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LUMBAR SPONDYLOLYSIS: ARE ANCILLARY MAGNETIC RESONANCE IMAGING FINDINGS USEFUL IN DIAGNOSIS?

Belgin Karan[1], Burhan Oral Güdü[2]

[1]İstanbul Medipol University Sefaköy Hospital, Department of Radiology, İstanbul, Türkiye
[2]İstanbul Medipol University Sefaköy Hospital, Department of Neurosurgery, İstanbul, Türkiye

ABSTRACT

Objective: To determine the frequency of ancillary magnetic resonance (MR) findings in patients with lumbar spondylolysis.

Materials and Methods: The MR images of 88 patients (41 male, 47 female; 14-80 years old) diagnosed with lumbar spondylolysis at 90 levels were retrospectively reviewed. The control group consisted of 58 patients in the same age group who had only lumbar disc degeneration. The rates of ancillary findings were determined, including increased sagittal canal ratio (SCR), posterior wedging of the vertebral body lumbar index (LI), reactive marrow changes in the pedicle, and epidural fat interposition (EFI) on sagittal MR images. These rates were then directly compared with those obtained from direct interpretation of pars interarticularis defects on MR images.

Results: Pars defects were misdiagnosed in 25 levels (28%) when the MR images were evaluated directly. EFI was the most common finding, present in 73 levels (81%) of lumbar spondylolysis. An increase in SCR was observed in 66 pars defect levels (73%), and LI was present in 62 levels (69%). EFI showed the highest sensitivity (81.1%), while SCR demonstrated the highest specificity (96.6%) and positive predictive value (97.1%). Reactive bone marrow changes were observed in the pedicle in 20 levels (22%). In the absence of spondylolisthesis at the level of the lumbar pars defect, EFI was present in 78%, SCR in 60%, and LI of the vertebrae in 60%. Spondylolysis was correctly diagnosed in 84 of 90 levels (93%) when at least one ancillary finding was included in the MR evaluation.

Conclusion: Direct visualization and evaluation of the pars interarticularis defects in lumbar spondylolysis, combined with ancillary findings, enhances the diagnostic sensitivity of MR imaging.

Keywords: Spondylolysis, MR imaging, spine, pars interarticularis, isthmic spondylolisthesis

INTRODUCTION

Spondylolysis is a bony defect of the pars interarticularis (isthmus) of a vertebra, typically resulting from repetitive microtrauma in vertebral regions that are congenitally prone to stress fractures[1-3]. It occurs in approximately 6-8% of the general population, but among young adults engaged in intensive sports, the prevalence can exceed 40%, making it a significant cause of lower back pain[3-6]. Early conservative treatment is the gold standard for spondylolysis, providing an opportunity for intervention before the pars defect progresses to more severe stages. If left untreated, it can lead to instability and spondylolisthesis over time[5,7].

Magnetic resonance imaging (MRI) is the first-choice diagnostic modality for patients presenting with back pain or radiculopathy. However, because MRI primarily focuses on the intervertebral discs and foramina, bone defects in the pars interarticularis are often overlooked, owing to congenital morphological variations in the pars, as well as its sagittal or transverse obliquity[8]. In contrast, certain indirect MRI findings indicating a pars defect may support the diagnosis of spondylolysis[4]. These include an increased anteroposterior diameter of the spinal canal[9,10], wedging of the posterior vertebral body[4,11], bone marrow changes in the posterior elements at the defect level[12], and epidural fat interposition (EFI), which is an important indirect sign supports the diagnosis of a pars interarticularis defect, it has been addressed in only a few studies[13].

This study aimed to evaluate the frequency and diagnostic value of indirect MRI findings in patients with pars interarticularis defects, with or without spondylolisthesis.

MATERIALS AND METHODS

This retrospective study was approved by the institutional review board, which waived the requirement for informed consent. The study was approved by the İstanbul Medipol

Address for Correspondence: Belgin Karan, İstanbul Medipol University Sefaköy Hospital, Department of Radiology, İstanbul, Türkiye
E-mail: belgink8@yahoo.com
ORCID ID: orcid.org/0000-0002-7034-7806
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University of Non-Interventional Clinical Research Ethics Committee (approval number: 802, date: 29.08.2024).

The MRI of 88 patients diagnosed with lumbar spondylolysis between July 2016 and September 2024 were reviewed. Unilateral or bilateral pars interarticularis defects in these patients were diagnosed using conventional radiography. Lumbar computed tomography (CT) images were available for 32 patients. Patients with endogenous or exogenous cortisol exposure, scoliosis, spinal stenosis, disc herniation, sacral spinal canal enlargement, dural ectasia, or insufficient clinical data were excluded.

Among the patients, 41 were male and 47 were female, with ages ranging from 14 to 80 years, and a mean age of 46 years. Bilateral spondylolysis was present in 83 patients. In 78 (94%) of these patients, the pars defect was at the L5 level. The pars defect was recorded at the L4 and L3 levels in two patients each, and at the L2 level in one patient. Two patients with bilateral spondylolysis had pars interarticularis defects at two levels (L3 and L5, L4 and L5). Unilateral pars interarticularis defects were observed in five patients: four defects at L5 and one at L4. Spondylolisthesis was observed in 45 out of 90 levels. Only one level showed a Grade 2 slip, whereas all other levels exhibited Grade 1 slips. MRIs 58 aged matched (12-75 years old) patients selected to serve as a control subjects were also analyzed. This patients did have only disc degenerations and had never had lumbar surgery.

MRI was performed with a 1.5T system (Avanto; Siemens; Erlangen, Germany) using a spine coil. All patients were examined in the supine position. The MRI pulse sequences were as follows: sagittal, turbo spin- echo T1-weighted sequences [repetetion time/echo time (TR/TE), 704/11 msec; field of view (FOV), 30 cm; matrix, 320x256; section thickness, 4 mm]; sagittal, turbo spin- echo T2-weighted images (TR/TE, 4250/109 msec; FOV, 30; matrix, 384x288; section thickness 4 mm); sagittal, T2- fat suppressed sequences (TR/TE/inversion time, 5000/62/160 msec; FOV, 30 cm; matrix, 320x240; section thickness 4 mm); axial, turbo spin-echo T2-weighted sequences (TR/TE, 5010/112 msec; FOV, 20 cm; matrix, 256x166; section thickness 3 mm). Fat suppression was performed using the short-tau inversion recovery technique.

The CT examinations were conducted using a 16-section CT system (Scope 16, Siemens, Erlangen, Germany).

The imaging parameters were as follows: 80-130 kilovolt peak tube voltage, 100-300 milliampere-seconds effective tube current, 0.75 s rotation time, and 0.75-1.5 mm detector collimation.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 21.0 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean ± standard deviation (SD) and median (minimum-maximum values), while categorical variables were expressed as frequencies (n) and percentages (%). A p-value <0.05 was considered statistically significant.

Sagittal Diameter of the Spinal Canal

The anteroposterior diameter of the spinal canal at the levels of spondylolysis and at L1 was measured using T1-weighted sagittal images[4,9,14]. At both levels, the first reference line was drawn tangent and parallel to the posterior border of the middle part of the vertebral body. Subsequently, a second parallel line was drawn along the anterior surface of the lamina at the spinolaminar junction of the same vertebrae. The midsagittal diameter of the spinal canal at this level was defined as the perpendicular distance between the two tangents (Figure 1).

The sagittal canal ratio (SCR) was used to normalize these measurements to the patient's anatomical variation. The SCR was calculated by dividing the midsagittal diameter of the spinal canal at the spondylolysis level by the midsagittal diameter at the L1 vertebral level. The normal mean values (±SD) of the SCR for each vertebral level were based on the analysis of data from 100 control subjects without spondylolysis[4,9]. The upper limit of the SCR (1.25) was adopted as a threshold to distinguish normal from abnormal values. When the SCR exceeded this limit at any level, an abnormally large midsagittal diameter was diagnosed[4,9], suggesting an open arch defect.

Wedging of the Posterior Vertebral Body

Wedging of the posterior aspect of the vertebral body at the level of spondylolysis is a characteristic finding observed in

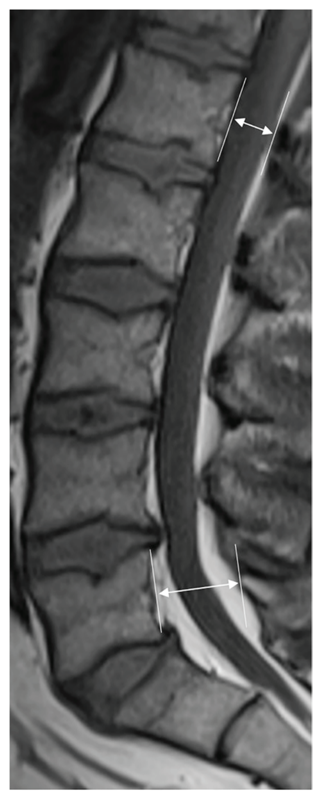

Figure 1. Thirty-eight-year-old woman with L5 spondylolysis. Midsagittal T1-weighted MR image shows that the midsagittal diameter of the spinal canal at the L5 level is increased compared to the diameter at L1 [sagittal canal ratio, (L5:L1)=1.39]
MR: Magnetic resonance

conventional radiography[4,11]. This wedging is also visible on the sagittal T1-weighted MRI of patients with spondylolysis. The lumbar index (LI) is calculated by dividing the height of the posterior aspect of the vertebral body by the height of the anterior aspect (normally, 0.87±0.06) (Figure 2). The LI is used to normalize the degree of wedging relative to the patient's anatomy. At the level of spondylolysis, an LI>2 SD below the normal range (<0.75) is classified as abnormal wedging of the posterior vertebral body.

Reactive Bone Marrow Changes

The signal intensity of the pedicles adjacent to the pars interarticularis defects was evaluated on T1- and T2-weighted sagittal MRI and compared with the signal intensity of the next higher-level pedicle on the same side of the spine (Figures 3, 4). Classification was based on the system developed by Modic et al.[15] for vertebral body changes in patients with degenerative disc disease.

- Type 1 changes; were characterized by decreased signal intensity on T1-weighted images and increased signal intensity on T2-weighted images of the pedicles adjacent to the defect. These changes are indicative of fibrovascular tissue in the pars interarticularis.

Figure 2. Twenty-four-year-old man with bilateral spondylolysis. Midsagittal T1-weighted MR image shows abnormally low ratio of height of posterior aspect of vertebral body (line 2) relative to height of anterior aspect of vertebral body (line 1) (lumbar index=line 2:line 1=0.55) at L5 level of spondylolysis. Also note increased midsagittal diameter of spinal canal at L5 level
MR: Magnetic resonance

- Type 2 changes; were characterized by increased signal intensity on both T1- and T2-weighted images, indicating fatty changes.
- Type 3 changes; showed decreased signal intensity in the pedicles on both T1- and T2-weighted images, indicative of sclerosis.

Epidural Fat Interposition

EFI refers to the fusion of posterior epidural fat pads, which are normally separated and layered between the dura mater and the spinous process. In spondylolysis, a pars defect in the isthmic lamina leads to biomechanical abnormalities in the vertebrae. The epidural fat pad, located between the dura mater and the spinous process of the vertebra, detaches from its usual position, causing the previously separated fat pads to merge. This appearance is described as the "continuous double hump sign" or EFI.[7,13] In patients with spondylolysis, the fusion of the epidural fat pads was assessed on midsagittal T1-weighted MRI at the vertebral level with a pars interarticularis defect (Figure 5).

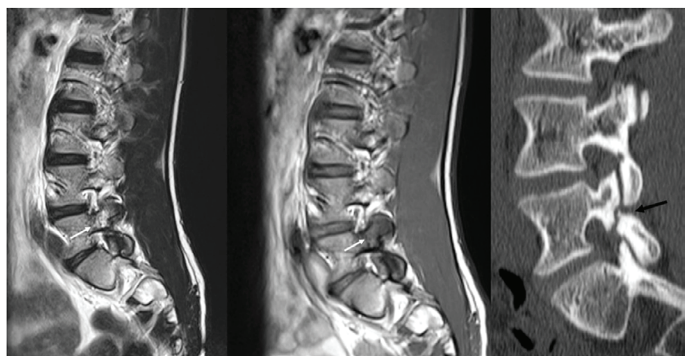

Figure 3. Seventeen-year-old man with spondylolysis and type 1 reactive marrow change at L5 level (arrows, A and B). It is characterized by increased signal intensity on T2-weighted images and decreased signal intensity on T1-weighted images. The sagittal reformatted CT scan confirms presence of defect in pars interarticularis at L5
CT: Computed tomography

Figure 4. Forty-three-year-old man with spondylolysis and type 2 reactive marrow change at L5 level (arrows, A and B). It is characterized by increased signal intensity on T1 and T2-weighted. The sagittal reformatted CT scan confirms presence of defect in pars interarticularis at L5
CT: Computed tomography

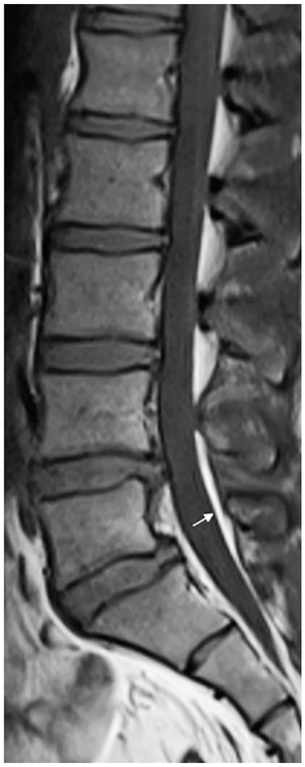

Figure 5. Twenty-two-year-old man with L5 spondylolysis. Mid-sagittal T1-weighted MR image demonstrates the separation between the dura mater and the spinous process of L5 with interposition of epidural fat between the two structures
MR: Magnetic resonance

Quality Assessment of Original Image Interpretation

In this study, we reviewed the initial radiological reports for all patients. Original interpretations were made by an experienced radiologist at our institution. The diagnostic accuracy of these interpretations was compared with the diagnoses established using conventional radiography or CT.

The sensitivity of the original interpretations was evaluated by comparing the frequency of supportive diagnostic findings observed in sagittal MRI with the total number of patients with spondylolysis. In most cases, conventional radiographs were obtained on the same day as the MRI. Consequently, the interpreting radiologist was unaware of the lumbar spondylolysis diagnosis when reviewing the MRI. Similarly, most CT examinations were performed at a later date, following the MRI studies, as is common in many hospitals.

RESULTS

Of the 88 patients referred for MRI, 63 (72%) were aged between 30 and 60 years. Spondylolysis was identified in 65 of the 90 levels (72%) on the initial MRI scans (Figure 6). Among the 25 misdiagnosed levels, 14 (56%) did not exhibit spondylolisthesis. Of the 25 patients with misdiagnosed levels, 17 (68%) were aged >40 years old. This aligns with the findings of Ulmer et al.[4], who suggested that pars interarticularis defects may be confused with findings of facet arthropathy or degenerative spondylolisthesis.

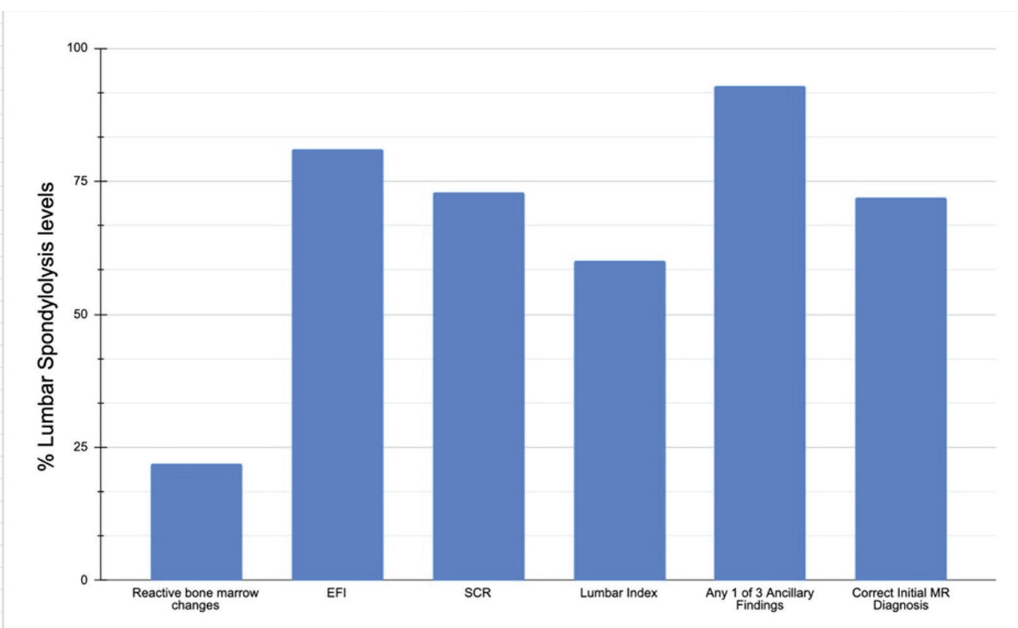

Figure 6. Bar chart shows proportion of patients with spondylolysis who had ancillary findings on sagittal MR images. Most patients showed epidural fat interposition (EFI) at level of spondylolysis. Fewer patients showed abnormally reactive marrow changes. Any one of three ancillary findings were present in 93% of patients examined. Spondylolysis was correctly diagnosed in 72% when the MR images were initially evaluated directly
MR: Magnetic resonance

Sagittal Canal Ratio

At 66 of the 90 lumbar spondylolysis levels (73%), the SCR was >1.25 (Figure 1), i.e., the anteroposterior diameter of the spinal canal was increased at the level of spondylolysis.

In 39 out of 44 levels (89%) with Grade 1 spondylolisthesis, an increased SCR was observed (range, 1.26-2.09). Elevated SCR (1.30) was also recorded in a single patient with Grade 2 isthmic spondylolisthesis.

Of the 45 levels with pars interarticularis defects but no spondylolisthesis, 25 (60%) exhibited abnormally elevated SCR values (range, 1.27-2.05). This finding is significant because it suggests the presence of isolated subluxation of the posterior elements[4].

In two of five patients with unilateral spondylolysis, an increased SCR was observed. In these patients, the pars interarticularis defect was located on the right side of L5. Increased SCR was present in only two patients (3.4%) in the control group.

Lumbar Index

In 62 of the 90 lumbar levels (69%), the LI measured on sagittal T1-weighted images was <0.75, indicating posterior wedging of the vertebral body (Figure 2). Of these, 61 were at the L5 level, and one at the L4 level.

Among the 45 levels without spondylolisthesis, 27 (60%) exhibited an LI <0.75. Of the 44 levels with Grade 1 spondylolisthesis, 32 (73%) had an LI <0.75. A single patient with Grade 2 spondylolisthesis also demonstrated an LI <0.75.

Posterior vertebral wedging was observed in three of the five patients with unilateral pars defects. Posterior vertebral wedging was presented in ten of 58 patients (%17) in the control group

Reactive Bone Marrow Changes

Reactive bone marrow changes were observed in 20 of the 90 lumbar levels with spondylolysis (22%), either in the pedicle of the vertebra with a pars defect or on the articular surface adjacent to the pars interarticularis defect (Figures 3, 4).

• Type 1 bone marrow changes associated with fibrovascular tissue in the posterior elements were noted in nine levels.

• Type 2 fatty bone marrow changes were observed in three levels.

• Type 3 changes, characterized by sclerosis, were present on the articular surfaces of eight lumbar levels.

The group with type 1 bone marrow changes in the posterior elements (average age, 27 years) was notably younger than the other two groups. Reactive bone marrow changes were observed in seven of 58 patients (12%) in the control group. Type 2 fatty bone marrow changes were presented in all patients

Epidural Fat Interposition

EFI was observed in 73 of 90 lumbar levels (81%) (Figure 5).

• Seventy-one were at the L5 level.

• Two were at the L2 and L3 vertebral levels.

In the L5 vertebra, three patients had unilateral pars interarticularis defects, while 68 exhibited bilateral defects.

Of the 45 levels without spondylolisthesis, EFI was present in 35 levels (78%). EFI was observed in only five of 58 patients (8.6%) in the control group.

The diagnostic performances of lumbar spondylolysis ancillary MRI findings are detailed in Table 1.

DISCUSSION

Pars interarticularis defects are typically first observed in radiographs obtained during late childhood or adolescence. These defects are often bridged by tissues comprising a mixture of fibrous, cartilaginous, or osseous materials, resulting in chronic non-unions. In some cases, healing and bony fusion may occur, accounting for 10-15% of cases with unilateral defects[4,5]. Pars interarticularis defects are located at the L5 vertebra in 90-95% of cases and are almost always bilateral. These defects are 2-4 times more common in males than in females[4].

In our study, spondylolysis was found at the L5 vertebra in 94% of cases and was bilateral in all but five patients. However, we observed no significant differences in the number of male and female patients.

Approximately 25% of the patients with lumbar spondylolysis develop lower back pain or radiculopathy later in life. The symptoms in these patients may stem from musculoskeletal strain, foraminal stenosis, facet or disc degeneration, disc herniation, or spinal canal narrowing[1,2,4].

Ulmer et al.[4] reported that a significant proportion of patients with lumbar spondylolysis are diagnosed using MRI at an age when degenerative facet disease and associated degenerative spondylolisthesis have developed. In their study, 40% of patients were diagnosed between the ages of 30 and 50 years, and 30% were diagnosed after the age of 50 years. In our study, the age of lumbar spondylolysis diagnosis based on MRI findings was 30-50 years in 50% of patients and >50 years in 40% of.

Table 1. The diagnostic performances of lumbar spondylolysis ancillary MRI findings

	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	Accuracy (%)
Sagittal canal ratio	73.3%	96.6%	97.1%	70.0%	82.4%
Lumbar index	68.9%	82.8%	86.1%	63.2%	74.3%
Reactive bone marrow changes	22.2%	87.9%	74.1%	75.0%	48.0%
Epidural fat interposition	81.1%	91.4%	93.6%	75.7%	85.1%

MRI: Magnetic resonance imaging

Direct radiography and CT are the imaging modalities that best visualize bony structures. CT is the most effective imaging technique for detecting spondylolysis in the presence of pars defects. However, CT can not clearly differentiate between active fractures and chronic non-unions[5,6,16].

On MRI, the fatty bone marrow in the normal pars appears bright on T1-weighted images, and this brightness is continuous. This appearance is present in only 30-66% of intact pars interarticularis structures[13]. Fat-suppressed T2-weighted MRI can detect acute bone marrow edema associated with spondylolysis[17]. Thin-section T1- and T2-weighted or contrast-enhanced MRI can increase the detection rate of pars defects[18,19]. Despite these advancements, there are certain limitations in the detection of pars interarticularis defects using MRI. Since MRI for back pain is generally performed with a focus on the intervertebral discs, oblique orientation of the pars interarticularis relative to the sagittal and transverse planes, sclerosis of the pars, facet osteoarthritis, or the partial volume effect caused by surrounding soft tissues can complicate the diagnosis of spondylolysis[5,6,13,16-18]. Additionally, incomplete pars defects in the absence of sclerosis or spondylolisthesis may present diagnostic challenges on MRI[4-6]. Progression of spondylolysis to spondylolisthesis in adults is rare and occurs infrequently after the age of 16 years[1,5].

In cases of spondylolisthesis, the anteroposterior diameter of the spinal canal increases with the anterior displacement of the vertebral body on midsagittal MRI is diagnostic without requiring additional markers. In spondylolysis without spondylolisthesis, isolated subluxation of the posterior elements can lead to expansion of the sagittal diameter of the spinal canal. This expansion is beneficial in distinguishing isthmic spondylolysis from degenerative spondylolisthesis[4-6].

In cases of spondylolysis without advanced displacement, the increase in the anteroposterior diameter of the spinal canal may be subtle, necessitating the calculation of the ratio between the spinal canal diameters at L5 and L1. In this study, 66 of 90 lumbar levels with spondylolysis (73%) exhibited a SCR >1.25. An increased SCR was observed in 89% of the 45 levels with isthmic spondylolisthesis. Additionally, 60% of the 45 levels without spondylolisthesis showed an increased SCR. These findings are consistent with those reported by Ulmer et al.[4].

The degree of wedging of the posterior vertebral body is associated with the degree of spondylolisthesis at the level of the pars interarticularis defect on radiography[4,10,11]. In our study, wedging of the posterior vertebral body was identified in 62 of the 90 lumbar levels (69%) on sagittal T1-weighted MRI. Of the 44 levels with Grade 1 spondylolisthesis, 32 (73%) exhibited wedging, whereas one level with Grade 2 spondylolisthesis exhibited wedging. However, as none of the patients had advanced spondylolisthesis beyond Grade 2, we could not evaluate the relationship between the degree of wedging and advanced spondylolisthesis.

Consistent with the findings of Ulmer et al.[4] We observed wedging of the posterior vertebral body in patients with spondylolysis without anterolisthesis. Wedging was observed in 27 of 45 levels without anterolisthesis (60%). Furthermore, wedging of the posterior vertebral body was identified in three of the five patients with unilateral pars defects.

We observed that wedging in a subset of patients with diagnostic difficulties may indicate the presence of a pars interarticularis defect[4].

In our study, reactive bone marrow changes were recorded in 22% of the 90 lumbar levels with spondylolysis, either in the pedicle of the vertebra with a pars defect or at the articular surface adjacent to the pars interarticularis defect. Reactive bone marrow changes were the least frequently observed indirect MRI finding supporting the pars defect in our study, which is consistent with previous research[4,12].

Type 1 reactive bone marrow changes are more common among adolescents[12,16]. These changes likely represent an intermediate phase between bone marrow damage in the pars interarticularis and the transition to regional fatty marrow, indicating a reparative response[12]. If the cause of bone injury is eliminated at this stage, the defect may not progress to a complete defect. However, if the injury persists, reactive fatty marrow changes (type 2) may develop, and chronic injury leads to bone sclerosis (type 3)[4,12].

In their study of 93 adolescents and young adults, Rush et al.[16] reported that reactive bone marrow edema in the pedicle or pars interarticularis observed on lumbar MRI during stress reactions may indicate a developing pars defect before a visible fracture is apparent on CT. The authors emphasized that early treatment at this stage could prevent the progression to a fracture.

In our study, the average ages of patients with type 1 and ype type 2 marrow changes were 38 and 33 years, respectively, whereas the group with type 3 changes, characterized by sclerosis in the pars interarticularis, had an average age of 61.

Reactive marrow changes associated with defects in the pars interarticularis can appear independent of other supporting observations, making them crucial clues for diagnosing spondylolysis using MRI[4,12].

In our study, EFI was observed in 81% of the 90 lumbar levels with spondylolysis. Sherif and Mahfouz[13] stated that the EFI observed on midsagittal T1-weighted MRIs between the dura mater and the spinous process of L5 represents the same pathological process as the increased anteroposterior diameter of the spinal canal at the level of a fractured pars interarticularis. In our study, EFI was the most common MRI finding indicating a pars interarticularis fracture. EFI was present in 78% of the 45 levels without spondylolisthesis. In cases of spondylolysis without displacement but associated with lumbar disc herniation, the specificity of EFI was reported to be 95%, sensitivity was 88.8%, positive predictive value was 94.11%, negative predictive value was 90.47%, and accuracy rate was 92.10%[7]. In a previous study by Güdü et al.[20], EFI was reported in 85% of 115 patients with spondylolysis. In our study, EFI showed the highest sensitivity (81.1%), while

SCR demonstrated the highest specificity (96.6%) and positive predictive value (97.1%). Reactive bone marrow changes had the lowest sensitivity (22.2%) and accuracy (48.0%), indicating limited diagnostic effectiveness as a standalone criterion. Conversely, EFI presented with the highest overall accuracy (85.1%), suggesting it as a robust ancillary MRI finding. LI demonstrated moderate sensitivity (68.9%) and specificity (82.8%) but relatively lower negative predictive value (63.2%). These findings suggest that while EFI and SCR are reliable indicators for lumbar spondylolysis, reactive bone marrow changes have limited diagnostic utility.

In this study, spondylolysis was correctly diagnosed in 93% (84 out of 90 levels) when assessed with one or more supporting findings on MRI.

Study Limitations

However, this study has some limitations. First, the retrospective nature of the study. Secondly, the relatively small sample size. As noted by Ulmer et al.[4], SCR may also increase in patients with dysplastic but intact neural arches. Posterior wedging of the vertebral body may be observed in patients with degenerative disc disease, and fatty changes in the pedicle or pars defects may be obscured by normal fatty marrow changes. The true sensitivity and specificity of MRI for lumbar spondylolysis requires further studies using blinded paradigms.

CONCLUSION

Although this study has some limitations, direct visualization of pars interarticularis defects combined with the assessment of ancillary findings, enhances the diagnostic sensitivity of MRI for lumbar spondylolysis.

Ethics

Ethics Committee Approval: The study was approved by the İstanbul Medipol University of Non-Interventional Clinical Research Ethics Committee (approval number: 802, date: 29.08.2024).

Informed Consent: Retrospectively study.

Authorship Contributions

Surgical and Medical Practices: B.K., B.O.G., Concept: B.K., B.O.G., Design: B.K., B.O.G., Data Collection or Processing: B.K., B.O.G., Analysis or Interpretation: B.K., B.O.G., Literature Search: B.K., B.O.G., Writing: B.K., B.O.G.

Conflict of Interest: No conflict of interest was declared by the authors.

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