Background Gradient Correction for Water and Fat Quantification in 2D Liver Imaging

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Introduction Fatty infiltration of the liver is one of the primary features of nonalcoholic fatty liver disease. Therefore, accurate quantification of the liver fat content is an important factor in detecting hepatic diseases. MRI is an efficient noninvasive tool for assessing liver fat content. A commonly used liver fat quantification technique with MRI is a dual echo imaging (two gradient sequences with different echo times). This technique relies on the chemical shift between water and fat. However, a more accurate approach is required to correct for T2* shortening effect such as iron deposition. In this matter, a multi-echo gradient echo imaging method can be used to compensate the T2* shortenings [1,2]. When using a multi-echo approach, the presence of macroscopic field inhomogeneities also shortens T2* values and can lead to underestimated T2* values of fat content in liver. Here, we propose to correct for these macroscopic inhomogeneities to accurately quantify T2* values and fat, water content using multi-echo 2D liver imaging. We base on our observation that for 2D imaging, inhomogeneities are dominated in the slice direction by a background gradient component [3].

Theory MR signal from liver containing water and fat can be modeled as bi-exponential signal. Because of the different resonance frequency between water and fat (3.4ppm), a phase term is added. Ignoring other effects, each initial magnitudes and relaxation times can be estimated from received signal by using a non-linear magnitude curve fitting algorithm (Levenberg-Marquardt method) [4].
In the presence of the macroscopic (which is larger than voxel size) field inhomogeneity, received signal further decays in gradient echo sequence. In 2D liver imaging, the voxel size in the slice-selection direction is typically larger than the in-plane direction. Inhomogeneity in the slice select direction will dominate and will lead to additional magnitude decay. While zeroth order field inhomogeneities need not be considered for magnitude fittings, first order field inhomogeneities can be magnitude compensated by using a first order approximation background gradient (Gb) component [5]. A linear background gradient can be modeled as a sinc decay [5]. Therefore, our model can thus be expressed as,

$$s_r(TE) = \left(s_w e^{-\frac{TE}{T2_w^*}} + s_f e^{-\frac{TE}{T2_f^*}+i2\pi\Delta f TE}\right) \times \mathrm{sinc}\left(\frac{\gamma}{2} G_b TE\right)$$

The influence of Gb can be appreciated from the above equation. For T2* quantification, it will lead to an under-estimation from the true T2* values for both water and fat, which ultimately affects the content values.

Methods Two experiments were performed to validate the correcting method for the macroscopic linear field inhomogeneity and to investigate its potential usefulness. For acquisition of the T2* relaxation curves, multi-echo gradient echo sequence was used (MEDIC sequence, Siemens Tim Trio 3T).
Scan1 Images were obtained from a well-shimmed condition and also by intentionally applying a linear background gradient in slice-selection direction. Gb correction was then performed to see whether the quantification values gave the results from the well-shimmed condition. (scan time:6.3s, TR:45ms, first echo:2.9ms, echo spacing:2.6ms, voxel size:2.5x2.5x10mm, FOV:320mm, flip angle:20 , 12 echoes)
Scan2 Images were obtained from a healthy volunteer and patient with fatty liver (TR:40ms, first echo:1.9ms, echo spacing:1.5ms, voxel size:2.5x2.5x10mm, FOV:320mm, flip angle:20 , 12 echoes)
Because the scan time was very short, all the participants were indicated to hold their breath without any triggering. The Levenberg-Marquardt algorithm was used for fitting to the bi-exponential model. The standard deviation between the sinc corrected signal and fitted bi-exponential signal was calculated for a G_b value. This process was repeated by varying Gb values and the minimum standard deviation was found, from which the four unknown variables (S_w, S_f, $T2_w^*$, $T2_f^*$) were determined. For quantification, approximately 400 voxels (20 by 20) were manually selected from the liver (Fig. 1).

Results Results from scan1 (Table 1) show that the T2* values were underestimated in the presence of linear gradient field. In the selected ROI, the determined G_b values were approximately 15~25Hz/cm and after linear Gb correction the corrected T2* values and fat content became similar to that of the well-shimmed condition. However, for fat T2* quantification, under-estimation still occurs which was most likely due to low SNR and non-optimized echo spacing selections. Figures 2 and 3 show results obtained from a healthy volunteer and a subject with fatty liver. Quantitative results are given in Table 2 which shows the increased values in the T2* estimates as well as in the fat content percentage.

Discussion & Conclusion For a more accurate measurement of T2* values and its magnitude, field inhomogeneity should be considered along with iron-induced T2* effect. Here, a post-processing technique for large scale linear field inhomogeneity correction was applied to the quantification of the T2* values and fat content to 2D liver imaging. While our preliminary work is based on magnitude data fitting, there is a limitation of this technique because the performance of the magnitude fitting highly depends on the echo times selected. Further applying this method to complex data fitting with increased SNR by optimizing the pulse sequence is expected to enhance the accuracy of the quantification.

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Reference [1] O'Regan et al. (2006). Radiology, 247:550-557 [2] Reeder et al (2005). MRM, 54:636-644 [3] Dahnke et al. (2005) MRM 53:1202-1206 [4] Marquardt (1963). J Soc Ind Appl Math 11:431-441 [5] Fernandez et al (2000). MRM, 44:358-366

	Well-shimmed	Linear Gb without correction	Linear Gb with correction
$T2_w^*$(ms)	25.59±4.23	13.28±2.78	23.49±5.93
$T2_f^*$(ms)	9.48±2.31	2.64±1.84	5.71±3.62
Fat content	8.34±4.28%	2.53±1.54%	10.36±6.36%

Table 1 Results of the scan1

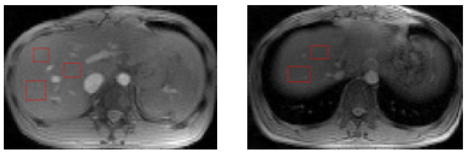

Figure 1 Liver images of the healthy and fiver fatty volunteer (Red rectangles are selected ROI)

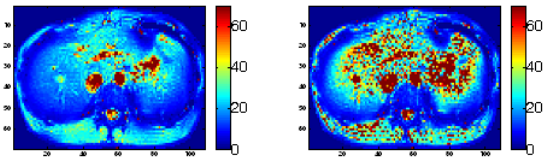

Figure 2 $T2_w^*$(ms) maps of the healthy volunteer (left: without correction, right: with correction)

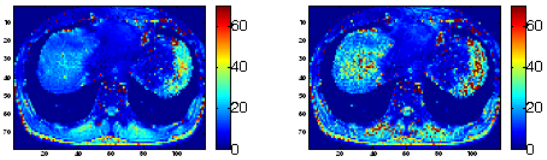

Figure 3 $T2_w^*$(ms) maps of the fatty liver volunteer (left: without correction, right: with correction)

	Healthy		Fatty Liver	
	without correction	With correction	without correction	with correction
$T2_w^*$ (ms)	13.72±2.65	23.25±7.99	18.4±3.52	36.23±9.58
$T2_f^*$ (ms)	3.91±2.11	5.56±2.93	5.57±2.38	6.58±1.96
Fat content	0.48±0.23%	1.82±0.77%	8.28±4.27%	19.23±11.26%

Table 2 Results of the scan2