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Comparison of monopolar and bipolar diffusion weighted imaging sequences for detection of small hepatic metastases

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ABSTRACT

Objective: To compare monopolar (MP) and bipolar (BP) diffusion weighted imaging (DWI) in detecting small liver metastases.
Materials and methods: Eighty-eight patients underwent 3-T MRI. The signal-to-noise ratios (SNR) of the liver parenchyma and lesions, the lesion-to-liver contrast-to-noise ratios (CNR), and the detection sensitivities were compared. The lesion distortion was scored (LDS) from 4 (no distortion) to 1 (excessive distortion), dichotomised as no-distortion and distortion, and the association between detected lesions for each reader in the MP or BP DWI group and the dichotomised lesion distortion degree was assessed.
Result: Forty-six hepatic metastases were confirmed. The CNR with BP images showed significantly higher values than with MP ($P = 0.017$). The detection sensitivities of the three readers were higher in the BP sequence than in MP, and one reader detected significantly more hepatic lesions with BP images ($P = 0.04$). LDS was significantly improved with BP sequence ($P = 0.002$). In the no-distortion group, excluding the MP DWI assessments of one reader, detection sensitivities were significantly higher than in the distortion group ($P < 0.001$ and $P = 0.002$, respectively).
Conclusion: Reduced lesion distortion improves the detection of small liver metastases, and BP is more sensitive in detecting small liver metastases than MP DWI.

1. Introduction

Diffusion-weighted imaging (DWI) has the potential to differentiate and evaluate liver tumours based on the high contrast between abnormal and normal tissue. DWI can direct the radiologist to findings that may otherwise be overlooked [1]. Gadolinium–ethoxybenzyl–diethylenetriamine pentaacetic acid (Gd–EOB–DTPA)- or mangafodipir trisodium-enhanced magnetic resonance imaging (MRI) reportedly show higher accuracy in detecting small hepatic metastases than does DWI, but the addition of DWI is useful [2–4].

The liver has a short T2 and low signal-to-noise-ratio, and as a result, the diffusion encoding gradients must be performed in the shortest possible echo time. A single Stejskal–Tanner monopolar (MP) sequence refocusing pulse can further shorten the echo time. However, unbalanced MP gradients can generate stronger eddy-current-induced distortions at high *b*-values [5]. In a previous liver diffusion study, a twice-refocused bipolar (BP) diffusion preparation was used [6] and featured intrinsic low eddy current artefacts, while BP showed a longer echo time than MP sequence.

Previous studies compared the image quality and intravoxel incoherent motion in normal liver between MP and BP DWI. However, a direct comparison between the two different DWI sequences in detecting hepatic metastases has not been performed. The present study compares MP and BP sequences to determine the superior technique for detecting small hepatic metastases measuring 2 cm or less.

2. Materials and methods

2.1. Patients

Eighty-eight patients underwent Gd EOB–DTPA-enhanced MRI including DWI to detect hepatic metastasis at the Department of Radiology, Kyoto University Graduate School of Medicine, Kyoto, Japan from January 2011 to October 2012. This retrospective study was performed in accordance with the Declaration of Helsinki [7] and approved by the local ethics committee. All patients provided

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Table 1
Patient and tumour sample size and clinical characteristics.

	Number of patients	Number of lesions
Histologically proven hepatic metastases	15	31
Hepatic metastases confirmed by follow-up imaging	8	15
Patients without hepatic metastases	5	0

Of the 23 patients, 8 had solitary lesions, 10 had two lesions, and the remaining 5 had three or more lesions (3 had three lesions, one had four lesions, and one had five lesions). In total, 17 patients had colorectal cancer, 4 pancreatic cancer, one gastric cancer, and one had breast cancer.

informed written consent to undergo imaging examinations. Of the 88 patients, 65 were excluded as follows: concurrent chemotherapy (one patient); absent histological diagnosis and follow-up confirmation (two patients); lesions greater than 2 cm (seven patients); greater than five lesions, which can potentially be misdiagnosed as hepatic metastases (14 patients); and no hepatic metastasis (41 patients). The remaining 23 patients (16 men and 7 women, aged 41–82 years, mean age: 67 years) were included in the final analysis comprising 17 patients with colorectal cancer, four with pancreatic cancer, one with gastric cancer, and one with breast cancer.

2.2. Lesion diagnosis

Fifteen patients underwent definitive surgery with intraoperative ultrasonography (US), and 31 small hepatic metastases were histologically confirmed in these patients. In eight patients without a histopathologic diagnosis, the 15 visible small hepatic tumours were considered metastatic based on tumour growth observed at follow-up imaging examinations 3–20 months after the initial MRI. Tumour growth was defined according to response evaluation criteria in solid tumours (RECIST) [8]. Hepatic cirrhosis was not observed in any patient. The presence or absence of hepatic metastases was diagnosed by consensus between two radiologists (R.Y. and H.I., with 8 and 24 years' experience, respectively, in gastrointestinal and hepatobiliary imaging) evaluating contrast-enhanced CT, US, positron emission tomography (PET) using F-18 fluorodeoxyglucose (FDG), and MRI; follow-up US, CT, FDG–PET, or MRI; and intraoperative US and serological examination. A total 46 small hepatic metastases (range: 0.3–2.0 cm; mean: 1.04 cm) in 23 patients were confirmed; five patients who did not have focal hepatic metastasis served as the control group (Table 1). Of the 23 patients, eight had solitary lesions, 10 had two lesions, and the remaining five had three or more lesions (three had three lesions, one had four lesions, and one had five lesions).

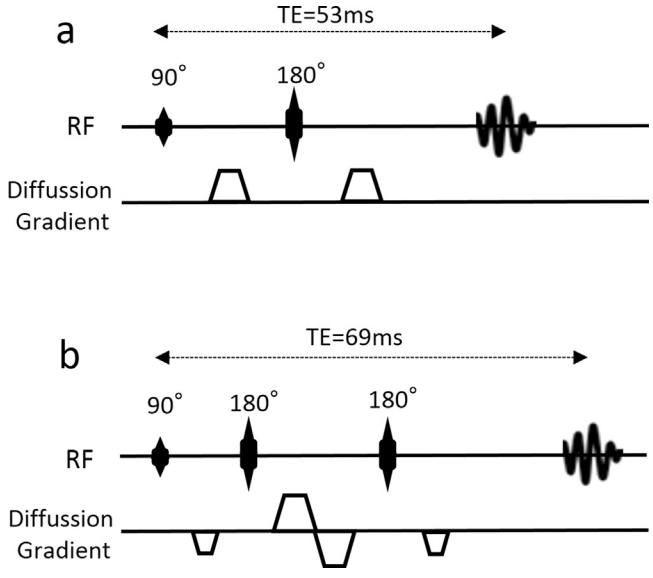

Fig. 1. Schematic sequence diagrams show diffusion preparation followed by a single-shot echo-planar imaging readout. RF: radio frequency, TE: echo time. (a) When using MP diffusion encoding, an echo time as low as 53 ms can be achieved. (b) When using BP diffusion encoding, a minimum echo time of 69 ms is required.

2.3. Imaging protocols

All MRI examinations were performed using a commercially available 3-T MR system (MAGNETOM Skyra; Siemens AG, Healthcare Sector, Erlangen, Germany) equipped with a spine matrix coil and body matrix coil. DWI using a single-shot spin-echo echo-planar imaging (EPI) sequence in the axial plane with respiration triggering using the PACE method (spectral presaturation with inversion recovery for fat suppression, TE = monopolar sequence: 53 ms and bipolar sequence: 69 ms, ETL = 86, ETS = 0.52 ms, slice thickness = 5 mm, gap between slices = 1.3 mm, matrix size = 86 × 128, FOV = 35 cm, number of slices = 30, *b* factors = 1000 s/mm^2, GRAPPA factor = 2) was acquired between the dynamic and hepatocyte phases using Gd–EOB–DTPA (Fig. 1). In this study, apparent diffusion coefficient (ADC) measurement was not because it fell outside the remit of this study.

2.4. Imaging analysis

2.4.1. Quantitative evaluation

Quantitative evaluations were performed by a radiologist (A.F. with 12 years' experience). Regions of interest (ROIs) were centred on the focal lesion and hepatic parenchyma using a commercially available DICOM viewer (YAKAMI Software, Kyoto, Japan) to measure signal intensity (SI) on DWI with a *b*-value = 1,000 s/mm^2. The ROI was constructed to maximally encompass the lesion while avoiding necrotic cystic regions at identical sites on MP and BP sequences. Because a parallel imaging technique was employed, the background noise standard deviation (SD) could not be used to calculate the image signal-to-noise ratio (SNR); therefore, SD of the normal liver SI adjacent to the lesion was used estimate local noise [9–11]. The ROI was centred in the adjacent liver parenchyma measuring at least 100 mm^2 and residing in a homogeneous portion devoid of vessels and prominent artefacts. The contrast-to-noise ratio (CNR) between the corresponding liver lesion and liver parenchyma, and the liver parenchyma or lesion SNR were calculated as follows:

$$\mathrm{CNR} = \frac{\mathrm{SI_L} - \mathrm{SI_P}}{\mathrm{noise}}, \mathrm{SNR_{parenchymaorlession}} = \frac{\mathrm{SI_P \ or \ SI_L}}{\mathrm{noise}}$$

where the liver parenchyma signal intensity is SI_P and the corresponding lesion signal intensity is SI_L. The CNR and SNR at an undetectable lesion were scored 0 and 1, respectively.

2.4.2. Qualitative evaluation

The two patient groups (MP and BP sequences) were statistically compared. Three readers (T.O., H.S., and S.K. with 8, 10, and 10 years' experience, respectively, in gastrointestinal and hepatobiliary imaging) who were not the two diagnostic radiologists