Imaging principles of spondylolysis

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Learning objectives

In this exhibit, review of the current concepts, pathogenesis, epidemiology, general treatment guidelines, besides an extensive discussion and review of the imaging principles for the diagnosis of spondylolysis was provided.
Background

Pars interarticularis is the conjunction of the pedicle, lamina and articular facet. The term spondylolysis refers to the defective appearance of pars interarticularis. Over time, the pars defect is filled with a cartilage and bone tissue. For this reason, it is inevitable that the pars defects gradually become a chronic process [1].

The incidence of lumbar spondylolysis is estimated to be around 6-8%, although this ratio can reach to the 60% in patients having specific sport activities [2]. A natural consequences of human structure play a big role in the occurrence of the pars interarticularis defect.

The purpose of our study is to offer a detailed review of the imaging methods and pathogenesis for spondylosis.
Findings and procedure details

PATHOGENESIS

The pathogenesis of lumbar spondylolysis is multifactorial. Genetic factors are believed to play a role in the establishment of the pars defects. It has been described that the incidence of spondylolysis among family members can reach up to 70% in some studies [3].

It is thought that dysplastic process have a role in the underlying mechanism of spondylolysis. The development of elongation and sclerosis is observed in the pars interarticularis due to dysplasia. Postural defects and some repetitive physical activities result in stress fractures. Additionally, multifactorial stress fractures developing on the basis of displastic pars interarticularis are thought to act as a major part in the pathogenesis of lumbar spondylolysis [4].

The damage mechanism causes spondylolysis is usually a combination of repetitive flexion, extension, and rotation movements of the vertebral column. For instance, during the extension of the lumbar column, pars interarticularis of the L5 vertebrae are exposed to mechanical strain from the lower articular protrusion of the L4 vertebra and the upper articular protrusion of the sacrum. The stress reactions on the pars interarticularis cause microfractures. Over time, incomplete and complete fractures arise as a consequence of continued mechanical stress on pars interarticularis [5]. This hypothesis, called "bony pincers", was discovered by Capener in 1931 and constitutes the basic mechanism of spondylolysis in athletes [4]. Dysplasia represents a factor that predisposes to the formation of lysis, which may be triggered by previously described mechanical forces. Spondylolysis is usually seen along the L5 vertebrae and this yields an explanation for the mechanism of dysplasia and the accompanying mechanical stress [6].

Studies by Ward et al. [7] measured the transverse length of interfacet joints in the lumbar vertebrae of 39 adult patients having L5 spondylolysis and 42 normal control subjects using anterior-posterior images. In patients with spondylolysis, a gradual increase in the transverse diameter of the interfacet joints was observed from the L3-L4 vertebra level to L5-S1 when compared to the control group. The authors of this study expressed that a comparatively modest increment in the transverse interfacial joint distance has caused a mechanical damage to the L5 pars interarticularis during hyperextension. As a result, bone resorption and spondylolysis developed.

IMAGING
Radiography

The anteroposterior radiographs with the angled projections of the lumbosacral spine give the best detail of spondylolysis. Oblique lumbar projection gives the appearance of a "Scotty dog" in which spondylolysis represents a fractured neck. Lateral radiographs with the flexion and extension projections can demonstrate the lumbosacral angulation [8].

The degree of dislocation above 50 percent in the lumbar column is considered to be an instable sign and tends to progress to the lumbosacral kyphosis. The slip angle used in the lumbosacral lordosis is the angle between the line drawn from the posterior edge of the sacrum and a perpendicular line from the inferior edge of the L5 vertebral end plate. The degree of chronicity of the vertebral listhesis can be understood by the blunting of osseous margins. The pelvic incidence is the angle between the line drawn from the center of the femur head to the tip of the sacrum and the perpendicular line drawn from the boundary of the sacrum. In patients with spondylolisthesis, it correlates with an increased slip angle. However there is still some debate about the significance of these measurements [9].

Single-Photon-Emission Computed Tomography (SPECT)

Single photon emission CT evaluates the signal properties of posterior vertebral arch, particularly the signal of the pars interarticularis. In addition to facilitating the diagnosis, studies have shown that it can also help to detect the efficacy of treatment. Increased signal intensity indicates an osseous activity and a potential for healing, while a lack of an increased signal refers to the decreased healing capacity [10].

Computed Tomography

Computed tomography has an important role in the diagnosis of spondylolysis. In the last decade, multidetector scanners have been developed along the improvements in CT technology. With the advance of post processing, images have begun to be obtained faster, with increased anatomical coverage and higher spatial resolution. This has increased the diagnostic sensitivity of spondylolysis. Axial CT images obtained from the pedicle level in normal patients can demonstrate continuous and closed neuron arc. The irregularity in this level indicates a pars defect known as incomplete ring sign [11].

CT should be taken in the presence of early signs of spondylolysis with normal appearing pars interarticularis and increased activity on the SPECT examination. The pre-spondylolysis condition may also be assessed by magnetic resonance imaging (MRI). Otherwise, non-union of the pars with low healing potency should be considered when
A pars defect is discovered on the CT imaging and there is no overlapping increased activity on the SPECT examination. CT is also an appropriate test to monitor healing of spondylolysis. Additionally, CT can identify underlying cause of low healing capacity such as dysplastic vertebra in atypical spondylolysis [12].

However, pars defects often interfere with the adjacent facet joints on CT, because both joints and defects are located in similar planes and only a small distance exists between them. It is necessary to examine the cortical contours and cortical edges of the joint capsule to separate spondylolysis from the facet joints. Pars defects have sinusoidal contours and irregular appearance but do not contain sclerotic notch. Sagittal reformat images can better illustrate the difference between pars defects and facet joints. Also, sagittal CT images are the most sensitive method to detect incomplete fractures [13].

In unilateral spondylolysis, CT is superior to radiography in terms of demonstrating sclerosis and hypertrophy in the contralateral pedicle. Furthermore, compensatory enlargement of the contralateral pedicle due to bone lesions such as osteoid osteoma can be differentiated from hypertrophy related to spondylolysis. Sagittal enlargement of the spinal canal due to subluxation of posterior elements can be found even in cases of spondylolysis without spondylolisthesis. In some instances, the fibrocartilagenous tissue filling the pars defect may calcify and subsequently become ossified. Computed tomography is the best method to detect the calcified fibrous tissue filling the pars defect. Tissue or bony protrusions in the defect may grow medially and produce compression laterally on the dural sac. The lateral recess syndrome with nerve root compression may occur when it extends along anterior plan. The most common cause of nerve root compression is due to distorted neural foramen [14].

The anterosuperior elongation of the fibrous tissue filling the pars defect may cause compression on the neural foramen. The compression effect of the hypertrophic tissue may not be detected with some imaging methods such as radiography. Sagittal reformat CT scans have a higher sensitivity to identify the compression on the neural foramen. Nevertheless, the relationship between the nerve root, the fibrous tissue filling the pars defect, and the disc material can be better assessed with MRI.

The density of the nerve root, disc material and tissue filling the pars defects have similar density on CT and can be traced only if the epidural fat tissue surrounds the nerve root. Active fractures and chronic non-unions can not be distinguished from each other on CT. Chronic fracture with large pars defect and sclerotic rim has no ability to heal with conservative treatment. On the contrary, cases with narrow pars defects and non-sclerotic edges that point to acute fractures can benefit from the immobilization. In patients having acute fractures, thoracico-lumbo-sacral orthosis materials should be used to limit lordosis and activity should be restricted [15].
The symptoms of back pain or radiculopathy will develop in almost 25% of patients with lumbar spondylolysis. Magnetic resonance imaging is a useful method to evaluate pre-spondylolysis having atypical clinical presentation and normal findings on CT. MRI can also be employed as a primary imaging modality in the assessment of high grade spondylolisthesis and radiculopathy.

The pars defects may be seen as focal hypointense areas due to sclerosis around the fracture site on sagittal T1 and T2 weighted MR images. Pars defects are best seen on T1-weighted images which can demonstrate a contrast between hyperintense bone marrow and hypointense bone cortex. If there is a gap in the defective area, the signal characteristic of tissue filling the defect may vary: low on T1-weighted images, low or isointense on T2-weighted images are seen in the presence of fibrocartilaginous tissue and hypointense signals from both sequences if there is osteofibrotic tissue. Sometimes, an abnormally high signal within the defect can be detected on long TR images, consistent with inflammatory tissue or fluid. Such findings can be very helpful in the recognition of pars defects. Hypointense appearance on T1-weighted images can occur in many cases other than spondylolysis.

Hollenberg et al. [18] suggested a reliable classification system that could be utilized in the diagnosis and assessment of lumbar spondylolysis on MR imaging. According to the classification; grade 0 (normal) represents normal bone marrow and intact bone contours; grade 1 (stress reaction) is with bone marrow edema and intact bone contours, grade 2 (incomplete fracture) is with bone marrow edema and incomplete cortical fracture; grade 3 (complete active fracture), bone marrow edema and concomitant complete pars defect and grade 4 (non-union fracture) represents complete pars defects without bone marrow edema. Incorporation of bone marrow signal intensity to this MRI classification allows for a morphological evaluation that can distinguish between active and inactive spondylolysis. Principally, it is important to distinguish stress reactions, acute incomplete and complete pars fractures which can respond to conservative treatment. Conversely, delayed diagnosis and treatment can evolve it to the non-union type pars defect. Campbell et al. [19] found MR imaging as an accurate method to demonstrate normal pars interarticularis (grade 0), acute complete defects (grade 3), and chronic pars defects (grade 4). Early spondylolysis (grade 1) can be recognized by increased signal intensity in pars interarticularis on STIR or fat-suppressed T2-weighted images by identifying bone marrow edema. However, recognition of incomplete (2nd degree) stress fracture is still a difficult part for MR examination.

Assessment of incomplete stress fractures is limited on MRI, but the presence of bone marrow edema as an evidence of acute spondylolysis can be detected by fluid-sensitive sequences. Auxiliary findings such as sagittal broadening of the spinal canal, wedging of
the affected vertebral corpus, and reactive bone marrow edema in the vertebral pediculus adjacent to the pars defect, that may serve to diagnose spondylolysis can be identified by MRI. Ulmer et al. [20] reported the accuracy of auxiliary imaging findings and the spinal canal expansion on the sagittal plane was discovered in %90 for patients with spondylolysis.

MRI is successful to delineate the causes of nerve compression such as hypertrophic tissue filling the pars defect, disc herniation, and neuronal foraminal stenosis. On T1-weighted spin-echo MR images, the nerve root has an intermediate signal intensity, the normal disc material has hypointense and tissue filling the pars defect may have a variable signal intensity depending on the containing amount of tissue such as cartilage, fat, and fluid. Additionally, MRI is quite effective in distinguishing nerve root compression whether in the foraminal or lateral recess levels.

Narrowing in the deformed neural foramen is the most common cause of nerve root compression. Sagittal MR images can demonstrate neural foramen and anteroinferior extent of the tissue filling the pars defect. Obliteration of the fat tissue surrounding the spinal nerve root indicates compression of the neural tissue in the foraminal level. Nerve root compression in the lateral recess or neural foramen is usually seen as the same level with the accompanying spondylololisthesis.
Fig. 1: Defective pars interarticularis is seen on sagittal reformatted CT image

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Fig. 2: Spondylolysis is seen on STIR MRI

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**Fig. 3:** Spondylolysis is seen on sagittal T2 weighted MRI

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**Fig. 4:** Defective pars interarticularis is seen on axial CT image

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Conclusion

In patients with predisposing conditions, lumbar spondylolysis usually develops due to microtraumas, which are not observed in radiography and CT. The stress reaction (grade 1) can transform into the incomplete stress fracture (stage 2) and the acute pars stress fracture (stage 3) by these repetitive microtraumas. In the absence of healing potency, the defective appearance of pars interarticularis progresses to a chronic inactive non-union fracture (stage 4). The diagnosis of stress reaction, acute incomplete or complete pars fractures is important, because conservative treatment can ameliorate these stages of pars fractures. In young athletes with stage 4 chronic spondylolysis, surgical treatment may be requisite to prevent chronic back pain and spondylolisthesis. For this reason, early diagnosis and staging of spondylolysis is important.

Stress reactions without progressing to complete pars fractures cannot be detected by radiography alone. CT, which provides excellent bone detail, is considered to be a reference imaging procedure for complete and incomplete pars fractures. However, CT can not reliably distinguish active or inactive lesions and exposes the patient to ionizing radiation. SPECT is an extremely sensitive technique for early detection of spondylolysis and can be applied to predict the healing potency of pars defects. Unfortunately, SPECT is not a specific imaging modality and can not differentiate stress reaction from pars defects. MR imaging can identify bone marrow edema to indicate early stress reaction. Furthermore, a known pars defect and accompanying spinal pathologies (eg, juvenile disc herniation) can be demonstrated with MR examination. SPECT imaging is usually not used, unless MR imaging is contraindicated. Unfortunately, neither MRI, CT and SPECT examinations can distinguish whether the incomplete stress fracture is in the progression or regression phase. Additionally, the relationship between symptoms of the pars defects and MR imaging findings needs to be further investigated.
References


