

Breath-hold Fast Recovery Fast Spin Echo versus Conventional Non-Breath-hold Fast Spin Echo T2-Weighted MR Imaging of Focal Liver Lesions

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Abstract

Introduction: We compare the breath-hold fast recovery fast spin echo (BHFRFSE) T2-weighted and non-breath-hold fast spin echo (NBHFSE) T2-weighted sequences in image quality and lesion characterisation of focal liver lesions. **Materials and Methods:** Fat-suppressed T2-weighted magnetic resonance (MR) images obtained with the 2 sequences (BHFRFSE and NBHFSE) in 79 patients with 113 liver lesions were analysed retrospectively. The image quality and nature of the lesions were evaluated by 2 experienced radiologists. **Results:** Based on receiver operating characteristic curve analysis, lesion characterisation was comparable for both sequences. The image quality of BHFRFSE was significantly better than that of NBHFSE. The NBHFSE missed 4 malignant lesions while BHFRFSE missed 2 malignant lesions. **Conclusion:** BHFRFSE performs similarly to NBHFSE in image quality and liver lesion characterisation.

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Key words: Comparative studies, Liver neoplasm, Pulse sequences, Receiver operating characteristic curve

Introduction

T2-weighted magnetic resonance (MR) imaging is an important sequence for characterisation of focal liver lesion.¹⁻³ Accurate characterisation of benign lesions, such as haemangioma or cyst, is important to prevent unnecessary procedure or surgery. Although conventional spin echo (CSE) provides the best T2-weighted contrast, fast spin echo (FSE) is popular in view of its shorter scan time.⁴ Rydberg et al⁵ demonstrated similar performance of FSE compared to CSE sequence. T2-weighted imaging of the liver is generally performed with fat saturation to reduce ghosting artifacts.⁶ It can be performed with or without breath-holding.

Recently, a fast recovery fast spin echo (FRFSE) sequence has been made commercially available on the General Electric MR scanners. FRFSE is a fast spin echo sequence with sequential 180-degree and minus 90-degree radiofrequency pulses applied at the end of the FSE sequence to forcefully recover the magnetisation vector. This results

in shorter repetition time (TR), longer echo train and shorter acquisition times. The slice ordering in the FRFSE sequence is also optimised for scanning the liver in multiple breath-holds. When the liver is acquired in 2 acquisitions, slices from the superior portion of the liver are acquired in one breath-hold, while the second breath-hold acquires slices from the inferior portion. Interleaving, if prescribed, occurs within each block of the liver scanned.

This innovation facilitates breath-hold imaging of the liver on the General Electric MR platform. With breath-hold FRFSE (BHFRFSE) imaging, the liver can be imaged in 2 breath-holds. It is known that increasing the echo train increases magnetisation transfer (MT) effects, which can potentially reduce the signal of non-cystic lesions.^{7,8}

The user with a General Electric machine is confronted with a choice of a BHFRFSE sequence or a non-breath-hold FSE (NBHFSE) sequence. Breath-holding may result in better image quality and savings in imaging time, but the increased echo train may result in diminished contrast of

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malignant lesions.^{4,9} The purpose of this study was to determine whether there is improved performance of BHFRFSE in the characterisation of focal hepatic lesions and image quality depicted on T2-weighted MR images compared with NBHFSE.

Materials and Methods

From 1 March 2001 to 31 December 2002, 79 consecutive patients with suspected liver abnormalities were referred for MR imaging. The inclusion criteria included all patients with focal lesions confirmed by pathological proof, follow-up proof or typical benign lesions satisfying a set of defined criteria. Twenty-eight patients fulfilled the inclusion criteria and formed the study population. This included 16 males and 12 females aged between 32 and 81 years (mean age, 56 years). These patients provided a total of 113 lesions for our study: 94 were benign [86 cysts, 7 haemangiomas and 1 focal nodular hyperplasia (FNH)] while the rest were malignant (7 hepatomas and 12 metastases). Twenty-three patients demonstrated multiple lesions while 5 had solitary lesions. Only the first 10 lesions were used in a patient with multiple lesions to decrease lesion bias.

Two cases of hepatocellular carcinoma had histological confirmation. Follow-up proof were available for 17 malignant lesions based on tumour growth over a period ranging from 4 to 12 months (mean, 7 months) on follow-up ultrasound, computed tomography or MR imaging. These malignant lesions included 5 hepatomas, 10 colonic metastases and 2 endometroid tumours of the ovary. The diagnosis of 86 cysts and 7 haemangiomas were established according to the criteria used by Katayama et al.¹⁰

The criteria for a simple cyst included a well-defined, imperceptible wall, high signal on T2-weighted imaging equivalent to cerebrospinal fluid (CSF), low signal on T1-weighted imaging and no enhancement on gadolinium-enhanced T1-weighted images. With regards to a haemangioma, features such as a peripheral nodular rim enhancement, persistent enhancement over time and moderately hyperintense signal on T2-weighted images are utilised. One FNH was established by characteristic findings on imaging (MR imaging and ultrasound scan) and stability on follow-up 6 months later. These lesions were selected by an investigator not involved in the reading.

The diameter of each hepatic lesion was measured from the picture archive and communication system (PACS) by an investigator not involved in the interpretation of moderate T2-weighted MR images using electronic calipers (Table I). Most (96.5%) of the lesions were small (<3 cm). MR imaging was performed with a 1.5T imager (Signa LX, GE Medical Systems, Milwaukee, WI, USA) using a gradient strength of 23 mT/m and a slew rate of 120 mT/m/s.

BHFRFSE and NBHFSE sequences were performed for

TABLE I: LESION SIZES

Lesion	<3 cm	>3 cm
Cyst	85	1
Haemangioma	7	0
Metastasis	11	1
Hepatoma	5	2
Focal nodular hyperplasia	1	0
Total	109	4

each patient. Both T2-weighted sequences were obtained in the axial plane with phased array multicoils, with each sequence having identical section thickness (7 to 8 mm), matrix (256 x 192) and interslice gap (1 to 2 mm). The echo time (TE) employed was also comparable (NBHFSE, 102 to 105 msec; BHFRFSE, 98.9 to 100 msec). Chemical fat suppression was used in both sequences. Flow compensation was applied in both sequences in the slice direction.

For NBHFSE images, the patient was instructed to breathe smoothly. The parameters for a NBHFSE were TR of 4400 to 5500 msec, effective TE of 102 to 105 msec, echo train of length (ETL) 12, received bandwidth of 31.2 kHz, signal average of 4, rectangular field of view (FOV) of 33 x 25 cm to 29 x 22 cm and acquisition time of 3.5 to 4.15 min. BHFRFSE were obtained during breath-hold at full inspiration with the following parameters: TR of 2,100 to 2,700 msec; effective TE of 98.9 to 100 msec; received bandwidth of 41.7 kHz; ETL of 20; signal average of 1; rectangular FOV of 30 x 22 to 32 x 24 cm; and acquisition time of 12 sections in 25 sec. The parameters allowed the entire liver to be imaged in 2 separate breath-holds. Antiperistaltic agent was not used.

Subsequent dynamic multiphasic three-dimensional fast spoiled gradient recall echo T1W gadolinium-enhanced imaging, including the arterial, portal and delayed phases, was performed on all patients. Two radiologists with experience in MR imaging of the liver served as readers. All images were stored on the PACS. The lesions were selected by an investigator not involved in the interpretation, and were presented on the PACS without displaying the imaging parameters to the 2 radiologists who interpreted in consensus. The 2 sequences were displayed side by side and the radiologists were allowed to scroll and window. Both sequences were randomly arranged to the left or right side of the monitor screen for each patient by the non-interpreting investigator.

The radiologists were unaware of patient's history, clinical or radiological findings. Each lesion was judged to be benign or malignant using a 5-point scale: (1) definitely benign; (2) probably benign; (3) equivocal; (4) probably malignant; and (5) definitely malignant. A score of zero

was given if the lesion is not discernible on the sequence in question. The equivocal category indicates that the lesion is seen, but cannot be classified as either benign or malignant.

The signal intensity and morphology of the lesion are the prime criteria used to determine the nature of the lesion. A lesion is considered benign if it has a homogeneous, high signal greater than that of the spleen and is comparable to CSF (cyst or haemangioma). A lesion is considered malignant if it has a moderately high signal on T2 (approximately equal to spleen). No attempts were made to distinguish malignant lesions from FNH, adenoma or abscess. Though benign, these lesions (1 FNH) were classified as “malignant” by the readers based on their T2 appearance.

The radiologists used a 4-point scale to assess image degradation (blood flow artifacts, flow artifacts and motion artifacts), blurring of margins and overall image quality: (1) minimal; (2) acceptable; (3) degraded; and (4) non-diagnostic. A “non-diagnostic” score was assigned when an image is extremely poor and no diagnostic information can be obtained. A “degraded” score was assigned to images that are degraded by artifacts and have limited diagnostic value. An “acceptable” score was assigned to images with artifacts that do not interfere with interpretation. These images have full diagnostic value. “Minimal” indicates excellent image quality with virtually no artifact and full diagnostic value.

Receiver operating characteristic (ROC) curve analysis was used to compare the performance of both imaging sequences using a nonparametric approach.¹¹ The analysis was performed using Stata Version 7.0 for Windows. Exact 95% binomial confidence intervals for the areas were calculated. The image quality of both sequences was compared using Wilcoxon signed rank test and performed using SPSS Version 10.0 for Windows.

Results

Of the 113 lesions, 11 were missed (i.e. not discernible) by both sequences and, thus, were not given a score. NBHFSE missed 4 malignant lesions and 5 benign lesions, while BHFRFSE missed 2 malignant lesions. The remaining 102 lesions were included in the comparison of the characterisation performances of both sequences.

Table II shows the performance of both pulse sequences according to lesion type. A sequence is considered to have performed better than the other if the readers assigned a better score than the corresponding sequence. For example, if a benign lesion was rated as probably benign by the first sequence and as definitely benign by the second, the latter is considered to be superior. BHFRFSE performed as well as NBHFSE in 75.2% of lesions. It was superior to the latter in 21.2% while NBHFSE performed better in 3.6% of lesions (Figs. 1 to 3).

TABLE II: NON-BREATH-HOLD AND BREATH-HOLD ACCORDING TO LESION TYPE

Lesion	BHFRFSE superior to NBHFSE	BHFRFSE = NBHFSE	NBHFSE superior to BHFRFSE
Cyst	19	65	2
Haemangioma	2	5	0
Metastasis	3	7	2
Hepatoma	0	7	0
FNH	0	1	0
Total	24	85	4

BHFRFSE: breath-hold fast recovery fast spin echo; FNH: focal nodular hyperplasia; NBHFSE: non-breath-hold fast spin echo

TABLE III: RESULTS OF NON-BREATH-HOLD AND BREATH-HOLD SEQUENCES

Variable	Non-breath-hold sequence (95% CI)	Breath-hold sequence (95% CI)
ROC curve area	0.946 (0.876–0.978)	0.953 (0.889–0.984)
Sensitivity	88.9% (67.2–96.9)	88.9% (67.2–96.9)
Specificity	94.1% (86.8–97.4)	96.4% (90.0–98.8)

CI: confidence interval; ROC: receiver operating characteristic

The ROC curves for both sequences are shown in Figure 4. The results of the ROC curve analysis, together with the sensitivity and specificity of both sequences, are presented in Table III. Both sequences have a similar performance in lesion characterisation, with no significant statistical difference ($P = 0.185$). By considering indeterminate scores as malignant lesions, BHFRFSE and NBHFSE have a similar sensitivity of 88.9% while the former has a slightly higher specificity compared to the latter (96.4% versus 94.1%).

The mean scores and standard deviations for ghosting/respiration, blurring of margins and overall image score for each imaging sequence are shown in Table IV. BHFRFSE had less ghosting/respiratory artifacts and demonstrated less blurring of margins. The overall image quality was also better. All differences are statistically significant.

Discussion

Although several studies have shown that FSE sequences are at least equivalent to CSE sequences for focal liver lesion detection and characterisation,^{12,13} there are, however, differences in the images of both sequences. Lesion contrast is decreased due to increased MT effects in FSE sequences.^{7,8} For this reason, single-shot FSE sequences may not be optimal for lesion detection even though it images the liver in one breath-hold.¹⁴ Radiologists are often faced with the dilemma of using a breath-hold FSE sequence versus a NBHFSE sequence. On the General Electric platform, the choice is between a BHFRFSE sequence or NBHFSE sequence.

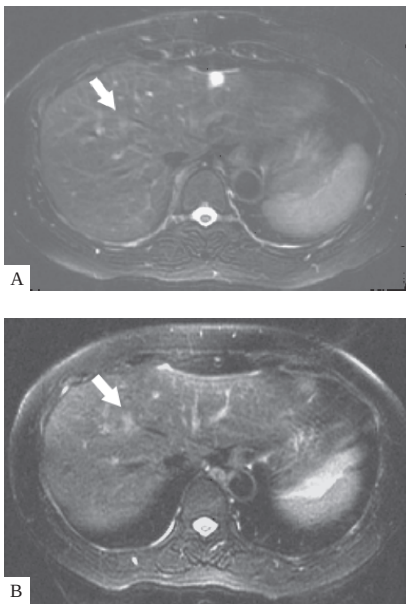


Fig. 1. A 51-year-old woman with a colonic metastasis. On the non-breath-hold fast spin echo MR image (A), the signal of the lesion is very faint, but is seen more clearly in the breath-hold fast recovery fast spin echo MR image (B).

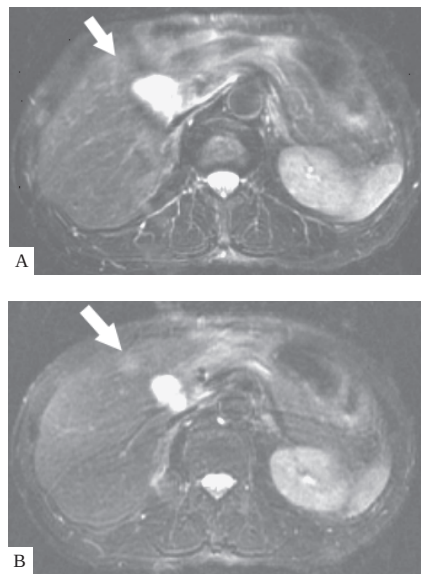


Fig. 2. (A) Non-breath-hold fast spin echo (TR/effective TE = 4,450/105 msec) and (B) breath-hold fast recovery fast spin echo (TR/effective TE = 2,200/98.9 msec) MR images of a 63-year-old man with a colonic metastasis. Ghosting artifacts are prominent in the former and the readers could not detect the lesion. However, the lesion is clearly visible in the latter (TE: echo time; TR: repetition time).

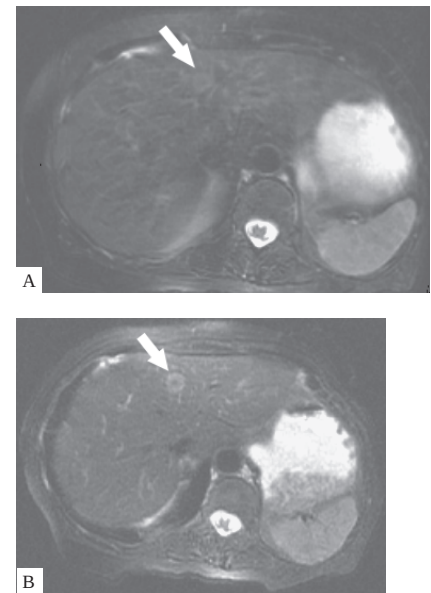


Fig. 3. (A) Non-breath-hold fast spin echo (TR/effective TE = 4,400/102 msec) and (B) breath-hold fast recovery fast spin echo (TR/effective TE = 2,200/100 msec) MR images of a 63-year-old man with a colonic metastasis. The lesion is less conspicuous on the former, but the signal intensity is better in the latter.

TABLE IV: QUALITATIVE EVALUATIONS OF IMAGE QUALITY AND ARTIFACTS

Artifact	NBHFSE (Mean $\pm$ SD)	BHFRFSE (Mean $\pm$ SD)	P value
Ghosting/respiration	2.43 $\pm$ 0.69	1.79 $\pm$ 0.74	0.002
Blurring of margins	2.36 $\pm$ 0.68	1.71 $\pm$ 0.71	0.001
Overall image score	2.50 $\pm$ 0.58	1.75 $\pm$ 0.70	<0.0001

BHFRFSE: breath-hold fast recovery fast spin echo; NBHFSE: non-breath-hold fast spin echo; SD: standard deviation

We undertook the study to determine if increased echo train and magnetisation effects of the breath-hold sequence would compromise the characterisation of malignant lesions, as well as to determine the benefits, if any, from the improved image quality. We found a similar sensitivity for the detection of malignant lesions and a similar area under the ROC curves in both sequences. Most of our malignant lesions are small (<3 cm). This suggests that the increased echo train and magnetisation effects of the BHFRFSE sequence did not compromise their detection. The BHFRFSE sequence had performed slightly better than the NBHFSE sequence based on ROC curve analysis, but this difference is not statistically significant.

One weakness of our study is the relative predominance of benign lesions. Further studies with larger numbers of small malignant lesions would be useful to confirm our findings. In their study comparing BHFRFSE with

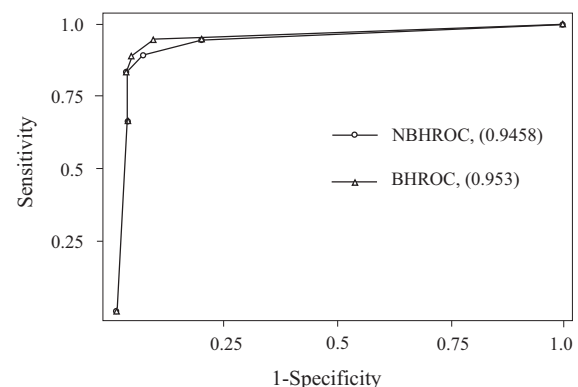


Fig. 4. Receiver operating characteristic (ROC) curves of breath-hold (BH) and non-breath-hold (NBH) sequences.

respiratory-triggered FRFSE, Katayama et al¹⁰ also found a predominance of benign lesions (121 versus 17 malignant lesions).

Another weakness of our study is the lack of follow-up proof for benign lesions. A large number of benign lesions were presumed based on typical appearances on MR imaging. Histology proof of lesions are often preferred; however, this is often difficult and not practical to obtain. Furthermore, our defined criteria are similar to that used by Katayama et al.¹⁰ There is also a bias in our study due to the inclusion of patients with >1 lesion. Finally, our study also did not assess lesions that were not visible on both sequences.

These lesions require proof either by intra-operative ultrasound and surgery or by interval follow-up with the sequence that shows it. Such lesions were not included in our study as we aimed to compare the relative efficacy of both T2-weighted sequences, and not to compare the relative performance of T2-weighted sequences against another type of sequence.

Our results suggest that breath-hold T2-weighted FRFSE is comparable to non-breath-hold T2-weighted FSE in lesion characterisation and image quality.

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