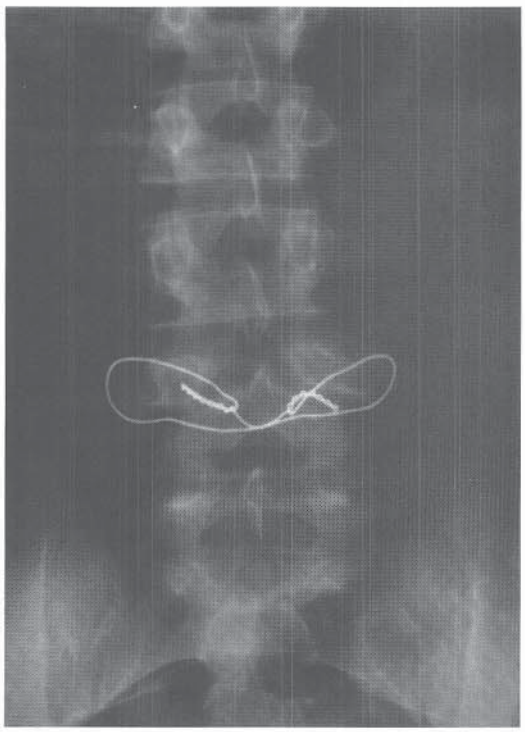

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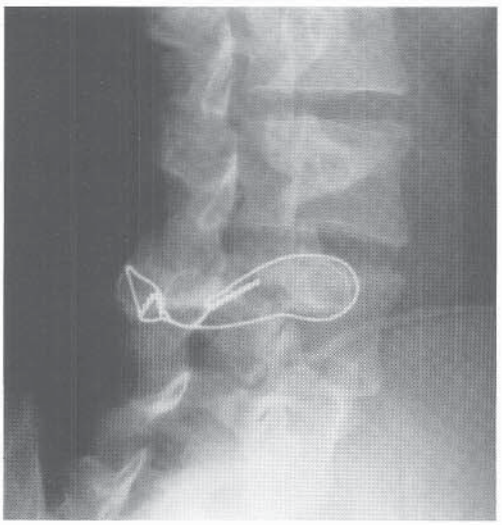

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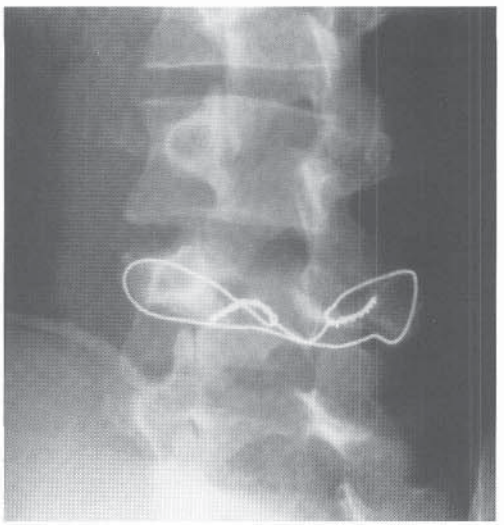

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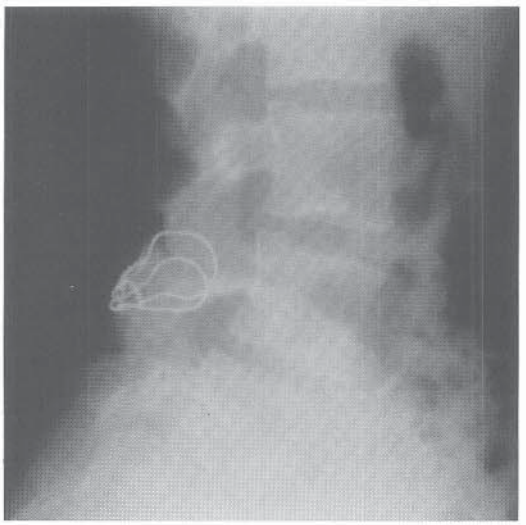


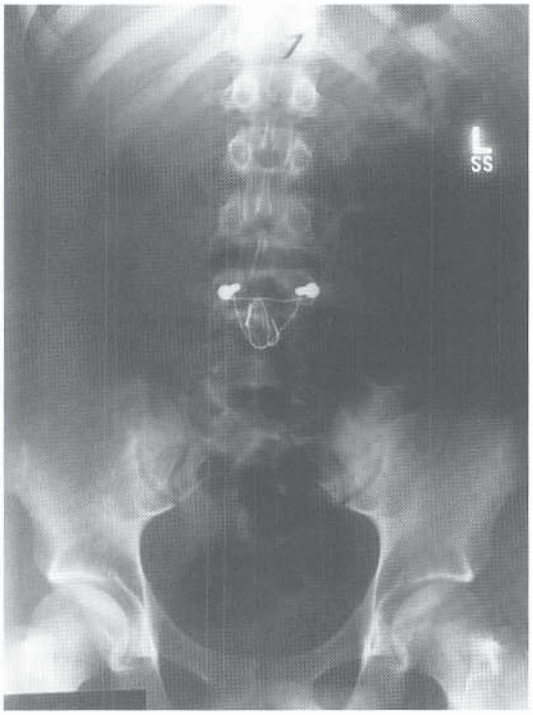
G

FIGURE 13–6 *Continued.* **D** to **G,** Radiographs obtained 18 months postoperatively. The pars defects have healed and the patient is without symptoms, but is less active than before presentation.

pression wire. However, the strength and stiffness of wire have proved suspect in mechanical studies,[67] which have shown that such a tension-band technique is loaded only in flexion. Because extension forces produce pars failure,[31] the biomechanical soundness of the wiring technique has been questioned.[47,67] More effective compression across the defect can be achieved by the pedicle screw-laminar "claw," with increased stiffness and fatigue resistance arising from the solid rod connecting the two points of fixation.[65,126] Unfortunately, healing of the pars defect cannot be assessed radiographically due to the volume of metal in the screw-claw technique, so that removal of the constructs is necessary to assess healing.

Low-Grade Spondylolisthesis (<50 Percent Slip). Low-grade spondylolisthesis may be treated in similar fashion as spondylolysis without slip, with one important exception or caveat: The presence or absence of dysplastic features should be determined as accurately as possible at the outset, as it may impact prognosis.[54,60,86] Age at onset, with children less than 10 years old being at increased risk in general, must also be taken into consideration.

An asymptomatic patient with an isthmic (acquired) spondylolisthesis of low grade and without dysplastic characteristics needs no active treatment. Follow-up is probably necessary only if symptoms arise, since further slipping will not occur without the appearance of symptoms. Patients



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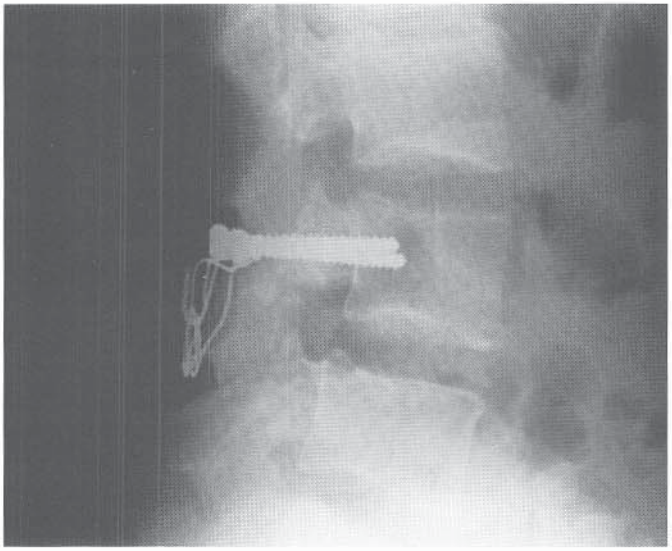


I

FIGURE 13–6 *Continued.* **H** and **I,** Alternative method using pedicle screws as wire anchors instead of looping around the transverse process. Same patient as in Figure 13–4.

less than 10 years old can be followed at 6-month intervals radiographically for maximum surveillance, with regular follow-up abandoned if the patient reaches near-pubertal status (age 11 for girls, age 13 for boys) without evidence of progression. The situation changes, however, if dysplastic changes occur, especially in the under-10 age group. Close follow-up is recommended, and if any lumbosacral kyphosis is present or develops, an argument can be made that prophylactic fusion should be performed.[28] This is particularly indicated in patients with listhesis without lysis, because of the increased possibility of neurologic deficit from forward slippage and constriction of the cauda equina.[107,108] Prophylactic fusion is also gaining acceptance due to the fear of a low-grade spondylolisthesis becoming a high-grade dysplastic spondylolisthesis once a spondylolytic defect occurs in the previously elongated pars. If the patient has presented with a low-grade dysplastic deformity, the surgeon must follow the patient closely and perform fusion early for any progression, especially if kyphosis (i.e., high dysplastic) develops.

The unique pathology associated with dysplastic spondylolisthesis without lysis often results in encroachment on the cauda equina, producing incapacitating back and leg pain and often neurologic deficit. Once such symptoms have occurred, nonoperative treatment is rarely successful.[24,54] Thus, whereas asymptomatic patients with low-grade dysplastic listhesis can be observed, operative treatment may be indicated earlier in high-risk patients (those with juvenile onset or evidence of progression). Dysplastic spondylolisthesis without lysis is significantly more likely to require surgical treatment than isthmic spondylolisthesis with a slip of the same magnitude.[54,107]

Patients with isthmic, acquired spondylolisthesis who are symptomatic can frequently be successfully managed nonoperatively.[6,95,110,120] As with spondylolysis without slip, about 60 percent of patients will become asymptomatic nonoperatively and as many as 83 percent will be asymptomatic on long-term follow-up.[42] Return to full activities depends on resolution following exercises and spine-stabilizing techniques[91,101] and is frequently possible, although the athletic adolescent must be carefully educated concerning identification of recurrent symptoms and the need for prophylactic spine exercises for the indefinite future. Should symptoms recur despite maximum physical therapy and nonoperative protection, the adolescent must choose between abandoning the provocative activity or undergoing surgical treatment.

Indications for surgical treatment for low-grade isthmic spondylolisthesis include intractable or recurrent pain, neurologic symptoms, including persistent radiculopathy, and the development of slip progression and more sinister neurologic findings such as gait and postural abnormalities and cauda equina symptoms. For a low-grade spondylolisthesis with or without lumbosacral kyphosis, the standard surgical treatment is in situ fusion, performed via a Wiltse paraspinal approach,[134] with autogenous bone graft placed between the transverse processes of L5 (or sometimes L4) and the sacral ala. Although no prospective randomized trials comparing surgical treatment to nonoperative treatment have been performed, most retrospective reviews indicate that in symptomatic patients in whom nonoperative treatment fails, in situ posterolateral fusion improves the natural history by eliminating pain and in most cases stabilizes both the radiographic and the neurologic situation.

Perioperative assessment should always include evaluation of cauda equina function, including a rectal examination for sacral sensation and sphincter motor tone.[107] It is recommended that the same examiner who assesses the patient preoperatively be available postoperatively if any ques-

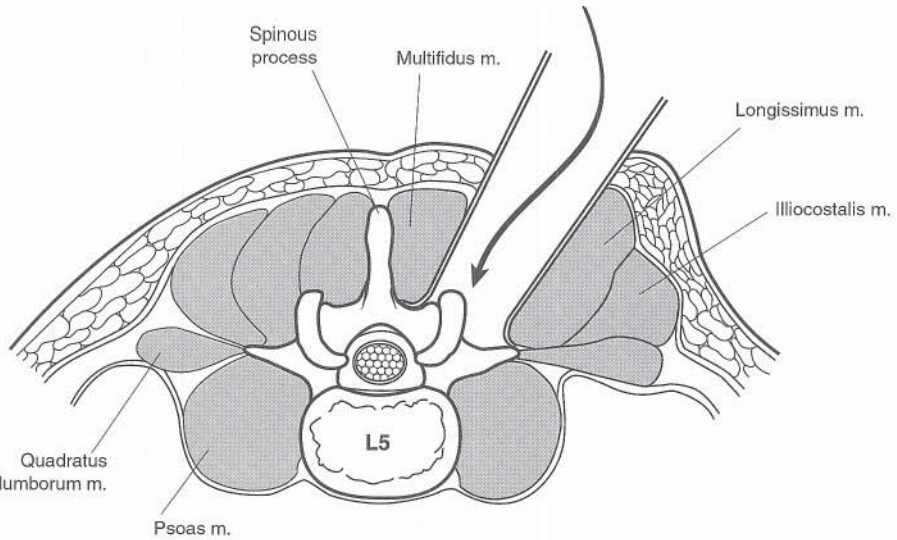


FIGURE 13–7 The Wiltse muscle-splitting approach.

tion of cauda equina problems arise, to detect partial loss of sphincter tone.[27] The surgical procedure itself is performed after carefully placing the patient in the prone position on chest rolls only, as there is evidence that cauda equina syndrome is more likely to occur on a frame that does not support the abdomen due to relaxation of muscle and ligament structures under anesthesia, with further forward slipping occurring as the abdomen hangs free between posts of the frame.[108] Although root or dermatomal monitoring may alert the surgeon to cauda equina dysfunction, it has been our experience that routine SSEP monitoring during in situ fusion does not detect evolving cauda equina complications.

The operative technique follows the classic method described by Wiltse.[134] A midline skin incision is used. Two paramedian incisions in the fascia approximately 5 cm lateral to the midline are made to split the paraspinous muscles bluntly and approach the articular facets and transverse processes from a more lateral direction (Fig. 13–7). The bony elements of the sacral ala and the facet joints of L5–S1 are exposed from lateral aspect to medial, with midline ligamentous structures being retained for stability. Exposure of L4 should be avoided unless fusion to that level is desired, and should not be necessary for most low-grade slips. The L5 segment should be exposed from the tip of the transverse process to halfway up the base of the spinous process if present. The sacral ala should be exposed in a subperiosteal plane as anteriorly as possible, as the more anterior the bone graft can be placed, the more it is under compression. Decortication of the sacral ala and the facet and transverse processes of L5 (and L4) is best accomplished with a high-speed bur. Since pounding with a mallet may increase the likelihood of a postoperative cauda equina syndrome, routine use of a gouge is not recommended when less traumatic decortication is possible. Ample autogenous bone graft is placed from the transverse process of L5 to the most anterior area of the sacrum. A flap of bone from the ala can be raised and turned toward L5 before the bone graft is placed. The incision is closed with running sutures placed in the superficial lumbodorsal fascia bilaterally. Postoperative care varies from no immobilization at all to a cast or TLSO. There is little evidence that immobilization increases the fusion rate,[10,72,88,136] but postoperative management of the patient may be easier with some type of orthosis for comfort.

Destabilization of the midline structures is avoided by Wiltse's technique. Exposure of the loose L5 lamina through a midline approach is unnecessary and in fact may be useless to achieve fusion; exposure is only indicated when L5 is to be removed for decompression or the pars defect is to be repaired as part of the fusion procedure. The destabilization produced by such exposure and removal may be responsible in great part for the reported continued progression of slip occurring after in situ fusion.[10,60,70,72,78,114] Although slippage following in situ fusion is also related to the greater severity of the slip and lumbosacral kyphosis, removal of midline structures during posterolateral transverse process fusion procedures mandates some form of postoperative immobilization (cast) or recumbency to prevent further slipping immediately postoperatively. Additionally, the advantage of the Wiltse approach may be appreciated later, should decompression be needed because of persistent neurologic symptoms.[88] In this situation, the midline structures are unaltered, and procedures such as the Gill laminectomy, nerve root decompression with partial pediculectomy, and sacroplasty are more easily performed through a midline not previously violated by surgery. The results of intertransverse process fusion show rates of 83 to 95 percent successful fusion, with 75 to 100 percent excellent or good clinical results.[10,24,43,88,110,135] It is because of these results that the bilateral transverse process fusion of Wiltse has become the gold standard operation for spondylolisthesis, especially in a low-grade deformity with less than a 50 percent slip. In adolescents and young adults with radicular symptoms (e.g., leg pain), these symptoms frequently resolve simply by achieving a solid arthrodesis of the lumbosacral junction.* Decompression for symptoms of spondylolisthesis is rarely indicated or necessary in adolescents because of the likelihood that symptoms will resolve after arthrodesis.[10,64,136] Indications for decompression with the index procedure include an *objective* motor neurologic deficit, not merely radicular

*See references 10, 54, 63, 64, 110, 111, 135, 136.

symptoms or tight hamstrings.[10] Should cauda equina syndrome complicate an in situ fusion procedure, the recommended management is immediate decompression by sacroplasty.[88,108]

In the rare situation of objective motor deficit accompanying low-grade listhesis preoperatively, decompression includes removal of the loose L5 lamina (Gill's procedure), but must not stop there. Appropriate decompression of the L5 nerve root, for example, requires removal of local hypertrophic callus and fibrotic tissue in the region of the pedicle. This callus is the offending compressing material, and mere removal of the loose L5 laminar segment is insufficient for this purpose. Thus, an extended Gill procedure is required in this rare instance of decompression accompanying fusion.[30]

Should decompression be performed as part of the index procedure, a meticulous fusion that includes *internal fixation* may be superior to an uninstrumented in situ fusion (Fig. 13–8). Normally decompression would be expected to destabilize a spondylolisthesis, risking progression of an unprotected in situ fusion. Decompression preceding fusion would therefore commit the surgeon to either external immobilization, probably recumbent, or internal fixation to maintain position. Thus internal fixation, not to reduce but to stabilize a decompressed spondylolisthesis, is indicated for in situ fixation under these circumstances. Additionally, in an uncooperative patient (e.g., one with mental retardation or autism) or in a patient with pathologic bone (e.g., osteogenesis imperfecta), internal fixation for stabilization offers definite advantages over instrumented fusions.

The goal of in situ fusion is to obtain a solid fusion. Surprisingly, several reports indicate that a satisfactory outcome can be achieved even though the quality of the fusion mass is suspect.[51,72,111] For this reason, radiographic evaluation of the postoperative fusion mass is an important part of evaluating the patient with incomplete resolution of symptoms, to determine if an actual pseudarthrosis is present, or whether the patient with a solid fusion should undergo decompression. Fusion mass grading[72] must be done on a Ferguson AP view postoperatively, and if a poor fusion mass is seen, a significantly poorer result can be expected.[88] On the other hand, if a solid fusion mass is noted, then further evaluation with MRI to rule out disk herniation and to evaluate dural effacement by the posterior edge of the sacrum is indicated. Finally, recurrence of mechanical symptoms in the presence of a radiographically solid fusion should raise the possibility of a new spondylolysis occurring at the next cephalad segment to the fusion mass (Fig. 13–9).[51]

The overall results of in situ fusion for low-grade spondylolisthesis are good to excellent in greater than 80 percent of patients, regardless of the quality of the fusion mass.[72,111] The complications of pseudarthrosis and progressive slip are much more likely in higher grade spondylolisthesis and might be suspected following fusion for low-grade deformity if symptoms persist.

High-Grade Spondylolisthesis (>50 Percent Slip). The treatment of high-grade spondylolisthesis is perhaps one of the most challenging in all of orthopaedics, with a great deal of controversy surrounding the question of acute intraoperative reduction of the deformity. As discussed in previous sections, the discovery of an asymptomatic low-grade dysplastic spondylolisthesis is unusual and fortunate. The discovery of a high-grade dysplastic spondylolisthesis without symptoms is almost unheard of, and while nonoperative treatment, including observation, may be carefully attempted in such an asymptomatic patient, it is very likely that surgical treatment will be necessary, although not certain.[30]

The usual clinical presentation is difficult to mistake for anything but severe spondylolisthesis: a patient with markedly altered gait due to the tight hamstrings, with flexed-hip, flexed-knee, and equinus positioning, a foreshortened trunk with protruding abdomen and lower rib cage impinging on the iliac crests, and significant hyperextension of the thoracolumbar spine above the lumbosacral kyphosis (see Fig. 13–3). Irritative, olisthetic scoliosis may also be present. The patient is frequently in forward sagittal balance with the C7 vertical axis falling well anterior to the anterior edge of the sacrum. An objective neurologic deficit may be present, but more likely the neurologic compromise is represented by the gait and postural abnormalities. As with any spondylolisthesis presenting for treatment, determination of cauda equina functions is essential.

Radiographically, not only is the translation greater than 50 percent, but lumbosacral kyphosis greater than 20 degrees as measured by the slip angle will be present. In the most severe case, the L5 body will appear to be falling off the edge of the anterior sacrum, with trapezoidal deformity to L5 and rounding off of the sacrum indicating the chronicity of the process. Spondyloptosis, the end stage of the process, exists when the L5 body lies in the front of the sacrum and below a horizontal line from the top of the sacral dome.

The major treatment controversy revolves around the need for reduction of the deformity in order to achieve the goals of solid fusion, neurologic stabilization and resolution, and prevention of later progression or recurrence. Few issues are debated more frequently in the orthopaedic literature.[12,33,58,96] The more significant deformity, the lumbosacral kyphosis, can be corrected by a variety of means, from traction and corrective casting* to posterior instrumented reductions with pedicle screw instrumentation† or the use of sublaminar wiring.[109] Proponents of reduction maintain that the incidence of pseudarthrosis and slip progression are decreased by the biomechanical restoration of lumbosacral alignment, and that reduction may actually produce "orthopaedic decompression" of stretched nerve roots and dura.[33,34,94] Additionally, improved sagittal plane balance is achieved if the reduction is maintained.[13] The controversy arises from the fact that neither posterior in situ fusion nor posterior acute reduction, with or without instrumentation, gives consistently good results or can be accomplished without significant risk of complications. Anterior methods of fusion[76,125] and circumferential fusion‡ have also been proposed as solutions to the progression or recurrence of deformity that is reported following posterior treatment methods in slips >50 percent. The selection of treatment of an individual patient depends to a great extent on the experience of the surgeon with a particular method and, more important, on a consideration of postoperative complications involving either progression of deformity, failure of neurologic signs or symptoms to resolve, or new neurologic deficits.

*See references 11, 12, 17, 32, 76, 78, 106.
†See references 3, 9, 29, 33, 49, 57, 71, 79, 116.
‡See references 12, 32, 51, 71, 82, 116, 125.

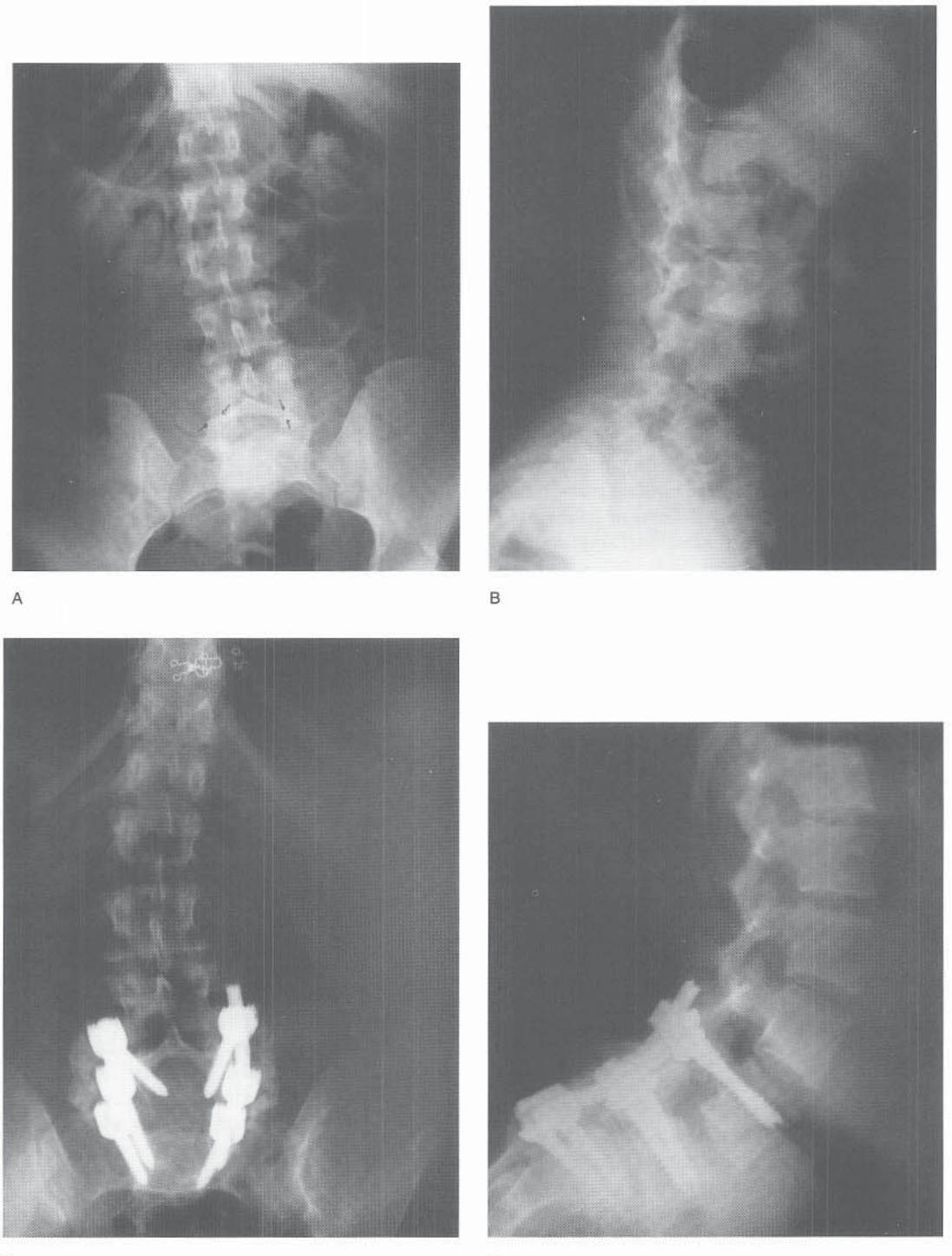


FIGURE 13–8 **A** and **B,** Radiographic appearance in a 17-year-old patient with Down syndrome who exhibited pain and weakness, and finally refused to walk on her left leg. Neurologic examination and imaging studies were inconclusive for root compression (in part because of the patient's retardation). The spondylolisthesis was low grade, and the hyperlordosis presumably causing the pars defects (*arrows* in A) was thought to be contributing to the symptoms. **C** and **D,** Midline decompression and root exploration was carried out, followed by internal fixation. The fusion was thought to be solid 9 months postoperatively. Because of the underlying diagnosis, the patient was maintained in a bivalved orthosis during this time. The patient recovered ambulatory function.

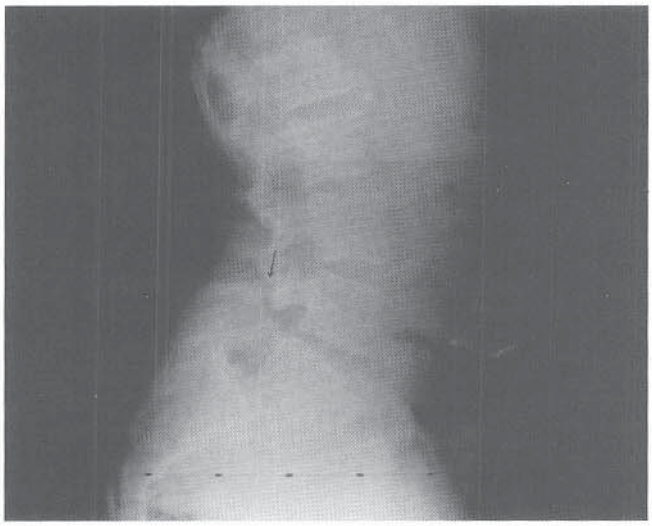


FIGURE 13–9 Radiographic appearance in an 18-year-old man who represented with the new onset of back pain 3 years after successful L5–S1 fusion for low-grade spondylolisthesis. An L4 stress fracture can be seen above the fusion mass.

In Situ Fusion. Posterolateral in situ fusion without decompression remains a valid option for most patients, particularly as an index procedure (Fig. 13–10). Numerous reports* have documented satisfactory results from in situ L4–S1 fusion in respect to relieving symptoms and restoring normal activity, and this has been achieved without significant morbidity, thus discounting some of the proposed benefits of reduction. Gait abnormalities, including the flexed-hip/flexed-knee posture, resolve after surgical stabilization.[113]

Proponents of reduction cite the increased risk of pseudarthrosis or progressive slip as the major drawback to in situ treatment. As with lower-grade slips, pseudarthrosis by itself does not condemn the patient to a poor outcome, but a poor outcome is more likely with a frank nonunion.[72,82,88] The reported incidence of pseudarthrosis is variable, ranging from minimal and none[41,51,63,93] to 25 to 45 percent.[10,72,82,96] Similarly, progressive L5 translation and lumbosacral kyphosis have been mentioned as frequent problems following in situ fusion, although the reports of nonprogression[41,51,63,95,96] are generally reassuring. There are also reports of radiographic progression in which clinical outcome does not necessarily suffer.[10,70,78,111,114] To resolve this debate, and achieve solid arthrodesis with in situ technique (to decrease morbidity), circumferential in situ fusion[125] may produce the best result of all with the least morbidity, by achieving a 100 percent fusion rate, eliminating progression due to anterior column support, and avoiding neurologic complications due to acute reduction. Thus, the need for reduction of high-grade spondylolisthesis remains controversial,[96] since the performance of reduction *must* result in a higher fusion rate and elimination of slip progression to justify the higher morbidity and complication rate. *Partial* reduction with circumferential fusion is another alternative reported to achieve solid fusion without neural deficit and to restore the sagittal balance.[71]

*See references 24, 41, 51, 54, 60, 63, 88, 93, 111, 135.

In the adolescent with high-grade dysplastic spondylolisthesis, the reducibility of the lumbosacral kyphosis and the degree of translation should be evaluated preoperatively by hyperextension radiographs obtained with the patient positioned over a bolster. If reduction of translation is satisfactory and reduction of the slip angle is achieved by simple hyperextension, then an in situ fusion is most attractive, followed by casting to maintain the reduction.[17,76,106] Although Burkus and colleagues reported no long-term functional or cosmetic differences in patients treated by in situ fusion and cast reduction versus fusion alone, these authors did achieve radiographic maintenance of correction with improved sagittal balance and thus avoided late progression of deformity with casting. Cast application is usually performed several days postoperatively following the in situ fusion and is best done with the patient awake so that neurologic function can be monitored during reduction maneuvers. Reduction includes hyperextension of the lower extremities and pelvis combined with anterior translation of the sacrum, usually by a posteriorly placed, anteriorly directed force (pelvic slings, pressure localizers) (Fig. 13–11).[76,106] Obviously, such cast application requires an experienced cast application team with appropriate Risser table, and the patient must be prepared for a period of up to 9 months—4 recumbent in a double pantaloon cast—in order to maintain reduction by such external positioning.[32,106]

INSTRUMENTED REDUCTION. The pseudarthrosis rate for in situ fusion has been reported to be 20 to 45 percent,[10,70,82] and progression of listhesis in spite of "solid" fusion occurs in up to 26 percent of patients.[10,11,78,82,111,114] Reduction of the spondylolisthesis, internally fixed by instrumentation, is attractive for the deformity improvement obtained, with restoration of trunk height and sagittal balance, but is more important for the maintenance of correction and presumably a higher rate of fusion. The benefit to the patient in not being immobilized in a pantaloon spica cast for several months is also self-evident, and if the reduction can be achieved without resorting to preoperative halo-femoral traction,[11,32] so much the better.

Harrington and Tullos[50] first proposed instrumented reduction with posterior Harrington rods from L1 to the sacral ala combined with posterolateral L4–S1 fusion. In spite of the relative length of the instrumentation (the entire lumbar spine), loss of reduction occurred when immobilization was discontinued. Thus DeWald et al[27] concluded that anterior fusion of at least L5–S1 was also necessary. They noted that posterior fusion alone was inadequate because of deficient posterior elements at this level and a fusion mass under tension due to lumbosacral kyphosis in their series. The Harrington rods were removed 6 to 12 months later, with maintenance of reduction and no slip progression from late remodeling. One of 14 patients, however, suffered a cauda equina syndrome, requiring abandonment of the instrumented reduction and fusion in situ, with complete neurologic recovery. DeWald and co-workers concluded that restoration of normal anatomy with circumferential fusion of the listhetic level was required to prevent pseudarthrosis and late slip progression, and established the validity of the instrumented reduction technique. They also emphasized

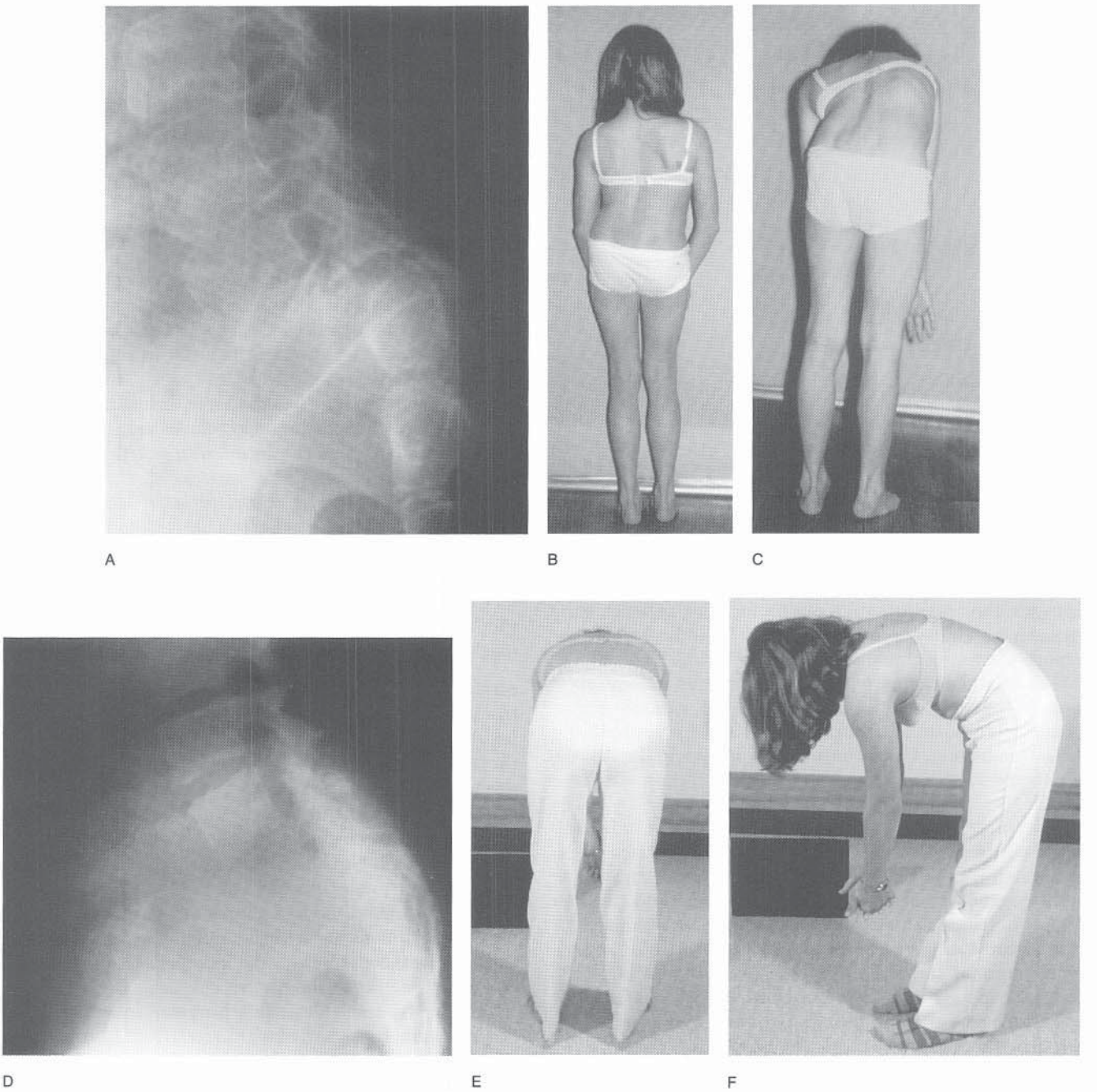


FIGURE 13–10 **A,** Lateral radiograph of grade V spondylolisthesis (spondyloptosis). **B.** The patient (same patient as in Figure 13–1B) was unable to stand with the right knee extended, owing to severe right hamstring spasm. Note the drop of the pelvis on the right. **C,** Marked olisthetic scoliosis and limitation of forward bending preoperatively. **D,** She underwent in situ posterolateral fusion. Within 6 months, symptoms were dramatically improved. At 12 years postoperatively, her fusion is solid. Note the improved slip angle occurring spontaneously with fusion in situ only. **E** and **F,** Excellent mobility 12 years postoperatively. The patient is asymptomatic.

the difficulty and complexity of the procedure and its neurologic risk.

For this reason, reduction of the spondylolisthesis *before* surgical treatment has been attempted by several methods. Halo-femoral traction (skin or skeletal) with additional pelvic slings to translate the sacrum anteriorly has been reported.[11,32] This technique realizes reduction slowly with awake neurologic monitoring. When reduction is satisfactory, a cast is placed to maintain position in a pantaloon/Risser cast, and then fused in situ posteriorly, or anteriorly/posteriorly, operating through a window or after bivalving the cast. Patients remain casted and recumbent for up to 4 months postoperatively.

Alternatively, Scaglietti and Marchetti perform reduction by serial casting over a period of weeks and then stabilize the reduction by fusion. Marchetti prefers anterior stabilization with bone graft and interbody screw fixation.[76,106]

Neurologic complications of reduction by traction or

casting are minimal, and these methods appear to be safer than instrumented reduction, if far more uncomfortable for the patient. With the use of anterior grafting complementing posterior or posterolateral fusion, there is a negligible pseudarthrosis rate. Earlier reports of reduction without circumferential fusion showed a high incidence of pseudarthrosis and further slippage.[12,13,96]

Distraction instrumentation flattens lumbar lordosis, which is an undesirable result for any corrective maneuver in the spine, especially if the lordosis is compensatory for a lumbosacral kyphosis. In addition, the instrumentation must be removed at a *second* procedure if fusion over the entire area spanned by the instrumentation is not performed. Consequently, alternative methods of instrumented reduction have been sought.[109] Pedicle screw fixation has been more effective in reducing the slip angle by direct extension of the L5–S1 segment as well as in translating the upper listhetic segment posteriorly and thus reducing the anterior translation.[49,116] Pedicle fixation is also more biomechanically stable than long distraction instrumentation.[115] Several reports of pedicle fixation to reduce and fuse high-grade spondylolisthesis are available.[3,9,29,79] Edwards developed a system specifically to produce distraction, sacral anterior rotation (extension) and posterior translation between L4 and S2, emphasizing gradual application of the three corrective forces intraoperatively to avoid neurologic complications. Although Edwards[34] reported a 5 percent rate of instrumentation complications (such as loss of sacral fixation) and a 15 percent incidence of lumbar root weakness (ankle dorsiflexion) in spondyloptosis reductions, others have reported up to a 65 percent incidence of neurologic complications and up to a 30 percent incidence of hardware failure.[3,9,12,29,57] The need for complete as opposed to partial reduction has been questioned, since anatomic studies have demonstrated that complete anatomic replacement of L5 on S1 in fact can increase tension of the L5 roots.[94] *Partial* reduction of translation and slip angle may decrease the neurologic risk of acute reduction, especially if decompression is carried out prior to reduction.[71] Because acute reduction of the slip angle actually produces anterior column deficiency at L5–S1

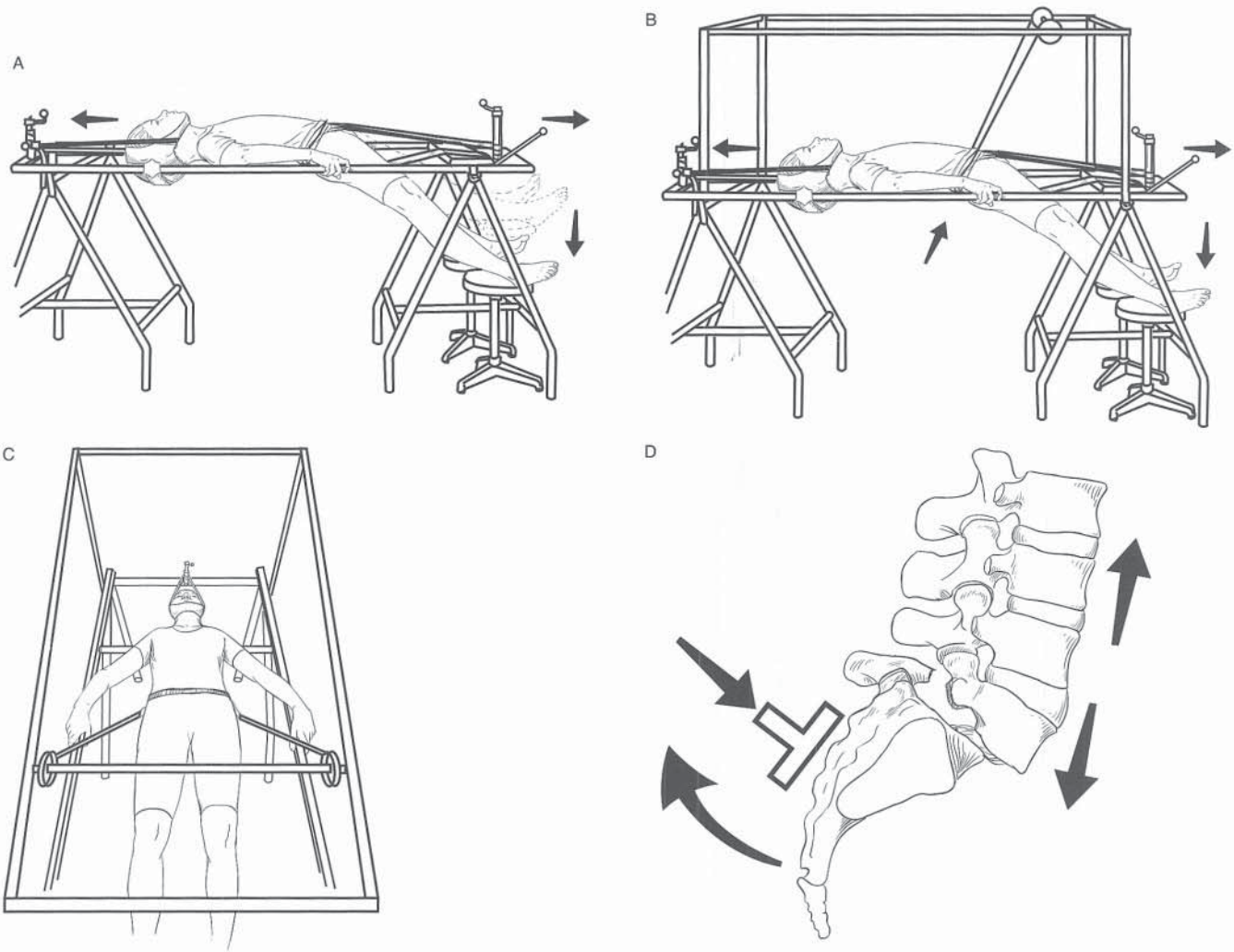


FIGURE 13–11 Traction-reduction casting for spondylolisthesis. **A,** The patient is placed in cervical-pelvic traction on the Risser table, and the hips are allowed to hyperextend. **B,** A sling is placed under the sacrum to translate it forward. The direction of pull is toward the feet, to make the anterior translation force perpendicular to the sacrum. Additional hyperextension can be achieved by dropping the leg supports further as the cast is applied and the sacrum elevated. **C,** View from the foot of the table. **D,** Diagram showing reduction forces.

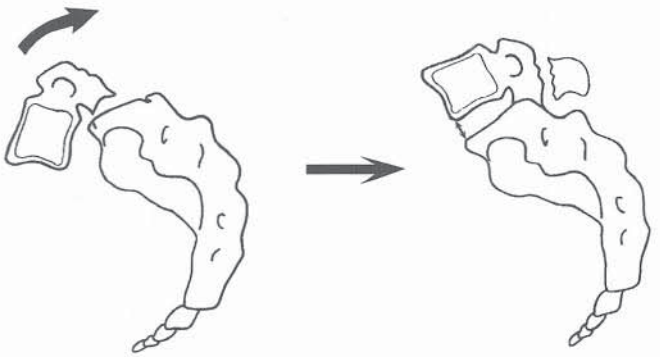


FIGURE 13–12 A significant reduction of lumbosacral kyphosis creates an anterior support deficiency. Posterior fusion alone fails by collapse of the L5–S1 disk back into kyphosis.

by virtue of distraction and lordosis, creating an opening of this disk space (Fig. 13–12), adding anterior column support is associated with diminished loss of fixation and fewer correction problems.[71,82] The addition of anterior fusion by fibular dowel or interdiskal graft/cage[9,32,49,57,71,76,82] or of posterior interbody fusion[49,116] appears to be the solution to loss of fixation with recurrence.

In summary, the indications for instrumented reduction of high-grade spondylolisthesis (and spondyloptosis) are in evolution. When successfully accomplished without neurologic complication, instrumented reduction improves the sagittal alignment, provides decompression of the dural sac and nerve roots, and allows early mobilization of the patient. It probably should be supplemented with anterior support to prevent loss of sacral fixation and achieve a high rate of fusion. Thus, instrumented reduction may require two operative procedures, anterior and posterior, and if anterior support fusion is attempted by a posterior interbody technique, transcanal surgery is necessary, with retraction of nerve roots already stretched by the deformity. The technical expertise needed to safely perform the multiple intraoperative steps in instrumented reduction is probably the most important aspect in achieving a result that exceeds that of an in situ treatment with or without instrumentation.

ALTERNATIVES TO REDUCTION. Two other options for treatment of high-grade spondylolisthesis and spondyloptosis are in situ fixation with screws or a fibular graft from the sacrum to L5 via a posterior approach[1,8,98,117] and L5 vertebrectomy with posterior L4–S1 fixation/fusion.[44] Each of these techniques involves its own special technical requirements, but because acute reduction is attempted, if at all, only *after* bony decompression of the dural sac, they may provide a greater degree of neurologic safety than instrumented reduction.

In fact, Bohlman's posterior decompression and in situ fixation[8,117] is probably best suited to the patient with preoperative motor or cauda equina deficit and 100 percent or greater listhesis—in other words, the patient with arguably the highest neurologic risk for reduction, since deficit already exists. Decompression by sacroplasty (Fig. 13–13), indicated by the presence of bowel or bladder deficit, is followed by fibular dowel grafting from the sacral pedicle or body to the L5 body situated directly anteriorly. Anterior fixation can be augmented by pedicle screw fixation,[1] thereby achieving both bony arthrodesis and internal fixation placed in situ with no reduction attempted. With this approach, all patients are reported to recover neurologic function, and 90 percent achieved solid fusion.[98,117] Since neural elements

FIGURE 13–13 Removal of the posterosuperior dome of the sacrum to decompress the dural sac and nerve roots (sacroplasty). A high-speed bur from each side is useful once dural sac and root retraction exposes the prominent sacral dome.

are adequately decompressed by sacroplasty, no additional reduction is necessary, and in situ arthrodesis is achieved by combining posterolateral fusion with the L5–S1 fibular fusion.

The high risk and technical difficulty of attempted reduction in spondyloptosis inspired Gaines to develop the two-stage L5 vertebrectomy and posterior L4–S1 fixation as the solution to this challenging deformity.[44] The L5 vertebra, in a first-stage procedure, is excised via a transperitoneal approach, thus making the acute reduction of L4 on S1 far less difficult or risky. The posterior procedure includes decompression by removal of the L4 and L5 posterior elements, followed by L4–S1 pedicle fixation and posterolateral grafting. In Gaines' series all patients have been anatomically reduced and are fused solidly, although L5 motor deficits have occurred. Retrograde ejaculation can also result from the L5 vertebrectomy procedure. The need for the more extensive Gaines procedure to deal with spondyloptosis deformity appears less evident, in light of the safety and neurologic recovery reported with Bohlman's procedure.

SUMMARY. The *ideal* treatment for high-grade spondylolisthesis would provide a sagittal plane realignment maintained by solid arthrodesis. Unfortunately, the achievement of both of these goals is often complicated by neurologic deficits in up to 65 percent of patients, although permanent deficit is less frequent, and by up to 30 percent pseudarthrosis with failure of internal fixation. The surgical technique of acute reduction and internal fixation is technically demanding and probably requires both posterior instrumentation and anterior L5–S1 fusion (performed transperitoneally or by posterior interbody technique) to obtain a high rate of fusion without failure or recurrence. While some experts have achieved a high rate of success with this demanding surgery,[49,82,116] the risks involved have led others to recommend in situ fixation with preemptive sacroplasty/decompression to achieve fusion without neurologic risks,[8,98,117] especially if serious neurologic signs and symptoms are present preoperatively.

In patients with high-grade spondylolisthesis without significant neurologic symptoms and with reducibility demonstrated preoperatively, in situ posterolateral fusion with cast immobilization is traditionally successful and the gold standard. We have continued to use this approach in the vast majority of patients as the primary surgical procedure for all degrees of listhesis (Figs. 13–10 and 13–14). A successful in situ fusion relieves symptoms, and the residual lumbosacral kyphosis is rarely a cosmetic or functional problem, as evidenced by the resolution of gait and postural abnormalities in most patients.[113] In patients who do not fully recover from hamstring spasm, sacroplasty at a second stage resolves these symptoms (Fig. 13–14).

The need for cast immobilization remains uncertain, as successful in situ management without progression is clearly possible without immobilization.[88,93] Given the importance of achieving solid fusion in the high-grade deformity, especially if anterior fusion is not going to be performed, immobilization to maintain reduction and improve chances for fusion is not unreasonable. If reduction of the slip angle to less than 30 degrees is not possible by hyperextension preoperatively, in situ fixation with circumferential fusion is probably indicated if no neurologic deficits exist, due to the higher risk of pseudarthrosis and progression. We have tended to reserve anterior fusion for patients with established symptomatic pseudarthrosis after previous posterolateral fusion has failed, regardless of the degree of deformity. Finally, with a neurologic deficit—motor or cauda equina syndrome—present preoperatively, root or dural decompression by sacroplasty, followed by circumferential fusion with internal or external immobilization, is indicated.

Summary of Treatment. The symptoms of spondylolysis usually resolve with symptomatic treatment. Occasionally, operative management is required for intractable or recurrent symptoms and can include direct repair of the spondylolytic defect, usually at the L4 or a more cephalad level, or in situ fusion at L5–S1. Since the spondylolysis without listhesis is predominantly an acquired lesion representing a stress fracture, long-term observation for progression of deformity is usually unnecessary, as any progression of slippage will be accompanied by a recurrence of symptoms and disability.

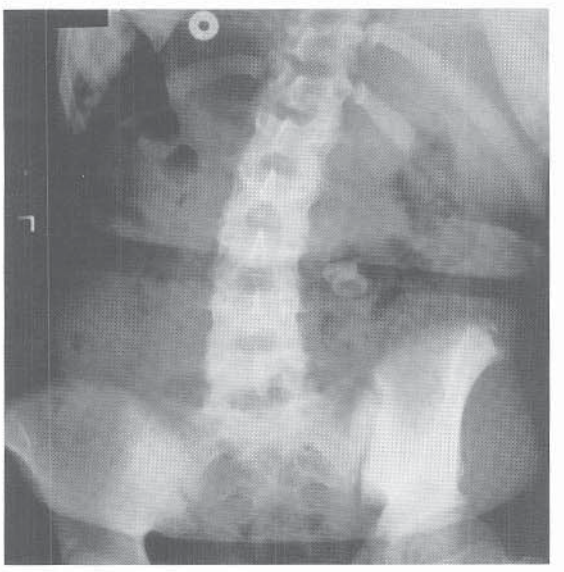
Low-grade spondylolisthesis (<50 percent slip) is also treated symptomatically, with surgical treatment reserved for patients with continued symptoms; disability; or, in the case of juvenile onset, evidence of progressive listhesis. Patients with dysplastic posterior elements without spondylolysis may require earlier operative treatment because of more significant neurologic risk. Patients with isthmic, acquired spondylolisthesis without significant lumbosacral kyphosis are best managed by an in situ posterolateral fusion (Wiltse[134]). Decompression for the rare patient with objective neurological deficit and low-grade listhesis requires a more meticulous stabilization postoperatively, which may include internal or external fixation with recumbency to avoid progressive listhesis postoperatively.

High-grade spondylolisthesis (>50 percent slip) usually requires surgical treatment. As outlined above, the ideal treatment, consisting of both reduction of sagittal alignment deformity and the achievement of solid arthrodesis to maintain it, is a surgically demanding procedure fraught with numerous complications. In patients without objective motor deficit, in situ posterolateral fusion can be effective in relieving symptoms and improving gait abnormalities and posture. This can be accomplished with or without cast immobilization. In patients who do not recover from hamstring spasm or other neurologic symptoms following in situ fusion, anterior sacroplasty decompression can be effective as a secondary procedure. Instrumented reduction requires anterior column support in most cases to ensure solid arthrodesis and to avoid both instrumentation failure and recurrence of lumbosacral kyphosis.

Finally, cauda equina syndrome may complicate any surgery for spondylolisthesis, and careful preoperative and postoperative monitoring, including intraoperative positioning of the patient, can reduce the rate of this complication.

Lumbar Disk Herniation

The diagnosis of a herniated lumbar disk must be considered in the differential diagnosis of low back pain in children and adolescents. However common this entity may be in adults, disk protrusion or herniation is an infrequent but nonetheless possible cause of significant morbidity in the



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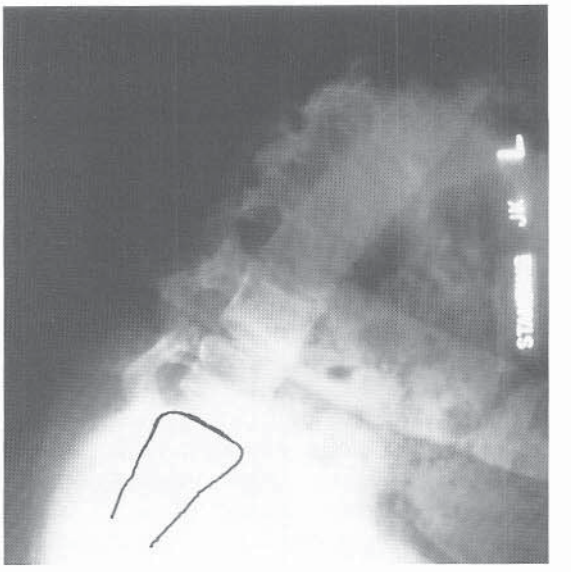

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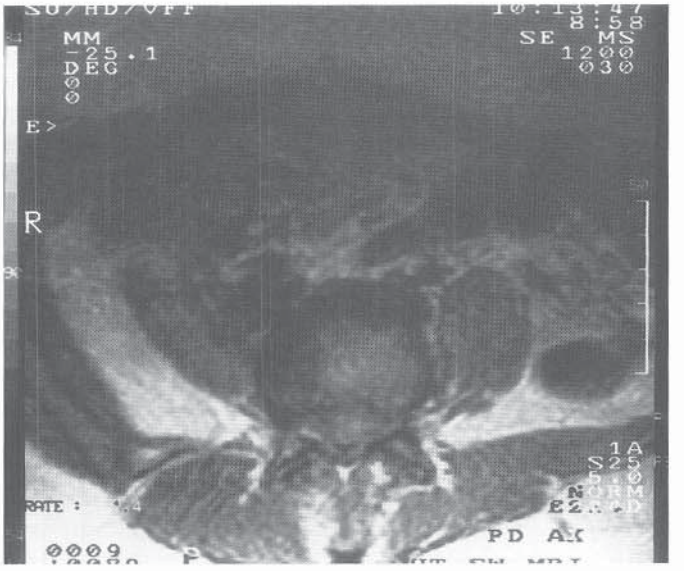

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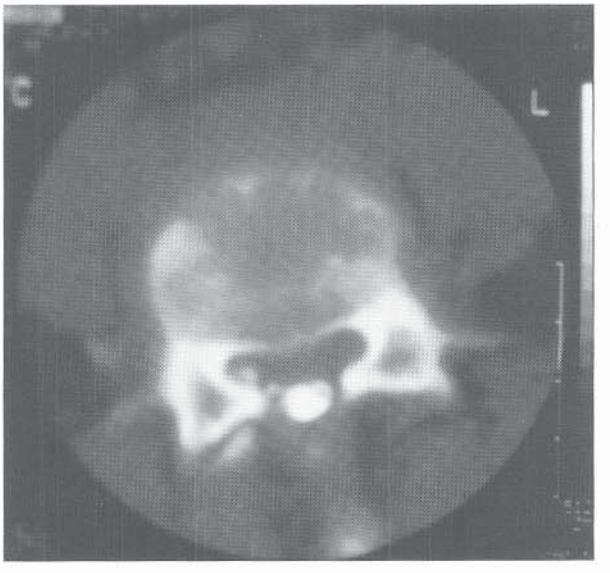


E

FIGURE 13–14 **A** and **B,** Presenting plain radiographs of an obese 12-year-old girl with a stiff, flexed scoliosis and severe back pain. The congenitally stenotic spinal canal is suggested by the very short pedicles. **C,** MR image showing central disk protrusion. The canal is severely compromised at L4–5. **D,** Lateral MR image showing disk herniation at L5–S1 as well as L4–5. **E,** CT myelogram showing severe canal encroachment with short pedicles at L4–S1. This patient was treated by two-level diskectomy due to her severe pain and postural disturbance.

pediatric and adolescent population. Thus, in the evaluation of a pediatric patient with low back pain and unremarkable plain radiographic studies of the lumbar spine, the possibility of a herniated lumbar disk must be considered.

INCIDENCE

The actual incidence of herniated lumbar disks in the pediatric age group is unknown. Although the condition was first described in a 12-year-old child by Wahren in 1945,[130] in large series of patients treated surgically the proportion of patients 18 years or younger is around 1%.[131] The diagnosis of disk herniation in children and adolescents may be increasing with growing physician awareness of it as a possibility. In Japan, for example, frequency has been reported to be much higher, possibly because of younger ages of employment.[37,69] Because reports of disk herniation invariably include only surgically treated patients, the true incidence is unknown, for these series do not include patients successfully treated nonoperatively.

There does not appear to be a sex predilection for herniated disks in children. Multiple investigators have reported a slight prevalence in boys,[20,26,36,37,52] thought to be due to delayed maturity, which exposes the immature spine to abnormal stresses for a longer period of time.

ETIOLOGY

Lumbar disk herniation in children and adolescents has been attributed primarily to trauma, especially in patients with predisposing congenital spinal stenosis or an abnormally narrow lumbar canal. Up to 70 percent of patients with herniated disks report antecedent trauma, either an acute event that is well remembered or a cumulative repetitive trauma that is exacerbated by a less traumatic event.[20,26] Certain competitive athletic events associated with back injuries—for example football, gymnastics, cheerleading—are the same kinds of activities that predispose to spondylolysis and are frequently reported by patients with herniated disks.

The association of congenital anomalies of the lumbar spine with disk herniation is also well known.[26,36,69,90] Sacralization of L5 or lumbarization of S1 are commonly described, although these anomalies are so ubiquitous in the population that their relation to lumbar disk herniation may be coincidental. More important is AP canal narrowing,[36] which can often be detected on the initial lateral lumbar spine radiograph and is confirmed with CT (Fig. 13–14). The smaller canal leaves less room available for nerve roots following a disk herniation and therefore increases the likelihood of symptoms from an intruding soft herniation.

A familial predisposition to disk herniation has been suggested.[84,129,139] Several reports noted an increased prevalence of disk herniation in first-degree relatives in up to one-third of patients, and up to 92 percent of adolescents with disk herniation had a history of low back pain or sciatica. Although genetic and environmental factors must be considered together, a familial predisposition to disk disease is likely among adolescents with disk herniation.

CLINICAL FEATURES

Disk herniation in children and teenagers differs from the condition in adults primarily because symptoms are intermittent and without dramatic neurologic findings. The diagnosis is often delayed because the initial complaint, back pain, often is not accompanied by sciatica, and thus when plain radiographs are found to be normal, no further investigation is undertaken. Eventually the clinically important disk herniation causes increasing low back pain and becomes more constant and disabling; later, sciatica develops. In addition, the teenager will describe back stiffness due to spasm and splinting by the paraspinous muscles, which may be noted as an abnormal posture or limp. Perhaps the most revealing symptom in the presciatic stage is the presence of increased back pain on straining or coughing or any type of lifting or strenuous maneuver.

The other typical finding in adolescent herniated disk is the relative absence of neurologic signs. Motor weakness or bowel and bladder dysfunction are rare, and except for a positive straight-leg-raising test, there may be essentially no neurologic findings. Up to 60 percent of patients are reported to have minor motor, sensory, or reflex abnormalities,[68] with the dysesthesia or motor weakness not necessarily conforming to the level of disk herniation. Reflex abnormalities are uncommon, with less than half of patients having an absent or decreased deep tendon reflex. Postural changes may also include an irritative or "olisthetic" type of scoliosis (Fig. 13–14) similar to that seen in a spondylolytic crisis, which again may be the only sign of a neurologic problem.

The lack of neurologic findings is attributed to the increased canal size in adolescents and the increased flexibility of the adolescent spine, which allows the canal to move away and accommodate intruding disk material from nerve roots.[46,90] Because of accommodation, there may be a discrepancy between the level of herniation and the subsequent neurologic findings, if any. Epstein and colleagues noted the unreliability of reflex changes to identify a specific level,[36] and Clarke and Cleak found that the neurologic findings correctly identified the level of disk herniation in only half of patients.[20] Because of the unreliability of the clinical signs, radiographic evaluation is mandatory to correctly identify the level of herniation.

RADIOGRAPHIC STUDIES

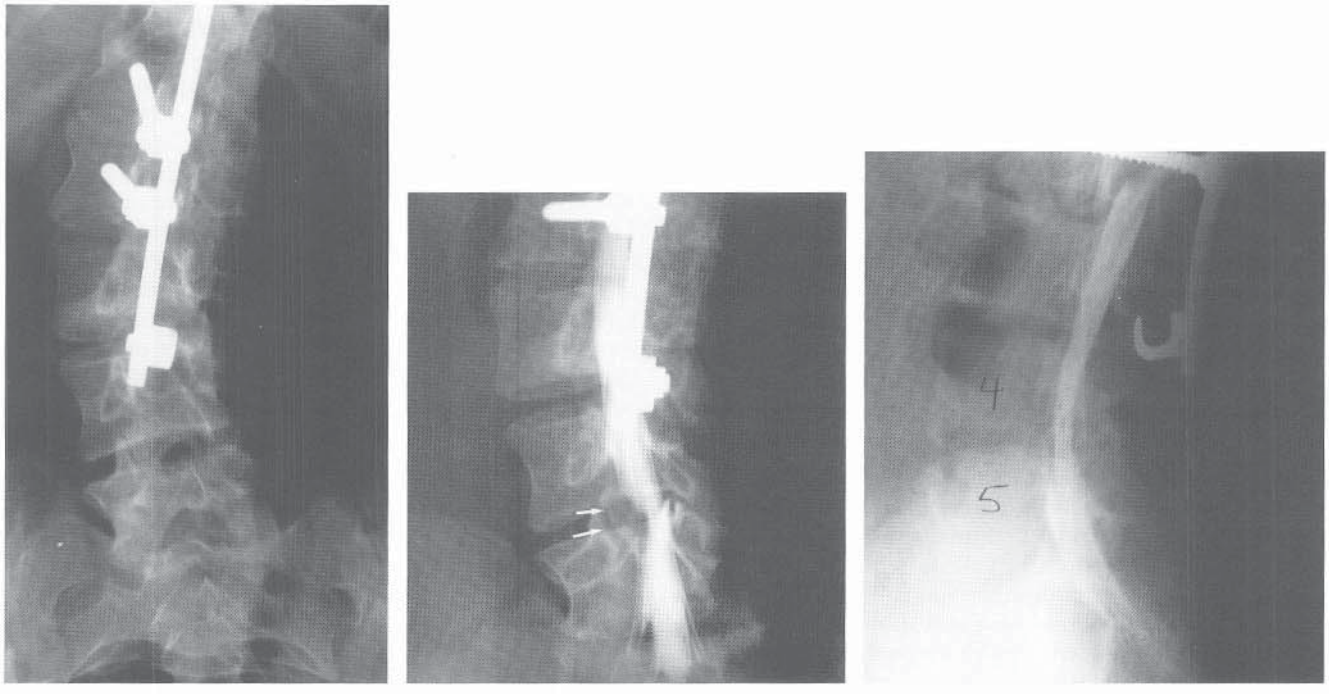
Plain radiographs of the lumbar spine are an important screening evaluation of any patient with low back pain. Standing AP and lateral films will help eliminate certain inflammatory or tumor-like conditions, and oblique radiographs will rule out spondylolysis. Typically plain radiographs show loss of lumbar lordosis on the lateral film. Other structural abnormalities may be present, including spina bifida occulta, sacralization of L5 or lumbarization of S1, or the presence of six lumbar vertebrae.[26,36,90] Disk space narrowing with or without lipping of vertebral margins or small avulsion fragments posterior to a vertebral body may indicate chronicity or the presence of a slipped lumbar apophysis. Spinal canal narrowing may also be suspected from the plain AP radiograph (Fig. 13–14). In at least half of patients with herniated disk, however, plain radiographs will be unremarkable.

MRI is probably the procedure of choice to diagnose disk herniation.[25] This study not only demonstrates the herniated disk, it can also be used to evaluate nerve roots and accurately

shows stenosis and narrowing of the disk space (Fig. 13–14). Free disk fragments can be identified in the canal as separate from the originating disk space. The need to address congenital spinal stenosis can also be determined preoperatively.[45]

CT myelography can also be used to visualize a herniated disk. The reported advantage of CT visualization is in the evaluation of bony lesions, specifically slipped vertebral apophysis, which is often associated with central disk herniation. MRI has been reported to be inferior to CT in the diagnosis of slipped vertebral apophysis,[37,38] which would have therapeutic implications in that the preoperative diagnosis of slipped vertebral apophysis is invaluable in planning the surgical approach. The obvious disadvantage in CT myelography is that it is an invasive study that requires radiation. The routine use of CT myelography in evaluating lumbar disk herniation is probably unnecessary unless MRI demonstrates an unusually large central herniation that has migrated either cephalad or caudad to the posterior aspect of the adjacent vertebra (suggesting a possible apophyseal avulsion).[4,25] CT myelography is also indicated when the MR images are severely artifactually degraded owing to the presence of stainless steel implants (Fig. 13–15).

As in adults, the L4–5 and L5–S1 disks account for about 95 percent of all herniated disks in children and adolescents.[20,26,36,46,90,100] Since the physical examination is unreliable in identifying the level of herniation in the pediatric population, the most essential use of MRI (or CT myelography) is to locate the precise anatomic level of herniation. In addition, should MRI of the lower lumbar canal fail to reveal a herniated disk or other lesion, evaluation of the nerve roots and the conus medullaris by MRI becomes mandatory



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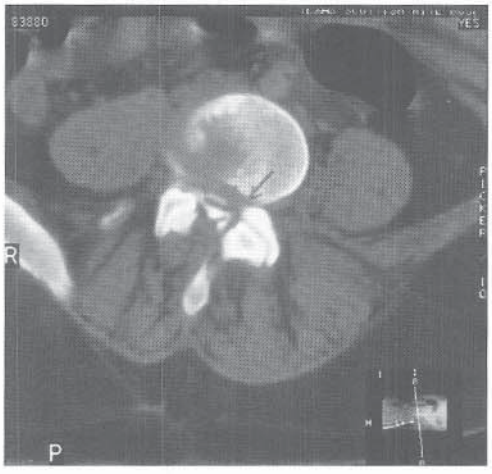

D

FIGURE 13–15 **A,** Radiograph in a 17-year-old girl who had undergone posterior spinal fusion of T5–L3 for a double major scoliosis 3 years previously. She presented with sciatica and less severe back pain. **B** and **C,** Myelography was performed due to the presence of stainless steel implants and revealed a left-sided L4–5 disk herniation. **D,** Axial CT section showing a left-sided disk at L4–5. Because the patient had already had a long spinal fusion to L3, epidural steroids were used in an attempt to avoid surgical treatment at L4–5.

to rule out other intraspinal neoplasms as the source of back pain.

TREATMENT

The treatment of herniated lumbar disks in children and adolescents is not unlike that for adults in that the initial treatment should be nonoperative. Exceptions are the patient with a progressive neurologic deficit that is well documented and the patient with a massive central herniation producing significant neurologic compromise, such as bowel and bladder dysfunction.

Nonoperative management traditionally has included rest, muscle relaxants and analgesics, and heat and physical therapy. Although bed rest, with or without traction, has been a traditional modality for adults, there is little objective evidence that bed rest is actually required to achieve the decreased activity that is an essential part of nonoperative management. Relative immobilization of the lumbar spine can be achieved with a variety of orthotic devices, which are better accepted by patient and parents because they allow the patient to at least attend school and take care of normal daily activities. There is little enthusiasm for the traditional complete bed rest regimen, and in patients who are in severe pain, we usually proceed to some type of corset or lumbar orthosis to immobilize the lumbar spine. The use of local modalities under the supervision of a physical therapist is also valuable; however, there is little evidence that such treatment significantly improves the clinical course.

The use of epidural steroids is controversial. Prospective studies of epidural steroid injections for acute disk herniation or radicular pain have not demonstrated a long-term benefit in adults.[21,22,97] Although epidural steroids, combined with local anesthetic, can provide acute relief of pain, there is no evidence that sciatica, which is generally predictive of an extruded disk fragment in the absence of back pain, is improved by epidural steroids. Since back pain, muscle spasm, and sciatica can be relieved with other nonoperative methods already alluded to, epidural steroids appear to have a limited role in the management of herniated lumbar disks in adolescents. Possible indications for their use would be as a temporizing modality in a patient with acute severe back pain and as a symptomatic modality in patients for whom surgery is not a treatment option or is extremely unattractive. An example of the latter might be a patient who has previously undergone spinal fusion to correct a deformity of the low lumbar spine and in whom a disk herniates at the first or next level (Fig. 13–15). In such a patient, the risk of producing additional degenerative changes following surgical treatment for a disk below a long fusion is high, and thus prolonged nonoperative treatment in an effort to avoid any surgery would be appropriate.

The natural history of disk herniation with sciatica is generally good, in that spontaneous resolution of symptoms without intervention over time can be expected.[132] At least 50 percent of young patients do well with nonoperative treatment on long-term follow-up.[20,139] Most patients can return to sports competition, although some will have recurrent back or leg pain. The challenge for the treating physician is to determine as quickly as possible at what point nonoperative treatment is unsuccessful to avoid unnecessary delay in surgical treatment.

Indications for surgery include failure of nonoperative management and persistence of symptoms after an appropriate period of nonoperative management, even if neurologic deficit cannot be demonstrated. The difficulty with the decision in the latter situation is that, given enough time, symptoms of sciatica in particular will resolve. On the other hand, the uniformly good early results following disk excision make it inappropriate to withhold surgery in the face of severe and persistent symptoms. While no definitive formula for operative intervention is possible, the patient who is clearly incapacitated or disabled by back pain or leg pain and who is not improving with a regimen of rest, immobilization, analgesics and muscle relaxants, and other physical therapy modalities should be considered a candidate for surgery within 1 month of the onset of treatment. Any patient who appears to have deteriorating neurologic findings should have expedient disk excision.

Prior to surgical intervention, exact localization of the level of disk herniation, either by MRI or by CT myelogram, is mandatory. Should there be a large central herniation, CT should also be obtained to determine whether there is an avulsed ring apophysis, since this can change the surgical approach and technique.

The operative technique in young patients generally does not differ from that used in adults.[56,119] Patients should be placed in the knee-chest position to increase access to the lumbar interspaces. Accurate placement of the incision is important, since minimizing exposure enhances early recovery and rehabilitation. The appropriate interspace, based on the preoperative imaging studies, should be identified with localizing radiographs. Aided by a lamina spreader, the ligamentum flavum is excised, and enough lamina is removed to allow exposure of the lateral aspect of the nerve root. It is usually unnecessary to resect bone from the intervertebral facet joint, and if the patient has a central herniation, bilateral laminotomies should be performed in order to adequately remove protruding disk material from both sides of the canal. Since adolescents have no preexisting disk degeneration, only the fragments protruding into the canal need to be excised, as the residual tissue in the disk space is normal. If the protruding disk material is attached in any way to the posterior longitudinal ligament or the cartilaginous end-plate, this should be carefully incised to remove the protruding material. Lateral exposure and foraminal decompression are necessary only if the nerve root is not freely mobile and without tension following evacuation of disk fragments from the canal.

Assuming the intervertebral joints have not been violated, there is no need to combine spinal fusion at the level of diskectomy. Patients can be mobilized rapidly on the day after surgery, with back supports for symptomatic relief only. Early range-of-motion strengthening exercises are recommended and the patients should be seen by rehabilitation personnel as indicated.

The results of surgery are generally gratifying, in that sciatic pain is reduced or vanishes almost immediately, and back pain resolves quickly. Reflex abnormalities and straight-leg-raising tension may require additional time to resolve. The long-term results of disk excision are unfortunately not as good as the immediate short-term results, in that varying residual back discomfort, and sometimes leg pain, can return in one-quarter to one-third of patients.[36,69,100]

The series with the longest follow-up[26] found that 44 of 49 patients had excellent or good results at 5 to 30 years postoperatively. However, over half of the 44 patients needed additional treatment for back pain including second operations and spinal fusions. It was estimated that 74 percent of the patients who underwent operation had good or excellent results, even when reoperation or persistent symptoms were considered a mark of failure. O'Connell reported that 29 percent of patients followed for up to 10 years had transient symptoms, although none was disabled.[90] From these longer-term studies, therefore, the prospect for relief of symptoms after diskectomy is somewhat guarded, despite the initial results being quite gratifying. For this reason, vigorous nonoperative treatment before proceeding to operative management continues to be the initial recommendation.[20,26,90,124] On the other hand, many patients who undergo surgery have had symptoms for longer than 5 months prior to surgery, and this is clearly too long to procrastinate prior to operative intervention. The key to managing herniated lumbar disks in adolescents as in adults is to proceed to operative management relatively quickly once it has been recognized that the patient is not improving on maximum nonoperative therapy, because the results of surgical treatment, both short and long term, are much improved the shorter the duration of symptoms prior to surgery.

Slipped Vertebral Apophysis

Avulsion of a bony fragment from the posterior caudal or cephalic rim of the vertebral body into the spinal canal produces what amounts to a large central disk herniation.[18,38,48,118] First reported in 1954,[5] the signs and symptoms are essentially the same as those of a herniated lumbar disk, although the entity is probably much rarer. Instead of disk material herniating through the annulus and posterior longitudinal ligament into the canal, this lesion involves separation of the partially ossified rim of the posterior vertebral apophysis at its osteocartilaginous junction, with varying amounts of posterior displacement of both the apophysis and the contiguous disk. As with herniated nucleus pulposus, trauma, either as a single event or as a cumulative process in sports such as weightlifting, gymnastics, or wrestling, is accepted as the cause of the fracture of the osteocartilaginous junction.[18,48,118] Extreme flexion of the spine combined with rotation appears to increase the risk of ring apophyseal avulsion.[59,66,73,75,105] The central herniated disk adjacent to the superior or inferior rim of the vertebra whose ring has been avulsed protrudes posteriorly, while the avulsed rim fragment stays attached to the posterior vertebral body by a periosteal sleeve. Typically the posterior longitudinal ligament remains intact. The majority of apophyseal avulsions in adolescents involve the L4–5 or the L5–S1 levels, with the most frequent avulsions originating from the inferior rim of L4 or the superior rim of the S1 body.[4,38,105,118] Lumbar apophyseal avulsions occur predominantly in males, again explained by the fact that boys reach skeletal maturity at a later age than girls and therefore have a longer period of exposure to trauma before maturity. Because of the activities associated with this lesion (weightlifting, wrestling) there appears to be an increased risk of lumbar flexion placing repetitive stress on the lower lumbar spine.

CLINICAL PRESENTATION

Patients with slipped vertebral apophysis present essentially with the same symptoms as patients with herniated lumbar disks. The most prominent complaint is intermittent but progressive low back pain, with or without sciatica, paraspinal muscle spasm, limitation of back motion and straight-leg raising, and minimal or no neurologic findings. Patients describe back stiffness and have a peculiar gait due to the abnormally decreased lumbar motion. Pain is exacerbated by activities such as lifting or straining when coughing or sneezing. Sciatica may or may not be present initially, but may develop later during the course. Limited straight-leg raising is common and is usually bilateral, owing to the central nature of the herniation. Postural scoliosis tends not to be as prominent as with herniated nucleus pulposus. Sensory findings and reflex findings are uncommon but have been observed.

Radiographically, fractures of the vertebral ring apophysis can be seen on the lateral x-ray of the lumbar spine as a small bony fragment posterior to the vertebral body from which it has been avulsed. CT myelography is the radiographic study of choice, in that the canal obstruction is easily seen in the lateral views and in the axial sections. The large central fragment of bone displaced into the canal and the defect in the vertebral rim are best seen on axial CT views. Frequently the amount of canal encroachment is dramatic, with almost complete occlusion of the spinal canal by the avulsed fragment and attached disk.

Three types of fracture morphology have been described,[123] according to the age of the patient and the size of the bony fragment avulsed with the rim of the apophysis. Type I and II fractures are seen in younger patients and are central in their origin from the vertebral body, with type II having a large bony fragment compared to type I. Type III lesions occur in older teenagers and young adults and are more lateral in location than midline. The differentiation between these types is made by studying the axial sections of a CT study and noting the size of the fragment and the amount of canal encroachment.

TREATMENT

Because the avulsion fracture of the vertebral apophysis involves a large central intrusion of bone, cartilage, and disk into the spinal canal, most patients are treated operatively to remove this mass, with good results. Short-term results with nonoperative treatment can be good, but there are no long-term results available for these patients.[68] Epstein and Savini have reported on young patients with spinal stenosis associated with central disk herniation and calcification and have suggested that this pathology may result from a ring apophyseal fracture at an earlier age.[38,105]

The decision about operative treatment depends primarily on the presence or absence of neurologic findings and the amount of canal encroachment by the avulsed apophysis. In a sense this is the same as the treatment for a herniated disk. In patients without findings and a capacious spinal canal, nonoperative management is appropriate, and a good outcome has been reported in the short term.[38] When operative treatment is indicated because of neurologic progression or failure of symptoms to resolve, the amount of the herni-

ated material must be taken into consideration in planning the surgical approach. Generally, because of the size of the lesion, a limited approach does not allow safe or complete removal of the entire mass of disk and bone. A bilateral laminotomy approach with excision of the inferior portion of the lamina above is necessary to gain full access to the canal and allow elevation of the thecal sac and nerve roots off the anterior mass protruding posteriorly. The mass may be as thick as 1 cm, composed of bone superiorly, cartilage and disk inferiorly, and may extend across the entire anterior canal. Thus, a more extensile exposure of the canal than is typical for a herniated nucleus pulposus is necessary.[68] Excision of fragments early in the course of the condition is generally easier than in a more chronic case, in which nerve roots and dural adhesions to the protruding mass make safe excision of the mass difficult.

Symptoms resolve immediately following successful excision of these lesions. The postoperative course and rehabilitation are similar to that for patients with herniated disks. Return to normal activities is based on the return of full back flexibility and rehabilitation to normal strength. In follow-up beyond 2 years, the majority of patients have returned to essentially normal activities, including sports.[38,48,75,105,118,123] Incomplete removal of protruding material or excessive retraction placed on a nerve root during excision can obviously compromise the result.

The essential difference between slipped vertebral apophysis and the more common herniated nucleus pulposus is determined by careful scrutiny of the plain radiographs, noting the small bony fragment visible in the spinal canal posterior to the vertebral body from which it has originated. In addition, if a large central disk herniation is seen on MRI, at least a few CT axial sections should be obtained through the vertebral body immediately adjacent to the disk to search for a posterior apophyseal rim avulsion or bony defect. By evaluating the spinal canal in this fashion preoperatively, the surgeon should be able to plan the appropriate exposure to deal with the intraspinal pathology.

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