Yonago Acta medica 1996;39:73–81

Evaluation of Fast Gradient System Breath-Hold FLASH Imaging in the Examination of Liver Tumors: Comparison with Conventional Spin-Echo Pulse Sequences

Kotaro Yoshida, Yuji Suto, Takashi Kato, Shuji Sugihara and Naoto Ohmura

Department of Radiology, Faculty of Medicine, Tottori University, Yonago 683, Japan

Forty one patients with various types of focal liver tumors were imaged with a multisection fast low-angle shot (FLASH) gradient echo sequence using a fast gradient MR system. We compared the T1-weighted images of the liver with the multisection FLASH and conventional spin-echo (SE) pulse sequences in order to determine whether FLASH images could replace SE images. The multisection FLASH sequence provided a significantly higher signal-to-noise ratio (SNR), liver-spleen contrast, liver-spleen contrast-to-noise ratio (CNR), liver-nodule CNR ($P < 0.01$) and liver-tumor contrast ($P < 0.05$) than did the T1-weighted SE sequence. The overall image quality of the multisection FLASH sequence was superior to that of the T1-weighted SE sequence ($P < 0.05$). The signal intensity features of liver tumors with both sequences were almost the same. There was a statistically mutual correlation in the signal intensity between hepatocellular carcinomas and metastases. The detectability of liver tumors in FLASH sequences was superior to that in SE sequences. These findings suggest that multisection FLASH sequence imaging can replace T1-weighted SE sequence imaging.

Key words: breath-hold FLASH; fast gradient; MRI; liver tumor

Magnetic resonance imaging (MRI) has an excellent contrast resolution, and its usefulness in detecting tumorous lesions of the liver and in its diagnosis has been reported (Li et al., 1988; Matsui et al., 1989; Rammeny et al., 1989; Kadoya et al., 1992). In previous clinical evaluation of liver tumors, the spin-echo (SE) method has been used. However, it has some drawbacks in that the image deteriorates due to breathing during the examination, and the time it takes to perform is too long (Felmlee and Ehman, 1987; Edelmann et al., 1988; Mitchell et al., 1988).

With the recent installation of the fast gradient MR system, the image quality of the T1-weighted fast low-angle shot (FLASH) sequence (Haase et al., 1986), one of the fastest imaging methods available, has improved the possibility of clear imaging as compared with that of the conventional low and slow gradient system.

In our present study, the breath-hold multisection FLASH imaging using the fast gradient MR system was compared with the conventional SE imaging, quantitatively and qualitatively, and tumor detectability of each method was evaluated, with computed tomography (CT) during arterial portography (CTAP) as the golden standard, in order to determine whether the FLASH method could replace the conventional SE method.

Abbreviations: CNR, contrast-to-noise ratio; CT, computed tomography; CTAP, CT during arterial portography; FLASH, fast low-angle shot; MRI, magnetic resonance imaging; N_{stat}, mean SI of background in the frequency-encoding direction (statistical noise without ghosting artifacts); N_{sys}, mean SI of background in the phase-encoding direction (large region of interest anterior to the abdomen, including ghosting artifacts); SE, spin-echo; SI, signal intensity; $SI_{background}$, SI of background; SI_{liver}, SI of the liver; SI_{spleen}, SI of the spleen, SNR, signal-to-noise ratio; TE, echo time; TR, repetition time.

Table 1. Results of quantitative evaluation

Parameter		Sequence FLASH	SE
Liver SNR		34.15 ± 12.60	13.98 ± 5.89*
Contrast	Liver-spleen	0.16 ± 0.05	0.09 ± 0.07*
	Liver-tumor (all nodes)	0.10 ± 0.08	0.08 ± 0.11**
CNR	Liver-spleen	9.44 ± 4.62	2.52 ± 1.98*
	Liver-tumor (all nodes)	7.23 ± 7.22	2.06 ± 2.29*
N_{sys}/N_{stat}		1.78 ± 2.37	5.12 ± 4.51*

CNR, contrast-to-noise ratio; N_{stat}, mean SI of background in the frequency-encoding direction (statistical noise without ghosting artifacts); N_{sys}, mean SI of background in the phase-encoding direction (large region of interest anterior to the abdomen, including ghosting artifacts); N_{sys}/N_{stat}, ratio between systematic noise and statistical noise; SI, signal intensity; SNR, signal-to-noise ratio at the liver.

Measurements obtained from the multisection fast low-angle shot (FLASH) images are significantly larger than those obtained from conventional T1-weighted spin-echo (SE) images (*$P < 0.01$, **$P < 0.05$).

Subjects and Methods

The subjects were 41 patients (35 males and 6 females, ages ranging from 33 to 83 years with an average of 63.5 years) with tumorous lesions of the liver who underwent MRI from September 1994 to July 1995. None of these patients had a previous history of abdominal operation.

Diagnosis of hepatic tumorous lesions was made based on the clinical findings, image findings and histological findings. There were 27 patients with 74 nodes of hepatocellular carcinoma, 8 patients with 65 nodes of metastatic liver tumor, 2 patients with 5 nodes of bile duct carcinoma, 1 patient with 1 node of adenomatous hyperplasia, 4 patients with 10 nodes of cavernous hemangioma and 2 patients with 13 nodes of liver cyst, the total number of nodes being 174.

We used a 1.5 T fast gradient superconducting MRI system (Magnetom Vision: Siemens, Erlangen, Germany; gradient magnetic field intensity 25 mT/m). In SE imaging, T1-weighted images were obtained with a repetition time (TR) of 600 ms and an echo time (TE) of 17 ms, with 4 signal averagings. The imaging time was 4 min and 58 s. Slice thickness was 10 mm, imaging matrix 123×256 and field of view 350 mm with a frequency band of 130 Hz/pixel.

In multisection FLASH imaging, T1-weighted images were obtained with a TR of 262 ms and a TE of 4.8 ms, with a flip angle of 65°. Signal averaging was 1 time. Imaging of the entire liver was performed (imaging time 26 s) with one breath held. The imaging matrix was 100×256 and field of view 350 mm with a frequency band of 130 Hz/pixel. With the conventional low gradient 1.5 T MRI system, the band width under nearly the same imaging conditions was 300 Hz/pixel.

The 2 imaging methods were compared in tumor detectability, with CTAP as the golden standard. CTAP was performed at the time of angiography which was performed 1 to 2 weeks after MRI. The apparatus used was Somatom Plus S (Siemens). Operating conditions were: 1 rotation/s, continuous 30 rotations, X-ray beam width 5 mm, and moving speed of the table at 5 mm/rotation. One hundred milliliters of Iohexol in concentration of 140 mgI/mL (Omnipaque 140, Daiichi Seiyaku, Tokyo, Japan) was injected at a speed of 2.5 mL/s, and imaging by spiral scan was started 30 s after the injection was begun.

Image analysis

Quantitative evaluation

In each image with FLASH and SE, mean signal intensities (SIs) of liver (SI_{liver}), spleen (SI_{spleen}) and background ($SI_{background}$) (outside of the abdomen in the phase-encoding direction, including ghosting artifacts of both a

Table 2. Results of quantitative evaluation of liver-tumor CNR and contrast

Parameter		Sequence	
		FLASH	SE
Contrast	Hepatocellular carcinoma	0.07 ± 0.08	0.03 ± 0.12**
	Metastasis	0.13 ± 0.07	0.12 ± 0.08
	Bile duct carcinoma	0.19 ± 0.07	0.22 ± 0.12
	Hemangioma	0.11 ± 0.08	0.05 ± 0.05
	Cyst	0.19 ± 0.06	0.16 ± 0.06
CNR	Hepatocellular carcinoma	3.49 ± 5.58	0.96 ± 2.25*
	Metastasis	9.56 ± 7.19	2.92 ± 1.73*
	Bile duct carcinoma	14.92 ± 6.10	4.49 ± 0.61**
	Hemangioma	6.85 ± 5.57	1.40 ± 1.25**
	Cyst	11.83 ± 4.60	4.21 ± 3.16**

CNR, contrast-to-noise ratio.
Measurements from the multisection fast low-angle shot (FLASH) images are significantly larger than those from conventional T1-weighted spin-echo (SE) imaging (*P <0.01, **P < 0.05).

respiratory and vascular nature) were determined with standard region-of-interest measurements. In addition, the signal-to-noise ratio (SNR) at the liver ($SI_{liver}/SI_{background}$), liver-spleen contrast $[(SI_{liver} - SI_{spleen})/(SI_{liver} + SI_{spleen})]$ and contrast-to-noise ratio (CNR) $[(SI_{liver} - SI_{spleen})/SI_{background}]$ were calculated. The tumor contrast and CNR were also calculated in the same manner. Contrast was a measure for the differentiation of 2 tissues without weighting. Furthermore, the mean SIs of background in the phase-encoding direction (large region of interest anterior to the abdomen, including ghosting artifacts) (N_{sys}) and in the frequency-encoding direction (statistical noise without ghosting artifacts) (N_{stat}) were determined with standard region-of-interest measurements. In addition, the ratio between systematic noise and statistical noise (N_{sys}/N_{stat}) was calculated as a measure for the intensity of motion artifacts in each imaging method. In the statistical analysis, Student's t-test was used, with $P < 0.05$ as significant.

Qualitative evaluation

Through consultation among 3 radiologists with experience of 5 years or more in MRI, images were evaluated in the following 4 grades and numerical rating: poor (1 point), fair (2 points), good (3 points) and excellent (4 points). Based on this numerical rating, comparative evaluation of the quality of FLASH and SE images was made with the Wilcoxon matched-pairs signed-rank test. The following 5 items were checked: i) artifacts due to breathing and vascular pulsation, ii) contrast (liver-spleen, liver-tumor), iii) capability to visualize blood vessels, iv) clarity around the border of the liver and v) overall image quality, taking into consideration the assessments in i) to iv).

In addition, SI in liver tumors was evaluated using the following 5 grades through consultation among the 3 radiologists: low, mild low, iso, mild high and high. Based on the criteria, comparison was made between FLASH and SE images. To determine tumor detectability, CTAP images and the images in each of the MRIs were sorted into groups according to the size of the tumors, and a comparative evaluation was made in each method, and then on the overall detection rate.

Results

Quantitative evaluation

The results of quantitative evaluation are shown in Tables 1 and 2. In Table 1, FLASH was significantly superior to SE in all items of evaluation as in the following: SNR, 144% increase

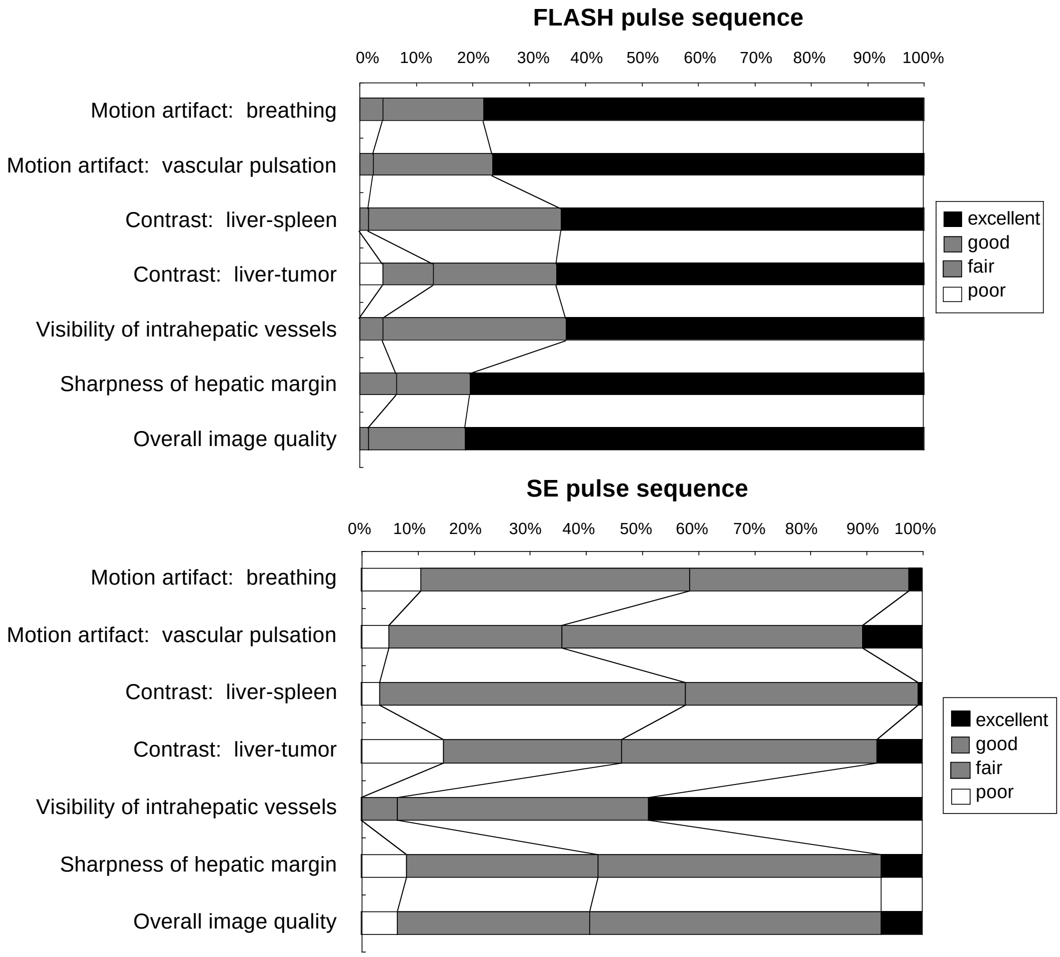

Fig. 1. Results of qualitative evaluation of image quality for 41 patients who underwent multisection fast low-angle shot (FLASH) and spin-echo (SE) imagings. FLASH images were significantly superior ($P < 0.05$) in each item of evaluation.

($P < 0.01$); liver-spleen, increases of 77% in contrast and 275% in CNR ($P < 0.01$); liver-tumor, increases of 25% in contrast ($P < 0.05$) and 251% in CNR ($P < 0.01$); and N_{sys}/N_{stat}, a decrease of 65% ($P < 0.01$).

Table 2 shows the results of evaluation by type of tumor (excluding 1 patient with 1 node of adenomatous hyperplasia). In CNR, significant increases were observed with FLASH in all types of liver tumor: $P < 0.01$ in hepatocellular carcinoma and metastatic liver tumor, and $P < 0.05$ in bile duct carcinoma, hemangioma and liver cyst. As regards contrast, significant increases ($P < 0.05$) were observed in hepatocellular carcinoma. However, in other types of tumor, no significant differences were seen.

Qualitative evaluation

Visual evaluation of images: Figure 1 shows the results of visual evaluation by the 3 radiologists. FLASH images were significantly superior ($P < 0.05$) in each item of evaluation. Figure 2 shows a case of hepatocellular carcinoma in which high signal intensity was actually observed.

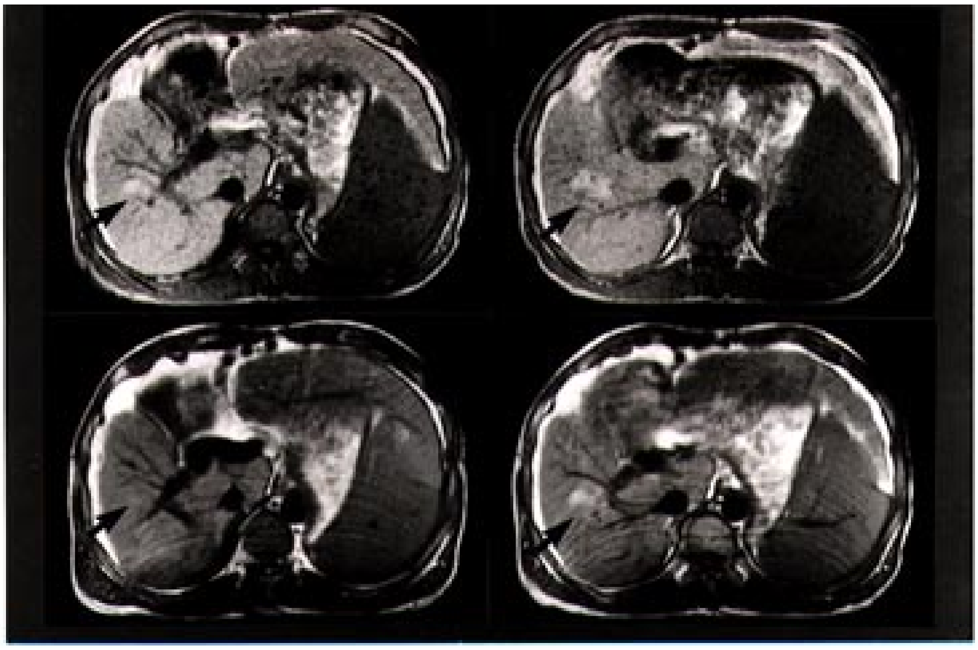

Fig. 2. MR images for a 70-year-old patient with hepatocellular carcinoma (arrows). Upper images are from a multisection fast low-angle shot (FLASH) sequence, and lower images are from a spin-echo (SE) sequence. The node on multisection FLASH sequences is of higher intensity and more distinct than on SE sequences.

Comparison in SI characteristics in hepatic tumor and tumor detectability: SI characteristics in liver tumors with FLASH and SE are shown in Table 3. In 31 nodes of hepatocellular carcinoma, 64 nodes of metastatic liver tumor, 4 nodes of hemengioma and in all of the nodes of bile duct carcinoma and liver cyst, a lower signal was observed as compared with the signal of nontumorous liver tissue. Of the nodes of hepatocellular carcinoma, 14 nodes showed a high signal. Seven nodes of hepatocellular carcinoma and 1 node of metastatic liver tumor showed iso SI to nontumorous liver tissue. In these types of tumor, the same tendency was observed with both FLASH and SE in SI characteristics (129 nodes/139 nodes).

In 6 nodes of hepatocellular carcinoma, 3 nodes of hemangioma and 1 node of adenomatous hyperplasia, the SI varied depending on the imaging method (10 nodes/139 nodes). In these types of tumor, no specific tendency was observed in SI with FLASH. With SE, however, the SI was equal to nontumorous liver tissue in all types. Included in these were 8 nodes which were indistinguishable as nodes in the liver. These results were put into a two-by-five contingency table, and statistical comparison was made approximately by χ^2 test. As a result, a significant correlation was observed in SI characteristics between hepatocellular carcinoma ($P < 0.05$) and metastatic liver tumor ($P < 0.05$). In other types of tumor, however, no significant correlation was seen.

Evaluation of tumor detectability, by size of tumor, with FLASH and SE methods in comparison with CTAP is shown in Table 4. The 17 nodes smaller than 1 cm detected with CTAP in hepatocellular carcinoma and liver cyst were not detectable with FLASH or SE. In detection of tumors of 1 cm or larger, the detection rate was greater for FLASH than for SE. With the detection rate of CTAP as 100%, the detection rate of FLASH and SE was 79.9% and 73.6%, respectively.

Table 3. SI features of liver tumors in multisection FLASH and SE images

	FLASH image	SE image: Low	Mild low	Iso	Mild high	High
Hepatocellular carcinoma**	High			1†	2	1
	Mild high			4	7	4
	Iso			7		
	Mild low	7	8	1		
	Low	8	8	1		
Metastasis**	High					
	Mild high					
	Iso			1		
	Mild low	4	1			
	Low	44	15			
Bile duct carcinoma	High					
	Mild high					
	Iso					
	Mild low					
	Low	2	1			
Hemangioma and cyst	High					
	Mild high					
	Iso					
	Mild low	1‡	1	2		
	Low	3‡	3	1		

FLASH, fast low-angle shot; SE, spin-echo; SI, signal intensity.
† Adenomatous hyperplasia.
‡ Cyst.
** A significant correlation is observed in SI characteristics between FLASH and SE in hepatocellular carcinoma ($P < 0.05$) and metastatic liver tumor ($P < 0.05$).

Discussion

There are various methods of obtaining fast and ultrafast MRI sequences, and these are selected according to the characteristics of each method such as imaging time, contrast resolution and spatial resolution. Generally these fast imaging methods are superior to the SE method in time resolution when used in examination of the uper abdomen. However, they tend to be inferior in contrast resolution. Besides, there is one drawback in that the shorter the imaging time, the lower the SNR, with a resultant decrease in spatial resolution.

Of these methods, FLASH is comparatively good in contrast and SNR. In fact, we had previously been studying a TR, a TE and a flip angle suitable for obtaining a T1-weighted image of good quality, when it was suggested that FLASH images could replace SE images (Unger et al., 1988).

In the comparison between the T1-weighted breath-hold FLASH image not using a presaturation pulse and the T1-weighted SE image, Taupitz and colleagues (1992) reported that although FLASH was superior in quantity to in SNR and CNR, it was slightly inferior in its capability to visualize intrahepatic blood vessels in image evaluation, and therefore, the 2 methods were equal to each other as a whole. However, since the quality of FLASH images is not as stable as that of SE images clinically, FLASH has previously been used only as an especial method, for example in dynamic studies (Kato et al., 1990; Inoue et al., 1994).

Table 4. Tumor detectability with FLASH, SE and CTAP images

	Tumor size (cm)				
	1<	≤1–2<	≤2–3<	≤3	Total
CTAP	17	41	46	74	174
Multisection FLASH pulse sequence	0 (0)	31 (75.6)	41 (89.1)	67 (90.5)	139 (79.9)
SE pulse sequence	0 (0)	31 (75.6)	37 (80.4)	60 (81.1)	128 (73.6)

( ), %.
CTAP, computed tomography during arterial portography; FLASH, fast low-angle shot; SE, spin echo.

As for recent systems, the fast gradient system is coming into wide use. With the fast gradient system, the building up of a gradient field is quick, which makes it possible to further shorten the imaging time in various methods of fast imaging. Formerly, with an apparatus of 10 mT/m, it was necessary to hold the breath for 34 s in FLASH imaging of the entire liver without using a presaturation pulse. Even in imaging with the same parameters, it is possible to operate at a narrow band width. Therefore, the SNR, which is in inverse proportion to the square of the band width, increases in spatial resolution. In our present quantitative evaluation, the liver SNR, liver-spleen and liver-tumor CNRs and tumor type-wise CNR were significantly higher with FLASH than with SE. Each of these is the ratio of SI difference against background noise. Since motion artifacts due to breathing and vascular pulsation are few with breath-hold FLASH, it is quite natural that FLASH was superior to SE. As compared with FLASH having the ordinary gradient magnetic field intensity, the breath holding time was shortened by 8 s, which means less burden on the patient. As a result, it has become possible to image the entire liver with one breath-holding even for a patient in unfavorable general condition, and to obtain images with less artifacts. Decrease in artifacts resulting from vascular pulsation due to presaturation pulse also contributed to decreasing noise.

The contrast in FLASH images was significantly higher than that of SE in both liver-spleen and liver-tumor. Among the tumors examined, a significant difference in liver-tumor contrast was observed only in hepatocellular carcinoma. In imaging by gradient echo, the magnetic field inhomogeneities and the presence of any magnetic substance decrease the SI (Ohtomo, 1993). Since much iron, which is a magnetic substance, is contained in the spleen, the SI decreases with FLASH. This may be why it was easier to produce a contrast of the spleen with the liver (Minami et al., 1989; Sagoh et al., 1989). Also, signal decrease in the liver and tumor due to artifacts was small with FLASH, and consequently, contrast with the tumor was higher than in imaging with SE.

Hemangioma, cysts and metastatic liver tumor are types of tumors in which sufficient contrast with the liver can be obtained even with SE, and therefore, scarcely any difference was observed in comparison with FLASH. In hepatocellular carcinoma, on the other hand, various degrees of intensity—low, high and iso signals—are seen, and its degree varies depending on fat and copper content (Ebara et al., 1991; Kitagawa et al., 1991). Therefore, as already mentioned above, decrease in SI is small in FLASH. This presumably made it possible to obtain images with higher contrast in FLASH which now has a higher spatial resolution in the fast gradient magnetic field.

In qualitative evaluation, the results of quantitative study were directly reflected. With increased spatial resolution, the drawback of a slightly weak capability to visualize blood vessels has been improved, leading to the above results of our image evaluation. In comparison to SI characteristics, FLASH visually showed nearly the same tendency in many cases of liver tumor as SE, which is superior in contrast resolution, and therefore, no great differences were observed. Statistically, a significant correlation was seen only between hepatocellular carcinoma and metastatic liver tumor. As regards liver tumors with evidently different SI, which were indistinguishable with SE from the liver parenchyma because of artifacts, etc., a clear distinction was obtained with FLASH as tumors of low signal in the high intensity area. Thus, in these tumors, FLASH exhibited excellent contrast resolution.

In the evaluation of tumor detectability with CTAP as the golden standard, the detection rate with FLASH was 79.9%, which was higher than the rate with SE reported in the past. The detection rate was nearly equal to the rate obtained by spiral scan in dynamic CT of the entire liver, about which there have been many reports (Kim et al., 1995; Matsuda et al., 1995; Uchida et al., 1995). In picking up tumors smaller than 1 cm, FLASH has a problem. However, since it has no difference in imaging time, its performance is considered satisfactory in screening tumors, considering that no contrast medium is used.

As for its shortcomings, FLASH is easily affected by magnetic field inhomogeneities. Therefore, where magnetic substances such as metal coil are kept in, the resulting artifact makes it difficult to make proper evaluation. In the case of severe liver cirrhosis, where there are many regenerated nodes, there may be many pseudotumors, making it difficult to detect real tumors (Murakami et al., 1989; Ohtomo et al., 1990). When a patient is unable to hold the breath firmly, a strong artifact is likely to occur. As a result, it becomes difficult to read the image. In such a case, it is better to use SE, since SE is less affected by the patient's condition. T1-weighted FLASH images with the fast gradient system are excellent in time, spatial and contrast resolutions, and the tumor detection rate with FLASH is equal to or better than that with SE. Therefore, it is possible for FLASH to replace SE as a method for detecting tumors in the liver.

Conclusion

T1-weighted multisection FLASH images performed with a fast gradient MRI system proved to have significantly higher liver-tumor contrast and tumor detectability than the SE images in patients with hepatocelllular carcinomas. Therefore, it seems that the FLASH images are useful for diagnosis of hepatocellular carcinomas. In other tumors examined, the FLASH images are also excellent in spatial and contrast resolution. Using the fast gradient MRI system makes it possible to shorten the imaging time in breath-hold multisection FLASH. It is considered that FLASH with the fast gradient MRI system can replace SE images for evaluation of liver tumors.

Acknowledgments: The authors wish to express their sincere gratitude to Prof. Yoshio Ohta, Dept. of Radiology, Faculty of Medicine, Tottori Univ., for his helpful suggestions and reading of the manuscript, and would like to thank very much Prof. Keiichi Ichihara, Second Dept. of Pathology, Faculty of Medicine, Tottori Univ. and Prof. Hironaka Kawasaki, Second Dept. of Internal Medicine, Faculty of Medicine, Tottori Univ., for many helpful discussions.

The abstract of this paper was presented at the 23th Congress of Japanese Magnetic Resonance in Medicine held in 1995.

References

1 Ebara M, Watanabe S, Kita K, Yoshikawa M, Sugiura N, Ohto M, et al. MR imaging of small hepatocellular carcinoma: effect of intratumoral copper content on signal intrensity. Radiology 1991;180:617–621.

2 Edelman RR, Atkinson DJ, Silver MS, Loaiza FL, Warren WS. FRODO pulse sequences: a new means of eliminating motion, flow and wraparound artifacts. Radiology 1988;166:231–236.

3 Felmlee JP, Ehman RL. Spatial presaturation: a method for suppressing flow artifacts and improving depiction of vascular anatomy in MR imaging. Radiology 1987;164:559–564.

4 Haase A, Frahm J, Matthaei D, Hänicke W, Merboldt KD. Fast NMR imaging using low flip angle pulses. FLASH imaging. J Magn Reson 1986;67:258.

5 Inoue E, Kuroda C, Fujita M, Hosomi N, Kadota T, Narumi Y, et al. Evaluation of multislice dynamic MR imaging of the whole liver. Nippon Igaku Hoshasen Gakkai Zasshi 1994;54:363–370 (in Japanese).

6 Kadoya M, Matsui O, Takashima T, Nonomura A. Hepatocellular carcinoma: correlation of MR

imaging and histopathologic finding. Radiology 1992;183:819–825.
7 Kato M, Hirohashi S, Maeda M, Otsuji H, Tsushima T, Kitano S, et al. [Usefulness of dynamic MRI of differentiation in liver tumor.] Nippon Igaku Hoshasen Gakkai Zasshi 1990;50: S330 (in Japanese).
8 Kim T, Oi H, Murakami T, Matsushita M, Kishimoto H, Takashima S, et al. Detectability of hypervascular small hepatocellular carcinoma by dynamic spiral CT. Nippon Igaku Hoshasen Gakkai Zasshi 1995;55:296–299 (in Japanese).
9 Kitagawa K, Matsui O, Kadoya M, Takashima T, Kawamori Y, Yamahana T, et al. Hepatocellular carcinoma with excessive copper accumulation: CT and MR findings. Radiology 1991;180:623–628.
10 Li KC, Glazer GM, Quint LE, Francis IR, Aisen AM, Ensminger WD, et al. Distinction of hepatic cavernous hemangioma from hepatic metastases with MR imaging. Radiology 1988;169:409–415.
11 Matsuda H, Abe K, Patrick CF. Utility of double helical CT for the detection of malignant hepatic tumors. Rinsho Hoshasen 1995;40:435–441 (in Japanese).
12 Matsui O, Kadoya M, Kameyama T, Yoshikawa J, Arai K, Gabata T, et al. Adenomatous hyperplastic nodules in the cirrhotic liver: differentiation from hepatocellular carcinoma with MR imaging. Radiology 1989;173:123–126.
13 Minami M, Itai Y, Ohtomo K, Ohnishi S, Niki T, Kokubo T, et al. Siderotic nodules in the spleen: MR imaging of portal hypertension. Radiology 1989;172:681–684.
14 Mitchell DG, Vinitski S, Burk DL Jr, Levy DW, Rifkin MD. Motion artifact reduction in MR imaging of the abdomen:gradient moment nulling versus respiratory-sorted phase encoding. Radiology 1988;169:155–160
15 Murakami T, Marukawa T, Kuroda C, Harada K, Fujita N, Tokunaga K, et al. Siderotic regeneration nodules in liver cirrhosis: evaluation by gradient echo (FLASH) imaging 1.5 T. Nippon Igaku Hoshasen Gakkai Zasshi 1989;49:1427–1429 (in Japanese).
16 Ohtomo K. [Non-Tumorous Lesion of Liver.] In: Kozuka T, ed. [Clinical application of MRI.] Tokyo: Nakayama-Shoten, 1993:233–239 (in Japanese) (Progress series of medical imaging, vol 3).
17 Ohtomo K, Itai Y, Ohtomo Y, Shiga J, Lio M. Regeneration nodules in hepatic cirrhosis: MR imaging with pathologic correlation. AJR Am J Roentogenol 1990;154:505–507.
18 Rammeny E, Weissleder R, Stark DD, Saini S, Compton CC, Bennett W, et al. Primary liver tumors: diagnosis by MR imaging. AJR Am J Roentogenol 1989;152:63–72.
19 Sagoh T, Itou K, Togashi K, Shibata T, Nishimura K, Minami S, et al. Gamna-Gandy bodies of the spleen: evaluation with MR imaging. Radiology 1989;172:685–687.
20 Taupitz M, Hamm B, Speidel A, Deimling M, Branding G, Wolf K-J. Multisection FLASH: method for breath-hold MR Imaging of the entire liver. Radiology 1992;183:73–79.
21 Uchida M, Kumabe T, Abe T, Kojima K, Nishimura H, Edamitsu O, et al. Dynamic CT findings of small hepatocellular carcinoma: the study of tumor detection and diagnostic rate by incremental and helical dynamic CT. Rinsho Hoshasen 1995;40:669–673 (in Japanese).
22 Unger EC, Cohen MS, Gatenby RA, Clair MR, Brown TR, Nelson SJ, et al. Single breath-holding scans of the abdomen using FISP and FLASH at 1.5 T. J Comput Assist Tomogr 1988; 12:575–583.

(Received March 19, Accepted May 22, 1996)