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FULL PAPER

The Dixon technique and the frequency-selective fat suppression technique in three-dimensional T_1 weighted MRI of the liver: a comparison of contrast-to-noise ratios of hepatocellular carcinomas-to-liver

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Objective: The use of three-dimensional T_1 weighted gradient echo sequences such as the Dixon technique and the frequency-selective fat suppression (FS) technique is currently widely accepted method in MRI examinations of the liver. To assess the image qualities of the Dixon technique and the frequency-selective FS technique, the contrast-to-noise ratios (CNRs) of hepatocellular carcinoma (HCC)-to-liver and fat-to-liver were compared between the two techniques in the hepatobiliary phase (HBP) following administration of gadolinium-ethoxybenzyl-diethylenetriamine penta-acetic acid.

Methods: MR images of 59 patients with a total of 86 HCCs were retrospectively evaluated. Images were consecutively obtained with the Dixon and frequency-selective FS methods in the HBP and their CNRs of HCC-to-liver and fat-to-liver were compared. CNRs and contrast ratios were

calculated by the mean value of the liver parenchyma, HCC, fat and standard deviation of the liver parenchyma. The Wilcoxon signed-ranks test was used for statistical analysis.

Results: The median CNRs for the frequency-selective FS and Dixon techniques of HCC-to-liver were 4.3 and 5.4 ($p < 0.01$), mesenteric fat-to-liver were 9.9 and 12.8 ($p < 0.01$) and subcutaneous fat-to-liver were 9.9 and 13.2 ($p < 0.01$), respectively.

Conclusion: The Dixon technique yielded higher CNRs of HCC-to-liver than that of the frequency-selective FS technique.

Advances in knowledge: There are a limited number of reports on quantitative analysis of the image qualities of the Dixon technique and the frequency-selective FS technique, particularly within the same patient and examination.

The use of three-dimensional (3D) T_1 weighted gradient echo sequences such as enhanced T_1 high-resolution isotropic volume excitation (e-Thrive) with administration of gadolinium-ethoxybenzyl-diethylenetriamine penta-acetic acid (Gd-EOB-DTPA), a gadolinium (Gd)-based contrast agent that is selectively taken up by the hepatocytes, is currently widely accepted method in MRI examinations of the liver. e-Thrive achieves fat suppression (FS) by the use of a type of adiabatic pulse called the spectral attenuated inversion recovery pulse, by which signals of fat are suppressed by frequency-selective inversion of its longitudinal magnetization. The inversion recovery time is adjusted such that the signals from fat are nullified and do not contribute to the MR signal. Hence, this technique has been shown to be effective in FS.¹

On the other hand, the Dixon^{2,3} method is a T_1 weighted gradient echo sequence that achieves FS using two different

echo times, namely the in-phase and opposed-phase of water and fat. The Dixon method can achieve better FS in the marginal regions than the frequency-selective FS approach.^{3,4} A modified version of the Dixon method, mDixon,^{5,6} is a “two-point” method that renders images by modifying the opposing “in” and “opposed” phases of the actual measurement to fit the theoretical value. This method can not only obtain four images (in-phase, opposed-phase, water and fat images) in a single scan but also circumvent the limits of the scan parameters because the images can be generated from any pair of phases, as it is not limited to the “in” and “opposed” phases.

mDixon has demonstrated superior image quality and improved FS compared with conventional FS techniques in Gd-enhanced 3D T_1 weighted MRI at 1.5 T.^{7,8} In another study, Gd-enhanced 3D T_1 weighted gradient echo images

at 3.0 T using mDixon showed superior homogeneity of FS and overall image quality compared with those using e-Thrive.⁹

To date, there are a limited number of objective comparisons of image quality between mDixon and e-Thrive, particularly within the same patient and examination.⁹ Although a visual assessment of mDixon and e-Thrive has been reported,⁹ little has been reported on quantitative analysis.

The aim of the present study was to objectively evaluate image quality by measuring the contrast-to-noise ratio (CNR), instead of mere contrast measurement or visual assessment, of hepatocellular carcinoma (HCC)-to-liver and fat-to-liver ratios between images obtained using mDixon and e-Thrive in the hepatobiliary phase (HBP) after Gd-EOB-DTPA administration.

METHODS AND MATERIALS

This retrospective study was approved by the ethics committee of our institution.

A total of 253 patients underwent liver MRI with Gd-EOB-DTPA for a follow-up study between March 2011 and December 2011 in Osaka Red Cross Hospital. In this study, 59 patients with hepatitis B or C (41 males and 33 females; mean age, 73 years; age range, 44–92 years) were enrolled for the evaluation of a total of 86 highly suspected advanced HCCs (size range, 10.1×10.2 to 55.8×73.8 mm; mean, 16.6×16.7 mm). We excluded 194 patients for the following reasons: suspected HCC but diameter of <10 mm ($n = 15$), suspected HCC but unclear evidence ($n = 67$), green hepatoma ($n = 3$), focal nodular hyperplasia ($n = 4$), cyst ($n = 16$), arteriportal shunt ($n = 10$), haemangioma ($n = 12$), metastasis ($n = 12$), fatty liver and fat-containing lesions ($n = 6$), no evidence of any hepatic disease ($n = 41$), metal artefact ($n = 2$), liver cirrhosis ($n = 5$) and *Schistosomiasis japonica* ($n = 1$).

HCCs were diagnosed based on imaging findings by a board-certified radiologist by conforming to the EASL-EORTC Clinical Practice Guidelines.¹⁰ Hepatic lesions with the following MRI findings were diagnosed as HCC; (a) higher signal intensity relative to the surrounding liver in the early phase images (obtained 20–30 s after the administration of Gd-EOB-DTPA), (b) elevation of signal intensity relative to the pre-contrast images in the early phase images, (c) lower signal intensity relative to the surrounding liver in the equilibrium phase (approximately 2 min after administration of Gd-EOB-DTPA) and in the HBP (approximately 20 min after administration of Gd-EOB-DTPA) and (d) diameter of 10 mm or larger.

Dynamic contrast studies were performed using a 1.5-T MRI unit (Achieva, SENSE XL Torso coil; Philips Medical Systems, Best, Netherlands) with mDixon [repetition time, 5.9 ms; echo time, 1.0 and 1.8 ms; echo time, 2.0 and 4.0 ms; sensitivity encoding (SENSE) factor, 2; flip angle, 15°; scan time, 16.7 s] following injection of Gd-EOB-DTPA at a rate of 0.1 ml kg^{-1} of body weight. HBP images were subsequently obtained using both mDixon and e-Thrive (repetition time, 3.6 ms; echo time, 1.75 ms; SENSE factor, 1.7; flip angle, 12°; profile order, linear Z; scan time, 17.9 s) approximately 20 min after Gd-EOB-DTPA injection with the same field of view (350 mm) and pixel size

(matrix, 240; reconstruction matrix, 384; pixel size, 1.46; actual pixel size, 0.91 mm; band width, 541.1 Hz per pixel), same slice thickness (2 mm; overcontiguous slice procedure) and same half scan factor (Y, 0.7; Z, 0.8). The HBP images with e-Thrive and mDixon were obtained within less than 1 min of each other.

The CNR of HCC-to-liver and fat (mesenteric and subcutaneous)-to-liver ratios was measured using the following formulas:

$$\text{CNR of HCC-to-liver ratio: } \text{CNR}_{\text{HCC}} = \frac{(S_{\text{Liver}} - S_{\text{HCC}})}{\text{SD}_{\text{Liver}}}$$

$$\text{CNR of fat-to-liver ratio: } \text{CNR}_{\text{Fat}} = \frac{(S_{\text{Liver}} - S_{\text{Fat}})}{\text{SD}_{\text{Liver}}}$$

The contrast between HCC and its surrounding normal liver parenchyma was calculated using the following formula:

$$\text{Contrast} = \left| \frac{(S_{\text{Liver}} - S_{\text{HCC}})}{(S_{\text{Liver}} + S_{\text{HCC}})} \right|$$

where S_{Liver} is the mean value of the region of interest (ROI) of the normal liver parenchyma, S_{HCC} is the mean value of the HCC ROI, S_{Fat} is the mean ROI value of subcutaneous and mesenteric fat and SD_{Liver} is the standard deviation (SD) ROI of a homogeneous area of normal liver parenchyma.

The ROIs were circular and placed over the HCCs so as to occupy as much area of the lesion as possible. The ROI of the normal liver parenchyma was selected in the vicinity of the HCCs and the other ROIs were placed over subcutaneous and mesenteric fat. ROIs of the normal liver parenchyma and fat tissues were placed over areas that were as homogeneous as possible by avoiding intrahepatic vessels. Equal ROI sizes in both images were selected at the same anatomic location.

Noise measurement with parallel imaging is tricky because the signal and noise depend on the coil geometry and acceleration factor and vary spatially throughout the MR image. This prohibits the use of a conventional method of measuring noise by placing the ROI over air.^{11,12} Moreover, since there is generally less accidental error in areas with higher signal intensity, the SDs of liver parenchyma can be expected to be more reliable than that of air. Hence, we used the SD of adjacent normal liver parenchyma as an estimate of local noise.^{11–13}

Because not all of the data followed a normal distribution, the Wilcoxon signed-ranks test was used for statistical analysis (JMP Pro v. 11.1.1; SAS® Institute Inc., Cary, NC).

RESULTS

The median (interquartile range) e-Thrive/mDixon CNRs of HCC-to-liver were 4.3 (2.4)/5.4 (2.5) ($p < 0.01$) (Figure 1), mesenteric fat-to-liver were 9.9 (3.3)/12.8 (3.7) ($p < 0.01$) and subcutaneous fat-to-liver were 9.9 (2.9)/13.2 (4.1) ($p < 0.01$) (Figure 2). The mean CNR of mDixon was higher than that of e-Thrive in every statistical analysis. Contrast ratios between HCCs and their surrounding normal liver parenchyma showed

Figure 1. Contrast-to-noise ratio (CNR) for hepatocellular carcinoma (HCC). The median CNR for enhanced T1 high-resolution isotropic volume excitation (e-Thrive)/mDixon of HCC-to-liver ratios was 4.3/5.4 ($p < 0.01$), respectively. The CNR of mDixon was higher than that of e-Thrive.

no significant differences between e-Thrive and mDixon ($p = 0.29$) (Figure 3).

DISCUSSION

Our study demonstrated that the CNRs of HCC-to-liver at the HBP of Gd-EOB-DTPA-enhanced MRI using mDixon were higher than those using e-Thrive. The reason that we measured the CNR instead of mere contrast measurement is because the CNR has been shown to accurately reflect tissue differentiation in MRI.¹⁴ Our result is in accordance with that of a study that reported superior detectability of HCC with mDixon.⁹ We believe our quantitative approach has a higher degree of objectivity than that of a receiver operating characteristic analysis. Other strengths of our study are the large number of patients included and that the compared images were obtained at an interval of less than 1 min, as opposed to several months in another study.⁹

The CNR is composed of two factors, namely the contrast and signal-to-noise ratio (SNR). Our results show that the CNR derived from mDixon was higher than that derived from

Figure 2. Mesenteric and subcutaneous fat-to-liver contrast-to-noise ratio (CNR). The median CNR for enhanced T1 high-resolution isotropic volume excitation (e-Thrive)/mDixon of mesenteric and subcutaneous fat-to-liver was 9.9/12.8 ($p < 0.01$) and 9.9/13.2 ($p < 0.01$), respectively. The CNR of mDixon was higher than that of e-Thrive.

Figure 3. Contrast between hepatocellular carcinoma (HCC) and its surrounding normal liver parenchyma. There were no significant differences in contrast measurements of HCC and its surrounding normal liver parenchyma between enhanced T1 high-resolution isotropic volume excitation and mDixon.

e-Thrive, whereas there were no significant differences in contrast measurements. Hence, it follows that mDixon yields a higher SNR than does e-Thrive. This result may be attributable to fundamental differences in the method of FS. mDixon achieves FS by the calculated separation of water and fat, whereas e-Thrive utilizes a pulse to suppress fat-induced signals, which as a result attenuates the net signal and consequently decreases the SNR.

The SNR in SENSE image data (SNR_s) with respect to SNR of standard full Fourier encoding (SNR_f) is given by:

$$SNR_s = \frac{SNR_f}{\sqrt{R} \cdot g}$$

The root of the reduction factor R accounts for the decrease of SNR owing to reduced data sampling, whereas the local geometry factor g describes geometry-related noise enhancement inherent to SENSE.^{15–20} Therefore, the higher SNR of mDixon images from our results allows for use of a higher SENSE factor, which enables reduction of the effective acquisition time for each temporal frame. Moreover, since the improved Dixon technique does not consist of a chemical shift-selective pulse, the scan time is shorter. Such reductions in acquisition time are particularly favourable for breath-hold examinations that are often necessary in liver MRI.

Homogeneous FS is an important factor in liver MRI because tissue contrast enhancement must be differentiated from both intrahepatic and extrahepatic fat signals. It is also helpful in detecting hepatic lesions that occasionally include fat tissue such as HCC. A recent report on the Dixon method has focused on the improvement of phase correction through post-processing algorithms, data acquisition or a combination of both to reduce the effects of B_0 inhomogeneity and facilitate reliable water/fat separation.² For example, comparisons of breast MRI results have shown that mDixon provides better FS than do conventional FS

techniques.²¹ The significantly higher fat-to-liver CNR from our results demonstrated that mDixon excelled in this respect, which was in accordance with the findings of other reports regarding better FS by mDixon.^{7,9}

There were three limitations to this study. First, the HCCs were not pathologically confirmed. However, in this study, we focused on the comparison of the qualities of the images obtained between MRI sequences rather than the diagnostic accuracy of hepatic lesions. We believe that pathological confirmation is not essential with regard to this. Second, no comparison with a visual assessment regarding the homogeneity of FS, artefacts and sharpness was made. We instead focused on more objective criteria in this study. The third

limitation was the lack of a comparison between e-Thrive and mDixon in the earlier phases of the dynamic study. The earlier phases, including the arterial, portal, venous and equilibrium phases, are vital to the diagnosis of HCC. However, in clinical practice, multiple dynamic studies cannot be performed in a single MRI examination because the degree of filling-in and washing-out of the contrast medium in the tissues is highly time dependent. Therefore, we instead focused on the HBP where the difference in contrast material concentration owing to the time interval was negligible.

In conclusion, mDixon yielded higher CNRs of HCC-to-liver than e-Thrive. We believe that higher quality images can be achieved using mDixon for liver MRI examinations.

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