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FULL PAPER

Detection of vertebral metastases: a comparison between the modified Dixon turbo spin echo T_2 weighted MRI and conventional T_1 weighted MRI: a preliminary study in a tertiary centre

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Objective: To compare the diagnostic performance of modified Dixon (mDixon) turbo spin echo (TSE) T_2 weighted MRI and conventional T_1 weighted MRI in vertebral metastasis detection.

Methods: Between September 2014 and October 2016, 33 patients with 68 metastases who had undergone whole-spine MRI were enrolled. The following sagittal image sets were evaluated: T_1 WI, and mDixon TSE T_2 weighted water and fat images. Two radiologists independently evaluated each image-set for metastasis. The MR findings were compared with positron emission tomography-CT (PET-CT) scans. Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were calculated for each sequence. The diagnostic performance of each sequence was evaluated using receiver operating characteristic (ROC) curves.

Results: Sensitivity, specificity, PPV and NPV for reviewer 1 were 83.8, 99.1, 89.1 and 98.6%, respectively, with T_1 WI; 79.4, 98.8, 85.7 and 98.2%, respectively, with mDixon TSE T_2 weighted water imaging; and 86.8, 99.1, 89.4 and 98.8%, respectively, with mDixon TSE T_2 weighted fat imaging. For reviewer 2, the respective scores were 91.2, 99.2, 91.2 and 99.2%; 85.3, 99.5, 93.4 and 98.7%; and 89.7, 99.3, 92.4 and 99.1%. With PET-CT as the gold standard, the ROC curves of the three sequences showed no significant difference (all $p > 0.05$).

Conclusion: The diagnostic performance of mDixon TSE T_2 weighted water and fat imaging was comparable to that of conventional T_1 WI in the detection of vertebral metastases.

Advances in knowledge: mDixon TSE T_2 WI can be a good alternative to conventional T_1 WI for detecting vertebral metastases.

INTRODUCTION

Vertebral metastases occur in 10% of patients with malignant neoplasms and account for 39% of all skeletal metastases.^{1,2} Detection of vertebral metastasis is important in ensuring appropriate treatment of the primary malignancy, and for decreasing morbidity caused by pain or complications.³ MRI, which has higher accuracy and better diagnostic performance than other modalities in detecting marrow lesions, plays an important role in diagnosing vertebral metastases.^{4,5} MRI protocols consisting of appropriate and sufficient sequences should be further developed to improve the detection of vertebral metastases. The MR sequences widely used for the detection of metastatic lesions include T_1 weighted MRI (T_1 WI) and fat-suppressed T_2 weighted MRI (T_2 WI).^{6–10} T_1 WI is a fundamental sequence that reveals normal fatty marrow, which is

useful for detecting an abnormal signal intensity (SI) in the vertebrae.^{6–8} In addition, T_2 WI is important in detecting metastatic lesions, in that they can be better visualized on fat-suppressed T_2 WI.^{9,10}

The Dixon MRI technique is widely used because of its ability to simultaneously reconstruct fat and water images.¹¹ Using different echo times, the Dixon technique can acquire in- and opposed-phase images, as well as water and fat images, which are analytically calculated.^{11,12} The modified Dixon (mDixon) technique is known to provide robust and high-quality fat quantification by accommodating spectral peak modelling of fat with flexible echo times,^{12–16} such echo times allow it to calculate and apply the shortest echo time needed to obtain the best quality water and fat images. Total scan time can be decreased, while the effect of

patient motion artefacts is reduced.^{14,17} In addition, the mDixon technique can be applied to spin-echo sequences, providing high signal-to-noise and contrast-to-noise ratios.

Currently, the number of papers reporting on the clinical applications of the mDixon technique is small.^{16–18} We hypothesized that the diagnostic ability of mDixon turbo spin echo (TSE) T_2 WI would be comparable to that of conventional T_1 WI in the detection of vertebral metastases. The purpose of this study was to evaluate the diagnostic ability of mDixon TSE T_2 WI in comparison with that of T_1 WI in the detection of vertebral metastases.

METHODS AND MATERIALS

Patient selection

This retrospective study was performed with the approval of our institutional review board. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. A total of 381 patients underwent whole-spine MRI for the evaluation of spine metastases at our

cancer centre between September 2014 and October 2016. Of these patients, 34 with 75 bone metastases met the following inclusion criteria: (1) underwent whole-spine MRI with spin-echo-based mDixon TSE MRI; (2) had documented primary or secondary diagnosis of bone metastasis [*International Classification of Diseases, 10th Revision (ICD-10)*, diagnosis code No. C79.5]; and (3) underwent positron emission tomography-CT (PET-CT) within a previous or subsequent month. We excluded cases of innumerable small (<0.4 cm) bone metastases because such lesions did not show on PET-CT scans (whose scanner resolution was 4–5 mm), and because they were also difficult to count and measure on MR images. In addition, seven metastases with pathological fractures were excluded in order to eliminate potential biases in the detection of lesions via vertebral deformity instead of SI difference. The final study group thus consisted of 33 patients [20 males and 13 females; mean age, 65.4 years (range: 33–83 years)] with 68 bone metastases (Figure 1).

Primary malignancies included lung cancer ($n = 14$), thyroid cancer ($n = 3$), stomach cancer ($n = 2$), hepatocellular carcinoma ($n = 2$), renal cell carcinoma ($n = 2$), oesophageal cancer ($n =$

Figure 1. Flowchart of the patient selection.

Table 1. MRI parameters

	T_1 weighted imaging	mDixon TSE T_2 weighted water/fat imaging
TR (ms)	400	2000
TE (ms)	10	100/automated shortest TE
Slice thickness (mm)	4	4
Slice gap (mm)	0.4	0.4
FOV (cm)	28 ($\times 3$ scans)	28 ($\times 3$ scans)
Matrix	448 $\times$ 220	448 $\times$ 220
NEX	1	1
Bandwidth (Hz/pixel)	398.6	336.2
Scan time	4 min 14 s	6 min 15 s

Reference scan time (about 15 s) and calibration scan time (about 90 s) are not included in the scan time.

FOV, field of view; mDixon, modified Dixon; NEX, number of excitations; TE, echo time; TR, repetition time; TSE, turbo spin echo.

1), lymphoma ($n = 1$), nasopharyngeal cancer ($n = 1$), pancreatic cancer ($n = 1$), rectal cancer ($n = 1$), tongue cancer ($n = 1$), multiple myeloma ($n = 1$), prostate cancer ($n = 1$), bladder cancer ($n = 1$) and breast cancer ($n = 1$). The primary tumour was confirmed in 24 patients by core needle biopsy, and in nine patients by excisional biopsy. PET-CT scans showed all vertebral metastases in these patients clearly. They also revealed metastases at other non-vertebral sites in 17 patients (17/33, 51.5%). Six patients (6/33, 18.1%) underwent biopsy at these other sites, and pathological analyses confirmed the diagnosis.

Metastases were located in the cervical ($n = 7$ lesions), thoracic ($n = 34$), lumbar ($n = 21$) and sacral vertebrae ($n = 6$). 63 metastases were located in the vertebral body, 4 metastases were located in the spinous process and 1 metastasis was located in the right pedicle.

Whole-spine MRI

All whole-spine MRI procedures were conducted with a 3.0-Tesla MR system (Ingenia® 3.0T, Philips Healthcare, Best, Netherlands) with a built-in posterior coil and posterior neck coil. The mDixon TSE T_2 WI utilized in our study is a medically approved commercial product in both the United States and Europe. Whole-spine images were obtained in three stacks. The images obtained included conventional T_1 weighted sagittal images [repetition time (TR): 400 ms; echo time (TE): 10 ms] and mDixon TSE T_2 weighted sagittal images (TR: 2000 ms; TE1: 100 ms; TE2: automated shortest second TE). Details of the MR parameters are described in Table 1. We tried to acquire T_1 weighted sagittal slices and mDixon TSE T_2 weighted sagittal slices with the same geometric placement.

Imaging interpretation

In the first interpretation session, two radiologists (a 2-year-trained resident and a radiologist with 10 years of musculoskeletal imaging experience) reviewed the MRI scans. They independently reviewed the MR images at random regardless of

patient, sequence, or the vertebral level of the scanned MR images without the process of consensus. They were also completely blinded to the radiological reports, patient clinical information and MRI sequence parameters. They were asked to evaluate the presence/absence of metastasis on a 4-point confidence scale, and to confirm the level of metastasis in the vertebrae on each MR sequence. Vertebral metastasis was defined as a focus of replacement of the fatty signal of bone marrow, which shows low SI compared with skeletal muscle on T_1 WI, high SI compared with hypointense bone marrow on mDixon TSE T_2 weighted water images and low SI compared with hyperintense bone marrow on mDixon TSE T_2 weighted fat images. The confidence scale grades were defined according to likelihood of metastasis as follows: Grade 1, <25%; Grade 2, 26–50%; Grade 3, 51–75%; and Grade 4, 76–100%. The confidence scale grade was influenced by SI, morphology and location of the metastasis in the vertebrae. The vertebrae containing metastases were recorded as one level of the whole spine, which was divided into the sacrum and the 7 cervical, 12 thoracic and 5 lumbar vertebrae.

In the second review session, a third radiologist with 3 years of musculoskeletal imaging experience independently evaluated the review findings of the first two readers with reference to PET-CT scans obtained within the previous or subsequent month from the MRI examination date. The independent review performed by the third radiologist did not alter the initial review findings of the first two readers, and was not influenced by those. In addition, the third radiologist measured the largest anteroposterior diameter of metastases on each MR sequence, and then evaluated the CT characteristic (osteolytic or osteoblastic) of the metastases on PET-CT. A “metastatic” MRI lesion was determined to be “positive” when it was identical to that detected on PET-CT, had intense fluorodeoxyglucose (FDG) uptake and was interpreted as metastatic by a fellowship-trained nuclear physician. When the aforementioned conditions were met, the third radiologist defined the lesion as metastatic even if both reviewers judged otherwise. To avoid false positives on the PET-CT scans, causes of FDG uptake (other than metastasis such as haemangioma) were carefully excluded.

All measurements were performed with a picture archiving and communication system (PACS; Centricity Radiology RA 1000; GE Healthcare, Barrington, IL). Changing of the window width and level or magnifying MR images was permitted if needed.

Statistical analyses

We compared the measured average size of the metastases on each MR sequence by one-way analysis of variance. The sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of both reviewers for each sequence were calculated with reference to the PET-CT scans. An inter-reader agreement for each MR sequence was also calculated. The degree of agreement was determined by using the kappa value, and categorized as follows: 0–0.20, slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, good agreement; and 0.81–1.00, excellent agreement. We also compared the confidence scale grade on each MR sequence via Kruskal-Wallis test. The diagnostic performance of each

Figure 2. An 83-year-old male with lung cancer. A metastasis can be observed in the L2 vertebral body (yellow arrows) on the T_1 weighted image (a), mDixon TSE T_2 weighted water image (b) and mDixon T_2 weighted fat image (c). The PET-CT axial scan (d) shows the osteoblastic metastasis with FDG uptake. FDG, fluorodeoxyglucose; mDixon, modified Dixon; PET-CT, positron emission tomography-CT; TSE; turbo spin echo.

sequence was evaluated by using the receiver-operating characteristic (ROC) curve and area under the curve (AUC). The statistical significance was defined as $p < 0.05$ for all comparisons. Statistical analyses were performed in MedCalc Statistical Software v. 16.2.1 (MedCalc Software BVBA, Ostend, Belgium).

RESULTS

The measured mean ($\pm$ standard deviation) size of the metastases was 2.37 ± 0.82 cm (range: 0.65–3.98 cm) on T_1 WI; 2.35 ± 0.82 cm (range: 0.64–3.98 cm) on mDixon TSE T_2 weighted water imaging; and 2.37 ± 0.83 cm (range: 0.77–3.98 cm) on mDixon TSE T_2 weighted fat imaging. No significant difference was found among the mean sizes on the three MR sequences ($p = 0.983$). In addition, of the 68 metastases, 49 lesions were osteolytic, 16 were osteoblastic and 3 were mixed, as revealed on PET-CT.

Reviewer 1 detected 57 lesions on T_1 WI, 54 lesions on mDixon TSE T_2 weighted water imaging and 59 lesions on mDixon TSE T_2 weighted fat imaging. Reviewer 2 detected 62 lesions on T_1 WI, 58 lesions on mDixon TSE T_2 weighted water imaging and 61 lesions on mDixon TSE T_2 weighted fat imaging (Figures 2–4).

The calculated sensitivity, specificity, PPV and NPV for each reader are provided in Table 2. With respect to the mDixon TSE T_2 weighted water images, both reviewers simultaneously reported four false-positive and six false-negative cases of metastases, respectively. On mDixon TSE T_2 weighted fat imaging, none of the cases were simultaneously false-positive for both reviewers, whereas five simultaneous false-negative cases were identified.

The inter-reader agreement for each MRI sequence was also calculated (Table 3). All sequences had excellent inter-reader agreement. Among the three sequences examined, mDixon

TSE T_2 weighted water imaging had the highest agreement and T_1 weighted imaging had the lowest agreement.

When evaluating the mean confidence scale grade for each MR sequence in the 68 metastases examined, reviewer 1 obtained 2.72 ± 0.17 (estimated mean $\pm$ standard error) on T_1 WI, 2.69 ± 0.19 on mDixon TSE T_2 weighted water imaging and 2.88 ± 0.17 on mDixon TSE T_2 weighted fat imaging. No significant difference was found among the three MR sequences ($p = 0.727$). Reviewer 2 obtained 3.31 ± 0.15 (estimated mean $\pm$ standard error) on T_1 WI, 3.06 ± 0.18 on mDixon TSE T_2 weighted water imaging and 3.26 ± 0.16 on mDixon TSE T_2 weighted fat imaging. On average, reviewer 1 had the most confidence in interpreting mDixon TSE T_2 weighted fat images, and reviewer 2 had the most confidence in interpreting T_1 WI scans.

By using PET-CT scan as the gold standard, the ROC curves of the three MR sequences for the two reviewers were constructed (Figure 5), and the AUC of the three MR sequences for the two reviewers are listed in Table 4. No significant difference was found in the comparison of the AUC of each MR sequence for reviewer 1 (T_1 weighted imaging vs mDixon TSE T_2 weighted water imaging, $p = 0.414$; T_1 weighted imaging vs mDixon TSE T_2 weighted fat imaging, $p = 0.529$; and mDixon TSE T_2 weighted water imaging vs mDixon TSE T_2 weighted fat imaging, $p = 0.149$, respectively) or reviewer 2 (0.270; 0.603; and 0.334, respectively).

DISCUSSION

The contrast difference between normal marrow fat and marrow-replacing metastatic lesions enables the detection of metastatic lesions. The overall SI of vertebral bone marrow will show fat-containing SI, depending on its fat content.⁶ If normal fatty marrow and cellular elements are replaced by a metastasis,

Figure 3. A 45-year-old male with lung cancer. A metastasis can be seen at T9 (white arrows) on the T_1 weighted image (a) and mDixon TSE T_2 weighted fat image (c) of the thoracic-lumbar junction. However, the mDixon TSE T_2 weighted water image (b) does not show the distinct metastatic border at T9. The PET-CT sagittal scan (d) shows the osteoblastic metastasis at T9 with FDG uptake. FDG, fluorodeoxyglucose; mDixon, modified Dixon; PET-CT, positron emission tomography-CT; TSE; turbo spin echo.

a local decrease in the proportion of fat within the affected area will be evident.¹⁹ This marrow compositional change enables the differentiation of metastasis from normal bone marrow. Therefore, T_1 WI and fat-suppressed T_2 WI have been widely used for the detection of metastatic lesions, as this SI difference is well evident within normal bone marrow and metastasis on these two MR sequences.

Our study identified the sensitivity, specificity, PPV and NPV of T_1 WI and mDixon TSE T_2 WI for the detection of vertebral metastases and demonstrated excellent diagnostic performance of each sequence, using ROC curves. In addition, excellent inter-reader agreement was evident between the two reviewers for T_1 WI and mDixon TSE T_2 WI, despite their different levels of experience.

The detection rates with mDixon TSE T_2 WI for both reviewers were somewhat lower than expected. In a study that dealt with whole-body MRI with a fast spin-echo triple-echo Dixon sequence, a greater proportion of metastases were detected in the cervical, thoracic and lumbar spine (85.6%).²⁰ The detection rate was close to the results of mDixon TSE T_2 WI in our study. In addition, previous studies reported that T_1 WI has high sensitivity (85.4%) and specificity (92.7%) when differentiating

between neoplastic and normal bone marrow elements.²¹ This observation was similarly evident with the T_1 WI results of our study. We think that the results of our study are sufficient for comparison with those of other MRI sequences in the detection of vertebral metastases.

In the review of false-positive and false-negative cases, four simultaneous false-positive and six simultaneous false-negative cases on mDixon TSE T_2 weighted water images and only five simultaneous false-negative cases on mDixon TSE T_2 weighted fat images were reported by both reviewers. With respect to the mDixon TSE T_2 weighted water images, the false-positive cases were Schmorl's nodules ($n = 3$) and indistinct SI ($n = 1$); the false-negative cases were metastases at the corner of the vertebral body ($n = 5$) and indistinct SI ($n = 1$), respectively. On mDixon TSE T_2 weighted fat imaging, the false-negative cases were evident as metastases at the corner of the vertebral body ($n = 4$) and Schmorl's nodules ($n = 1$).

Schmorl's nodules might have mimicked the nodular metastases located near the end plate, while small metastases located at upper vertebral body might be misconceived as Schmorl's nodules. Metastases at the corner of the vertebral body were potentially misinterpreted as endplate signal changes, such as

Figure 4. A 33-year-old male with tongue cancer. A single metastasis is located in the L2 vertebral body (white arrows). The metastasis on the T_1 weighted image (a) and mDixon T_2 weighted fat image (c) is observed. However, the metastasis in the mDixon TSE T_2 weighted water image (b) is almost invisible. Both reviewers did not detect this metastasis on the mDixon TSE T_2 weighted water image. The PET-CT axial scan (d) shows the osteolytic metastasis with FDG uptake. FDG, fluorodeoxyglucose; mDixon, modified Dixon; PET-CT, positron emission tomography-CT; TSE; turbo spin echo.

Modic changes. Notably, there was a tendency to misidentify a metastatic nodule when it was small and located near intervertebral discs. The mean size of metastases that were located at the corner of the vertebral body and identified as false-negatives in mDixon TSE T_2 weighted water and fat images were 1.83 cm and 1.65 cm, respectively. Two cases showed indistinct SI on mDixon TSE T_2 weighted water images; these were individual false positive and negative cases that each showed osteosclerotic lesions on the PET-CT scans. We think that it was difficult to differentiate these lesions from adjacent normal bone marrow because both showed low SI on mDixon TSE T_2 weighted water images.

mDixon TSE T_2 weighted fat images look like T_1 WI, because mDixon TSE T_2 weighted fat images are reformatted from separated fat signals from T_2 WI. Therefore, we think that mDixon TSE T_2 weighted fat images can be used for discriminating between normal marrow fat and a marrow-replacing lesion

based on the high and low SIs, respectively. In our comparative study of diagnostic performance, mDixon TSE T_2 weighted fat imaging showed no significant differences with T_1 WI. This result supports the hypothesis that mDixon TSE T_2 weighted fat images may be a good alternative to T_1 WI for bone marrow evaluation. A previous study showed that mDixon TSE T_2 weighted fat images had a diagnostic ability compared to T_1 WI for the evaluation of subchondral sclerosis in ankylosing spondylitis.¹⁸ Recently, a study similar to ours has been reported which showed that diagnostic performance of Dixon T_2 weighted fat-only and water-only imaging was not significantly inferior to the standard protocol for the detection of bone metastases.²²

In addition, mDixon TSE T_2 weighted water imaging also look like fat-suppressed T_2 WI.²³ T_2 WI with fat suppression or sequence selective, fat-suppressed T_2 WI can supplement T_1 WI.²⁴ Although not compared with fat-suppressed T_2 WI

Table 2. Sensitivity, specificity, PPV and NPV of three magnetic resonance sequences for each radiologist

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Reviewer 1				
T_1 weighted imaging	83.8 (72.9–91.6)	99.1 (98.1–99.6)	89.1 (79.5–94.5)	98.6 (97.5–99.2)
mDixon TSE T_2 weighted water imaging	79.4 (67.9–88.3)	98.8 (97.8–99.5)	85.7 (75.6–92.1)	98.2 (97.1–98.8)
mDixon TSE T_2 weighted fat imaging	86.8 (76.4–93.8)	99.1 (98.1–99.6)	89.4 (80.0–94.7)	98.8 (97.8–99.4)
Reviewer 2				
T_1 weighted imaging	91.2 (81.8–96.7)	99.2 (98.3–99.7)	91.2 (82.3–95.8)	99.2 (98.3–99.6)
mDixon TSE T_2 weighted water imaging	85.3 (74.6–92.7)	99.5 (98.7–99.9)	93.4 (84.5–97.5)	98.7 (97.7–99.3)
mDixon TSE T_2 weighted fat imaging	89.7 (79.9–95.8)	99.3 (98.5–99.8)	92.4 (83.5–96.7)	99.1 (98.2–99.5)

Notes: Nnumbers in parenthesis are 95% confidence intervals.

mDixon, modified Dixon; NPV, negative predictive value; PPV, positive predictive value; TSE, turbo spin echo.

Table 3. Inter-reader agreement for three magnetic resonance sequences

Sequence	
T_1 weighted imaging	0.835 (0.765–0.906)
mDixon TSE T_2 weighted water imaging	0.887 (0.827–0.948)
mDixon TSE T_2 weighted fat imaging	0.852 (0.785–0.919)

Notes: Data are presented as kappa values. Numbers in parenthesis are 95% confidence intervals.

mDixon, modified Dixon; TSE, turbo spin echo.

directly, mDixon TSE T_2 weighted water imaging showed no significant differences from T_1 WI. A previous study showed that mDixon TSE T_2 weighted water images were comparable with conventional T_2 WI with STIR fat suppression in paediatric spine imaging.²³ Another study showed that the mean contrast-to-noise ratio of 34 lesions with bone marrow oedema or osteitis was higher on mDixon TSE- T_2 weighted water images than on T_2 WI with SPAIR fat suppression in the evaluation of ankylosing spondylitis.¹⁸ Therefore, we think that mDixon TSE T_2 weighted water imaging could be an acceptable substitute for fat-suppressed T_2 WI.

The reason we chose mDixon TSE T_2 WI, not mDixon TSE T_1 WI, was to obtain respective similar images to T_1 WI and fat-suppressed T_2 WI in one acquisition. These two conventional sequences are important in the detection of vertebral metastases. If mDixon TSE T_2 WI is used instead of T_1 WI and fat-suppressed T_2 WI, several advantages of mDixon techniques such as adequate fat suppression²³ and decreased scan time will be realized in the detection of vertebral metastases. As is well known, this fast imaging can reduce the amount of sedative drug use for infants or children, and can make patients with claustrophobia better tolerate an MRI scan. Adding other needed sequences such as diffusion-weighted MRI or dynamic contrast-enhanced MRI is also possible in the limited scan time of clinical practice. Moreover, fat signal fraction assessment of bone marrow with mDixon images can provide useful additional clinical information such as the quantitative differentiation of benign and malignant marrow signal change,¹⁶ or acute osteoporotic and malignant vertebral fractures.²⁵ The results in our study support the proposition that

Table 4. AUC of three magnetic resonance sequences for two reviewers

	AUC	95% Confidence interval
Reader 1		
T_1 weighted imaging	0.914	0.893–0.933
mDixon TSE T_2 weighted water imaging	0.891	0.868–0.912
mDixon TSE T_2 weighted fat imaging	0.929	0.910–0.946
Reader 2		
T_1 weighted imaging	0.952	0.935–0.965
mDixon TSE T_2 weighted water imaging	0.924	0.904–0.941
mDixon TSE T_2 weighted fat imaging	0.945	0.927–0.960

AUC, areas under the curve; mDixon, modified Dixon; TSE, turbo spin echo.

mDixon TSE T_2 WI can be included in the spine MRI protocol in lieu of T_1 WI and fat-suppressed T_2 WI.

Our study had several limitations. First, our study design was retrospective, and there might have been a selection bias due to the inclusion and exclusion criteria. Nonetheless, this was reconciled by including consecutive patients who underwent spine MRI during the determined period. Second, as a confirmative pathological diagnosis of vertebral metastases was not possible in all the enrolled patients owing to ethical considerations concerning the risk-to-benefit ratio, MR findings with reference to PET-CT scans were settled, instead of the use of pathological findings. There has been controversy about the best option between MRI and PET-CT for the detection of bone metastases.^{26,27} These discordant results may be influenced by the degree of glucose metabolism of the primary malignancy. However, most primary malignancies except prostate cancer in our study are known to have high glucose metabolism.²⁷ In addition, PET-CT is the only diagnostic method which shows similar sensitivity and specificity for the detection of bone metastases when compared with MRI.²⁸ Third, mDixon TSE T_2 WI in- and opposed-phase images obtained from mDixon technique were not evaluated in our study. T_2 WI in-phase images look like conventional T_2 WI. Bone metastases lead to a longer T_1

Figure 5. Receiver-operating characteristic curves of three MR sequences for reviewer 1 (a) and reviewer 2 (b). mDixon, modified Dixon.

relaxation time and show decreased signal compared to the high signal of the fatty tissue on T_1 WI while changes caused by bone metastases in the T_2 weighted relaxation times are variable and show different SI on T_2 WI, being low-, iso- and high-intensity compared to bone marrow.²⁶ Therefore, we thought that it would show lower diagnostic performance than expected. In addition, opposed-phase images show a characteristic Indian ink artefact, and we thought that might negatively influence the detection of vertebral metastases.

In conclusion, the diagnostic performance of spin-echo-based mDixon TSE T_2 weighted water and fat imaging was comparable to that of conventional T_1 WI in the detection of vertebral metastases.

We suggest that mDixon TSE T_2 WI can be a good alternative to conventional T_1 WI for detecting vertebral metastases.

COMPETING INTERESTS

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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