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Spondylolisthesis and Spondylolysis

By Serena S. Hu, MD, Clifford B. Tribus, MD, Mohammad Diab, MD, and Alexander J. Ghanayem, MD

An Instructional Course Lecture, American Academy of Orthopaedic Surgeons

The term "spondylolisthesis" refers to slipping, or olisthesis, of a vertebra ("spondylos" in Greek) relative to an adjacent vertebra. The term "spondylolysis" refers to dissolution of, or a defect in, the pars interarticularis of a vertebra. To these original terms has been added "spondyloptosis," from the Greek "ptosis" (falling off or down) to indicate a vertebra that is completely or essentially completely dislocated.

There are five types of spondylolisthesis: dysplastic, isthmic, degenerative, traumatic, and pathologic[1]. In the dysplastic type, facet joints allow anterior translation of one vertebra on another. Because the neural arch of the olisthetic vertebra is intact, it can compress the cauda equina as it translates. This type accounts for the only reported case of spondylolisthesis at birth[2]. "Isthmic" is from the Greek, meaning narrow. The isthmic type involves a lesion of the pars interarticularis (the narrow part of bone between the superior and inferior articular processes) (Fig. 1). There are three subclasses: A, which is due to a stress fracture of the pars interarticularis; B, an elongation of the pars interarticularis; and C, which is due to an acute fracture of the pars interarticularis. Dysplastic and isthmic are the two subtypes found in children, with the latter accounting for approximately 85% of cases.

Degenerative spondylolisthesis is secondary to osteoarthritis leading to facet incompetence and disc degeneration. This condition allows anterior translation of one vertebra on another. Traumatic spondylolisthesis is due to a fracture of the posterior elements, other than the pars interarticularis, leading to instability and olisthesis. A pathologic spondylolisthesis is due to a tumor or another primary disease of bone affecting the pars interarticularis or the facet joints and leading to instability and olisthesis.

The dysplastic and isthmic patterns can be classified as congenital, whereas the degenerative, traumatic, and pathologic patterns are considered acquired[3]. The dysplastic type is considered to be high if L5 is abnormal and low if L5 is normal. The low types are higher-grade deformities, with domed-shaped S1 end plates and a trapezoidal L5 vertebral body. The severity of spondylolisthesis is graded on the basis of the percentage of translation of one vertebra relative to the caudal vertebra[4]: grade I is translation of up to 25%; grade II, 26% to 50%; grade III, 51% to 75%; grade IV, 76% to 100%; and grade V, >100% (spondyloptosis). The majority (75%) of the cases of spondylolisthesis are grade I, and 20% are grade II. A simpler classification system divides spondylolisthesis into cases with translation of ≤50% (stable) and those with translation of >50% (unstable)[5].

Pathophysiology

When the lumbar spine extends, the inferior articular process of the cranial vertebra impacts the pars interarticularis of the caudal vertebra[6,7]. Repetitive impacts can produce a stress or fatigue fracture of the pars interarticularis. Lumbar hyperextension activities, such as gymnastics and American football, and lumbar hyperextension secondary to spinal deformity, such as Scheuermann disease, are associated with spondylolysis, findings that support the traumatic mechanism[8-10]. This mechanism is consistent with the observation that spondylolysis never has been reported in individuals who cannot walk and the fact that up to 40% of athletes

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with spondylolysis recall a specific back injury[11,12]. This direct compression by means of a "nutcracker" mechanism is one explanation, but another is that the pars interarticularis fails in tension through a traction mechanism[13,14]. Which of the two mechanisms is more likely to be present in a given individual is thought to be determined by the lordosis of the spine and the lumbosacral relationship. More recently, reviews of surgical and radiographic findings in patients with high-grade spondylolisthesis as well as biomechanical studies have suggested that abnormalities of the sacral growth plate may be an etiology of high-grade slippage. Yue et al. found that the only constant abnormal anatomic feature in twenty-seven patients treated for spondyloptosis was rounding of the proximal sacral end plate[15]. Biomechanical studies of immature calf spines placed under shear loads showed the growth plate to be the site of failure in all cases[16]. These studies have raised the question of which of these abnormalities, the pars interarticularis defect or the sacral growth plate, is the primary cause of spondylolysis and spondylolisthesis.

Genetics

Family history, gender, and race all are implicated. Spondylolysis occurs in 15% to 70% of first-degree relatives of individuals with the disorder[17-19]. Lysis is two to three times more frequent in boys than girls, but slippage affects girls two to three times more often than boys[20]. The prevalence of spondylolysis is approximately 6% in the white population, a rate that is two to three times higher than that in the black population[21,22]. In the Inuit population, the rate is as high as 25%[23].

Natural History

The prevalence of a defect in the pars interarticularis is approximately 5% in the general population. Fredrickson et al. started a prospective study of 500 first-grade children in 1955[22]. The prevalence of spondylolysis was 4.4% at six years of age and 6% in adulthood. It was twice as common in males. Pain was not associated with the development of the pars interarticularis defect. Approximately 15% of individuals with a pars interarticularis lesion had progression to a spondylolisthesis. The slip was seen predominately during the growth spurt, with minimal change after the age of sixteen years. Progression to a slip did not cause pain. After these individuals had been followed for forty-five years, thirty had a pars interarticularis defect and twenty-two of the thirty had final lumbar radiographs[24]. No slip was >40%. Slip progression also appeared to slow with each decade and, of particular note, the results from a back pain questionnaire and a Short Form-36 (SF-36) survey were no different from those for an age-matched general population control group.

Patients with low dysplastic spondylolisthesis have a lower prevalence of progression than those with high dysplastic spondylolisthesis. Patients with higher grades of spondylolisthesis and higher slip angles, a measure of lumbosacral kyphosis, have a higher risk of progression[25-27]. Low-grade isthmic spondylolisthesis can progress in an adult, but the progression is thought to be secondary to progressive degeneration of the L5-S1 intervertebral disc[28].

Fig. 1

Lateral radiograph showing isthmic spondylolisthesis. The arrow points to the pars interarticularis defect.

Clinical Presentation

In most children (75%) with back pain, the cause is idiopathic or so-called "overuse"[29,30]. The most common identifiable cause of back pain in a child is spondylolysis. The child typically describes a history of activity-related pain, and 40% recall a specific traumatic event[12].

The child may have lumbar hyperlordosis, which may be the cause of the spondylolysis, or lumbar flattening if he or she has severe pain or a high-grade spondylolisthesis. A high-grade spondylolysis in a child is characterized by a palpable lumbosacral step-off as well as lumbosacral kyphosis with a retroverted sacrum that results in a heart-shaped buttocks. Hyperextension of the lumbar spine may cause pain, particularly during single-limb stance. Hamstring contracture is common, although the mechanism of this is unknown, but it resolves with spinal fusion. In severe cases, the child has a

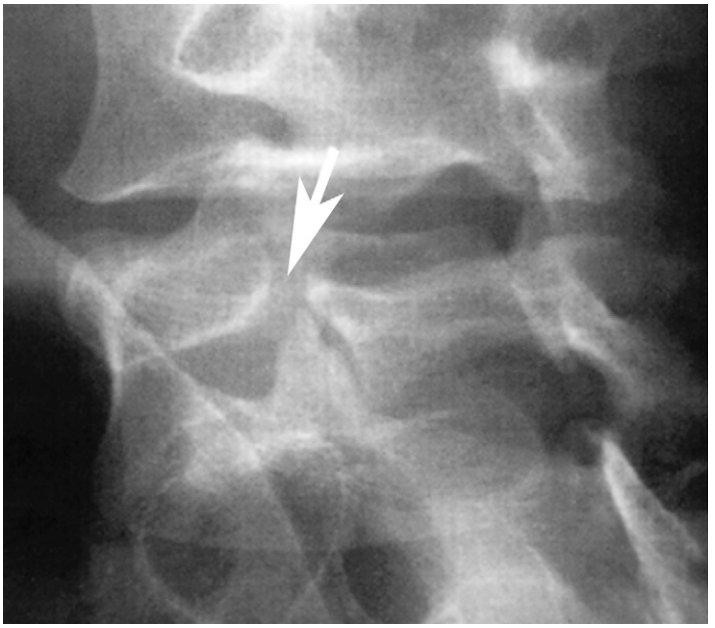

Fig. 2
An oblique radiograph showing a ''collar'' (arrow), or ''broken neck,'' of the ''Scotty dog.'' The nose of the Scotty dog is the transverse process, the eye is the pedicle, the neck is the pars interarticularis, the ear is the superior articular facet, the front leg is the inferior articular facet, and the body is the lamina.

gait disturbance characterized by crouching, a short stride length, and an incomplete swing phase, as described by Phalen and Dickson[31].

The child may have a radiculopathy that manifests as changes in sensation, a motor deficit, or tension signs distinct from the hamstring contracture. When a child has high-grade olisthesis (translation of >50%), a rectal examination should be done. An abnormal finding suggests compromise of the sacral roots. The importance of this finding is highlighted by reports of cauda equina syndrome after surgery presumably due to loss of reflex protection under anesthesia, which makes the patient more vulnerable to nerve root injury[32-34].

Scoliosis may be associated with spondylolysis[35]. When the scoliosis is due to pain, it (the scoliosis) usually resolves spontaneously following successful treatment of the spondylolysis.

When an adult with low-grade isthmic spondylolisthesis seeks medical attention, pain, usually lower-limb pain, is invariably the chief symptom[36]. It is important to correlate the pain pattern with the findings of the diagnostic work-up, since adults may have other spinal disease that is causing the pain.

Imaging

Radiography

Collimated lateral and angled (according to the inclination of the L5-S1 intervertebral disc) anteroposterior radiographs of the lumbosacral spine reduce parallax and provide the best detail[27,28,31]. Oblique lumbar views highlight the "Scotty dog," the ear of which is the superior articular process, the eye is the pedicle, the nose is the transverse process, the neck is the pars interarticularis, and the front limb is the inferior articular process. Spondylolysis is seen as a broken neck or a collar (Fig. 2). Full-length radiographs of the spine are essential to determine spinal balance, especially in the sagittal plane, and to evaluate for associated deformity. Flexion and extension lateral radiographs help to determine how much postural reduction of the lumbosacral angulation and translation can be obtained.

The degree of slip, slip angle, sacral inclination, chronicity of the slip, and pelvic incidence are all seen on the lateral radiograph[13,14,37-39]. The degree of slip is the percentage of displacement, with a slip of >50% considered unstable and associated with progression and

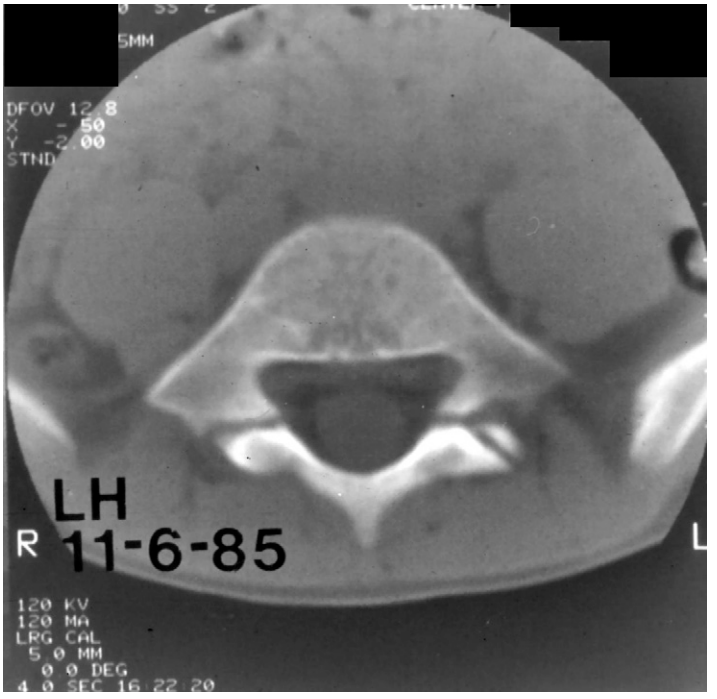

Fig. 3
Computed tomography scan showing a right pars interarticularis defect.

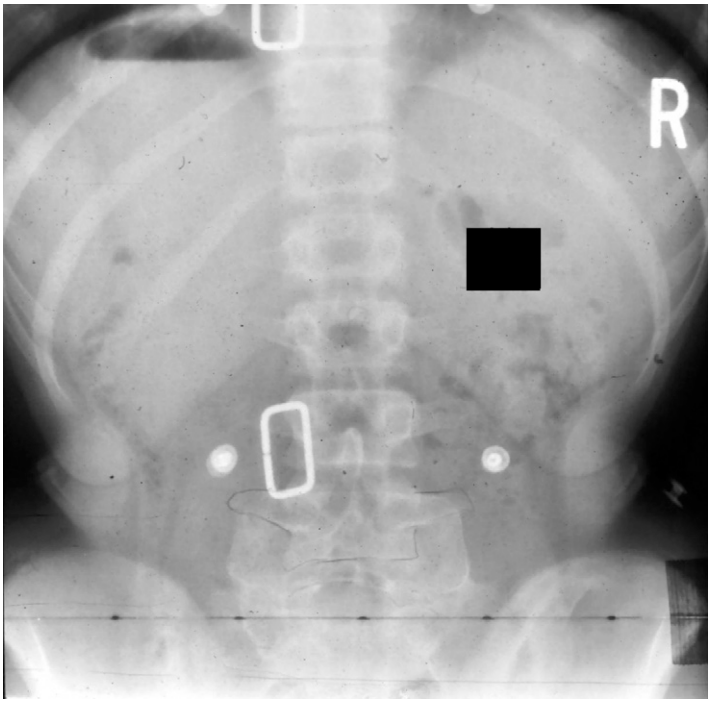

Fig. 4
Anteroposterior plain radiograph made after use of a bilateral lateral fusion to treat a spondylolysis between L5 and S1.

lumbosacral kyphosis. The slip angle is the angle between a line drawn perpendicular to the posterior aspect of the sacrum and a line drawn along the inferior end plate of L5, and a positive value is defined as lumbosacral lordosis. The sacral inclination is the angle between the posterior aspect of the sacrum and the vertical, and a value of >60° is associated with progression. The chronicity of the slip is reflected by blunting of the osseous margins; a trapezoidal L5 and a domed shape or rounding of the superior end plate of S1 indicate long-standing alterations. The pelvic incidence is the angle between a line drawn between the center of the femoral head to the midpoint of the sacral end plate and a line perpendicular to the center of the sacral end plate; it is increased in patients with spondylolisthesis, and it correlates with the slip angle[13,14]. There is controversy about the relevance of this measurement[40-42].

Single-Photon-Emission Computed Tomography

Tomography of a scintigram enables localization of signal to the posterior vertebral elements, specifically the pars interarticularis[43]. In addition to facilitating a diagnosis, the study may aid treatment of spondylolysis. Increased signal intensity suggests osseous activity and healing potential, whereas absence of an increased signal suggests a nonunion and diminished healing potential[44].

Computed Tomography

Computed tomography scans may play several roles[45-47]. When the pars interarticularis appears normal on the computed tomography scan but there is increased activity on the single-photon-emission computed tomography scan, a stress response, or "pre-lysis" defect, is the diagnosis. This is akin to the "pre-

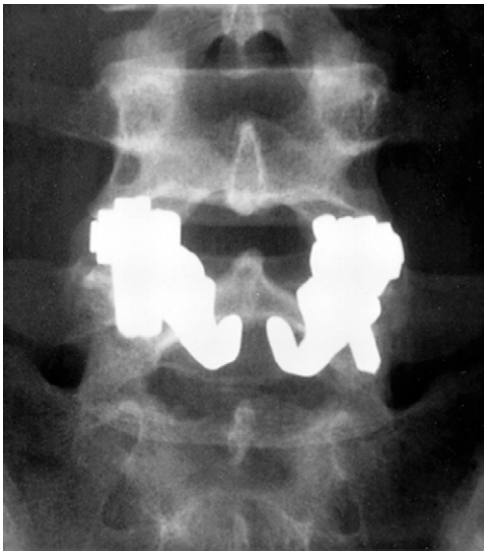

Fig. 5-A

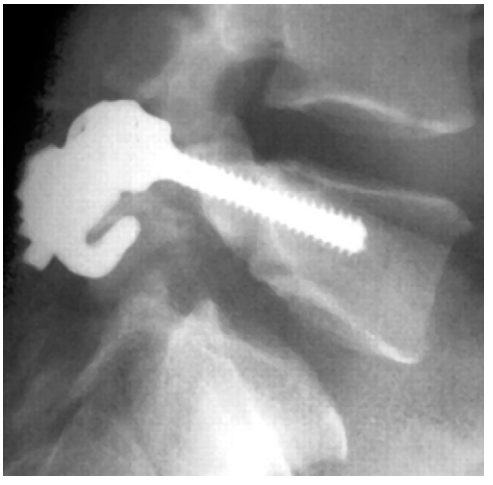

Fig. 5-B

Anteroposterior (Fig. 5-A) and lateral (Fig. 5-B) radiographs made following internal fixation of a pars interarticularis defect.

Fig. 6-A

Fig. 6-B

Figs. 6-A and 6-B An adult with severe lower-limb pain secondary to spondylolisthesis and a herniated disc at L5-S1. **Fig. 6-A** Preoperative lateral radiograph. **Fig. 6-B** Postoperative lateral radiograph made after posterior spinal fusion with transforaminal interbody fusion performed because removal of the herniated disc had increased the instability of the spine.

slip" condition in slipped capital femoral epiphysis. Pre-lysis may be evaluated further with magnetic resonance imaging. On the other hand, when the pars interarticularis is seen to have a defect on the computed tomography scan and there is no increased activity on the single-photon-emission computed tomography scan, the patient probably has a nonunion with little healing potential. Computed tomography scans are also excellent for the follow-up evaluation of healing, to rule out another lesion (e.g., osteoid osteoma) when there is an atypical presentation, and for surgical planning in cases of dysplastic vertebrae or associated anomalies (Fig. 3).

Magnetic Resonance Imaging

Magnetic resonance imaging is useful to evaluate an atypical presentation, including pre-lysis, when the computed tomography scan shows normal findings[48]. Magnetic resonance imaging is indicated for patients with high-grade spondylolisthesis and for those with a radiculopathy[49,50].

Medical Treatment

Activity modification, including cessation of inciting sports activities, and nonsteroidal anti-inflammatory agents are combined with an exercise regimen aimed principally at the reduction of lumbar lordosis as well as at the treatment of hip flexion and hamstring contracture[51]. This is sufficient for a child in whom it alleviates symptoms or reduces them to an acceptable level. The child should be evaluated annually through maturity because of the risk of progression during the adolescent growth acceleration[52].

Physical therapy should be the first line of treatment for adults with symptoms from spondylolisthesis. Hamstring stretching, trunk strengthening, and avoidance of inciting activities are beneficial for adults. Steroid injections, at the nerve root and/or the pars interarticularis, can be both diagnostic and therapeutic in adults.

The key role of spinal orthotics in the treatment of spondylolysis is reduction of the lumbar lordosis. The orthotic device is typically molded at 15° of flexion of the lumbar spine[53,54]. It is indicated for a child with unacceptable symptoms and for one with positive findings on a single-photon-emission computed tomography scan, which suggest healing potential. The typical recommendation is three months of full-time wear (more than twenty hours per day) with no sports activities followed by three months of full-time wear with sports activities allowed[55]. The patient is evaluated at the

Fig. 7-A

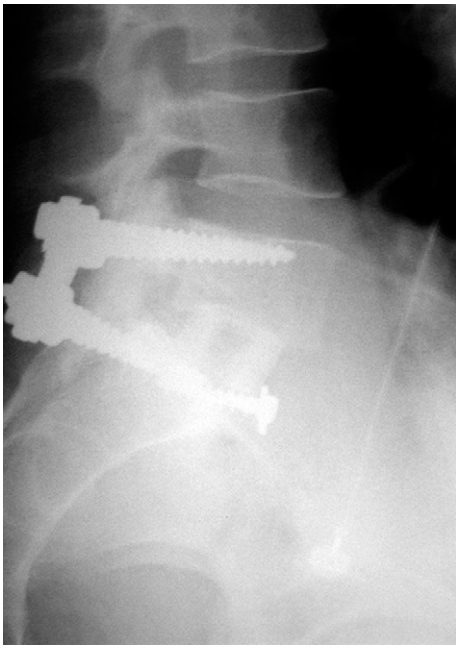

Fig. 7-B

Figs. 7-A and 7-B A patient with spondylolisthesis and a degenerated disc between L5 and S1. **Fig. 7-A** Preoperative lateral radiograph. **Fig. 7-B** Postoperative radiograph. Stability has been obtained with posterior instrumentation, and the disc height has been restored with a bone graft placed from an anterior approach.

conclusion of each phase, principally to confirm that the pain has been alleviated. If the pain persists, surgical intervention should be considered, as discussed below.

Outcome of Nonoperative Management

More than 80% of children treated nonoperatively have resolution of symptoms. There is no consensus in the literature on the healing rate of spondylolysis, but it has been estimated that 75% to 100% of acute lesions heal, all unilateral acute lesions heal, 50% of bilateral acute lesions heal, but no chronic defects heal. There is an intermediate defect, with only magnetic resonance imaging findings, that has a variable healing rate[48]. Cephalad lumbar defects heal more often than L5 lesions do. Even with these numbers, ≥90% of children return to their previous levels of activity[56]. This suggests that the stability of a fibrous union can be acceptable.

Surgical Options

An L5-S1 in situ fusion with autogenous posterior iliac crest bone graft is the standard of care for patients with a symptomatic L5 spondylolysis[57-60]. Instrumentation is not necessary because the spine is inherently stable. The procedure may be performed through a midline approach or through a paraspinous muscle-splitting approach[61]. The former approach has the advantages of familiarity to surgeons and a greater surface area for fusion, whereas the latter approach is associated with less blood loss and preserves the soft-tissue stabilizers. Postoperative protocols vary widely, from no immobilization to the use of a lumbosacral orthotic with unilateral hip immobilization. We are not aware of any data supporting the efficacy of one bracing protocol over another, but we prefer to use at least a lightweight rigid brace for most patients, with a greater degree of immobilization for younger patients who have a greater slip and a lesser degree of immobilization for older adolescents or young adults with a lesser degree of slip.

A repair of the pars interarticularis is recommended for adolescents and young adults with L4 or more cephalad spondylolysis and a normal intervertebral disc. The transverse process, which may serve as an anchor site or a site for fusion, is sufficiently large compared with a relatively small L5 transverse process (Fig. 4). In addition, loss of motion from a fusion cephalad to L4 is more relevant clinically than a loss between L5 and S1. Instrumentation techniques include placement of a screw across the lytic defect in the pars interarticularis, placement of a wire between the transverse process and the spinous process, or attachment of a pedicle screw to the spinous process with a rod and hook or a wire[62-68] (Figs. 5-A and 5-B).

Kakiuchi reported on sixteen patients treated with bilateral L5 transpedicular fixation with rod and sublaminar hook fixation[66]. Preoperatively, the patients had persistent pain and a positive response to lidocaine infiltrated into the pars interarticularis defect. Thirteen patients reported having no back pain after healing, and the other three had only occasional back pain without limitations in their activity.

In adults with a potentially reparable pars interarticularis defect, it is important to establish that that defect is the source of the pain[69]. Pain relief after a lidocaine injection at the pars interarticularis supports the concept that the defect is the cause of the pain. When the L5-S1 intervertebral disc appears normal on a magnetic resonance imaging scan and there is minimal dynamic instability, a pars interarticularis repair can be considered. The most common technique is excision of the nonunion site, placement of a pedicle screw, bone-grafting, and placement of a sublaminar hook with connection of each hook by means of a rod to the ipsilateral pedicle screw (Figs. 6-A and 6-B).

Surgical decompression is indicated when the patient has neural compromise, with a radiculopathy or bowel or bladder dysfunction[34,70,71]. Decompression must be wide and bilateral with removal of the loose lamina (a Gill procedure) and a foraminotomy, possibly including a facetectomy. Decompression increases the rate of pseudarthrosis and increases instability, which can result in progression of deformity if instrumentation is not used[72]. In the literature, there is both support for and advice against concomitant decompression and fusion for patients with spondylolisthesis[70-76]. We usually recommend decompression at the time of fusion with instrumentation if there is any lower-limb pain or neural compression.

Carragee enrolled forty-six adults with symptomatic low-grade isthmic spondylolisthesis into a randomized prospective study to evaluate the effect of decompression[72]. All smokers were treated with transpedicular instrumentation, whereas the nonsmokers had no instrumentation. Patients were randomized with regard to whether or not they underwent a formal decompression. Only one of the twenty-four patients without decompression had an unsatisfactory result. Obtaining fusion was more important than the decompression, and use of instrumentation was found to improve the fusion rate.

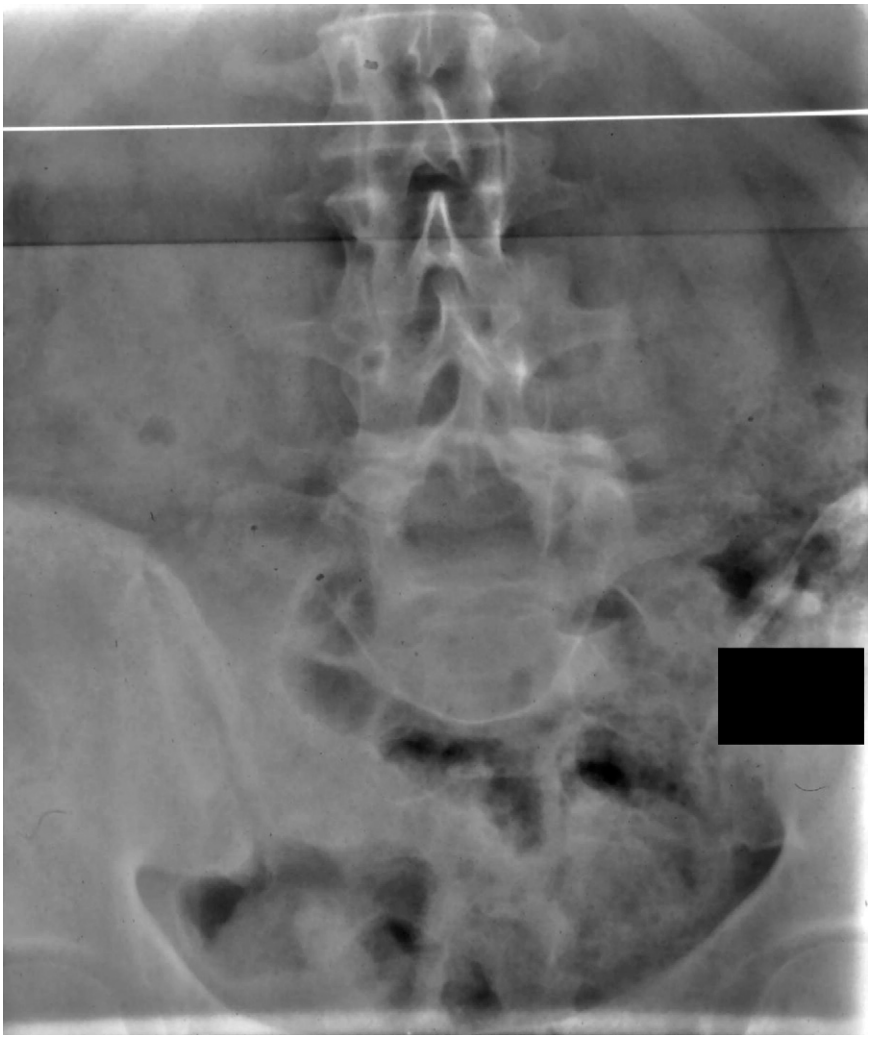

Fig. 8-A

Figs. 8-A through 8-E A patient with spondyloptosis who had severe lower-extremity and back pain. **Figs. 8-A and 8-B** Preoperative anteroposterior (Fig. 8-A) and lateral (Fig. 8-B) radiographs.

Instrumentation

The use of instrumentation in the treatment of low-grade isthmic spondylolisthesis in adults increased with the widespread use of pedicle screws and the belief that a fusion is necessary to obtain a good result. Transpedicular fixation does increase the rate of fusion, and there is a positive correlation between successful fusion and clinical outcome[77-83]. On the other hand, Möller and Hedlund found that instrumentation offered no advantage when they compared patients treated with in situ fusion with transpedicular fixation and those treated with in situ fusion without transpedicular fixation[84,85]. Furthermore, the patients who were treated with instrumentation had greater blood loss and a longer operative time[84,85]. Therefore, an in situ arthrodesis without instrumentation remains a reasonable option, particularly in patients with osteoporotic bone. Despite this, and because of better fusion rates and at least a suggestion of better outcomes with a solid fusion, we recommend instrumentation with transpedicular fixation, especially when a decompression is done.

Interbody Fusion

There are several theoretical advantages to adding anterior column support to

Fig. 8-B

the standard posterolateral fusion. These include providing a larger surface area for bone graft incorporation, placing the bone graft under compression, obtaining an indirect reduction of foraminal stenosis by using the graft to restore the height of the intervertebral disc, improving lumbar lordosis, and ablating the degenerated disc (a potential source of pain) (Figs. 7-A and 7-B). The interbody device or bone graft may be placed through a transforaminal lumbar interbody fusion approach or through a posterolateral approach. The disadvantages of performing the interbody fusion through a posterolateral approach are the additional surgical time compared with that needed for posterior-only surgery and the risk of injury to the neural elements with the retraction required for disc excision and placement of the interbody device[86-90].

The interbody fusion can be done through an anterior approach without a posterior fusion. This is called an anterior lumbar interbody fusion. Proponents of this approach prefer it because it provides the same treatment advantages of the interbody fusion while avoiding disruption of the posterior paraspinal muscles and the exposure of the neural elements[91-93]. An anterior-only interbody fusion in a patient with spondylolisthesis must achieve inherent stability or it will displace. One of us (C.B.T.) had encouraging results after utilizing an anterior plate and an interbody component to fuse the site of an isthmic spondylolisthesis with an anterior-only approach in a small group of patients. The anterior approach adds the risk of retrograde ejaculation in males and of vascular complications. Aunoble et al. reported successful outcomes of anterior lumbar interbody fusion in a series of twenty patients[92].

Combining both posterior and anterior approaches in the treatment of low-grade isthmic spondylolisthesis in an adult has both advantages and disadvantages compared with the single approaches. The anterior approach allows better reduction of the deformity than is possible with the posterior approach, whereas the posterior approach allows a direct decompression of compressed nerve roots and transpedicular fixation increases the rigidity of the construct. The combined approach addresses the pars interarticularis defect, foraminal stenosis, degenerative disc disease, a "loose lamina," and the dynamic instability. The disadvantage is that this technique requires two separate procedures, with increased operative time and morbidity. In a prospective study, patients who had undergone the combined approach had better outcome measures in all categories at six and twelve months postoperatively compared with patients treated with posterior fusion only[94]. The differences were less pronounced at two years.

The treatment approach for a high-grade spondylolisthesis should differ from that for a low-grade spondylolisthesis (Figs. 8-A through 8-E). The management of patients with >50% slippage (grade III or higher) or lumbosacral kyphosis is more complex. High-grade spondylolisthesis can be associated with dysplastic L5-S1 facets without a pars interarticularis defect and therefore is more likely to cause severe stenosis since, with the displacement of the vertebral body, the posterior lamina is pulled forward rather than remaining posteriorly (separated from the vertebral body), as occurs if there is a pars interarticularis defect. While the preferred surgical treatment is fusion in situ, that procedure is associated with a higher rate of slip progression, pseudarthrosis, neurologic

Fig. 8-C

Preoperative T2-weighted magnetic resonance imaging scans showing severe spinal canal stenosis. The patient was treated with a resection of L5, reduction of the malalignment, interbody fusion, and posterior instrumentation.

injury, and, if instrumentation is used, failure of the hardware even in young patients[95-98].

Even without reduction, management of a high-grade spondylolisthesis is risky[32,34]. The management of an adult with a high-grade spondylolisthesis should start with nonoperative methods that include physical therapy and epidural steroids. A child with a high-grade spondylolisthesis or an adult who does not respond to nonoperative care should have surgical stabilization. An in situ fusion can be successful in many young patients. Because these patients often have a dysplastic L5 transverse process and because an L5-S1 fusion would place the fusion bed under tension, inclusion of L4 is generally required to achieve a successful fusion. A paramedian Wiltse approach is preferred, to maintain the integrity of the midline structures. An external brace is usually applied until the fusion site heals. Patients followed over the long term after an in situ fusion generally are found to have good function and pain relief, although the surgery does not affect their appearance[99,100]. Although the hamstring tightness that many of these patients exhibit is suspected to be related to neurologic compression, it usually resolves without decompression when a successful fusion has been achieved. This may take up to eighteen months, however, and some authors believe that a subtle gait abnormality persists[59].

Reduction of high-grade spondylolisthesis has become more common, probably because of the availability of smaller implants, which are needed in these patients, as well as the higher prevalence of unsuccessful fusion in patients with high-grade spondylolisthesis[100]. A patient who is considered for a reduction of a spondylolisthesis should have substantial angulation of L5 over S1 (a slip angle of >45°, lumbosacral kyphosis, or an inability to stand upright with the head balanced over the pelvis), require a decompression, have demonstrated progression of the slip angle, have demonstrated progression after an attempted fusion, or have an unacceptable clinical appearance. It is important that the patient and his or

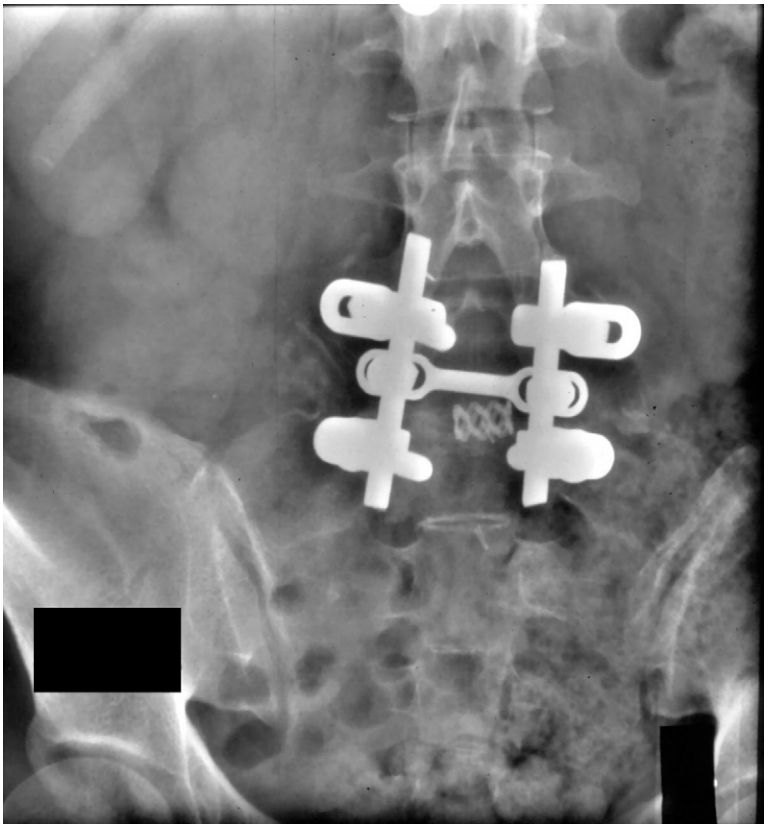

Fig. 8-D

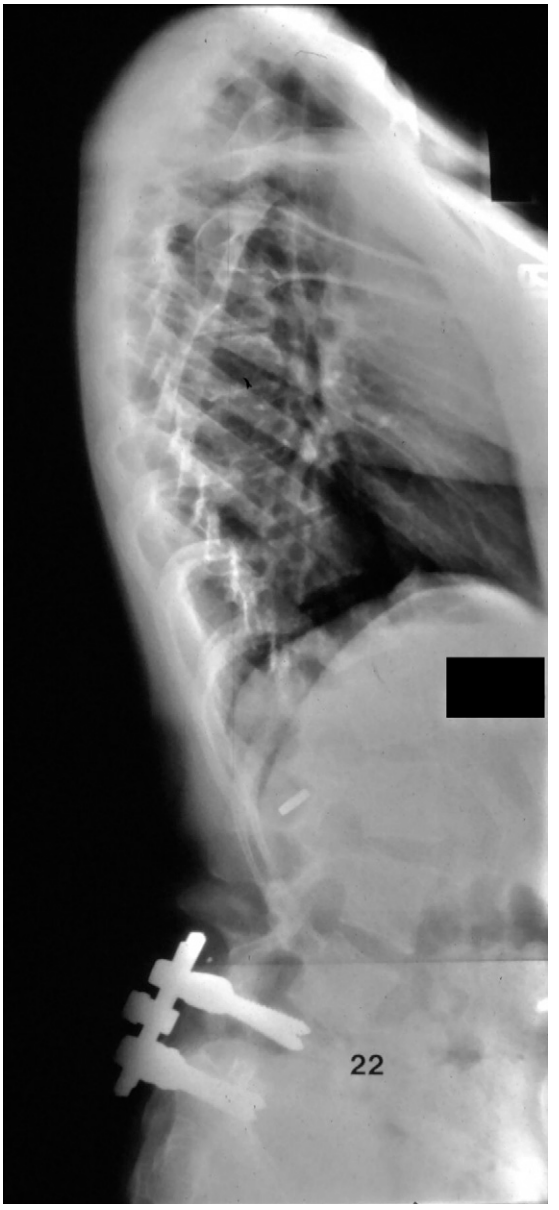

Fig. 8-E

Postoperative anteroposterior (Fig. 8-D) and lateral (Fig. 8-E) radiographs.

her family understand and accept the risks associated with a reduction.

Reduction can be done with external cast techniques, particularly in very young patients in whom pedicle screw fixation may not be possible[101]. The reduction is performed after the bone graft is placed and the wound is closed. The patient is placed on a spica table or Stryker frame and should be awake so that he or she can report any neurologic changes. A padded support is placed over the sacrum and the spine is allowed to extend, to reduce the lumbosacral kyphosis. The trunk and at least one thigh are then incorporated into a spica cast. A brace with a thigh extension can be used when early healing is apparent on radiographs, usually at six to twelve weeks.

Open reduction with instrumentation is used for patients who require a decompression or for whom a fusion attempt without instrumentation has failed, with progression of the slip. A wide surgical decompression is performed, with care taken to adequately decompress the nerve roots (usually L5). A temporary distraction rod is applied from L3 to the sacrum, usually with temporary hooks. Pedicle screws are then placed in L4 and L5, and sacral screws are directed to the sacral promontory, where maximal purchase in the sacrum is achieved, or the sacral screws can be drilled through the sacrum into L5. Neurophysiologic monitoring is advised. We have found that it helps to monitor several muscle groups, both

motor and sensory, as well as electromyographic activity and sphincter activity. Removal of the L5-S1 disc and/or osteotomy of the sacral dome can be done to improve the reduction. The reduction maneuvers of distraction and translation should be performed slowly. The final millimeters of translation and the final degrees of angular reduction are the most risky, and partial reduction is an option[102]. Care should be taken during the reduction, not just because of the neurologic risk but also because of the risk of pedicle screw pullout. This is particularly true for the caudal fixation. Transsacral screws, iliac screws, and Jackson intrasacral buttress rods have all been used to improve the strength of the caudal fixation with varying degrees of success. Once correction has been achieved, a decision regarding whether to perform an interbody fusion is made. A standard interbody cage filled with bone or a transsacral fibular graft provides additional stability during the posterior approach[103-105]. An alternative surgical option is combined anterior and posterior fusion, with the anterior fusion done first to release the anterior structures and thus make the reduction and placement of the interbody spacer easier[106,107].

The long-term results of the different treatment options for high-grade spondylolisthesis are relatively good. In one study of sixty-seven children and adolescents, the results of posterolateral, anterior, and circumferential fusion were compared at an average of seventeen years postoperatively, and the best clinical outcome, as measured with the Oswestry Disability Index, was found after the circumferential fusion[108]. A review of the results of posterolateral decompression and fusion with transsacral placement of a fibular graft in fourteen patients demonstrated complete neurologic recovery in patients in whom neurologic deficits had developed after the surgery and incorporation of the fibular graft and achievement of a solid fusion in all but one of the patients[105]. In a similar series, one patient was not satisfied with the cosmetic result and one patient had a nonunion and continued back pain[109]. The results after reduction of high-grade spondylolisthesis are generally good[103,110-113].

When a patient has complete spondyloptosis, particularly with L5 below the level of the sacral end plate, resection of L5 and reduction of L4 onto the sacrum, through a combined anterior and posterior approach (the Gaines procedure), can be considered[114]. Although this is a spine-shortening procedure and thus intended to be associated with a decreased risk of neurologic injury in this particularly high-risk patient group, the rate of neurologic injury was 76% in Gaines's original series[114]; however, only two of the thirty patients in that series required lower-extremity bracing at the time of long-term follow-up[115].

Degenerative Spondylolisthesis

Unlike isthmic spondylolisthesis, degenerative spondylolisthesis occurs most often (in 85% of cases) at L4-L5. The L3-L4 level is the next most common level (Figs. 9-A, 9-B, and 9-C), with L5-S1 rarely being involved. Degenerative spondylolisthesis is most common in the sixth decade of life and is more common in females than in males (a ratio of 6:1).

The pathophysiology of this type of spondylolisthesis has been postulated to be a combination of disc and facet joint degeneration. Patients with degenerative spondylolisthesis have more sagittally oriented facet joints than do patients without degenerative spondylolisthesis; however, it is unclear whether the facet orientation is a primary cause or a secondary effect[116,117]. The slip rarely progresses beyond grade I.

Patients usually present with neurogenic claudication or radicular symptoms from the spinal stenosis, and some patients recount a long history of back pain prior to the development of

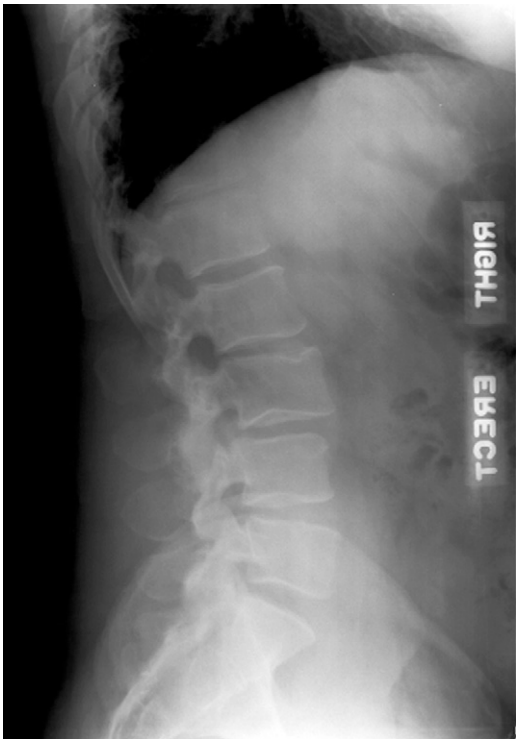

Fig. 9-A

Figs. 9-A, 9-B, and 9-C A patient with degenerative spondylolisthesis at L3-L4 and severe lower-extremity and low-back pain refractory to conservative treatment.

Fig. 9-A Preoperative lateral radiograph.

Fig. 9-B

Fig. 9-B Preoperative sagittal T2-weighted magnetic resonance imaging scan revealing moderately severe stenosis at L3-L4.

Fig. 9-C

Fig. 9-C Postoperative lateral radiograph.

lower-extremity symptoms. Evaluation of a patient with degenerative spondylolisthesis is similar to that of any patient with a back condition, with a careful neurologic examination and evaluation of the spine, including the patient's stance and sagittal balance. Vascular insufficiency and peripheral neuropathy need to be considered as alternative causes of the symptoms. Patients whose symptoms do not correspond to the level of the stenosis should have a complete neurologic work-up or electromyographic studies. Patients who do not have palpable peripheral pulses, do not have relief of pain with sitting, or do not need to sit to relieve the claudication are more likely to have vascular insufficiency. Spinal tumors, infection, and nonspinal etiologies also need to be considered. As is the case with isthmic spondylolisthesis, upright radiographs are necessary to determine the degree of degenerative spondylolisthesis[118]. Magnetic resonance imaging scans are ideal for assessing the severity of spinal canal and foraminal narrowing.

Conservative management may help many patients with symptoms of degenerative spondylolisthesis. Nonsteroidal anti-inflammatory medications, physical therapy, and cardiovascular conditioning as well as alternative treatments such as acupuncture may relieve symptoms to the point where surgery is not necessary. Patients with substantial radicular or claudication symptoms often benefit from epidural steroid injections or selective nerve root blocks.

Surgical management is offered when nonoperative options have not adequately relieved symptoms. While both nonoperative and operative treatment can substantially decrease symptoms, surgery seems to provide faster and greater improvement for patients with severe symptoms and associated severe stenosis[119]. The most common operative treatment options are a limited decompression (laminoforaminotomy or interlaminar decompression),

laminectomy, or laminotomy with fusion (with or without instrumentation). The severity of the stenosis and where it is located (foraminal, lateral recess, central, or [most commonly] a combination of these sites) determine the extent of decompression required and therefore the likelihood of slip progression without fusion. A limited decompression may be considered for patients who have unilateral disease without evidence of motion on flexion-extension radiographs[120]. At least 50% of the facet joints and the interspinous ligaments need to be preserved during the decompression to maintain inherent stability.

Most patients who undergo surgery should have a laminectomy and fusion. Herkowitz's group and others have shown that patients who have a laminectomy and fusion do better than patients who have a laminectomy alone[121-125]. Short-term follow-up did not show an advantage to using instrumentation with the fusion, which increased the prevalence of complications. However, longer follow-up revealed that patients did better if a fusion had been achieved, and fusion was achieved more reliably with internal fixation. Patients with substantial comorbidities or with osteoporosis and/or substantial disc space narrowing may be better treated by fusion without internal fixation. The majority of symptomatic patients with degenerative spondylolisthesis who are in reasonable health and for whom nonoperative treatment has failed should have a laminectomy and fusion with instrumentation. Such an approach has resulted in a high fusion rate and excellent clinical success[124,126].

To improve the fusion rate and patient outcomes, some surgeons are including interbody fusion in their surgical approach. Posterior-based transforaminal interbody fusion or posterolateral interbody fusion may improve restoration of disc and foraminal height[127,128]. However, to our knowledge there are no published studies that demonstrate improved outcomes with the addition of posterior-based transforaminal interbody fusion or posterolateral interbody fusion to the surgical procedure in patients with degenerative spondylolisthesis.

Currently, motion-preservation and nonfusion devices are receiving tremendous attention in the lay press. While early, preclinical Investigational Device Exemption studies[129,130] have shown favorable results, the use of these devices in patients with degenerative spondylolisthesis has yet to be validated in independent randomized prospective studies. Indeed, with the selection criteria used in the preclinical studies, only small numbers of cases of degenerative spondylolisthesis were included.

Overview

Spondylolisthesis is a common condition and the majority of people are successfully treated without surgery. Patients for whom surgery is indicated usually have good outcomes. Young patients may require only a fusion in situ; however, patients who have evidence of neural compression may need a decompression to relieve symptoms, and fusion is usually also indicated in these cases. Additional adjuncts have been proposed to improve outcomes, but there are few randomized prospective trials to demonstrate superiority of one technique over another.

Serena S. Hu, MD
Mohammad Diab, MD
Department of Orthopaedic Surgery, University of California, San Francisco, 500 Parnassus Avenue, Room MU 320W, San Francisco, CA 94143

Clifford B. Tribus, MD
Department of Orthopedic Surgery and Rehabilitative Medicine, University of Wisconsin, K4/746 Clinical Science Center, 600 Highland Avenue, Madison, WI 53792
Alexander J. Ghanayem, MD
Department of Orthopaedic Surgery and Rehabilitation, Loyola University Chicago, 2160 South 1st Avenue, Maywood, IL 60153

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