ORIGINAL

Zero-echo time (ZTE) and fast field echo resembling a CT using restricted echo-spacing (FRACTURE) on 3-T MRI for the cervical spine

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Abstract : Background : Detailed depiction of bony structures on conventional magnetic resonance imaging (MRI) is difficult and the modality is inferior to computerized tomography (CT) for showing bony injuries, ossification and calcification. Novel sequences such as zero-echo time (ZTE) and fast field echo resembling a CT using restricted echo-spacing (FRACTURE) may overcome the weak points of conventional MRI. The objective of this study was to determine the usefulness of these sequences on 3.0-T MRI for imaging the cervical spine. Methods : ZTE and FRACTURE images were obtained from 3.0-T scans for three representative cases of ossification of the posterior longitudinal ligament, retro-odontoid pseudotumor, and fracture in the cervical spine and compared with CT. Results : FRACTURE images were superior to ZTE images in both of 2D images and 3D images reconstructed from 2D images. But, both ZTE and FRACTURE images from 3.0-T scans could take the place of CT and fused images reconstructed from 2D images and MR angiography could be used instead of CT angiography. Conclusion : High-resolution MRI sequences may completely replace CT and appear very useful when surgical strategies are considered for patients with allergies to contrast agents or renal failure for whom use of contrast agents is contraindicated. J. Med. Invest. 72 : 266-271, August, 2025

Keywords **:** *3.0-T MRI, bony structure, cervical spine, 3D-image*

INTRODUCTION

Clearer images are obtainable with 3.0-T magnetic resonance imaging (MRI) than with 1.5-T MRI. Moreover, various sequences such as perfusion imaging, diffusion-weighted imaging, diffusion tensor imaging, and MR spectroscopy with 3.0-T MRI could provide valuable information for diagnosing and understanding the intracranial lesions such as cerebrovascular disease and brain tumors. On the other hand, the special sequences for 3.0-T MRI of the spine have yet to be spread for diagnosing and understanding of the spine disease. We therefore examined representative cases of cervical spine diseases and trauma and report on the usefulness of zero-echo time (ZTE) and fast field echo resembling a CT using restricted echo-spacing (FRACTURE) sequences with 3.0-T MRI.

Recent studies have assessed the utility of ZTE-MRI for the evaluation of cortical bones and cervical neural foraminal stenosis (1, 2). ZTE-MRI uses specialized acquisition and reconstruction techniques to capture ultrashort components before signal decay. In 2021, Johnson *et al*. (3) reported FRACTURE as a 3D gradient echo approach for superior cortical and trabecular bone contrast that yields clinically relevant information for patient management. FRACTURE is based on conventional 3D gradient echo sequences available on most commercially available MRI scanners, and 3D acquisition allows for multiplanar reformatting. Since 2021, only one report has been published about FRACTURE, focusing on the knee and ankle joints (4). In this report, we show 2D images using ZTE and FRACTURE sequences on 3.0-T MRI of patients with pathologies of the cervical spine compared to conventional CT and 3D images fused with MR angiography (MRA) without gadolinium enhancement compared to CT angiography (CTA).

METHODS

All MR scans that included ZTE were performed using a 3.0-T scanner (SIGNA Architect, GE Healthcare, Chicago, USA). Scan parameters for ZTE MRI were set as follows to adjust the scan times to 2 min 32 s : echo time (TE), 0.016 ms ; repetition time (TR), 475 ms ; Number of excitations (NEX), 6 ; and slice thickness, 1.0 mm. Scan parameters for 3D time of flight (TOF) MRA were set as : TE, 3.4 ms ; TR, 19 ms ; flip angle (FA), 15 ; matrix, 320×224 ; and slice thickness, 2.0 mm.

All MR scans that included FRACTURE were performed using a 3.0-T scanner (Achieva dStream, Philips Healthcare, Best, the Netherlands). Scan parameters for FRACTURE were set as follows to adjust the scan times to 2 min 23 s : TE, 2.3 ms, 6.9 ms, 11.5 ms, and 16.1 ms ; TR, 18.1 ms ; NEX, 1 ; and thickness, 3 mm. Scan parameters for 3D TOF MRA were set as : TE, 3.5 ms ; TR, 20 ms ; FA, 20 ; matrix, 224×160 ; and slice thickness, 2.2 mm.

An AquilionONE GENESIS Edition multislice CT scanner (Canon Medical Systems, Otawara, Japan) was used to perform CTA. Scan parameters were : slice thickness, 0.5 mm ; 160 rows ; collimation, 80 mm ; interslice gap, 0.3 mm ; helical pitch, 0.806, 100 kilovolts (peak). For contrast, 56 mL of contrast agent was injected intravenously at 4 mL/s. Data were acquired in the axial plane and reformatted on an Advantage version 4.7 workstation (Canon Medical Systems, Otawara, Japan by a CT technician. Fused 3D images reconstructed from ZTE MRI and

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FRACTURE images and MRA, 3D-CT and MRA were created manually on an Aze Virtual Place workstation (AZE, Tokyo, Japan).

RESULTS

The first case involved a 55-year-old man with neck pain and left hemiparesis (Fig. 1). T2-weighted imaging showed a retro-odontoid pseudotumor severely compressing the spinal cord. Conventional CT disclosed ossification of the posterior longitudinal ligament (OPLL) at the C2-3 level. ZTE-MRI could depict the vertebral cortex in both sagittal and axial images similar to CT images, but could not depict trabecular bone sufficiently on sagittal images. The morphological characteristics of OPLL, such as continuity with the posterior wall of the vertebral body, were evident on both sagittal and axial images. The most important point when deciding the surgical strategy is whether a high-riding vertebral artery (VA) is present. With this ZTE, the resolution was not high, but could show the shape of the intervertebral foramen and suggest that bilateral VAs were not high-riding. Screw trajectory should be discussed and carefully determined before the cervical posterior fixation surgery, to avoid VA injury from incorrect screw insertion. As a preoperative examination, CTA is very useful for understanding the location of the VAs, although contrast agent is needed. Figure 2 shows

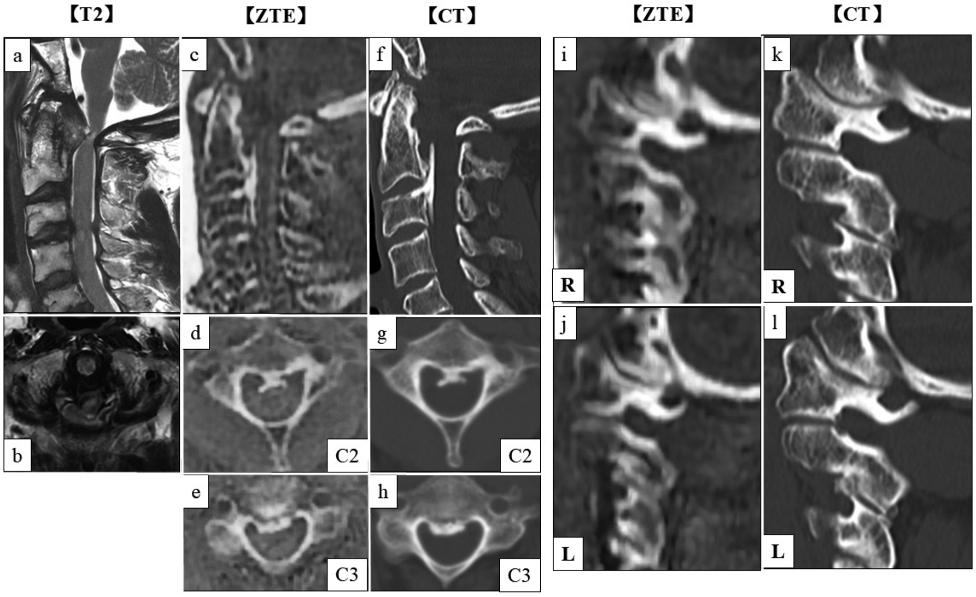

Figure. 1. A 55-year-old man with neck pain and left hemiparesis. T2-weighted imaging and zero-echo time (ZTE) imaging on 3.0-T MRI of the retro-odontoid pseudotumor compared with computed tomography (CT)
a, b) Sagittal and coronal T2-weighted imaging shows a retro-odontoid pseudotumor compressing the spinal cord
c–e) Sagittal and axial ZTE images show OPLL at C2-3
f–h) Sagittal and axial CT images show OPLL at C2-3
i, j) Sagittal ZTE images on the right and left sides show no high-riding VA
k, l) Sagittal CT images on the right and left sides

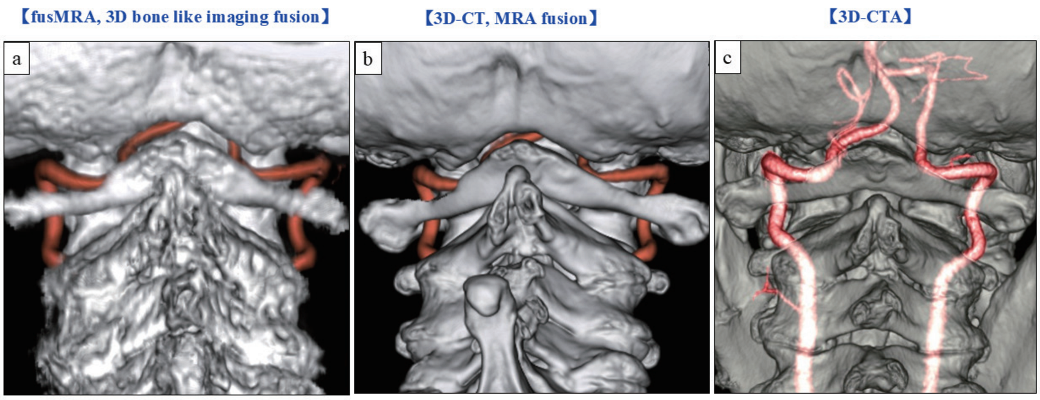

Figure. 2. Comparison of various 3D images of the above same patient
a) Fusion 3D images reconstructed from ZTE and MRA images
b) Fusion image of 3D-CT and MRA images
c) 3D-CTA

3D fusion images reconstructed from ZTE MRI (3D-ZTE) and MRA, 3D-CT and MRA, and 3D-CTA of the above same patient. The resolution of 3D-ZTE MRI and MRA was not high compared to 3D-CT and MRA, or CTA, but provided sufficient quality for identifying the location of the VAs.

The second case involved a 61-year-old man with neck pain and loss of dexterity in the left hand. Conventional CT disclosed OPLL at C4-5. FRACTURE clearly depicted not only the vertebral cortex, but also trabecular bone in both sagittal and axial images comparable to CT myelography (Fig. 3). The slice width was 3 mm. The morphological characteristics of OPLL were evident on both sagittal and axial images, but borders between the superficial and deep layers of the OPLL were not clearly shown. Compared to ZTE-MRI, FRACTURE showed the cortex, trabecular bone and OPLL more clearly.

The third case involved a 79-year-old man referred for neck pain after a fall. Conventional CT revealed odontoid fracture (Anderson and D'Alonzo type III) and cortical fracture of the right C2 pedicle, while FRACTURE detected fracture lines in the cortex and trabecular bone of the C2 body and cortex of the C2 pedicle similar to CT on both sagittal and coronal views (Fig. 4). Conservative therapy is usually chosen for odontoid fracture (Anderson and D'Alonzo type III), although a surgical strategy might be considered for various reasons. As discussed above, the location of the VA must be checked. Fused 3D images reconstructed from FRACTURE and MRA (3D-FRACTURE) were as useful as 3D-CTA for understanding the course of the VA. Similar to 2D images, 3D images from FRACTURE were higher quality than those from ZTE-MRI.

Six neurosurgeons independently assessed the quality of 2D and 3D images in both of ZTE and FRACTRE compared to 2D CT scans and 3D-CTA. All neurosurgeons judged that these were not excellent but good images for understanding the pathogenesis and planning for the surgical methods.

To improve the quality of 3D-ZTE MRI, the slice width of ZTE-MRI was set to 1 mm and the depiction of trabecular bone was unclear. Then, images from ZTE-MRI with slice widths of 1 mm and 4 mm from a healthy 45-year-old man were compared

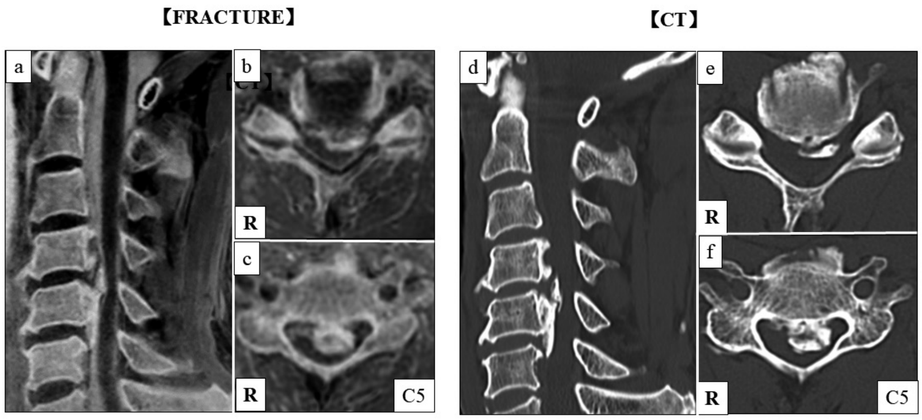

Figure. 3. A 61-year-old man with neck pain and loss of dexterity in the left hand. Comparison of fast field echo resembling a CT using restricted echo-spacing (FRACTURE) images (a-c) and CT (d-f) of the cervical region in a patient with OPLL
a, d) Sagittal images
b, e) Axial images at C4/5
c, f) Axial images at the C6 body level

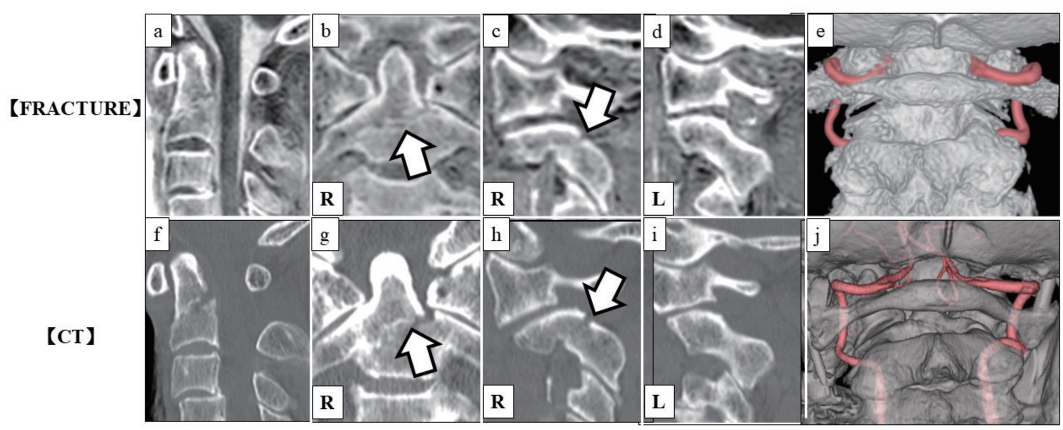

Figure. 4. A 79-year-old man with neck pain. Comparison of FRACTURE images (a-d) and CT (f-j) of the odontoid fracture and fusion 3D image reconstructed from FRACTURE and MRA images (e) and 3D-CTA (j). White arrow, fracture line at C2

(Fig. 5). One disadvantage of 4-mm slice data from ZTE-MRI is that 3D images cannot be reconstructed, but axial and coronal images with a 4-mm slice width were clearer for both cortex and trabecular bone than 1-mm slices and appeared comparable to CT images. This may allow a more detailed understanding of cortical and trabecular injuries.

To evaluate ZTE-MRI and FRACTURE on 3.0-T MRI, we made comparisons with volumetric interpolated breath-hold examination (VIBE) MRI on a 1.5-T scanner (MAGNETOM Altea, Siemens Healthineers, Erlangen, Germany). As shown in Figure 6, VIBE MRI on a 1.5-T scanner could clearly detect lumbar spondylolytic spondylolisthesis at L5/S1 of a 35-year-old

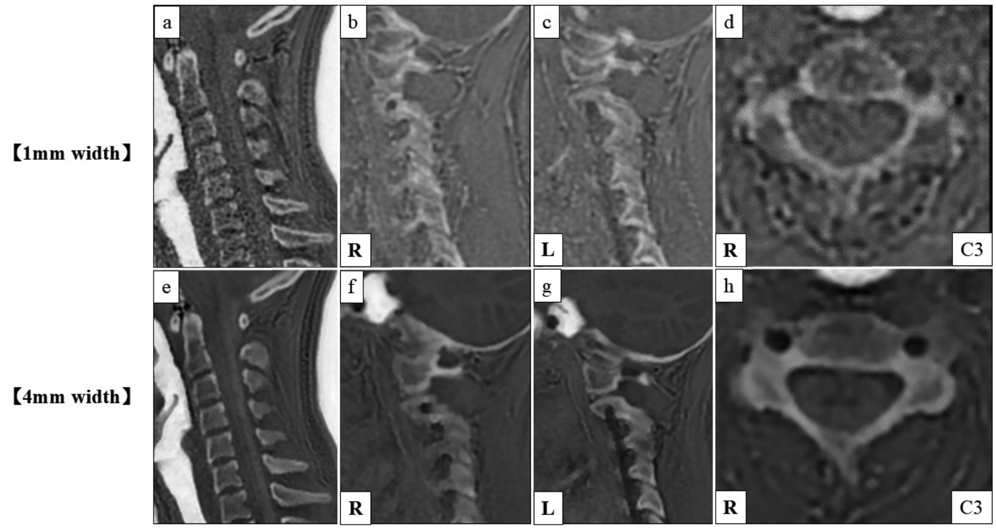

Figure. 5. Comparison of ZTE images at the cervical spine of a healthy 45-year-old man taken with widths of 1 mm (a–d) and 4 mm (e–h)
a, e) Sagittal image in the midline
b, f) Sagittal on the right side
c, g) Sagittal on the left side
d, h) Axial images at C3

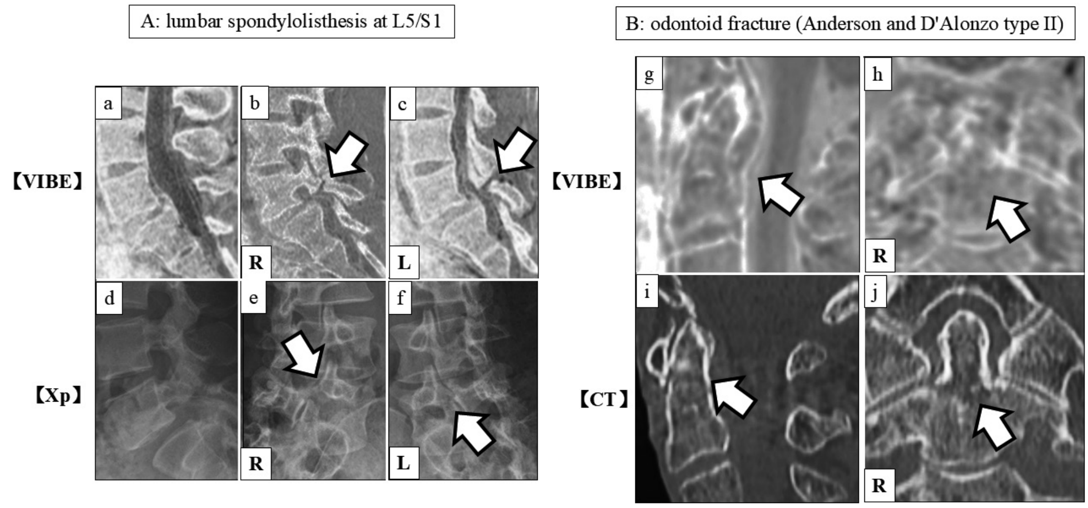

Figure. 6. Volumetric interpolated breath-hold examination (VIBE) MRI on a 1.5-T scanner showing a 35-year-old woman with lumbar spondylolytic spondylolisthesis at L5/S1 (A) and a 78-year-old woman with odontoid fracture (B)
A) Comparison of VIBE MRI and X-ray. White arrows show separated portions
a–c) Sagittal images on VIBE MRI in the midline and on the right and left sides
e–g) X-ray, lateral, anterior flexion and posterior flexion
B) Comparison of VIBE MRI (g, sagittal ; h, coronal) and CT (i, sagittal ; j, coronal)
White arrows show fracture line at C2

woman. Compared to ZTE-MRI and FRACTURE on 3.0-T MRI, the depiction of the trabecular bone is slightly poorer, although cortical bone is clearly visualized. On the other hand, odontoid fracture (Anderson and D'Alonzo type II) could not be depicted in a 78-year-old woman in the acute phase.

DISCUSSION

MRI could obtain more detailed information of soft tissues than CT scans and conventional sequences are useful for the diagnosis of various pathogenesis such as spondylosis, intra- and extra-dural tumor, and abnormal vascular lesion in the cervical spine. However, conventional MRI imaging depicts the internal structures of the bones and the presence of ossifications and calcifications less clearly as compared with CT. We showed that the novel MRI techniques of ZTE-MRI and FRACTURE on 3.0-T MRI of the cervical spine could show OPLL and bone fractures similar to CT. The comparisons between ZTE and FRACTURE are shown in Table 1. ZTE-MRI has been developed as a method for direct imaging of the bones by the signal acquisition of the cortical bones (5, 6). On the other hand, FRACTURE is a 3D gradient echo pulse sequence with restricted echo-spacing combined with an automated post-processing for superior cortical and trabecular bone contrast (3). In this report, we could not present ZTE-MRI of the traumatic cervical bone fracture case. FRACTURE could depict the cortical and trabecular bone fractures in acute phase with high quality.

MRI is prone to distortion artifact. Argentieri EC *et al*. (1) discussed the diagnostic accuracy of ZTE-MRI for the evaluation of cervical foraminal stenosis compared to CT and substantial agreement was found between ZTE-MRI and CT-based grades. Schwaiger BJ *et al*. (7) accessed the agreement for quantitative parameters such as anterior and posterior heights of the vertebral body between T1-weighted spoiled gradient-echo (T1SGRE) and CT and it was excellent (intraclass correlation coefficients, 0.99). T1SGRE is one of 3D gradient-echo sequences and FRACTURE is a modified technique from 3D gradient-echo sequence. Although we could not demonstrate quantitative assessment between ZTE-MRI, FRACTURE and CT, the distortion artifact is thought to be small.

In particular, 3D-ZTE and 3D-FRACTURE could be substituted for 3D-CTA. When planning surgical strategies for the cervical spine, the course of the VAs must be checked and 3D-CTA requires contrast agents for this. We believe that 3D-ZTE and 3D-FRACTURE would thus be beneficial for patients allergic to contrast agents or for whom contrast agents are contraindicated due to renal failure. ZTE-MRI and FRACTURE require similar amounts of time. Although the slice width of ZTE-MRI was set to 1 mm to improve the quality of 3D-ZTE, the quality of 3D-ZTE seemed to be not high compared to 3D-FRACTURE and the depiction of trabecular bone was unclear compared to FRACTURE. Therefore, we consider FRACTURE as superior to ZTE-MRI in terms of resolution and image quality.

Moreover, we presented VIBE MRI on a 1.5-T MRI to evaluate ZTE-MRI and FRACTURE on 3.0-T MRI. VIBE is a form of volumetric imaging using fast 3D gradient-echo sequences that produce T1 images and was first introduced by Rofsky in 1999 (8). By applying high-resolution, small field of view imaging to a part of the musculoskeletal system that has such high intrinsic contrast resolution, VIBE sequences can be utilized to clearly define normal cortical bony anatomy when surrounded by fat and muscle. Several reports have confirmed the utility of VIBE MRI with regard to the detection of lumbar osseous injuries and malignant vertebral tumors (9-14). As shown at Figure 6, it might indicate that VIBE MRI on a 1.5-T scanner could not clearly visualize fracture lines in the absence of bony separation or cortical bone fracture in the acute phase without bony sclerosis. Moreover, the biggest disadvantage of VIBE MRI on 1.5-T is that visible 3D images could not be reconstructed because the resolution of 2D images is not as high as that from 3.0-T imaging.

This study had some limitations. We could not show ZTE and FRACTURE images on 1.5-T scanner and VIBE MRI on 3.0-T scanner and compare the images on 3.0-T scanner with 1.5-T scanner at the same sequences. Therefore, we could not demonstrate that the images on 3.0-T scanner have higher resolution

Table 1. Features of ZTE and FRACTURE image for MR bone imaging

	ZTE (zero-echo time)	**FRACTURE (fast field echo resembling a CT using restricted echo-spacing)**
vendor	GE Healthcare	Philips Healthcare
Technique	direct imaging of cortical bone	indirect imaging of cortical bone
	zero echo time	high resolution 3D gradient echo-based technique
depiction of cortical bone	+	+
depiction of trabecular bone	-	+
depiction of soft tissues (ligament, muscles, tendon, etc)	-	+
artifact due to the metal in the body	not sensitive	sensitive
available on commercial scanners	not generally available	commonly available
this study		
slice thickness of 2D image	1 mm	3 mm
quality of 3D image	not high	high
scan time	2 min 32 sec	2 min 23 sec

than 1.5-T scanner at the same sequences and were more useful for diagnosis. But, we could compare the quality of the images by showing the different sequences on 3.0-T and 1.5-T scanners which could depict bony structures and ossification. Moreover, we showed only visual comparison and could not present quantitative results about the assessment of the accuracy of ZTE and FRACTURE images compared to CT images.

CONCLUSION

Conventional MRI is essential to correctly diagnose and determine proper surgical strategies for diseases of the spine. However, some forms of information can be difficult to obtain. This report showed the possibility of ZTE MRI and FRACTURE on 3.0-T MRI, which could be substituted for CT not only with 2D imaging but also with 3D imaging of the cervical spine. Various sequences that can detect such information were reported. Further research into the utility of these imaging techniques in clinical practice is needed.

CONFLICTS OF INTEREST AND SOURCE OF FUNDING

There are no conflicts of interest.

DECLARATION OF PATIENT CONSENT

The authors certify that they have obtained all appropriate patient consent.

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