Optimal MR Pulse Sequences for Hepatic Hemangiomas:
Comparison of T2-Weighted Turbo-Spin-Echo, T2-Weighted Breath-hold Turbo-Spin-Echo, and T1-Weighted FLASH Dynamic Imaging

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Purpose: To optimize MR imaging pulse sequences in the imaging of hepatic hemangioma and to evaluate on dynamic MR imaging the enhancing characteristics of the lesions.

Materials and Methods: Twenty patients with 35 hemangiomas were studied by using Turbo-spin-echo (TSE) sequence (T2-weighted, T2- and heavily T2-weighted breath-hold) and T1-weighted FLASH imaging acquired before, immediately on, and 1, 3 and 5 minutes after injection of a bolus of Gd-DTPA (0.1 mmol/kg). Phased-array multicoil was employed. Images were quantitatively analyzed for lesion-to-liver signal difference to noise ratios (SD/Ns), and lesion-to-liver signal ratios (H/Ls), and qualitatively analyzed for lesion conspicuity. The enhancing characteristics of the hemangiomas were described by measuring the change of signal intensity as a curve in T1-weighted FLASH dynamic imaging.

Results: For T2-weighted images, breath-hold T2-weighted TSE had a slightly higher SD/N than other pulse sequences, but there was no statistical difference in three fast pulse sequences (p=0.211). For lesion conspicuity, heavily T2-weighted breath-hold TSE images was superior to T2-weighted breath-hold or non-breath-hold TSE (H/L, 5.75, 3.81, 2.87, respectively, p < 0.05). T2-weighted breath-hold TSE imaging was more effective than T2-weighted TSE imaging in removing lesion blurring or lack of sharpness, and there was a 12-fold decrease in acquisition time (20 sec versus 245 sec). T1-weighted FLASH dynamic images of normal liver showed peak enhancement at less than 1 minute, and of hemangioma at more than 3 minutes; the degree of enhancement for hemangioma decreased after a 3 minute delay.

Conclusion: T2-weighted breath-hold TSE imaging and Gd-DTPA enhanced FLASH dynamic imaging with 5 minutes delay are sufficient for imaging hepatic hemangiomas.

Index Words: Liver neoplasms, MR
Magnetic resonance (MR), comparative studies
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techniques not only overcome these problems but also can improve image quality (11-17). For the optimum evaluation of hepatic hemangiomas, several investigators have recently compared MR imaging pulse sequences. Pulse sequences include fast or turbo spin-echo (FSE, TSE), rapid acquisition with spin echo (RASE), fast low-angle shot (FLASH), Turbo-FLASH and fast imaging with steady-state precession (FISP) sequences, usually with body coil. The image quality has been improved, and examination time has been decreased. To our knowledge, however, fast MR imaging pulse sequences with single breath-hold for T2-weighted and heavily T2-weighted study using a phased-array multicoil in obtaining adequate images for hepatic hemangiomas have not been compared and optimized.

The purpose of this prospective study was to compare several different techniques for fast MR imaging of hepatic hemangioma and to optimize adequate MR pulse sequences in imaging hepatic hemangiomas. The enhancing characteristics of lesions on dynamic FLASH MR imaging were also described.

Materials and Methods

Selection of Patients

During an eight-month study period, 20 consecutive patients with 35 hepatic hemangiomas were prospectively selected. Their age ranged from 39 to 63 years (mean, 55). Hemangioma was diagnosed on the basis of characteristic findings on ultrasound (n=35), CT (n=12), and angiography (n=1), and no change on follow-up examinations for at least six months. Of the 20 patients, 14 had single and six had multiple hemangiomas, with diameter ranging from 0.9 to 9.7 cm.

MR Imaging

MR imaging was performed on a 1.0T system (Magnetom, Siemens, Erlangen, Germany), using a phased-array multicoil. T2-weighted imaging included T2-weighted turbo-spin-echo (TSE), and T2-and heavily T2-weighted breath-hold TSE imaging. T2-weighted TSE imaging was performed with a repetition time (TR) of 5000 msec, echo time (TE) of 112 msec, echo train length of 15, flip angle of 180°, four signal averaged, a matrix size of 129×256, and 245-second acquisition. T2-and heavily T2-weighted breath-hold TSE imaging were performed with TR of 3500 msec, TE of 138 and 165 msec, respectively, echo train length of 29 and 27, respectively, flip angle of 180°, one signal averaged, matrix size of 116×256 and 108×256, respectively, and 18-second acquisition. T1-weighted FLASH dynamic imaging was performed before, immediate, and 1, 3, and 5 minutes after gadopentetate dimeglumine (Magnevist, Schering, Berlin, Germany) (0.1 mmol/kg) was administrated as a rapid bolus injection. Imaging parameters were TR of 150 msec, TE of 6.5 msec, flip angle of 70-80°, one signal averaged, 129×256 matrix, and 20-second acquisition. Section thickness was 8 mm, with a 2 mm intersection gap, and saturation pulses superior and inferior to the section were used for all sequences.

Quantitative Analysis

For quantitative analysis, signal intensities from lesions, the adjacent normal liver, and the background were obtained with region-of-interest (ROI) measurements in the same locations for each sequence. Signal intensity measurements of lesions were obtained with the largest possible circular ROI located within the lesion and adjacent normal liver. Signal intensity measurements of the liver were obtained with the same circular size, and large blood vessels were avoided within the circle. Background noise was measured with a large ROI ventral to the patients (phase encoding direction). Signal difference to noise ratios (SD/Ns) between the lesion and the liver were calculated in all lesions using the following formula: SD/N = (SIH -
SI(Ls)/SI noise, where SI = signal intensity, H = hemangioma, L = normal liver. Lesion to liver signal intensity ratios (H/Ls) were also calculated in all lesions using the following formula: SIH/SIL. The paired student t-test was used to determine the statistical significance of SD/Ns and H/Ls among T2-weighted imaging pulse sequences (TSE T2-, breath-hold TSE T2-and heavily T2-weighted imaging), and T1-weighted FLASH dynamic imaging, respectively.

**Qualitative Image Analysis**

MR images were evaluated independently by two experienced radiologists (W.C.W., B.I.C) for the following features: (a) lesion conspicuity, (b) motion artifact. Lesion conspicuity was graded as follows: poor (ill-defined, faint outer margin), fair (between poor and excellent), and excellent (well-defined, sharp outer margin). Grade of motion artifact due to breathing and vascular pulsation from the aorta and inferior vena cava was classified into none (no artifact), mild (artifact on the image without appreciable image deterioration), moderate (sufficient to confuse the observer but not enough to give rise to a misleading diagnosis) and

| Table 3. Comparison of Sequence Performance for Imaging Artifact |
|---------------------------------|--------|--------|--------|--------|
| None                           | Mild   | Moderate| Severe |
| TSE E-T2                       | 0 (0)  | 16 (80)| 3 (15) | 1 (5)  |
| TSE-T2BH                       | 18 (90)| 2 (10) | 0 (0)  | 0 (0)  |
| TSE- HT2BH                     | 18 (90)| 2 (10) | 0 (0)  | 0 (0)  |
| FLASH-TI                       | 15 (75)| 4 (20) | 1 (5)  | 0 (0)  |

Numbers are numbers of patients. Numbers in parentheses are percentages.

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**Fig. 1.** MR images of a 47-year-old woman with multiple hepatic hemangiomas. (A) T2-weighted non-breath-hold TSE (5000/112, ETL=15) image. (B) T2-weighted breath-hold TSE (3500/138, ETL = 29) image. (C) heavily T2-weighted TSE (3500/165, ETL =27) image and (D) T1-weighted FLASH (150/6.5, flip angle 75) image. Note the lack of motion artifact and lesion blurring on breath-hold images, and intrahepatic structures are blurring on non-breath-hold image. Lesions show high signal intensity on T2-weighted and heavily T2-weighted images, and low signal intensity on T1-weighted FLASH image with sharp border.
severe (useless image). Kendall’s test was used to determine the statistical significance of difference of grade of lesion conspicuity and artifact.

Results

The results of T2-weighted images are summarized in Table 1. Breath-hold TSE T2-weighted images had a slightly higher SD/N (10.62 ± 7.19) than non-breath-hold TSE T2- and breath-hold TSE heavily T2-weighted images (8.34 ± 4.45, 8.49 ± 4.01, respectively), but the differences were not statistically significant (p = 0.211). T2- and heavily T2-weighted breath-hold TSE images had higher H/Ls than T2-weighted non-breath-hold TSE images (p < 0.001). For lesion conspicuity, all breath-hold sequences were superior to non-breath-hold sequence (p < 0.05) (Table 2). Motion artifact was more frequently seen in T2-weighted non-breath-hold TSE images than in breath-hold sequences (p < 0.05, Table 3, Fig. 1). Except for the post-contrast FLASH T1-weighted imaging sequence, there were almost no aortic or IVC pulsation artifacts in these sequences, due to a saturation pulse superior and inferior to the selected section.

Lesions showed high signal intensity on T2-weighted images, and low signal intensity on precontrast T1-weighted FLASH images with a sharp border (Fig. 1). Dynamic images of normal liver showed peak signal intensity at less than 1 minute, and of hemangiomas at more than 3 minutes after administration of contrast material (Fig. 2). After 3 minutes, the degree of enhancement decreased, but for delays of 3 and 5 minutes, the difference was not statistically significant. Enhancement was usually peripheral globular with progressive centripetal enhancement for hemangiomas larger than 1.5 cm in diameter, enhancement was uniform without peripheral washout on the delay phase for hemangioma as smaller than 1.5 cm in diameter (Fig. 3–4). One hemangioma 2.0 cm in diameter showed immediate homogeneous enhancement, however; peak signal intensity time was also more than 3 minutes.

Discussion

The development of pulse sequences with short imaging times and the elimination of motion induced image artifacts are the major direction of research for the detection of liver lesions in MR imaging of the abdomen. T2-weighted spin-echo images are considered the most sensitive for lesion detection at high field strength (1–11). TSE sequences can provide T2-weighted images and heavily T2-weighted imaging of the entire liver during single breath holding (12–15), in which case respiratory motion artifact is minimal or absent.

TSE is based on the rapid acquisition with the relaxation enhancement (RARE) technique, by using an altered echo train length method of K-space filling. It is possible to obtain T2-weighted SE images within the required time, but several factors could affect the contrast, signal-to-noise ratio, and image quality of T2-weighted images. TSE thus requires careful attention on regards choice of imaging parameters. Breath-holding necessitates a short acquisition time, usually less than 30 seconds. The acquisition time for TSE is calculated using the following formula: TR × Nphase × NEX / ETL, where N phase = number of phase encoding, NEX = number of excitations, and ETL = echo train length. We adjusted these parameters to obtain a diagnostically useful image, and in order to obtain breath-hold image sequences for the entire liver, kept acquisition time below 20 seconds. If we reduce matrix size and increase echo train length, the signal-to-noise ratio is low, and image quality cannot be improved by signal averaging for breath-hold imaging (16–18). In our prospective study, a phased-array multicoil was employed for improving SNR and CNR, and an asymmetric (3/4) field of view and partial Fourier imaging methods were used to acquire

Fig. 2. Correlation of signal intensity of liver and hemangioma in dynamic FLASH MR imaging
Numbers are mean signal intensity of 35 hemangiomas and 20 patients
adequate images of at least 192 × 256 effective spatial resolution within a breath-hold period of 18 seconds. The phased-array multicoil increases SNR and CNR by more than 60% compared to the body coil (19, 20), and makes possible the use of a small slice thickness and narrow intersection gap without loss of SNR and image quality.

The results of our study demonstrate that T2-weighted breath-hold TSE imaging provides higher lesion-to-liver signal intensity ratios (H/Ls) than T2-weighted non-breath-hold TSE imaging, though SD/N for T2-weighted breath-hold TSE imaging was slightly higher than for T2-weighted non-breath-hold TSE imaging (no statistically significant difference). The acquisition time for T2-weighted breath-hold TSE imaging was much shorter, however, and was useful in clinical application (18 seconds for breath-hold TSE T2 vs 245 seconds for non-breath-hold TSE T2). Due to an inhomogeneous high signal near the phased-array coil, only two of 35 small hemangiomas (less than 1.5 cm in diameter) located in the peripheral liver had lower SD/N and H/L but higher signal intensity than other hemangiomas in breath-hold imaging. In order to prevent peripheral inhomogeneous high signal intensity

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**Fig. 3.** MR images of a 52-year-old woman with hepatic hemangioma of right lobe (3.5 cm in diameter). (A) precontrast T1-weighted FLASH (150/6.5, flip angle 75) image and postcontrast immediate (B), 1 minute (C), 3 minutes (D), 5 minutes (E) image. Note peripheral globular with progressive centripetal enhancement.
near the phased-array multicoil, we use a field-of-view (FOV) as small as possible, and so this effect may be less important.

Our preliminary results indicate that T2-weighted TSE imaging provides higher SD/N, H/Ls, and shorter imaging time than T2-weighted SE imaging, results which have been confirmed by several investigators (9, 11, 12) (SE T2-weighted sequence was not included in this study). Our results for lesion detection showed no significant difference between T2-weighted TSE and T2-weighted breath-hold TSE imaging including breath-hold TSE heavily T2-weighted imaging; these findings are different from those of Rydberg et al (15), who subjectively judged lesion detectability of T2-weighted breath-hold TSE imaging to be inferior to that of the first echo of the T2-weighted SE sequence. This may be partly due to the fact that their procedures involved a shorter echo time (TE < 80 msec), a greater section thickness (10 mm), and a wider intersection gap (5 mm), resulting in higher SNR and lower SD/N than with our techniques, where echo time was longer (TE > 100 msec), thickness was less (8 mm), and the intersection gap was narrower (2 mm).

A measured T2 relaxation time greater than 80 msec...
is considered diagnostic of hepatic hemangioma, with an accuracy of 84% (1). More heavily T2-weighted images showed increased tumor conspicuity (7). Our results also suggested that heavily T2-weighted breath-hold TSE was superior to T2-weighted breath-hold TSE imaging for lesion conspicuity. Some small hemangiomas show shorter T2 relaxation time, and this may be due to the partial volume effect.

Masses with long T2 relaxation time, however, including cysts, abscesses, metastases with liquefactive necrosis, and hypervascular metastases may simulate a hemangioma (10). We therefore consider that T2-weighted breath-hold TSE imaging with long echo time (heavily T2WI) may not be sufficient for differentiating a benign mass from a malignant tumor; this was also the view of Semelka et al (2). Dynamic MR imaging after the administration of contrast material is useful in confirming a diagnosis of hemangioma. T1-weighted FLASH dynamic imaging of the abdomen is rapidly becoming a routine examination procedure at many hospitals. One of the advantages of a T1-weighted FLASH imaging sequence is that the entire liver can be imaged in a single breath-hold, providing good T1-weighted image quality, the absence of respiration-induced motion artifact, and good lesion detection and lesion conspicuity. The disadvantage is flow artifact (2—9, 16, 17). In this study, presaturation pulses superior and inferior to the slice section were used in all fast sequences in order to avoid flow artifact.

Hepatic hemangiomas show nodular enhancement immediately after a bolus injection of contrast agent, but complete fill-in of the lesion usually requires a long time. The optimal delay time for hemangiomas is still uncertain. Our study showed that immediate nodular enhancing with progressive centripetal fill-in was frequently seen in hemangiomas larger than 1.5 cm in diameter and immediate uniform enhancing was seen in hemangiomas smaller than 1.5 cm in diameter. One hemangioma 2.0 cm in diameter showed immediate homogeneous enhancement. Despite these enhancement characteristics, dynamic MR imaging of normal liver showed peak signal intensity at less than 1 minute, and of hemangiomas at more than 3 minutes after a bolus injection of contrast agent; the signal intensity of hemangiomas decreased after a delay of 3 minutes, but for delays of 3 and 5 minutes the difference was not significant. These results are important for differentiating hemangiomas from malignant tumors, because peak signal intensity time of less than 20 seconds for hypervascular malignant tumors after a bolus of contrast agent has been confirmed by previous studies (4—7). We believe that for the diagnosis of hepatic hemangiomas, a long time delay in T1-weighted FLASH dynamic imaging may not be necessary; five minutes may be enough.

With regard to overall image quality of each pulse sequence, our results showed that breath-hold TSE and FLASH sequences were superior to the non-breath-hold sequence. Respiratory motion artifact was minimal or absent on breath-hold images but was present to varying degrees on non-breath-hold images. Lesion blurring or lack of sharpness was frequently seen in non-breath-hold images. Although the chemical shift artifact may be less problematic in imaging hepatic hemangiomas, we eliminated this by using the in phase FLASH imaging technique in order to make this optimal pulse sequence even more useful for clinical application.

A limitation of this study was that confirmation of hemangioma was not by pathologic examination, but by typical findings in the imaging modality and by observing an unchanged size and shape on follow-up more than six months later. This limitation is a common problem in studies involving hemangiomas and may be acceptable, since MR imaging is generally regarded as pathognomonic (1—10).

In conclusion, we believe that T2-weighted TSE imaging with breath-hold and Gd-DTPA enhanced FLASH dynamic imaging with 5 minutes delay are sufficient for imaging hepatic hemangiomas. The peak signal intensity time of more than 3 minutes after a bolus injection of contrast agent in hemangiomas may be important for differentiating hemangiomas from hypervascular malignant tumors.

References

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간 혈관종의 최적 자기공명 필스시퀀스: T2강조 터보스핀에코, T2강조 호흡정지 터보스핀에코, T1강조 FLASH 역동적영상간의 비교

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목적: 간 혈관종의 자기공명영상 (MRI)에서 펄스시퀀스들간의 차이점을 비교하여보고 영상화에 이용되는 펄스시퀀스를 최적화 하고자 하였다. 또한 역동적 자기공명영상에서 혈관종의 조영증강특성을 알아보고자 하였다.

대상 및 방법: 20명의 환자에서 35예의 혈관종을 대상으로 터보스핀에코 (Turbo-spin-echo, TSE) (T2강조, T2 및 심한 T2강조 (Heavily T2WI) 정지호흡)와 T1강조 FLASH 방법으로 조영전 및 조영후 1, 3, 5분영상 각각 얻었으며, 조영제는 Gd-DTPA를 0.1mmol/kg의 용량으로 순간 정주하였다. 위상정렬 다중코일 (phased-array multicoil)을 사용하였다. 자기공명영상은 병변 대 간 신호차이를 잡음비로 나눈값 (SD/Ns), 그리고 병변 대 간 신호비 (H/Ls) 등의 변수로 양적분석을 하였고, 병변의 대조도로 질적분석을 하였다. 혈관종의 조영증강특성은 T1강조 FLASH 동적영상에서 신호강도의 변화를 측정하여 기술하였다.

결과: T2강조영상에서 호흡정지 T2강조 TSE가 다른 필스시퀀스에 비하여 약간 높은 SD/N을 보였으나 세가지 급속 필스시퀀스들간에 통계학적으로 유의한 차이는 없었다 (p=0.211). 병변대조도는 심한 T2강조 호흡정지 TSE영상이 T2강조 호흡정지 또는 비호흡정지 TSE영상보다 각각 더 우월하였다 (H/L: 각각 5.75, 3.81, 2.87, p<0.05). T2강조 호흡정지 TSE영상은 T2강조 TSE영상보다 병변의 혼란 (blurring)이 적어 병변이 더욱 선명하였으며, 영상확두시간은 12분의 1로 감소하였다 (20초 대 245초). T1강조 FLASH 역동적영상은 정상관에서는 1분 이내에 조영증강의 절정에 도달하였으며, 혈관종에서는 3분이상이 소요되었고, 혈관종에서 3분 지역영상 후에는 그 조영증강의 정도가 감소하였다.

결론: T2강조 호흡정지 TSE영상과 Gd-DTPA조영증강 FLASH 역동적영상 및 5분 지역영상은 간 혈관종의 영상화에 적합한 필스시퀀스이다.