Total liver fat quantification using a 3D respiratory self-gating technique

Carolina Arboleda Clavijo[1], Daniel Aguirre-Reyes[1], Cristián Tejos[1], Loreto Muñoz[2], Catalina Carvajal[2], Pablo Irarrazaval[1], Marcelo Andia[3], and Sergio Uribe[3]
[1]Department of Electrical Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile, [2]Chemistry and Bioprocesses Department, Pontificia Universidad Católica de Chile, Santiago, Chile, [3]Department of Radiology, Faculty of Medicine, Pontificia Universidad Católica de Chile, Santiago, Chile

Target audience: Gastroenterologists and liver imaging researchers.

Purpose: In the last years, there has been extensive research on non-invasive MRI techniques that provide quantitative fat-fraction (FF) measurements of the liver. A traditional method acquires images at multiples echoes, and multiple slices are obtained during several breath holds to cover the entire liver. Unfortunately, the number and length of the breath holds limits the achievable spatial resolution, number of echoes acquired and coverage. Moreover, these sequences may show imprecise alignment of the acquired slices, so a 3D liver FF map obtained from this approach may be inaccurate. Therefore, alternative motion correction strategies are necessary for fat quantification in the entire liver. Respiratory bellows and navigator beams[1,2,3], can be used to correct respiratory motion, but they imply either using an external device or adding extra RF pulses, which might increase scan time and interfere with the imaging process[4,5]. To address these limitations, we propose to integrate a real-time respiratory self-gating approach to a 3D 3-point Dixon imaging sequence for total liver fat quantification.

Methods: A respiratory self-gating technique was integrated into a 3D 3-point Dixon turbo gradient-echo sequence on a Philips Achieva 1.5T clinical scanner. We acquired a non-angulated coronal volume covering the whole liver with the read-out placed in the foot–head direction. The k-space center was revisited throughout the acquisition to monitor the position of the liver. The respiratory motion-detection algorithm is explained in detail elsewhere[5]. The gating strategy was performed in real time and forced the reacquisition of rejected data. The window of acceptance was adjustable by the user and the scan efficiency was displayed continuously, which allowed us to monitor the breathing pattern. To validate the method, we performed experiments in phantoms with different fat fractions and in normal-weight and overweight volunteers. The phantom consists of 5 water-fat emulsions with known fat content (0, 5, 20, 45 and 50 %). In both the phantom and volunteers, we carried out a 3D 3-point Dixon sequence (TE_s =2.3, 3.5 and 4.7 ms) with and without respiratory self-gating. In the phantom, this experiment was performed to see if the acquisition of the extra k_0 profiles interfered with the quantification of fat. In the in-vivo scenario, these scans allowed us to assess how breathing motion affected the FF computation. For comparison purposes, a breath-hold multi-2D 3-point-Dixon sequence (TE_s =2.3 ms, 3.5 ms and 4.7 ms, TR =15 ms, flip angle = 10º and NSA=2) was also performed. The FF maps were computed as the ratio of the fat signal to the sum of the water and fat signals. In volunteers, three 3D ROIs in the superior, middle and inferior liver, respectively, were drawn and the mean FFs of these ROIs are reported in this work. A statistical analysis of the mean and variance of the FF obtained in volunteers was performed using a paired t-test and a one-way ANOVA test respectively. We also present a Bland Altman plot comparing the different techniques.

Results: The self-navigated method yields more precise FF values and much lower standard deviations, compared to the 2D method. In addition, it does not interfere with the quantification (Table 1). A drastic reduction of motion artifacts can be appreciated in the water images of a volunteer (Fig. 1). A FF map corresponding to the middle-liver transverse slice of another volunteer is shown in Fig. 3. The FF map obtained from the 2D method is contaminated by noise, which contributes to a higher standard deviation. The means and standard deviations of the fat percentages of the whole group of volunteers were 11.8±2.8, 10.5±2.13 and 11.0±4.97 for the free breathing, self-gating and multi-2D approaches, respectively. The mean acquisition time was 3.5 minutes for the multi-2D breath-hold and 5 minutes for the 3D self-navigated acquisition. Statistical analysis showed a not-statistically-significant difference in the mean between the 2D and any of the three methods; however, analysis of the variance shows a significant difference between the 2D and any of the 3D methods. In particular, the variation coefficients were 0.5, 0.33 and 0.34 for the multi-2D, 3D free breathing and 3D self-gating respectively. Bland Altman plots show a negligible bias when comparing the FF values between the proposed approach and the standard multi-2D method (Fig. 2).

Table 1. Fat percentages (mean ± standard deviation) in the phantom

Theoretical	M-2D	Non-self-navigated	Self-navigated
0	1.95±0.99	0.88±0.36	0.97±0.41
5	5.26±1.26	5.09±0.40	5.00±0.42
20	21.58±1.29	20.7±0.38	21.08±0.47
45	47.02±1.38	45.2±0.55	45.69±0.65
50	52.04±1.44	51.06±0.55	51.96±0.69

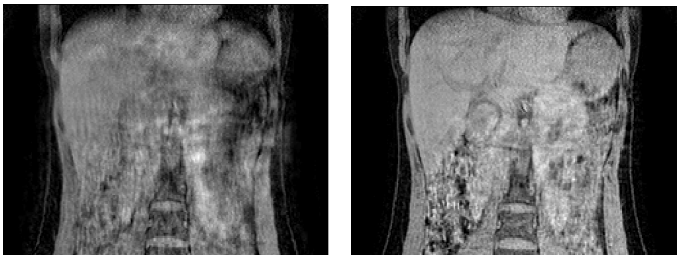

Fig. 1. Left: Free-breathing. Right column: Self-navigated

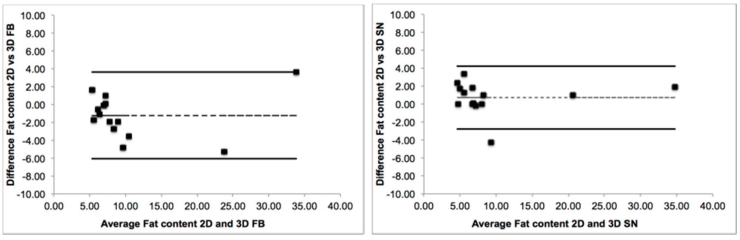

Fig. 2. The Bland-Altman plot between the self-navigated technique and the multi-2D approach (right) shows a smaller bias and standard deviation than the Bland Altman plot between the multi-2D and the free-breathing acquisition (left).

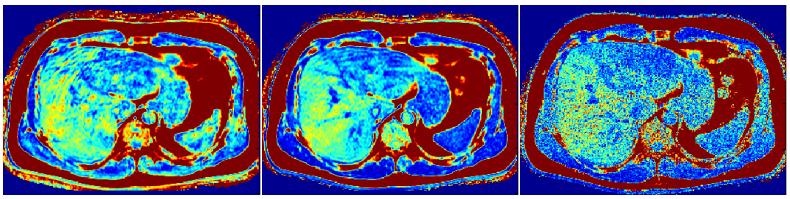

Fig. 3. Fat fraction maps. From left to right: 3D free-breathing, 3D self-navigated and multi-2D. Corresponding fat percentages: 28.64±2.63, 24.54±2.78 and 27.10±8.06.

Discussion: The results obtained evidence that the 3D self-navigated fat quantification sequence allows a more precise quantification of fat, compared to the widely used breath-hold multi-2D acquisition sequences. Our experiments showed that switching from a multi-2D to a 3D acquisition scheme contributes to improve the accuracy and reliability of fat quantification; however, free breathing introduces significant distortions in the fat quantification (Fig. 3). We showed that our sequence proved to be able to correct respiratory motion (Fig. 1) and to yield precise FF maps of the entire liver in a single free-breathing scan.

Conclusion: A 3D self-navigated MR sequence for liver fat quantification was introduced and tested both in-vitro and in-vivo. It proved to be successful for the correction of respiratory motion and to yield more precise FF than the values obtained from the current standard breath-hold multi-2D acquisitions.

References: 1. Danias PG et al. Radiology 1998. 2. Hu X et al. MRM 1995; 3. Sachs T et al. MRM 1994; 4. Brau ACS, et al, MRM 2006. 5. Uribe S et al. MRM 2007.