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Usefulness of free-breathing readout-segmented echo-planar imaging (RESOLVE) for detection of malignant liver tumors: Comparison with single-shot echo-planar imaging (SS-EPI)

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ABSTRACT

Purpose: We aimed to clarify the usefulness of free-breathing readout-segmented echo-planar imaging (RESOLVE), which is multi-shot echo-planar imaging based on a 2D-navigator-based reacquisition technique, for detecting malignant liver tumor.
Materials and methods: In 77 patients with malignant liver tumors, free-breathing RESOLVE and respiratory-triggered single-shot echo-planar imaging (SS-EPI) at 3-T MR unit were performed. We set a scan time up to approximately 5 min (300 s) before examination, measured actual scan time and assessed (1) susceptibility and (2) motion artifacts in the right and left liver lobes (3, no artifact; 1, marked), and (3) detectability of malignant liver tumors (3, good; 1, poor) using a 3-point scale.
Results: The median actual scan time of RESOLVE/SS-EPI was 365/423 s. The median scores of each factor in RESOLVE/SS-EPI were as following in this order: (1) 3/2 (right lobe); 3/3 (left lobe), (2) 2/3 (right lobe); 1/2 (left lobe), and (3) 3/3, respectively. Significant differences were noted between RESOLVE and SS-EPI in all evaluated factors ($P < 0.05$) except for susceptibility of left lobe and detectability of the lesions.
Conclusion: Despite the effect of motion artifacts, RESOLVE provides a comparable detectability of the lesion and the advantage of reducing scanning time compared with SS-EPI.

1. Introduction

Single-shot echo planar imaging (SS-EPI) is widely used as diffusion-weighted imaging (DWI) for the identification of focal liver lesions, and is known to be useful for the detection of malignant liver tumors [1–4]. However, SS-EPI has some problems, such as geometric distortion (particularly at tissue-air boundaries) and T2*-induced blurring mainly governed by slow traversal through *k*-space [4–11]. Furthermore, these artifacts become even more prominent with an increase in static magnetic field strength.

Multi-shot echo-planar imaging (MS-EPI), in which *k*-space is divided into several segments, can reduce the effect of susceptibility and T2* decay by accelerating the *k*-space traversal along the phase-encoding direction. On MS-EPI, motion during the diffusion-sensitizing gradients leads to a spatially-dependent phase variation and this causes a high level of artifacts. To compensate for this phase variation and to prevent motion artifacts, navigator echo acquisitions were introduced to monitor shot-to-shot phase changes [9–12]. However, conventional MS-EPI, i.e. interleaved EPI, diffusion-weighted data may partially overlap in the phase-encoding direction, leading to gaps in *k*-space that cause ghosting artifacts in the image [5,8,9]. For this reason, interleaved EPI is used mainly in organs at rest such as the brain or spinal region [6,10,13].

Readout-segmented echo-planar diffusion-weighted imaging (RESOLVE) is a kind of MS-EPI sequence that divides *k*-space into several segments along the direction of the readout [5,7–9]. On RESOLVE, each segment is densely sampled in the phase-encoding direction as SS-EPI. A short range of readout direction (k_x) in each segment can reduce echo spacing and geometric distortion (susceptibility artifacts). In addition, phase correction between segments is performed using navigator echo and a navigator-based reacquisition technique, which provide a robust correction for motion-induced phase artifacts.

RESOLVE is clinically available and provides data with high resolution and reduced levels of susceptibility artifacts in organs at rest,

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especially in the head [5] and breast region [14]. To our knowledge, the usefulness of RESOLVE under free breathing has been unclear in restless organs such as the liver. We therefore aimed to investigate the advantages and disadvantages of RESOLVE under free breathing for detecting malignant liver tumors.

2. Materials and methods

This prospective study was approved by our institutional ethics committee and written informed consent was obtained from all participants.

2.1. Patients

Between April 2012 and November 2012, 77 patients (52 men and 25 women; age range, 28–86 years old; mean age, 68.5 years old), who had malignant liver tumors and underwent magnetic resonance imaging (MRI) including both respiratory-triggered SS-EPI and free-breathing RESOLVE sequences, were enrolled in this study.

Malignant liver tumors comprised hepatocellular carcinoma (HCC) (51 patients), metastasis (19 patients), intrahepatic cholangiocarcinoma (5 patients), primary liver carcinoid (1 patient), and lymphoma (1 patient). The primary sites of liver metastases were the colon (7 patients), pancreas (4 patients), lung (2 patients), esophagus, ovarian, breast, bile duct, stomach, and vulvar (1 patient). To prevent case selection bias, a maximum of 5 lesions were selected in decreasing order of tumor size when patients had multiple malignant liver lesions. A total of 135 lesions were assessed, made up of 79 HCCs in 51 patients, 41 metastases in 19 patients, 5 intrahepatic cholangiocarcinomas in 5 patients, 5 carcinoid lesions in one patient, and 5 lymphoma lesions in 1 patient. Long axis of the tumor was measured and regarded as the tumor diameter. Mean tumor diameter and standard deviation was 16 ± 19 mm (range of diameter: 2–180 mm).

Surgical resection was performed in 19 patients with HCC, 2 with a metastatic liver tumor, 4 with intrahepatic cholangiocarcinoma. Twenty-two HCCs, two metastases and 4 intrahepatic cholangiocarcinomas were pathologically proven. In the patient with malignant lymphoma, the pathological diagnosis was obtained with a biopsy. In the remaining patients, tumors were diagnosed based on CT and MR findings (including follow-up studies), as well as clinical information (including existence of a primary malignant tumor and elevation of tumor markers).

2.2. MRI data acquisition

All images were obtained with a 3-T MR unit (Trio Tim, Siemens Healthcare, Erlangen) by using a standard body array coil and a spine matrix coil provided by the manufacturer.

Routine MRI examinations were performed, including axial T2-weighted imaging [half-Fourier acquisition single-shot turbo spin-echo (HASTE) and fat-suppressed fast spin-echo (FSE) sequence] and axial T1-weighted gradient-echo (GRE) imaging, followed by free-breathing RESOLVE and respiratory-triggered SS-EPI. Dynamic contrast-enhanced T1-weighted MRI with fat-suppression (using gadoxetic acid) was performed as necessary.

In this study, free-breathing EPI was not used because respiratory-triggered EPI was recognized as an optimal DWI technique for detecting malignant tumor [15] and could demonstrate focal liver lesions, even when the diameter of lesions was 10 mm or less [16]. Imaging parameters of RESOLVE were as follows: TR/TE = 3500–4500/58–60 ms; b factor = 50 and 800 s/mm^2; field of view (FOV) = 18–31 × 36–50 cm; number of average = 4; acquisition matrix = 64–96 × 128, and slice thickness/gap = 5/1 mm Imaging parameters of SS-EPI were as follows: TR/TE = 2475–6354/61–73 ms; b factor = 50 and 800 s/mm^2; FOV = 19–31 × 36–50 cm; number of average = 5; acquisition matrix = 64–96 × 128; slice thickness/gap = 5/1 mm Because we set the scan time for approximately 5 min in RESOLVE and SS-EPI, some parameters, such as TR, TE, FOV and acquisition matrix, were varied in accordance with patients' body size.

2.3. Comparison between RESOLVE and SS-EPI

Although an acquisition time of approximately 5 min (300 s) was set in each sequence, the actual (required) scan time ranged widely depending on a patient's respiratory cycle. Therefore, we measured the actual scan time of each patient manually to compare the efficiency of RESOLVE and SS-EPI quantitatively.

Image quality was assessed qualitatively based on factors, such as susceptibility artifact, motion artifact and detectability of malignant liver tumors, by two abdominal radiologists (HT and YF, with 5 and 20 years of experience, respectively). All MR images were reviewed with a commercial software package (EV Insite; PSP corporation, Tokyo). Two readers were blind to patient identifiers and clinical information and independently assessed factors in the right and left lobes of the liver.

Susceptibility artifacts were assessed by a 3-point scale based on parenchymal distortion (score 3, no distortion; score 2, arc shaped hyperintensity with slight distortion was seen [moderate]; score 1, obvious distortion was seen [marked]).

Motion artifacts were also assessed by a 3-point scale based on the degree of blurring (score 3, every segmental portal branch was clearly visible [no artifact]; score 2, segmental portal branches were partially visible [moderate]; score 1, no segmental portal branches were visible [marked]). If portal veins were occluded or severely compressed, we assessed motion artifacts based on the visibility of right and left hepatic veins.

Detectability of malignant liver tumors was also assessed by a 3-point scale (score 3, good; score 2, fair [slight signal change]; score 1, poor). When the score by each reader was not unanimously agreed upon, disagreement was resolved by discussion and consensus.

2.4. Statistical analysis

Statistical analyses were performed with a statistical software package (Prism, version 6; GraphPad Software, San Diego, CA). Differences in the actual scan time and the factors of image quality were assessed using a Wilcoxon signed rank test. A P value of <0.05 was considered to indicate a statistically significant difference.

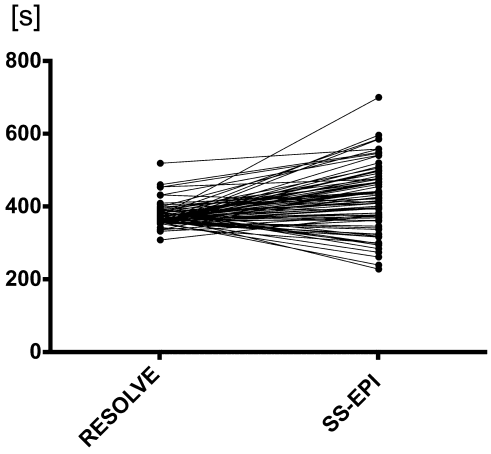

Fig. 1. Actual scan time of readout-segmented echo-planar diffusion-weighted imaging (RESOLVE) and single-shot echo planar diffusion-weighted imaging (SS-EPI).