ORIGINAL

Extraosseous Signal Changes on Magnetic Resonance Imaging in Pediatric Patients with Early-Stage Lumbar Spondylolysis

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Abstract : Purpose : To analyze extraosseous signal changes (ESCs) on magnetic resonance imaging (MRI) in pediatric patients with stress fractures occurring in the lamina. Methods : This study was a retrospective review of 69 consecutive pediatric patients with stress fractures occurring in the lamina. We analyzed MRI scans obtained at the first presentation. Results : We used mainly axial short tau inversion recovery images acquired through the pedicle of these 84 fracture sites to identify the ESCs. These were then divided into three groups: "invisible" when no ESC was detected, "periosteal" for ESC seen on only the dorsal side of the lamina, and "perimuscular" for ESC distinctly spread around/in the paravertebral muscles. In total, 78 (92.9%) fracture sites showed ESCs on the dorsal side of the lamina among which 72 ESCs were located on only the "dorsal" side, while 6 ESCs were on the ventral side against the transverse process. Conclusion : ESCs on MRI were detected in more than 90% of patients before stress fracture became apparent in the lamina, which was considered similar to findings of periosteal thickening/edema detected at the onset of stress fracture in long bone. J. Med. Invest. 68 : 136-139, February, 2021

Keywords **:** *MRI, lumbar spine, pediatric, spondylolysis, stress fracture*

INTRODUCTION

Periosteal hyperplasia can be detected at the onset of stress fracture of the long bones, and its identification using ultrasonography is now being used for early diagnosis of stress fracture before the fracture line is apparent on X-ray (1). Thus, stress fracture can be identified by extraosseous changes in soft tissue, including the periosteum, muscle, and subcutaneous tissue even before the fracture line becomes apparent.

Lumbar spondylolysis (LS) has been considered a stress fracture of the pars interarticularis (2-4). Signal changes in bone marrow edema on magnetic resonance imaging (MRI) have been widely used for the diagnosis of early spondylolysis in recent years (5-7). Similarly, ESCs on MRI have been identified even in LS (Figure 1). While a finding of extraosseous hematoma or edema may be a possible cause of radiculopathy in young patients with the LS (8), few studies have investigated this matter.

The purpose of this study was to analyze the ESCs on MRI in pediatric patients when the fracture in the lamina occurred (early-stage LS), and to explore the potential utility of this finding as a diagnostic tool for routine medical examination of LS.

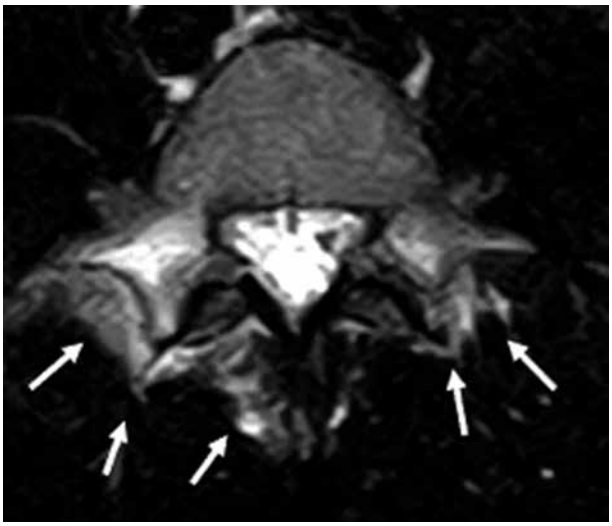

Figure 1. The presence of extraosseous signal changes (ESCs) on MRI (arrow) has been identified in patients with spondylolysis.

MATERIALS AND METHODS

Patients

We retrospectively reviewed the medical records of 69 consecutive pediatric patients (51 boys and 18 girls) with a diagnosis of stress fracture occurring in the lamina (very early- and early-stage LS) collected from January 2013 to September 2018 at our outpatient clinic. The average age was 14.3 years (range : 9-17 years). The database was collated to include previously published data from January 2012 to December 2015 (9). Institutional review board approval was waived for this study in view of the study design, which involved a retrospective review of anonymized imaging data.

Diagnostic imaging

LS was diagnosed on the basis of findings on plain radiographs, multi-detector computerized tomography (CT) scans (Optima CT 660 ; GE Healthcare, Little Chalfont, UK), and MRI scans (1.5 T Achieva ; Philips Healthcare, Amsterdam, The

Received for publication December 2, 2020 ; accepted December 18, 2020.

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Netherlands). The fracture line or bony defect was classified as early, progressive, or terminal on CT using the system devised by Fujii *et al*. (10), whereby a hairline fracture is visible in the early stage, progresses to a gap in the progressive stage, and manifests as pseudoarthrosis in the terminal stage. In this study, we further added "very early stage" as described in previous reports (6, 9, 11). The very early stage defect showed a faint and noncontinuous hairline at the pars interarticularis, while the hairline was visible in the early stage. In both the very early and the early stage, the fracture is considered to be incomplete.

In this study, we retrospectively analyzed MRIs at the first presentation only for patients diagnosed with very early- and early-stage spondylolysis to identify ESCs around the fracture site. Cases with progressive or terminal spondylolysis, and recurrent cases were excluded. In addition, two senior orthopedic surgeons evaluated the radiological findings and intra-observer and inter-observer reliability were analyzed. Intra-observer and inter-observer agreement were estimated using the κ statistic.

RESULTS

In this study, we analyzed a total of 84 fracture sites in 69 patients aged 9 to 17 years based on our criteria ; 37 fractures were located in L5, 36 in L4, 9 in L3, and 2 in L2. There were 12 patients with bilateral fractures, and 57 patients with unilateral fracture including 3 patients with multi-level fractures. Basically, axial short-tau inversion recovery (STIR) images acquired through the pedicle are the best image to detect the signal changes in bone marrow edema on MRI and they have been widely used for the diagnosis of early spondylolysis in recent years. In addition, those images were the easiest views to identify the ESCs. We used mainly axial images through the pedicle on STIR of these 84 fracture sites to identify the ESCs and divided these into three groups.

We defined the findings as follows : "invisible" when no ESC was identified, "periosteal" for ESC seen on only the dorsal side of the lamina, and "perimuscular" for ESC distinctly spread around/in the paravertebral muscles (Figure 2A). We further divided them into "dorsal" and "ventral" groups according to their position relative to the transverse process (Figure 2B).

Of the 84 fracture sites, 63 were in the perimuscular group, 15 were in the periosteal group, and 6 were in the invisible group (Table 1). In total, 78 (92.9%) fracture sites showed ESCs on the dorsal side of the lamina. Among these 78 fractures, 72 ESCs were located on only the dorsal side, while 6 had ESCs on the ventral side.

Intra-observer and inter-observer reliability were 0.77 and 0.646, respectively.

Table 1. Number of stress fractures with extraosseous signal changes

Extraosseous signal change	Invisible	Periosteal	Perimuscular (Dorsal/Dorsal and Ventral)	Total (n = 84)
Number	6	15	63 (57/6)	84
Rate (%)	7.1	17.9	75.0	100

DISCUSSION

LS is considered a stress fracture in the pars interarticularis, and frequently occurs in adolescent athletes (2-4). If it can be detected before the fracture line becomes complete, the bone is able to heal with conservative treatment (9-11). But, if the fracture completes, it can be a possible cause of lifelong chronic low back pain and/or leg pain due to synovitis around the bone defect (12, 13), or subsequent spondylolisthesis (14, 15).

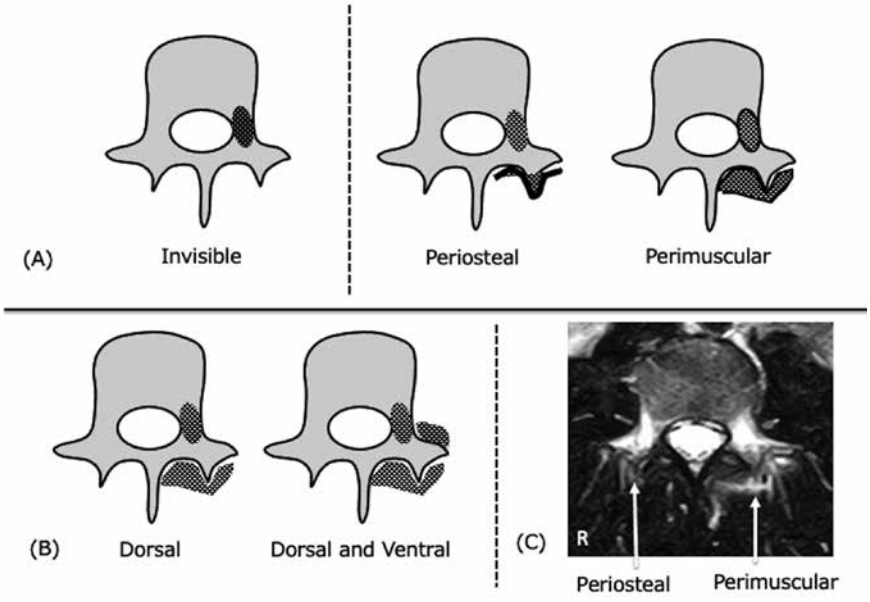

Figure 2. Using axial images through the pedicle on STIR, the identified ESCs were divided into three groups : "invisible" when the ESC was not identified, "periosteal" seen on only the dorsal side of the lamina, and "perimuscular" distinctly spread around/in the paravertebral muscles (A). ESCs were further divided into "dorsal" and "ventral" groups, according to their position relative to the transverse process (B). High signal changes as the ESCs are seen on the STIR-MRI (C).

Currently, MRI is the best tool for making an early diagnosis of LS, with no risk of radiation exposure. A reliable diagnostic sign is high signal changes at the pedicle adjacent to the fracture site on T2 weighted or STIR images, and this high signal change is a known indicator of the potential for bony healing (5-7). However, as is well known, not all hospitals have MRI equipment and so it cannot be used for screening and may also be prohibitively expensive for many patients. In addition, it has been reported that MRI is not always definitive for detecting early stage injuries (16). To decrease the number of patients with LS, prevention by screening on the athletic field is desirable, but there is unfortunately no screening method at present.

Recently, ultrasonography has been used to identify extraosseous changes in soft tissue, including the periosteum in periosteal hyperplasia, muscle, and subcutaneous tissue, before the fracture line becomes apparent on X-ray (1). Moreover, ultrasonography machines are portable and carry no risk of radiation exposure, and so where available, this is the most appropriate tool for screening.

To date, few studies have investigated ESCs on MRI in patients with LS. It was previously considered that a finding of extraosseous hematoma or edema may be a possible cause of radiculopathy (8). In this study, a total of 92.9% fracture sites showed demonstrable ESCs on the dorsal side of the lamina when the fracture in the lamina occurred (early-stage LS). These are possibly considered similar to findings such as periosteal thickening/edema detected at the onset of stress fracture of the long bones.

As mentioned above, we expect that the presence of ESCs can be used for routine medical examination, and have started using ultrasonography for this purpose. Here, we present the preliminary results of this investigation (Figure 3). The potential use of ESC findings for screening of LS with ultrasonography will allow for much earlier diagnosis of LS before the fracture line becomes apparent, similar to stress fracture of the long bones ; it provides clues to diagnosis, by showing hypoechoic haematoma with periosteal elevation, soft tissue edema and cortical break (17). This would ultimately improve outcomes for pediatric patients. More data should be accumulated and analyzed in the future although there are many limitations.

We acknowledge that there are several limitations to this study, arising mainly from its retrospective design in a single institution and inclusion of a limited number of subjects. However, all patients were diagnosed under the same imaging conditions using the same equipment and software, which would be an advantage for this radiological study. In addition, there was no pathological data for the ESCs, because obtaining such data is currently considered ethically challenging.

ESCs on MRI were detected in more than 90% of patients before stress fracture occurred and was visible in the lamina, which was considered a similar finding to periosteal thickening/edema detected at the onset of stress fracture in long bone. While we acknowledge there are several limitations to this study, our findings show that ESCs on MRI may be a significant finding accompanied with stress fracture in the lamina. We hope these findings will be used for a screening tool for the early detection of LS using ultrasonography in the future.

CONFLICT OF INTEREST

All authors confirm that there are no conflicts of interest with people or organizations regarding this report.

ACKNOWLEDGEMENTS

We would like to thank the staff of Suihou Daiichi Hospital for helping to generate the records used in this study.

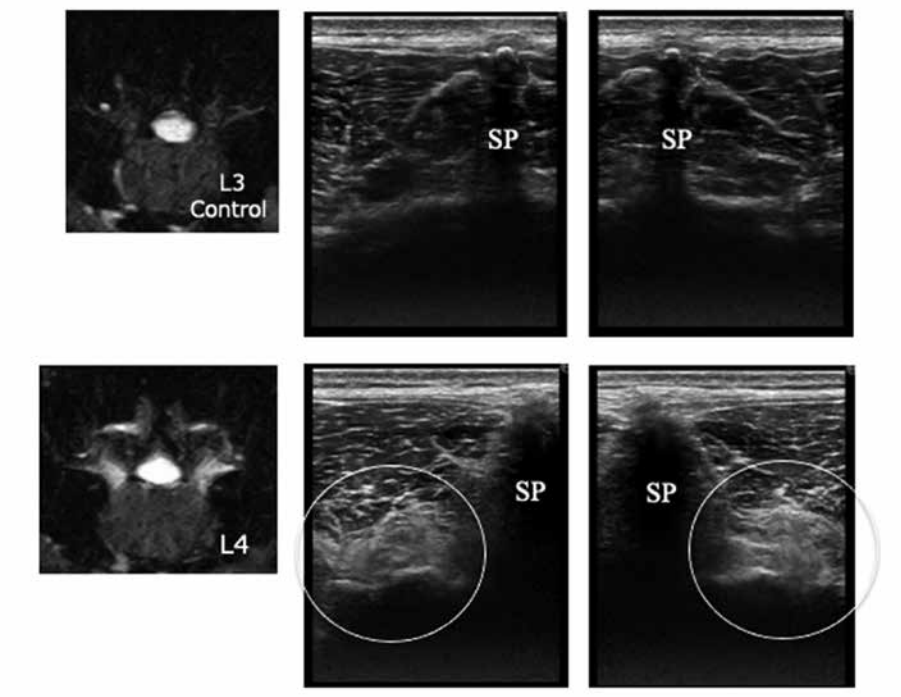

Figure 3. Test case of ultrasonography used in an 18-year-old boy with L4 stress fracture of the lamina presenting with ESCs on MRI, with disarray of the muscular fibers.

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