Fat Quantification in Liver with 3D Multi-Echo GRE Dixon in a Single Breath-Hold: Comparison with HISTO and 2D Multi-Echo GRE Dixon

Xiaodong Zhong[1], Puneet Sharma[2], Wesley D Gilson[3], Vladimir Jellus[4], Stephan Kannengiesser[4], Brian M Dale[5], Berthold Kiefer[4], and Diego R Martin[2]

[1]MR R&D Collaborations, Siemens Healthcare, Atlanta, GA, United States, [2]Radiology Department, University of Arizona, Tucson, AZ, United States, [3]Corporate Research, Siemens Corporation, Baltimore, MD, United States, [4]Siemens AG Healthcare Sector, Erlangen, Germany, [5]MR R&D Collaborations, Siemens Healthcare, Cary, NC, United States

Introduction. Recently, a high-speed T2-corrected multiple-echo 1H-MRS sequence (HISTO) and other equivalent methods demonstrated to be clinically viable by providing accurate hepatic lipid estimation in a single breath-hold (1,2). In contrast, Dixon imaging methods may be more suitable for clinical application, due to full liver coverage (3). As known, hepatic lipid measurement with MRI should compensate for T1 and T2 effects, among other variables, and several 2D and 3D methods currently exist with algorithms of various complexities (2,4). While complex multi-frequency lipid analysis provides high accuracy, conventional multi-echo ($\geq$ 3) Dixon methods may afford comparable results (2). Prior clinical studies using Dixon methods mostly performed a 2D acquisition, with the advantages of interleaved slices, reduced T1 effects, and greater number of echoes for T2* compensation. However, it generally provides relatively low number of slices (15-25 slices), leading to reduced slice resolution (6-10 mm) for whole-liver coverage in single breath-hold (2). 3D Dixon techniques allow limited in- (IN) and opposed-phased (OPP) echoes, but provide high SNR with optimal slice resolution. To our knowledge, no previous studies have compared both 2D and 3D Dixon results to the MRS results in patients. In this study, we sought to (1) develop and evaluate a 3D single breath-hold multi-echo Dixon method with whole liver coverage to quantify the liver fat for clinical use, and (2) compare 2D and 3D single breath-hold Dixon methods for hepatic lipid measurement in clinical patients using HISTO as a reference standard.

Methods. In accordance with protocols approved by our local IRB, 15 patients (55.2 ± 11.6 years, six males) were imaged on a 1.5T MRI system (Avanto, Siemens Medical Solutions, Germany). Three pulse sequences were applied to all the subjects, namely HISTO, 2D GRE Dixon and 3D GRE Dixon. The parameters for HISTO included TR = 3000 ms, TM = 10 ms, TE = 12, 24, 36, 48 and 72 ms, voxel size = 20 or 30 mm, bandwidth = 1200 Hz, sampling points = 1024, and acquisition time = 15 s. A custom Matlab program (Mathworks, Natick, MA) was used to integrate water and fat peaks in the HISTO spectrum, fit the T2 of water and fat, and calculate the fat percentage (FP) using T2-corrected water and fat integral values (1). For the Dixon methods, a 2D multi-slice GRE sequence, and a 3D GRE sequence optimized for volumetric interpolated breath hold examination (VIBE) (5) were modified to perform multi-echo acquisition and image reconstruction online. The parameters of 2D GRE Dixon included TR = 300 ms, slices = 15, slice thickness = 8 mm, slice gap = 2 mm, pixel size = 1.4 – 1.6 mm, acquisition time = 20 s, and TE = 2.38, 4.76, 9.53, and 14.29 ms. Acquisitions with three different FAs, 10˚, 20˚ and 30˚, were performed to investigate the balance between SNR and T1 contamination. The parameters of 3D GRE Dixon included TR = 11.7 ms, FA = 10˚, partitions = 48, partition thickness = 5 mm, pixel size = 1.4 – 1.6 mm, acquisition time = 19 s, and TE = 2.38, 4.76, and 9.53 ms. The magnitude of all IN echoes were used to fit a T2* map, which was used to correct the first IN and OPP echoes. Next, the algorithms described in (6) were performed for phase correction and fat and water image reconstruction. FP maps were then calculated. Offline data analysis was done with ImageJ (National Institutes of Health, Bethesda, MD) and Excel (Microsoft, Redmond, WA). The HISTO VOI was registered across 2-3 slices or 4-6 partitions on the 2D or 3D GRE Dixon images, respectively. SNR, T2* and FP within the HISTO VOI for 2D and 3D GRE Dixon were calculated. Mean FP values within the HISTO VOI were compared by linear regression and Bland-Altman analysis between every two of HISTO, 2D and 3D GRE Dixon. Student t-test and analysis of variance (ANOVA) were performed to evaluate the statistical significance. Data is reported as mean ± standard deviation.
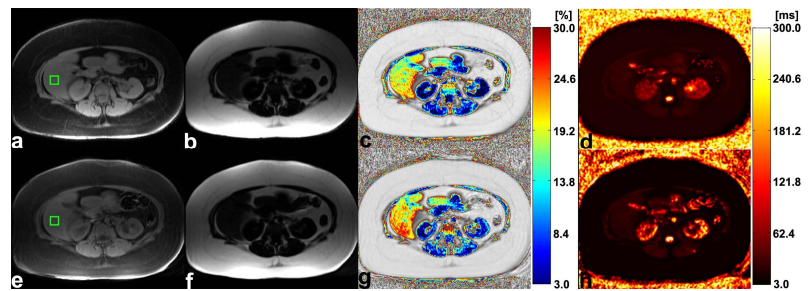

Fig. 1 Example water images (a,e), fat images (b,f), FP maps (c,g), and effective T2* maps (d,h) obtained with 2D (a-d) and 3D GRE Dixon (e-h), respectively, from one patient. The green boxes in a and e indicate the HISTO VOI. FP maps (c,g) were double-thresholded to colorize the FP for organs such as liver, and fused with the original gray scale image mainly showing the subcutaneous fat. T2* maps (d,h) were also colorized for better appreciation.
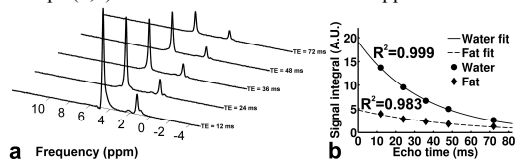

Fig. 2 a: The HISTO spectra from the same patient in Fig. 1. b: The curve fitting for the water and fat integral values.
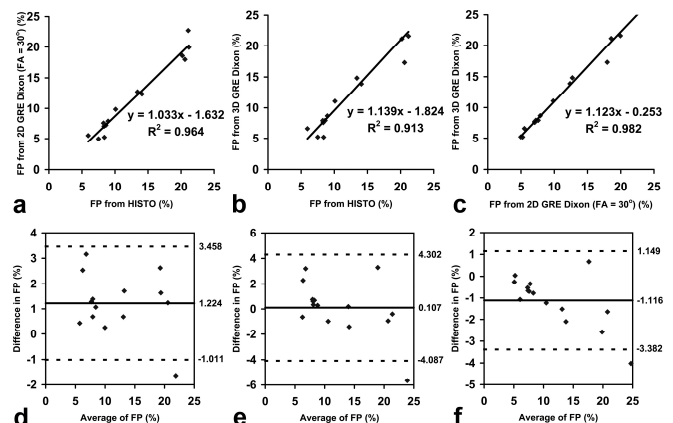

Fig. 3 Linear regression (a-c) and Bland-Altman (d-f). (a,d): HISTO vs. 2D GRE Dixon. (b,e): HISTO vs. 3D GRE Dixon. (c,f): 2D vs. 3D GRE Dixon.

Results. SNR within the HISTO VOI on the first OPP / IN images measured with 2D GRE Dixon with FAs of 10˚, 20˚ and 30˚ for all subjects were 35.5 ± 9.7 / 39.3 ± 10.7, 69.2 ± 26.6 / 78.7 ± 27.2, and 91.8 ± 29.9 / 103.5 ± 29.6, respectively, and indicated significant differences (P < 0.01). By comparison, the corresponding SNR of the 3D GRE Dixon was 89.9 ± 22.1 / 95.3 ± 27.9, which demonstrated significantly improved SNR noticing the difference of voxel size from the 2D methods. The corresponding mean T2* for the 2D methods were 34.3 ± 12.6 ms, 26.1 ± 5.6 ms and 25.7 ± 5.4 ms, respectively (P < 0.01 for 10˚ vs. 20˚ and 30˚). The mean T2* from 3D GRE Dixon was 27.9 ± 11.8 ms, and was significantly different from 2D method with 10˚ only (P < 0.01). The mean FP for the 2D methods were 11.5 ± 4.7 %, 11.1 ± 5.5 % and 11.1 ± 5.9 %, respectively. Mean FP for 3D GRE Dixon and HISTO were 12.2 ± 6.7 % and 12.3 ± 5.7 %, respectively. Using the data of FA = 30˚, example images and plots obtained with these three methods for one patient are shown in Fig. 1 and 2. The mean FP was 18.6% and 21.1%, and the T2* was 25.5 ms and 21.6 ms, measured with 2D and 3D GRE Dixon within the HISTO VOI, respectively. HISTO analysis indicated that the FP of this same patient was 20.2%, and the T2 values of water and fat were 36.2 ms and 52.1 ms, respectively. Good linear correlations were generally found among the FP results of the three methods within the HISTO VOI for all the patients (Fig. 3a-c). Bland-Altman plots also demonstrate good agreement (Fig. 3d-f). ANOVA showed no statistically significant difference among the FP results of these three methods.

Discussion and Conclusions. A single breath-hold multi-echo 3D GRE Dixon method with whole liver coverage was developed and preliminary evaluation was performed in clinical patients. This 3D GRE Dixon method produced similar liver fat quantification results to those measured with multi-echo 2D GRE Dixon, and a HISTO reference standard, for the protocols and patients tested in this study. This single breath-hold 3D Dixon method can be easily adopted in routine clinical scanning, and has great potential for efficiently evaluating the hepatic steatosis for obesity related liver diseases.

1. Pineda et al. Radiology 2009;252:568-576.
2. Yokoo et al. Radiology 2009;251:67-76.
3. Dixon. Radiology 1984;153:189-194.
4. Yu et al. MRM 2008;60:1122-1134..
5. Rofsky et al. Radiology 1999;212:876-884.
6. Jellus. US Patent 0201364 A1;2010.