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대한영상의학회지

Importance of Bone Marrow and Soft Tissue Edema to Improve the Diagnostic Accuracy of Lumbosacral MRI for Transverse Process Fractures and Sacral Fractures

요추 횡돌기 골절과 천추 골절의 자기공명영상 진단에서 골수 부종과 연부조직 부종의 중요성

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Purpose: To evaluate the magnetic resonance imaging (MRI) findings to improve the diagnostic accuracy for transverse process fractures and sacral fractures.
Materials and Methods: The lumbosacral MRI scans of 214 patients (mean age, 60 years; male-to-female ratio, 85:129), who had spine trauma between January and November 2015 were included. Two radiologists evaluated the presence, number, level, and anatomic site of the fractures on MRI with computed tomography as reference standard. Imaging findings were described as cortical disruption, marrow edema, or soft tissue edema on T1-, T2-, and fat-suppressed T2-weighted images. A statistical analysis was performed to compare the diagnostic accuracy of the MRI pulse sequences for the transverse process and sacral fractures.
Results: Of 168 fractures, 26 (15.5%) and 13 (4.9%) were in the transverse processes and sacra, respectively. A paravertebral soft tissue edema occurred in the transverse process fractures (80.8%) and presacral soft tissue and marrow edemas occurred in the sacral fractures (46.1%). The sensitivity for the transverse process fractures was 88% on the T2-weighted image. It was 92% on fat- suppressed T2- and T1-weighted images for sacral fractures.
Conclusion: Bone marrow and soft tissue edemas on the MRI could potentially improve the diagnostic accuracy of an MRI for fractures in the transverse process and sacrum.

Index terms
Magnetic Resonance Imaging
Lumbosacral Region
Spinal Fractures
Bone Marrow

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INTRODUCTION

Fractures in the transverse processes of the lumbar spine and sacrum are considered relatively minor injuries in patients with spine trauma (1) and are usually untreated. Nevertheless, these fractures should be detected because previously published studies reported that 21–51% of patients with transverse process fractures had been associated with abdominal visceral injuries (2, 3). In addition, sacral fractures, often undiagnosed and untreated, frequently lead to chronic neurological sequelae and an undetermined cause of low back pain (4). Unfortunately, the entire sacrum is usually incompletely included in the field of view on routine lumbosacral magnetic resonance (MR) axial sequences, which increases the probability of missing a diagnosis.

The clinical use of magnetic resonance imaging (MRI) in patients with spine trauma has been considered the final imaging diagnostic technique owing to its multiplanar capacity, and ability to assess muscles, ligaments, spinal cord, and spinal canal (5). Furthermore, currently, MRI is cheaper and more widely available in Korea.

Vertebral body fractures are relatively easy to diagnose on the basis of signal alteration of bone marrow or diminished height. However, transverse process and sacral fractures may be overlooked on routine lumbosacral MRI, because these structures are partially included and peripherally located on routine MRI.

The aim of this study was to retrospectively evaluate the imaging findings of transverse process and sacral fractures by comparing those of vertebral body fractures on lumbosacral MRI obtained in patients with spine trauma and to determine the diagnostic accuracy of lumbosacral MRI for the evaluation of transverse process and sacral fractures according to MR pulse sequences.

MATERIALS AND METHODS

Patients

Our Institutional Review Board approved this retrospective study, and waived the requirement for informed patient consent (IRB No. 2016-01-036). The lumbosacral MRI scans of 214 patients (mean age, 60 years; age range, 19–86 years; 85 men and 129 women) who incurred a spine trauma during a traffic accident, fall from height, or minor slip down injury between January 1, 2015, and November 10, 2015, were included in our study. Patients with prior spine surgery, infection, and malignancy were excluded. Computed tomography (CT), including abdominopelvic CT for evaluation of abdominal injuries or spine CT, or pelvic CT for suspicion of fracture was performed and used as reference standard. All CT were reviewed by musculoskeletal radiologists for diagnosis of fractures. The interval between CT and MRI were 2.1 days (range, 0–7 days). One hundred fourteen patients were referred for lumbosacral MRI via the department of emergency medicine; and 100 patients via other departments. Of the 214 patients, 116 (54.2%) had fractures of the lumbar spine or sacrum. The remaining 98 patients (45.8%) had no fractures of the lumbar spine or sacrum.

MRI protocols

MRI was performed with a 1.5-Tesla MRI scanner (Magnetom Avanto, Siemens Medical Systems, Erlangen, Germany). The MR protocol was the same for all MR examinations and consisted of a set of localizers in all three planes. Axial and sagittal T1-weighted [repetition time (TR), 400–700 ms; echo time (TE), 9.6-14 ms; matrix, 185 × 320 (axial) or 288 × 384 (sagittal); flip angle, 150°; field of view, 165 × 200 mm (axial) or 360 × 360 mm (sagittal); number of acquisition, 2 or 3], axial and sagittal T2-weighted [TR, 3500-5340 ms; TE, 79-84 ms; matrix, 212 × 256 (axial) or 358 × 448 (sagittal); flip angle, 160–180°; field of view, 165 × 200 mm (axial) or 360 × 360 mm (sagittal); number of acquisition, 3 or 4], and sagittal fat suppressed T2-weighted sequences (TR, 2150 ms; TE, 76 ms; matrix, 288 × 384; flip angle, 150°; field of view, 360 × 360 mm; number of acquisition, 1) were used for analysis. The scanning range was based on the lumbar spine MRI protocol of our institute and the Korean Institute for Accreditation of Medical Imaging. The sagittal scanning range was between the lateral borders of the vertebral body, which included some psoas muscle. The axial scanning range covered the disk with adjacent superior and inferior endplates. Consequently, the sacrum was included in most sagittal lumbosacral MRI scans, but the axial plane of the sacral level was not obtained in 113 of the 214 lumbosacral MRI scans.

Image Analysis

Two radiologists (a musculoskeletal radiologist with 14 years of experience and a senior radiology resident with 4 months of experience in musculoskeletal imaging) who were blinded to the imaging reports and clinical histories, retrospectively reviewed the MR images together, with differences resolved by consensus opinion.

The MR images were evaluated for the presence of fractures, number, level, and anatomic sites of fractures. The fracture level was recorded as L1, L2, L3, L4, L5, or sacrum. Fractures of the thoracic spine and other posterior elements of the lumbar spine were not analyzed. The anatomic sites were categorized as vertebral body, transverse process, or sacrum. Sacral fracture was defined as sacral body or alar fracture.

The MRI findings of the fractures were described as cortical disruption, marrow edema, or soft tissue edema. Cortical disruption was defined as cortical or endplate discontinuity and a fracture line in marrow space. Fracture line was defined as a dark line within marrow on a T1-, T2-, or fat-suppressed T2-weighted image. Bone marrow edema was defined as the area showing low signal intensities on T1-weighted images, and high signal intensities on fat-suppressed T2-weighted images. Soft tissue edema was defined as signal abnormalities around paravertebral muscles, including the spinal erector and psoas muscles and adjacent soft tissues. Imaging findings were recorded by each pulse sequence.

Statistical Analysis

We identified significant differences in sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) among three MR pulse sequences in the diagnosis of vertebral body, transverse process, and sacral fractures. Receiver-operating characteristic (ROC) curve and area under the ROC curve (AUC) were obtained to compare the diagnostic performance of the three MR pulse sequences in the sagittal plane. All statistical analyses were conducted using the SAS Statistical ver. 9.4 software (SAS Institute Inc., Cary, NC, USA). For all measurements, 95% confidence intervals were calculated.

RESULTS

Among the 116 patients with spine fractures, 91 had isolated vertebral body fractures, 6 had isolated transverse process fractures, and 6 had isolated sacral fractures. A combination of concomitant fractures was observed in 13 patients, of whom 6 had vertebral body and transverse process fractures, 4 had vertebral body and sacral fractures, and 3 had transverse process

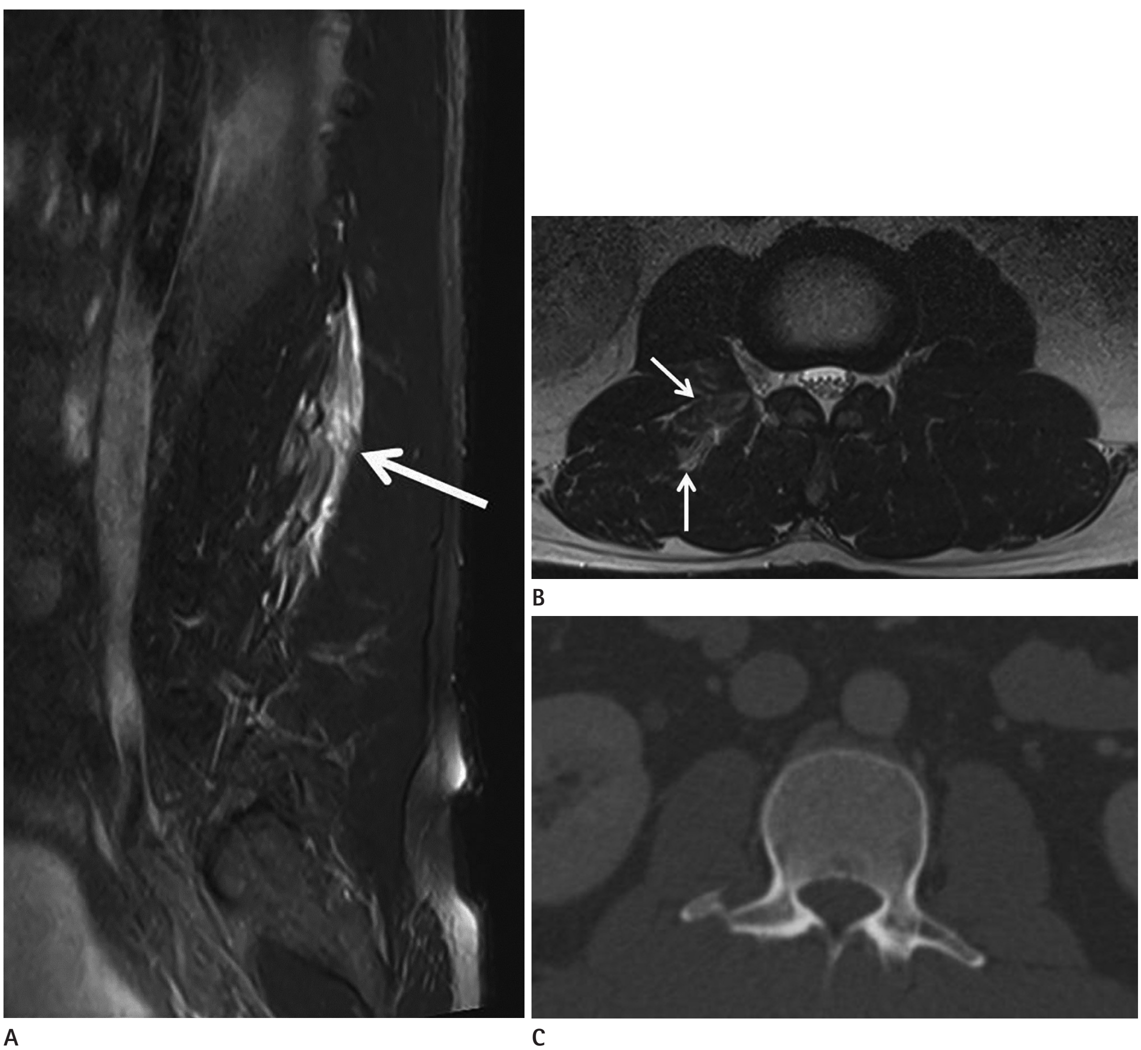


Fig. 1. A 45-year-old man who incurred right L2 and L3 transverse process fractures after falling from a 2m high guardrail.
A. Sagittal fat-suppressed T2-weighted MR image showing paravertebral soft tissue edema (arrow).
B. Axial T2-weighted MR image showing soft tissue edema in the right psoas and spinal erector muscles (arrows), which reflects a transverse process fracture.
C. Axial computed tomography scan showing a fracture at the right L3 transverse process.
MR = magnetic resonance

and sacral fractures.

The most common fracture level was L1 ($n = 57$). In decreasing order of frequency, the fractures were located at L2 ($n = 37$), L3 ($n = 30$), L4 ($n = 19$), L5 ($n = 12$), and the sacrum ($n = 13$). Single-level fractures were observed in 88 patients; and multilevel fractures, in 32 patients (2 levels in 18 patients, 3 levels in 12, and 4 levels in 2). Concomitant fractures were counted separately for anatomical sites and levels. Among 15 patients with transverse process fractures, 4 had single-level fractures, and 11 had multilevel fractures.

Among the 168 fractures in 116 patients, 26 (15.5%) were transverse process fractures, and 13 (4.9%) were sacral fractures. Although cortical disruption was frequently observed in 121 (93.8%) of 129 vertebral body fractures, it was not observed in any of the transverse process and sacral fractures on sagittal T1-weighted images. However, transverse process fracture based on marrow or paravertebral soft tissue edema was diagnosed in 23 (88.5%) of the 26 fractures on axial T2-weighted images and in 24 (92.3%) of the 26 fractures on sagittal fat-suppressed T2-weighted images (Fig. 1). Marrow or presacral soft tissue edema was observed in 12 (92.3%) of the 13 sacral fractures on sagittal T1- and fat-suppressed T2-weighted images (Fig. 2). Axial planes of the sacrum were not available in 5 (38.4%) of the 13 sacral fractures, and 8 (61.6%) of the 13 fractures showed marrow or presacral soft tissue edema. One false positive case showed presacral edema on sagittal fat-suppressed

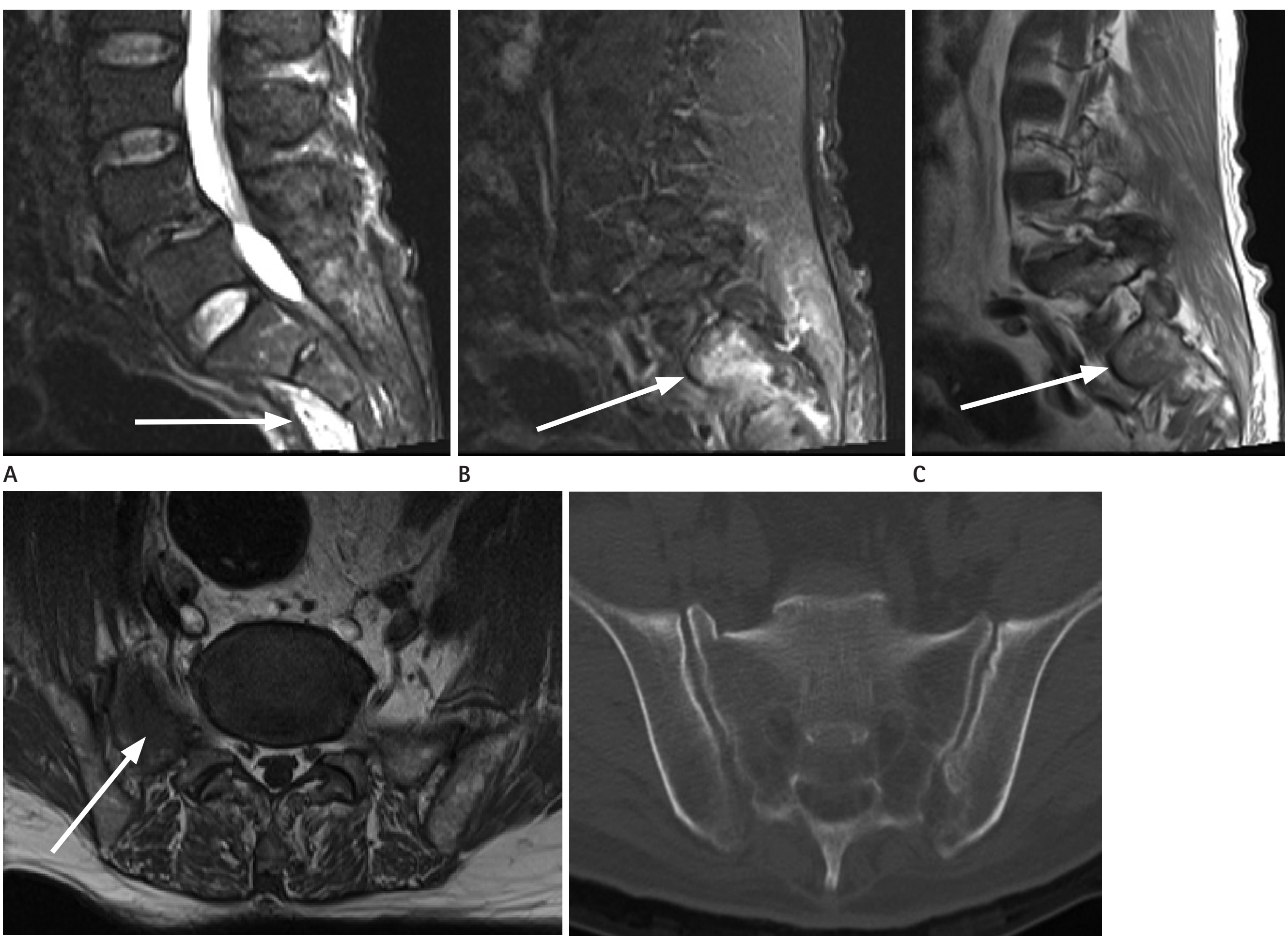
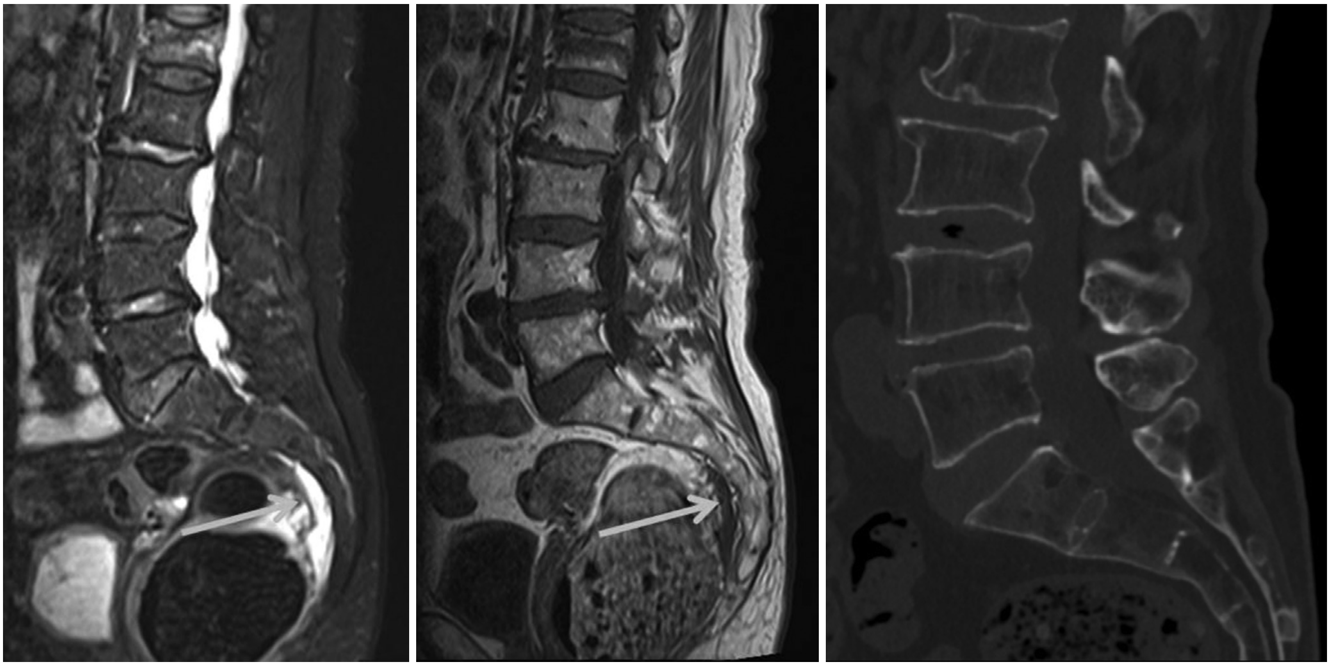


Fig. 2. A 67-year-old man who incurred a trauma with a sacral fracture during a car accident.
A. Midline sagittal fat-suppressed T2-weighted image showing presacral edema (arrow).
B, C. Parasagittal fat-suppressed T2-weighted **(B)** and T1-weighted **(C)** images showing bone marrow edema (arrows) in the right sacral ala.
D. Axial T2-weighted image showing bone marrow edema (arrow) in right sacral ala.
E. Axial CT scan showing a fracture at the right sacral ala.



A B C

Fig. 3. A false-positive case: a 78-year-old woman who had a low back pain after slipping down.
A, B. Sagittal fat-suppressed T2-weighted **(A)** and T1-weighted **(B)** images showing presacral edema (arrows).
C. No fracture can be observed in the sacrum on the sagittal computed tomography scan.

T2- and T1-weighted images. However, CT revealed no fracture in the sacrum (Fig. 3). Two false-negative cases had transverse process fractures.

The sensitivity, specificity, PPV, NPV, and AUC of the three MR pulse sequences in the diagnosis of vertebral body, transverse process, and sacral fractures are shown in Table 1.

The sensitivity and specificity for the diagnosis of vertebral body fracture at all MR pulse sequences were as high as 92% on the T2-weighted images, 99% on the fat-suppressed T2-weighted images, and 100% on the T1-weighted images. The sensitivity of MRI for the diagnosis of transverse process fractures was as low as 50%, especially on the T1-weighted images, and as high as 88% and 92% on the T2- and fat-suppressed T2-weighted images, respectively. The sensitivity of MRI for the diagnosis of sacral fractures was 84% on the T2-weighted images and 92% on fat-suppressed T2- and T1-weighted images. The specificity for sacral fractures was 99% on all MR pulse sequences.

DISCUSSION

In this study, we confirmed that both CT and MRI are good diagnostic tools for fracture. Although MRI has a special ability to evaluate spinal cords, nerves, and ligaments, transverse process and sacral fractures may be easily underestimated on MRI with the usual scan range. We found that the paravertebral muscle and presacral soft tissue edemas associated with transverse process fracture on axial T2- and sagittal fat-suppressed T2-weighted images, respectively, for the diagnosis of sacral fracture could improve the detection of fractures.

An MRI finding of acute spinal fracture is characterized by a low signal intensity line on T1-weighted sequences which is surrounded by a poorly defined area of bone marrow edema indicating bone contusion caused by microscopic compression fractures of cancellous bone (6, 7). MRI is efficient even in the detection of occult bone injuries due to signal changes in bone marrow and soft tissue (8, 9). Fat suppression images allow homogeneous background suppression of fat signals and display changes such as bone marrow edema clearly, which can be easily interpreted (9). In this study, we focused more on bone marrow and soft tissue edemas in addition to bony changes to increase the diagnostic accuracy of MRI for transverse process and sacral fractures.

A previous study mentioned that CT has been the most useful diagnostic tool for the evaluation of transverse process frac-

Table 1. The Diagnostic Accuracy of Magnetic Resonance Imaging in Spinal Fractures According to Fracture Sites and Pulse Sequences

Fracture Sites	Statistic	Magnetic Resonance Pulse Sequences		
		T2WI	FS T2WI	T1WI
Vertebral body	Sensitivity	0.92 (0.86–0.96)	0.99 (0.96–1.00)	1.00 (0.97–1.00)
	Specificity	0.98 (0.95–1.00)	0.99 (0.96–1.00)	0.98 (0.95–1.00)
	PPV	0.92 (0.98–1.00)	0.99 (0.96–1.00)	0.98 (0.95–1.00)
	NPV	0.93 (0.87–0.96)	0.99 (0.96–1.00)	1.00 (0.97–1.00)
	AUC	0.95	0.99	0.99
Transverse process	Sensitivity	0.88 (0.70–0.98)	0.92 (0.75–0.99)	0.50 (0.30–0.70)
	Specificity	0.97 (0.94–0.99)	0.95 (0.92–0.98)	0.99 (0.97–1.00)
	PPV	0.79 (0.60–0.92)	0.69 (0.51–0.83)	0.87 (0.60–0.98)
	NPV	0.99 (0.96–1.00)	0.99 (0.97–1.00)	0.95 (0.91–0.97)
	AUC	0.93	0.94	0.75
Sacrum	Sensitivity	0.84 (0.66–1.00)	0.92 (0.66–1.00)	0.92 (0.75–1.00)
	Specificity	0.99 (0.96–1.00)	0.99 (0.98–1.00)	0.99 (0.96–1.00)
	PPV	0.92 (0.74–1.00)	0.86 (0.66–1.00)	0.92 (0.75–1.00)
	NPV	0.98 (0.94–1.00)	0.99 (0.98–1.00)	0.99 (0.96–1.00)
	AUC	0.96	0.96	1.00

Data in parentheses are 95% confidential interval.
AUC = areas under the receiver operating characteristic curves, FS T2WI = fat suppressed T2-weighted image, NPV = negative predictive value, PPV = positive predictive value, T1WI = T1-weighted image, T2WI = T2-weighted image

tures of the lumbar spine (10, 11). The sensitivities of CT and radiography for identification of thoracolumbar fracture were 100% and 73%, respectively (11). In our study, for the diagnosis of transverse process fractures with MRI, most cases demonstrated soft tissue edema in paravertebral muscles, especially the posterior aspect of the psoas muscle and anterior aspect of the spinal erector muscle around the transverse process. These soft tissue changes were well demonstrated on axial and sagittal T2- and sagittal fat-suppressed T2-weighted images. With these valuable findings, the sensitivity of MRI to identify patients with transverse process fractures was as high as 92% on fat-suppressed T2-weighted images and 88% on T2-weighted images.

Sacral fractures are common in the aging population with concomitant fractures of the pelvis and proximal femur (12). The detection rate of sacral fracture on pelvis CT was reported to be 77% (12). In our study, lumbosacral MRI can detect sacral fractures with a sensitivity of 84% on T2-weighted images and 92% on T1- and fat-suppressed T2-weighted images. As for the diagnosis of sacral fractures, most cases demonstrate both bone marrow and soft tissue edemas.

The MRI protocol is important to avoid missing transverse process and sacral fractures. Several prior studies investigated the feasibility of a limited protocol lumbar spine MRI (13, 14). The overall sensitivity of the limited-protocol lumbar spine MRI with sagittal T1- and fat-suppressed T2-weighted images for detection of acute fracture, infection, and tumor was high, but transverse process or sacral fractures could be missed (14). On the other hand, it was useful to diagnose acute transverse process and sacral fractures on the basis of soft tissue and bone marrow edemas on sagittal T1-weighted, T2-weighted, fat-suppressed T2-weighted, axial T1-weighted, and T2-weighted images in our study.

The scan range of lumbosacral MRI for spinal trauma was different from the usual scan range for degenerative disease. The axial planes of routine lumbosacral spine MRI for degenerative disease were not continuously scanned and were usually obtained through the intervertebral disk as center with some upper and lower endplates. Therefore, the mid-portion of the vertebral body, pedicle, and transverse process were usually missed in the axial planes of MRI. The sagittal planes of MRI are usually scanned between the lateral margins of the vertebral body. Thus, off-midline structures such as the transverse process, psoas muscle, and sacral ala were usually either incompletely included or not imaged at all in the field of view of sagittal planes. If MRI covered the complete sacrum including the sacral ala and lower sacrum, in both the sagittal and axial planes, sacral fractures could be more confidently and easily diagnosed. Therefore, if radiologists suspect fractures from bone marrow and soft tissue edemas on MRI, an additional continuous scanning or three-dimensional imaging might be performed including the transverse process and sacrum.

Our study had several limitations. First, it was a retrospective study with an unintended selection bias. The study population did not truly reflect the entire patient populations with transverse process and sacral fractures because some patients who did not undergo MRI were not included in this study. An additional limitation of the study was that the two reviewers analyzed the MR images together with consensus opinion, thus rigorous statistical analysis including interobserver agreement was not performed. Finally, the field of view for the sacrum on routine lumbosacral MRI differed between patients. Therefore, the diagnostic performance for sacral fractures may have been underestimated.

In conclusion, the imaging findings of fractures inferred from marrow and soft tissue edemas will be helpful to improve the diagnostic accuracy of MRI for transverse process and sacral fractures.

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요추 횡돌기 골절과 천추 골절의 자기공명영상 진단에서 골수 부종과 연부조직 부종의 중요성

권지아 · 황지영* · 김민정 · 권혜영 · 김다훈

목적: 요추 횡돌기 골절과 천추 골절 환자에서 자기공명영상 소견과 진단적 정확성을 평가하고자 하였다.

대상과 방법: 척추외상으로 요천추 자기공명영상을 촬영한 214명의 환자(평균연령 60세, 남자:여자=85:129)를 대상으로 하였다. 2명의 영상의학과 의사가 골절의 유무, 개수, 척추 준위, 해부학적 위치를 평가하였고, 골절의 최종진단은 컴퓨터단층촬영 진단을 기준으로 하였다. 자기공명영상 소견은 피질골 단절, 골수 부종, 연부조직 부종으로 나누어 T1 강조영상, T2 강조영상, 지방억제 T2 강조영상에서 기술하였다. 횡돌기 및 천추 골절의 MRI 진단적 정확도를 펄스대열별로 비교하기 위해 통계학적 분석을 시행하였다.

결과: 168예의 골절 중 횡돌기 골절은 26예(15.5%), 천추 13예(4.9%)가 진단되었다. 흔한 영상소견은 횡돌기 골절 환자에서 척추 주변 연부조직 부종(80.8%), 천추 골절 환자에서 골수부종과 천추 앞 연부조직 부종(46.1%)이었다. 횡돌기 골절 진단의 민감도는 T2 강조영상에서 88%였고, 천추 골절 진단의 민감도는 T1 및 지방 억제 T2 강조영상에서 92%였다.

결론: 자기공명영상에서 골수 부종과 연부조직 부종 소견은 요추의 횡돌기 골절과 천추 골절의 진단적 정확성을 높이는데 도움이 될 것이다.

이화여자대학교 의과대학 목동병원 영상의학과