On the need for T2* correction in quantitative water-fat imaging of skeletal muscle

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Target audience: Basic scientists and clinical researchers working in water-fat separation

Purpose: Quantitative water-fat imaging of skeletal muscle has recently received considerable interest for assessing skeletal muscle fatty infiltration in myopathies [1,2], metabolic disorders [3] and other musculoskeletal pathologies [4]. Quantitative water-fat imaging has been successfully applied in different body parts using chemical shift based water-fat separation techniques after mitigation or correction of multiple factors confounding the aimed proton density fat fraction extraction. T_2* decay is a confounding factor in chemical shift based water-fat separation, extensively investigated in the context of liver fat quantification [5,6]. Specifically, it has been shown that T_2* decay effects can induce significant bias in the estimation of liver fat fraction, especially in the presence of short T_2* induced by iron overload [7]. Given the relatively moderate T_2* of skeletal muscle (of the order of 25 ms at 3 T), some previous muscle water-fat imaging studies have not used a T_2* correction. In parallel, recent work has shown that susceptibility-induced fat resonance shift effects can confound skeletal muscle fat quantification, but the effect is small when T_2* correction and a low number of echoes are employed [8]. However, it remains unknown whether T_2* correction is necessary in the presence of susceptibility-induced fat resonance shift effects. Therefore, the purpose of the present work is to characterize the effect of T_2* relaxation in water-fat imaging of skeletal muscle, where susceptibility-induced fat resonance shift effects are also present.

Methods: Simulations: A water-fat signal model was adopted taking into consideration the presence of multiple fat peaks [6,9], a single T_2* decay [5,6] (T_2* of water and fat peaks=25 ms) and the presence of susceptibility-induced fat resonance shift (labeled x) [8]. Synthetic data were generated for nominal fat fraction varying between 0 % and 100% in the absence and presence of susceptibility shift effects (x=0 and x=25 Hz). Methods accounting for the presence of multiple fat peaks with x=0, and employing either no T_2* correction or a single T_2* correction, were used to estimate the fat fraction. The simulations were repeated for first echo time (TE_1) and echo spacing (ΔTE) values varying between 0 and 2.4 ms.

In vivo measurements: An 8-channel extremity coil was used to coronally scan the calf muscle of a healthy volunteer on a 3 T Philips scanner. A six-echo mDixon acquisition [10] with six echoes per TR and flyback readout gradients was performed using a 3D spoiled gradient echo sequence with parameters: FOV=260x146x150 mm, TR/ΔTE=12/1.25 ms, flip angle= 3° (to minimize T_1-bias effects), acquisition matrix 64x98x100, bandwidth=3255 Hz/pixel. The acquisition was repeated with varying values of the first echo time TE_1 (1.1, 1.4, 1.7, 2.0 and 2.3 ms).

Results: Simulations: Fig. 1 shows the worst-case fat fraction bias when x=0 and x=25 Hz without and with T_2* correction. In the presence of susceptibility induced fat resonance shift (x=25 Hz), there is a significant bias in the fat fraction estimation when no T_2* correction is performed for certain combinations of TE_1 and ΔTE (e.g. point C with $TE_1/\Delta TE$=2.0/1.25 ms). The fat fraction bias is considerably reduced when T_2* correction is used. Fig. 2 shows an overestimation of the fat fraction for low fractions (<10%) (small arrow) and an underestimation of the fat fraction for fat fractions in the range between 30% and 60% (large arrow) when no T_2* correction is performed (for the echo times of point C of Fig. 1).

In vivo results: Fat fraction values were computed by averaging the signal and performing the water-fat decomposition across every row of ROI 1 (ROI in the border between muscle and subcutaneous fat) and by performing the water-fat decomposition for every voxel in ROI 2 (ROI containing both muscle and significant intramuscular fat) (Fig. 3a). The fat fraction estimated with the T_2* correction method using the data acquired with $TE_1/\Delta TE$=1.1/1.25 ms (point A) was employed as reference value. Figs. 3b and 3c show a strong dependency of the fat fraction estimation on the experimental parameters ($TE_1/\Delta TE$) when no T_2* correction is performed. A more stable estimation of the fat fraction across experimental parameters is observed when T_2* correction is used. Figs. 3d and 3e show an overestimation of the fat fraction for low fat fractions (small arrow) and an underestimation of the fat fraction in the range above 30% (large arrow), when no T_2* correction is performed.

Discussion & Conclusion: The overestimation of the fat fraction at the low fat fraction regime due to the lack of T_2* correction has been shown in previous studies [7]. However, the present results show an additional underestimation of the fat fraction at the moderate fat fraction regime, when no T_2* correction is performed in the presence of both T_2* decay and susceptibility induced fat resonance shift effects. The fat fraction underestimation due to the synergistic effect of T_2* decay and susceptibility shift is highly dependent on the choice of the employed echo time values. Single T_2* correction reduces fat fraction bias due to the synergistic effect of T_2* decay and susceptibility shift, independent of the choice of TEs. Therefore, single T_2* correction should be considered as a way to improve the robustness of skeletal muscle fat quantification across different choices of TEs.

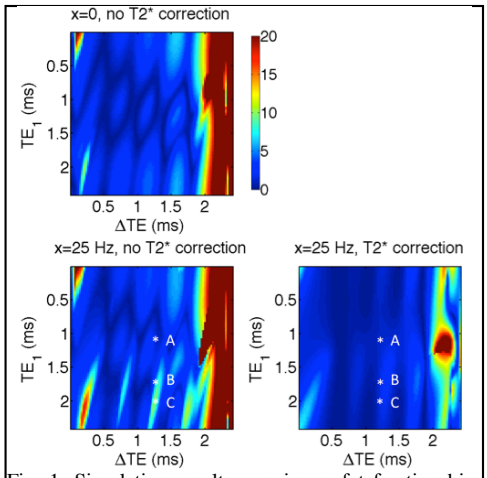

Fig. 1: Simulation results: maximum fat fraction bias (0%<nominal FF<45%) as a function of TE_1 and ΔTE.

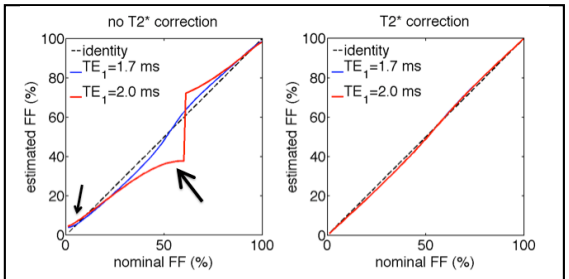

Fig. 2: Simulation results: fat fraction in the presence of susceptibility-induced fat resonance shift for the echo times of points B and C (Fig. 1) without and with T_2* correction.

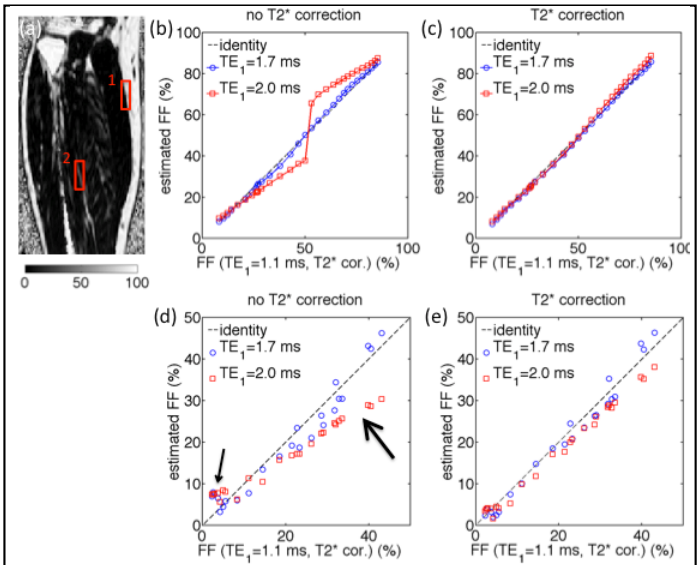

Fig. 3: *In vivo* results: (a) fat fraction map, (b, c) fat fraction bias over ROI 1 at different TE_1 without (b) and with (c) T_2* correction, (d, e) fat fraction bias over ROI 2 at different TE_1 without (d) and with (e) T_2* correction.

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Acknowledgement: The present work was partially supported by Philips Healthcare.