General

Spondylolysis

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Spondylolysis is a bony defect of the pars interarticularis and most often results from repetitive stress. Although spondylolysis is usually asymptomatic, symptomatic spondylolysis is the most common cause of identifiable back pain in children and adolescent athletes. A thorough history and physical exam, as well as appropriate imaging studies are helpful in diagnosis. General first-ine therapy for spondylolysis is conservative and consists of rest from sports, core strengthening, as well as spinal bracing. Patients who have failed conservative therapy may consider surgical repair. This article aims to review the epidemiology, pathophysiology, presentation, and treatment options of spondylolysis.

INTRODUCTION

Spondylolysis is a bony defect in the pars interarticularis, which represents the junction of the superior articular process, inferior articular process, lamina, and pedicle of the vertebra.[1,2] A lesion of the pars interarticularis can be bridged by osseous, fibrous, or cartilaginous material resulting in a chronic non-union.[3,4] The defect can occur unilaterally or bilaterally. When unilateral, there is an increased chance of bony healing compared to bilateral lesions.[5,6] As reported by Fuji et al., patients with a unilateral lesion at the 4th lumbar vertebrae that are detected early are predicted to have complete bony healing.[7] However, bilateral lesions may potentially result in spondylolisthesis, which is the anterior, lateral, or posterior displacement of the vertebral body in relation to the sub-adjacent vertebra. Although cases of cervical spondylolysis have been reported, it is much more prevalent in the lumbar vertebrae.[4,8,9] The incidence of spondylosis increases with age until patients reach an age of 18; incidence plateaus at this point.[10] Spondylolysis is often asymptomatic and found incidentally on imaging.[2,11] When symptomatic, spondylolysis often presents as low back pain and is more commonly observed in adults. However, back pain is uncommon in children and adolescents, and presence of low back complaints may indicate further workup for spondylolysis in children, especially in higher-risk populations such as young athletes.[12,13] Although spondylolysis is often asymptomatic, a comprehensive physical exam in addition to imaging is often helpful in confirming the diagnosis. If pain persists, treatment may be necessary. The purpose of this manuscript is to provide a detailed review of spondylolysis regarding its epidemiology, pathophysiology, risk factors, clinical presentation, diagnostic criteria, and current treatment guidelines and options.

EPIDEMIOLOGY

Spondylolysis is a relatively common condition in adults, affecting between 6-8% of the general adult population.[14,15] It is rare in children, with incidence increasing in proportion to age up until the age of 18.[13,16,17] This is postulated to be due to weight bearing as a risk factor for spondylolysis, since virtually no cases of spondylolysis has been reported in non-ambulatory patients. Although spondylolysis is less common in children, it has been shown to be the leading cause of low back pain in adolescent athletes, explaining nearly 47% of low back pain in this population.[12,13,18] Additionally, adolescent athletes are at increased risk of suffering from low back pain, especially in spinal extension-intensive sports such as gymnastics. Studies have shown that up to 30% of young athletes experience low back pain compared to 18% in their non-athlete counterparts.[19,20] Historically, spondylolysis was thought to occur two to three times as often in males than females. How-

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ever, since adolescent female participation in competitive sports has increased, especially in female-dominated sports such as gymnastics, the prevalence of spondylolysis in females has increased four-fold.[21,22] In the United States, race and genetic sex seem to also play a role in the spondylolysis prevalence rate. Caucasian males are most commonly affected with a prevalence of 6.4%; African American males, Caucasian females, and African American females are also notable with prevalences of 2.8%, 2.3%, and 1.1%, respectively.[23]

PATHOPHYSIOLOGY/RISK FACTORS

Although the exact cause of spondylolysis is unknown, the postulated mechanism is a most likely a due to fracture due to environmental stress in a population with an underlying genetic predisposition.[24] 95% of spondylolysis cases occur at the L5 vertebrae, and is most likely due to repetitive rotation, extension, or flexion of the spine, causing the inferior articular process of the L4 vertebrae and with the superior articular process of the S1 vertebrae to exert a shearing stress on the pars interarticularis of L5.[9] This shearing stress is hypothesized to cause a microfracture that can eventually progress to a complete fracture after years of repetitive stress.[4,15,16,24–26] This mechanism of injury is supported by studies performed by Ward et al., who compared transverse interfacet distances in patients with spondylolysis with healthy patients. Radiographs from the two groups displayed that spondylolysis patients had consistently decreased interfacet distances at the L3-S4 levels when compared to control, suggesting an increased magnitude of shear stress with lumbar spine motion and therefore greater susceptibility to development of spondylolysis in comparison with patients with normal spacing evident on imaging.[4,27,28] When shear stress results in bilateral spondylolysis, studies have suggested increased risk of progression from spondylolysis to spondylolisthesis, or anterior, lateral, or posterior displacement of vertebral discs due to both a reduction in stability and an increase in mobility of the posterior spine.[29,30]

Participation in competitive sports that involve excessive spinal motion is the most common risk factor for developing spondylolysis.[31] High amounts of stress may be absorbed by the pars interarticularis during extreme spinal extension and rotation.[32–34] Athletes in sports requiring asymmetric lumbar extension and rotation, such as rowing, are at increased risk of development of spondylolysis, with a prevalence of between 17-25%. Other sports which require extreme spinal extension and rotation, such as soccer and baseball, have an impressive prevalence of spondylolysis at approximately 30% as well.[31,35,36]

Literature has suggested that spinal deformities and genetics may also be potential risk factors in the development of spondylolysis. In a study by Sakai et al., 92.6% of children from age five to twelve with spondylolysis at the L5 vertebra were shown to have concurrent spina bifida occulta.[37] Similarly, a retrospective study in Japan showed that patients with spina bifida occulta had a 3.7-fold increase in the incidence of spondylolysis.[38] Patients with Scheuermann's kyphosis have been reported to have a 30-50% incidence rate of spondylolysis, which is most likely due to an increase in lumbar lordosis and lumbar extension when compared to the general population.[39,40] Several studies have also shown that spondylolysis most likely contains a genetic component, as there is a higher incidence of spondylolysis in siblings and children of patients with confirmed spondylolysis compared to the general population.[25,41,42]

CLINICAL PRESENTATION

Although most cases of spondylolysis are asymptomatic (87%), it remains the most common cause of lower back pain in children and adolescents.[43–45] Patients commonly complain of mild lower back pain on exertion that is relieved with rest.[46–48] The pain may initially related to strenuous activity but may also progress in severity and interfere with pursuit of daily living activities.[46,48] Patients may also experience tenderness localized to the lumbosacral region and buttocks, as well as decreased lumbosacral range of motion.[2,47] Neurologic deficits are uncommon, but progression from spondylolysis to spondylolisthesis may lead to nerve root compression and dermatomal radiculopathies, as well as neurogenic claudication, bowel and bladder dysfunction, and rarely, cauda equina syndrome.[2,43,45] An estimated 96% of spondylolysis cases occur at the L5 and S1 vertebrae, but may also less commonly involve L1, L2, L4, and cervical vertebrae.[45,49,50] Of note, pain with sitting, worsening pain at rest, and consistent pain at night are all considered atypical and concerning for an alternative etiology of low back pain such as sacroiliac joint injury, progression to spondylolisthesis, or malignancy, and further workup should be pursued.[46]

As mentioned previously, spondylolysis may result from microtrauma in adolescents who participate in athletic activities that lead to stress fractures of immature vertebrae.[37,48] Notably, excessive spinal rotation and extension have been especially associated with spondylolysis development and may exacerbate clinical symptoms.[37,48] Although lumbar flexion does not typically provoke pain, patients may complain of exacerbation of symptoms when rising from spinal flexion, especially against resistance.[2] Other symptoms of spondylolysis include paraspinal muscle tenderness and spasm, as well as hamstring tightness.[2,46] Paraspinal muscle spasms are often mild but have rarely been known to progress and result in spinal deformities.[51] Hamstring tightness can go unnoticed, although patients may notice decreased range of motion on knee extension.[52] Regardless, physical exam techniques such as spinal palpation and careful measurement of knee range of motion can be a telling sign of disease.[2,53]

DIAGNOSIS

Although spondylolysis is often asymptomatic, a thorough history and careful physical exam may be helpful in diagnosis. Spondylolysis often presents insidiously, although some patients may recall an episode of acute trauma which instigated the onset of their symptoms.[46] History collection should be focused on well-established risk factors of spondylolysis. Due to the close association between history of athletic activity and disease development, it is crucial to

obtain an accurate and extensive history of previous athletic activities. It may also be beneficial to inquire about congenital spinal defects such as spina bifida, as well as prior family history of spondylolysis.[8,48] The physical exam should begin with a visual inspection of the patient to assess for spinal asymmetry, lumbar lordosis/kyphosis, and gait abnormalities.[2,45,51] Low back pain and hamstring tightness may manifest as a stooped gait, although patients may also commonly present with a normal gait and stride length.[2,46] Paraspinal muscle and focal spinal tenderness may also be palpated on exam. Additionally, spondylolysis may be complicated by progression to spondylolisthesis, which may be evident on exam by the presence of a step-off deformity on spinal palpation.[2]

Since spondylolysis is commonly asymptomatic, the efficacy of certain physical exam maneuvers in diagnosis remains questionable. Nevertheless, certain findings may prove invaluable in early detection of spondylolysis.[53,54] A frequently reported finding is reproducible low back pain with lumbar extension and is evident by a positive one-leg hyperextension test (i.e. stork test).[2,46] This test is conducted by having the patient stand on one foot while hyperextending the contralateral hip, and resulting pain arises due to increased tension in posterior vertebral structures, as seen in spondylolysis. Bilateral spondylolysis may elicit pain with hyperextension of both legs, where unilateral pars interarticularis lesions may experience discomfort with extension of only the ipsilateral hip.[2,46] Interestingly, the reported sensitivity and specificity values of the one-leg hyperextension test are relatively low at 81% and 39%, respectively. Despite its popularity, it is unclear as to whether the one-legged hyperextension test contains diagnostic value in the setting of spondylolysis.[53,54] Measurement of the popliteal angle on full knee extension may be performed in order to assess for hamstring tightness, with angles greater than 30-45 degrees considered abnormal.[46,48]

Imaging results are often required to make a definitive diagnosis of spondylolysis.[55] Useful imaging modalities include plain-film imaging, computed tomography (CT), magnetic resonance imaging (MRI), single-photon emission computed tomography (SPECT), and bone scintigraphy. Of note, while imaging results are vital for diagnosis of spondylolysis, correlation between radiographic findings and disease morbidity has yet to be established.[56] Imaging workup often begins with plain radiographs in lateral, anteroposterior, and oblique views and shows a lucent gap which tracks inferiorly and laterally in the pars interarticularis (in contrast to an apophyseal joint disruption, which appears similarly but instead tracks inferiorly and medially).[46,48,51] Reports suggest that the collimated lateral view is most sensitive (84%) for assessing bony defects at the level of the pars interarticularis.[51,57] Oblique views may be helpful when a fracture is not appreciated on lateral views, although they are not ideal for initial workup as iliac wings may obscure visualization of the L5 and S1 vertebral segments.[46,48,51,58] Although x-rays remain incredibly useful in spondylolysis cases with frank pars interarticularis fracture due to speed of imaging, low cost, and low radiation exposure, this modality is limited by its inability to effectively visualize minor pars defects or early spondylolysis where no fracture is present.[58]

Computed tomography (CT) is a superior imaging modality for assessment of bony defects and is widely considered the gold standard for visualizing fractures in the pars interarticularis.[46,50,58] On CT, spondylolysis presents as a hypodense cortical ring fracture in the pars.[46] Additionally, wide sclerotic margins along the pars defect may be observed in chronic disease, although the reliability of this finding is unclear.[4,48] Although CT imaging is limited due to high cost and radiation exposure, it is the best imaging modality for assessing spondylolysis progression and resolution, and is often used for surgical planning.[58] However, similarly to x-ray imaging, CT scans are only helpful for diagnosing progressive or terminal spondylolysis in which a pars fracture line is present.[4] Therefore, a negative x-ray or CT cannot rule out disease, and further advanced imaging modalities such as MRI, bone scintigraphy, or SPECT are required, especially in cases where clinical suspicion for spondylolysis is high.[46]

Early spondylolysis is best evaluated with thin-sliced MRI and SPECT which can visualize the inflammatory changes which proceed spondylolysis stress fractures.[55,58] MRI is also beneficial in assessment of both pathologic and morphologic abnormalities, although its efficacy in identification of morphologic lesions remains inferior to CT.[4,58] Osteoblastic activity and edema due to early spondylolysis may be evident with hyperintensity in the pars interarticularis. Fractures may also be noted as low-intensity cortical bone defects.[4,58] MRI is also often utilized for visualization of neurologic complications such as nerve root compression.[4,45]

The clinical efficacy of SPECT and bone scintigraphy has been restricted by their limited ability to visualize morphologic pars defects, with positive findings likely requiring further investigation with CT or MRI.[4,46] However, SPECT and bone scintigraphy do not detect uptake in fibrous unions often seen in chronic spondylolysis, and are therefore useful in determining acute vs. chronic spondylolysis when paired with x-ray imaging.[46] Additionally, SPECT and bone scintigraphy allow for visualization of osteoblastic activity seen in early spondylolysis.[48,58] Positive signs of spondylolysis on these tests include a characteristic triangle-shaped area of increased cellular activity when viewed from the lateral angle.[46] Limitations of SPECT and bone scintigraphy include high radiation exposure, as well as high false positive and false negative rates, as other etiologies of back pain (i.e. tumors, infection, and autoimmune diseases) may present with similar findings on imaging; Therefore, further investigation with MRI or other imaging modalities is often warranted.[4,46]

Lastly, CT and MRI imaging also exhibit the ability to assess for sacral table angle (STA) abnormalities, which has been previously shown to carry prognostic value for progression of severe spondylolysis to vertebral slippage and development of spondylolisthesis.[59,60] A low STA results in augmented anterior force on the L5 vertebrae, predisposing to pars interarticularis fracture.[59] Importantly, low STA values were found to be only associated with terminal and severe cases of spondylolysis, with no association in early or progressive disease.[59]

TREATMENT OPTIONS

CONSERVATIVE TREATMENT

Conservative management is first line therapy in patients with spondylolysis, and aims to heal the spinal lesion, prevent further progression of injury, and provide symptomatic relief. Commonly utilized therapies include restrictive activity modification, physical therapy, carefully regulated exercise, bracing, and external electrical stimulation.[61–71] Therapies may be used in isolation but are often utilized in conjunction for greater efficacy, and have been shown to be particularly effective in younger patients with unilateral spondylolysis.[61,62,64,66,69,70,72–76] Three conservative management strategies that have shown particularly promising results in past studies include anti-lordotic spinal bracing in young athletes, external electrical stimulation, and core muscle strengthening, and will be further discussed in this section.

Although isolated activity modification is a popular approach to conservative management of spondylolysis in young athletes, studies have suggested improved outcomes when prescribed in conjunction with anti-lordotic spinal bracing. Spinal bracing has shown to be effective but usage is often delayed until after a failed trial of activity modification rather than a first-line treatment option.[64,76,77] Thoracic lumbar sacral orthosis bracing has been shown to be especially effective in management of unilateral spondylolysis, and is often indicated for 6 to 12 weeks in young athletes.[62,73,76] Progress is monitored with CT scans and remobilization may be pursued after progressive bone healing is evident on imaging. Patients should also be pain-free on lumbar extension and rotation.[76,78,79] Although spinal bracing is effective in younger patients, results have suggested reduced efficacy in adults likely related to diminished initiation of bone healing. Therefore, other treatment options may be better suited for adult athletes.[64]

External electrical stimulation use to repair bone fractures was first described in the mid-1800s.[80] Common uses include delayed or non-union fractures, internal and external fixation, osteotomy, bone grafts, lower extremity stress fractures, and osteonecrosis.[81–85] Studies have previously demonstrated that electrical stimulation increases migration and proliferation of bone-forming stem cells, and induces mineralization, formation of extracellular matrix, as well as increase the expression of osteogenic genes.[80] Electrical stimulation has shown promise in treatment of spondylolysis, even in absence of activity restriction, and is also often used in conjunction with surgical therapy such as bone grafts in spinal fusion.[86] Prior cases have also cited significant success in healing of both unilateral and bilateral spondylolysis with use of electrical stimulation with spinal bracing, with complete healing of the pars interarticularis seen on CT.[72] Additionally, some cases suggest that 30 minutes of daily external electrical stimulation may demonstrate superior results to bracing and spinal exercise therapy in certain people, although the exact population in which this is true has yet to be determined.[63,72]

Lastly, exercised aimed at strengthening the musculature supporting the spine have also been shown to be effective in recovery from spondylolysis.[69,76] Common exercises aim to improve core strength, especially the deep abdominal muscles as well as the lumbar multifidus.[69] Although exercises have not been definitely correlated with changes in imaging results, they are consistently linked to reduction in pain as well as improvements in ability to pursue activities of daily life.[64,69,76]

In summary, conservative management of spondylolysis aims to improve pain and promote fracture healing while avoiding further progression of disease. Lumbar orthosis bracing should be considered for between 6-12 weeks in young athletes. Consideration of electrical stimulation therapy may also be appropriate. Physical therapy and targeted exercises ought to be considered, even in patients with symptomatic low back pain as studies have been associated with improvements in pain with strengthening of core musculature. Young athletes may gradually return to sport with progression of physical therapy, resolution of pain, and evidence of bony fracture healing on imaging studies.

SURGICAL TREATMENT

Although conservative management is often effective, studies have shown that between 9-15% of spondylolysis patients fail to improve with conservative treatment and require more invasive interventions.[87] Consideration of surgical treatment is appropriate in patients who have had greater than 6 months of conservative therapy with no impressive improvement in pain, associated symptoms, as well as evidence of persisting fracture on imaging studies.[65,76,77,88,89] Often, confirmatory testing with anesthetic block to the fractured pars interarticularis will be performed prior to recommendation of surgical therapy.[4] Treatment options are classically divided into direct repair and spinal fusion, and selection of the most appropriate surgical intervention is largely directed by both the severity of the lesion as well as the clinical goals and outlook of the patient.

Fusion has shown significant efficacy in pain reduction, with up to 70% of patients with evidence of high grade spondylolysis experiencing significant levels of pain relief.[77,90–92] L5/S1 fusion with autogenous posterior iliac bone graft is often first-line surgical therapy in patients with symptomatic L5 spondylolysis. However, spinal fusion also results in limited passive and active range of spinal motion. While this clinical sequelae is often appropriate in populations with advanced age, it is often undesirable in younger or more active patients. Additionally, post-op recommendations vary between complete lack of immobilization to use of lumbosacral orthotics.[68,77,88]

Direct repair preserves spinal range of motion but is usually reserved for low grade spondylolysis.[65,71,77] Therefore, direct repair is often recommended as first line surgical therapy for younger athletes under 20 years of age as well as patients with active lifestyles, in effort to prioritize functionality and hasten return to sport.[68,88] Multiple techniques to perform direct repair have been described, including single lag screw fixation (i.e. Buck's), hook screw fixation, Scott's wiring technique, pedicle screw fixation, and robot-assisted direct repair.[68,88,93] Songer's technique is a specific type of pedicle screw fixation and is performed utilizing the pedicle as an anchor point to subsequently stabilize the pars defect.[88,94,95] Although complications in-

clude wire, cable, and rod breakages, studies have suggested that pedicle fixation direct repair techniques are correlated with minimal adverse events and superior outcomes, and are therefore preferred when performing direct repair.[88,94–96]

CONCLUSION

Spondylolysis is a bony defect of the pars interarticularis and most often results from repetitive stress. Athletes, especially those who participate in sports which require extereme and asymmetric spinal extension and rotation (such as gymnastics or rowing) are at increased risk of developing spondylolysis. Additionally, patients with underlying genetic or spinal deformities such as spina bifida have been correlated with increased risk of development of spondylolysis in comparison to the general population. The incidence of spondylolysis is correlated with activity and weight-bearing and increases with age until adulthood. Although spondylolysis is usually asymptomatic, symptomatic spondylolysis is the most common cause of identifiable back pain in children and adolescent athletes. Patients may rarely present with bilateral pars interarticularis lesions and subsequently be at increased risk of progression from spondylolysis to spondylolisthesis, which is the anterior, lateral, or posterior translocation of vertebral discs. Physical exam of patients with spondylolysis may include low back pain with lordotic posturing, tight hamstrings, and pain with lumbar spinal extension. The single-leg hyperextension test may be positive as well, although the diagnostic value of this maneuver is unclear. The diagnosis is usually made with imaging studies; although CT is often preferred, x-ray, MRI, SPECT, and bone scintigraphy are all useful in further workup of spondylolysis as well as its various differential diagnoses. Initial treatment of spondylolysis is conservative and consists of rest from sports, core and spinal muscle strengthening, as well as spinal bracing. Patients who fail conservative therapy for 6 months may consider surgical repair. Common techniques include direct repair and spinal fusion. Although spondylolysis is relatively common, early clinical recognition, diagnosis, and treatment are essential in preventing further complications.

CONFLICT OF INTEREST

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