# Dual Double-gradient-echo MRI for Liver Fat Content Analysis

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（Received October 21st, 2005, in final form November 14th, 2005）

**Abstract :** We have devised a modified Dixon method for analyzing fatty infiltration of the liver using a dual double-gradient-echo (DDGRE) sequence. To correct the T2* decay, fourfold echo images were obtained by out-of-phase (TE = 2.3/6.9 ms) and in-phase (4.6/9.2 ms) double-echo sets during a single breath-hold scan on a 1.5 T MRI. The liver fat fractions obtained using the DDGRE method were determined in patients with fatty liver and in healthy volunteers as controls. Moreover, the fat fractions determined in vitro using the DDGRE method were compared with those determined by the conventional double-gradient-echo method, other MRI methods, and X-ray CT. The average fat fractions in patients with fatty liver obtained with the DDGRE method was over 10%, and was significantly greater than those in healthy volunteers. The fat fraction of the phantom obtained with the DDGRE method showed the closest agreement with the actual fat content. The DDGRE method with a single breath-hold makes it possible to simply and accurately analyze fatty infiltration of the liver.

**Key words :** MRI, Fatty liver, Fat content, Double gradient-echo, Phase cycling

## 1. INTRODUCTION

It has been reported that assessment of fat fractions in the liver is helpful for diagnosis of fatty liver, hepatoma, etc. [1,2]. On magnetic resonance imaging (MRI), some techniques could be measured liver fat content. These methods have both advantages and disadvantages [3-5]. In particularly, double-gradient-echo (double-GRE) based on the Dixon method [6] is often used to measure fat fraction [5,7]. However, it has the problems related to T2* decay and indeterminate phase cycling.

To resolve these problems, we devised a dual double-gradient-echo (DDGRE) sequence and an analytical method, which allows accurate determination in both phantom and human studies such as liver lesions. We describe characteristics of the new method and its clinical application.

## 2. MATERIALS AND METHODS

### 2.1 Method for Calculation of Fat Fractions by DDGRE

Fourfold gradient-echo images in each echo time (TE) were obtained with DDGRE sequence and signal intensities in each image were measured. These signals were fitted by using equation (1) to correct T2* [8] and phase cycling [5] (Fig.1) :

$$I_t = \{\,|\,I_w\,|^2 + |\,I_f\,|^2 + 2\,|\,I_w\,||\,I_f\,|\cos\triangle\omega t\}^{\frac{1}{2}} \quad\cdots\cdots (1)$$

$$I_w = I_{w0}\exp(t/T2_w^*)$$

$$I_f = I_{f0}\exp(t/T2_f^*),$$

where $I_w$ and $I_f$ represent the signal intensities of water and
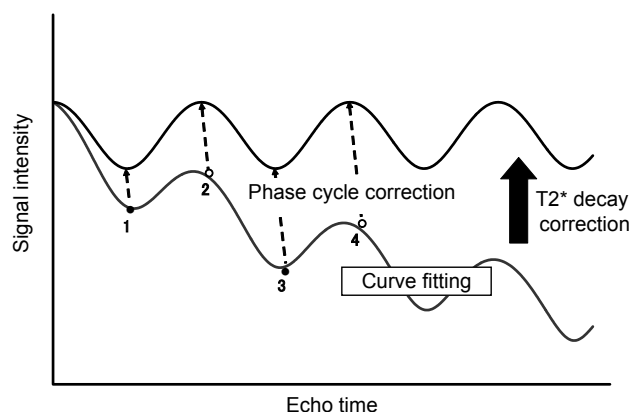


**Fig.1** Curve fitting for correcting T 2* decay and phase cycling. [●1, ●3] indicate the first scan and ［○2, ○4] show the second scan. If only double-GRE [●1, ○2] was obtained, it could not be corrected T 2* decay effect.

fat, respectively, and $I_{w0}$ and $I_{f0}$ represent initial signal intensities of water and fat. $\triangle\omega t$ represents the frequency difference between water and fat signals, and $T2_w^*$ and $T2_f^*$ represent T2* values of water and fat, respectively.

The fat fraction was calculated by substituting the initial signal intensities into equation (2).

$$Fat\ fraction\ (\%) = 100I_{f0}\,/\,(I_{w0}+I_{f0})\quad\cdots\cdots (2)$$

### 2.2 In Vitro Study

Phantoms containing neutral fat (triglyceride), water, and emulsifying agent were adjusted for fat fractions to become 0-100% (weight%) (Fig.2).
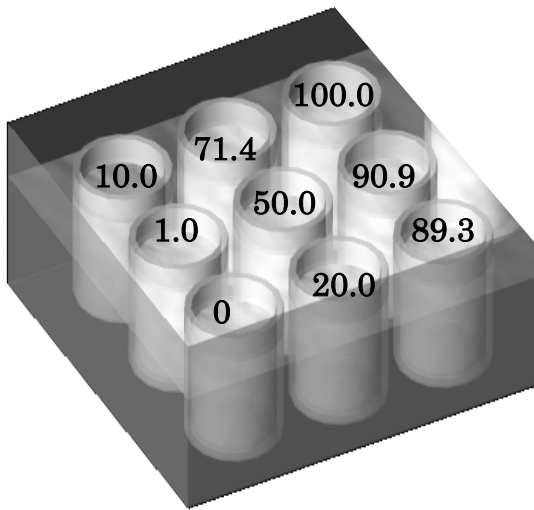
**Fig.2** Phantom containing varying amounts of neutral fat by weight %.

The DDGRE method was compared with other techniques to evaluate the accuracy of fat fraction measurement. The other techniques were used with pulse sequences of double-GRE [5,7], spectral presaturation with inversion recovery (SPIR) [3], binomial pulse (ProSet water selective excitation : WS and fat selective excitation : FS) [4] and X-ray CT [9]. Fat contents were calculated from the following equations.

Double-GRE method :
$$Fat\ fraction\ (\%) = 100(I_{in} - I_{out})/2I_{in} \qquad \cdots\cdots (3)$$

SPIR method :
$$Fat\ fraction\ (\%) = 100(SPIR_{off} - SPIR_{on})/SPIR_{off} \cdots\cdots (4)$$

ProSet WS method :
$$Fat\ fraction\ (\%) = 100(WS_{off} - WS_{on})/WS_{off} \qquad \cdots\cdots (5)$$

ProSet FS method :
$$Fat\ fraction\ (\%) = 100FS_{on}/FS_{off} \qquad \cdots\cdots (6)$$

### 2.3 In Vivo Study
The fat fractions of the livers of 7 healthy volunteers and 4 patients with fatty liver diagnosed by US were determined. We measured signal intensities in each echo image by setting of region of interest at the right lobe of the liver (not included vessels in the multislice transverse plane). The study was performed after informed consent was obtained from the volunteers and patients.

### 2.4 Imaging Conditions
MR imaging was performed on a 1.5 T Gyroscan Intera (Philips Medical Systems) and SIGNA (GE Medical Systems). Scan parameters of DDGRE sequence were set ; TR = 122 ms, TE = 2.3/6.9 ms (out-of-phase) and 4.6/9.2 ms (in-phase), FOV = 220×220 mm, slice thickness = 5 mm, matrix size = 256×205, NSA = 4 in the in vitro study, and TR = 122 ms, TE = 2.3/6.9 ms (out-of-phase) and 4.6/9.2 ms (in-phase), FOV = 350×350 mm, slice thickness = 8 mm, matrix size = 166×208, NSA = 1 in the in vivo study. Flip angle was set at 12 degrees to eliminate the difference in T 1 between the water and fat signals in both studies [10].

## 3. RESULTS

### 3.1 In Vitro Study
Fig.3 shows a comparison between fat fractions with the DDGRE method and with other techniques. Fat fractions of the phantom determined with the DDGRE method agreed most with the actual fat fractions (Fig.3a). Fat fractions determined with the SPIR method also showed good agreement with the actual fat fractions (Fig.3b). The X-ray CT number showed good agreement with the actual fat fractions (Fig.4).
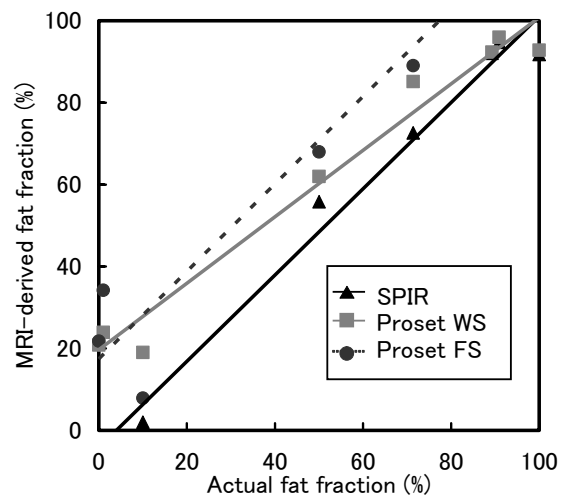
### 3.2 In Vivo Study
The mean fat fraction of the fatty liver group measured using the DDGRE method was 14.6%, which was significantly greater than that in the control group (average, 2.1%) (Fig.5).

## 4. DISCCUSSION

For in vitro study, the double-GRE method yielded overestimations under conditions of high fat content and underestimations in low fat fractions because of T2* decay
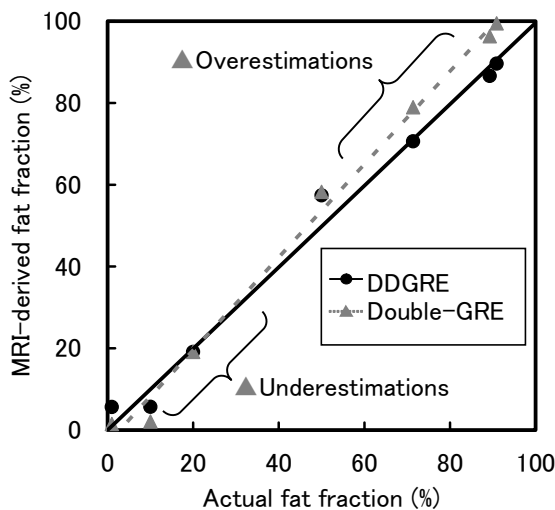


(a)



(b)

**Fig.3** Relationship between actual and MRI-derived fat fractions in each method. (a) DDGRE, double-GRE, (b) SPIR, ProSet WS/FS.
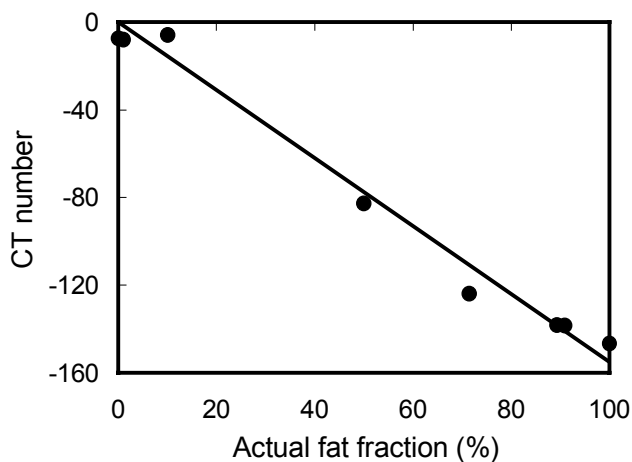
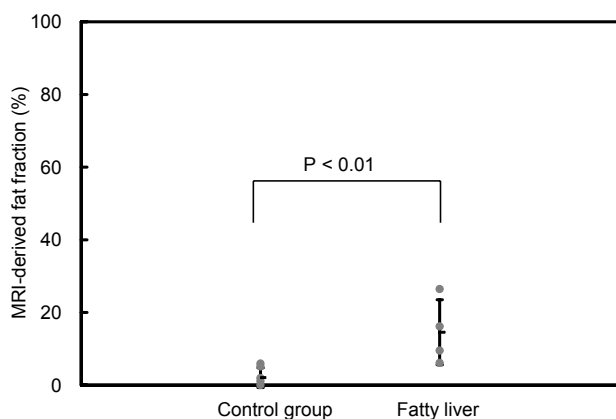**Fig.4** Relationship between the actual fat fraction and CT number.



**Fig.5** Fat fractions determined using the DDGRE method in each group. The mean fat fraction of the fatty liver group was significantly greater than that in the control group (p<0.01).

(Fig.3a). Therefore, it was distinct that T2* remarkably influenced the double-GRE method in the part which has shorter T2* and the DDGRE method with T2* correction was proved useful. On the other hand, fat fractions determined with the SPIR method also showed good agreement with the actual fat fraction (Fig.3b). However, it was difficult to match the two changing slice positions by breathing because the method required acquisition twice with and without SPIR pulse. In the same way, ProSet WS and FS methods also required acquisition twice and the accuracies of fat fractions were inferior to the DDGRE method (Fig.3b). Therefore, they would not be practical. In addition, a strong correlation was observed between CT number and the actual fat fraction of the phantom (Fig.4). However, CT number is defined as normalization of the linear attenuation coefficient and not direct fat content [11]. Furthermore, X-ray CT has problems with radiation exposure.

For in vivo study, fatty liver is defined as that in which the fat fraction is over 10% by weight [11]. The mean fat fraction of the fatty liver group determined with the DDGRE method satisfied this criterion in the present study (Fig.5).

## 5. CONCLUSION

In the in vitro study, fat fractions determined using the DDGRE method agreed best with the actual fat fractions in comparison with other techniques. Moreover, the applicability of the DDGRE method for clinical use was confirmed in the in vivo study.

The DDGRE method with a single breath-hold makes it possible to both simply and accurately analyze fatty infiltration of the liver in a non-invasive manner.

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