Fat Fraction Bias Correction using Estimated T₁ Values

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Introduction: T₁ independent, T₂* corrected chemical shift based fat-water separation methods with accurate spectral modeling of fat (quantitative IDEAL) [1, 2] have been employed to non-invasively quantify liver fat content. Unlike liver biopsy, MRI is unaffected by sampling variability due to the inhomogeneous distribution of steatosis. However, as noted by Liu et al. [1], the difference in the T₁ between fat and water protons results in bias in the fat fraction measurement. Liu et al. [1] proposed two solutions: acquire images by utilizing iterative Decomposition of water and fat with Echo Asymmetry and Least-squares estimation (IDEAL) with spoiled gradient echo (SPGR) at a small flip angle (~5°); or using two consecutive IDEAL acquisitions at different flip angles to calculate proton density of water and fat, which would be independent of T₁. The problem with the latter method is a doubling in scan time due to the need to acquire two images. As noted by Wiens et al. [3], the increased scan time with two acquisitions resulted in lower noise efficiency compared to single image acquisition. The small flip angle method does not correct for the T₁; instead it reduces bias by decreasing the influence of T₁ on the measured signal. However, as signal intensity is related to the flip angle, using a small angle results in decreased SNR. Previous work has demonstrated how to use prior knowledge of the fat T₁ (T₁f) and liver water T₁ (T₁w) to select the maximal flip angle that will result in an acceptable degree of bias in the fat fraction estimate [4]. In this study, we aimed instead to investigate the effect of applying T₁ corrections by using estimated T₁ values for liver and fat to minimize T₁ bias in the fat fraction estimate.

Methods: Initial simulations emulated fat fraction acquisitions over a range of flip angles. We used fat and water T₁ values of 382 and 809 ms to simulate the signal we would see from fat and liver at 3T [5]. We simulated IDEAL SPGR acquisitions with various flip angles and a TR of 14.8 ms. The resulting estimated fat fraction and its deviation from true fat fraction was determined. Follow up experiments were performed on three fat-water phantoms of varying concentrations of peanut oil and water (20%, 47% and 60% fat fraction). The true phantom fat fractions were verified with STEAM spectroscopy obtained at TEs of 14 and 30 ms. The areas under fat and water peaks in each spectrum were determined, and then corrected for T₂ decay by an exponential fit from which proton density was calculated. True fat fractions were determined by taking the ratio of the T₂ corrected area under the fat peak and the combined area of fat and water peaks. Phantoms were imaged at 3.0T (Discovery MR 750, GE Healthcare, Waukesha, WI) using Quantitative IDEAL acquisitions at varying flip angles. Imaging parameters were: TR=14.7 ms, TE=[1.5, 2.1, 2.6, 3.1, 3.7] ms, NEX=256, Nz=256, FOV=28cm x 28cm, and slice thickness=8mm. The true T₁ for both fat and water were estimated using DESPOT with IDEAL images acquired at flip angles of 5° and 29° [6] and found to be 453 ms for fat and 1517 ms for water. T₁ bias corrections were performed on the phantom water and fat images to convert them to estimated proton density maps using either 3.0T T₁ estimates for subcutaneous fat (T₁f=382 ms applied to the fat image) and liver (T₁w=809 ms, applied to the water image) obtained by Bazelaire et al [3], or the true T₁s determined by DESPOT. The T₁ corrected fat and water images were used to create fat fraction maps. The measured fat fractions were then compared to the true fat fractions.

Results: Figure 1 shows the simulated result of fat fraction bias acquired over a range of flip angles at 50% fat fraction before and after T₁ correction. Simulated bias corrections utilized T₁w overestimation and T₁f underestimations of 10% and 20% to the true T₁s, because these estimations produced the largest amount of residual bias. Figure 2 shows the measured fat fraction using T₁ correction with T₁s obtained from literature and correction with T₁ values obtained from DESPOT (T₁f=1517 ms, T₁w=453 ms). Bias decreased even when corrected with literature based estimates of T₁ significantly different than the true T₁. Figure 3 shows the fat fraction images obtained with flip angle of 10° before and after T₁ correction was performed with measured T₁ values and estimated T₁ values. When using estimated T₁ values, the difference between the observed fat fraction and the true fat fraction was reduced by 11% in the 20% fat fraction phantom, 11% in the 47% fat fraction phantom and 9% in the 60% phantom.

Discussion: Figures 1 and 2 show that even with estimated T₁s as much as 46% different from the true T₁, there will still be a decrease in the fat fraction bias compared to no correction. This bias is much larger than what would be expected in-vivo due to the large difference between T₁w and T₁f. Although the residual bias after increase corrections with increasing flip angle, images can be acquired at a greater flip angle and have the same amount of bias if a lower flip angle was utilized, with the benefit of increased SNR. While making corrections using T₁ values obtained by algorithms such as DESPOT reduce bias more than using an estimate, dual flip angle acquisitions are difficult to achieve during patient scans and in any case would yield lower SNR than two averages of a single flip angle acquisition. Noise bias was not considered in this experiment, which results from using the magnitude of the signals. Unlike T₁ bias, noise bias decreases with increasing flip angle due to increased SNR. The optimal tradeoff between T₁ bias and noise bias will be examined in future work.

Conclusion: Correction of T₁ bias with an assumed value of T₁ for fat and water signal is shown to be a simple yet practical method of reducing bias in fat fraction quantification that is effective even when the T₁ used for correction is substantially different from the true T₁.

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