Fat Correction of MRI Phase Images for Accurate Susceptibility Mapping in the Head and Neck

Anita Karsa[1], Shonit Punwani[2], and Karin Shmueli[1]

[1]Department of Medical Physics and Biomedical Engineering, University College London, London, United Kingdom, [2]Centre for Medical Imaging, University College London, London, United Kingdom

Synopsis

Susceptibility Mapping (QSM) is increasingly applied in parts of the body where fatty tissue is present. QSM uses the phase of the complex MRI signal which contains both susceptibility-, and chemical-shift-induced components. For accurate QSM, the latter need to be suppressed. Here we compared a range of different fat-correction strategies for QSM in head-and-neck images. Techniques providing reliable fat-fraction maps also gave similar susceptibility values in fatty fascia. However, some of these methods were not robust to the choice of echo times. In-phase imaging was found to be the best candidate for robust fat-correction in QSM of the head-and-neck.

Purpose

Susceptibility mapping (QSM) is a recent technique that calculates tissue magnetic susceptibility from MRI phase images[1-2]. It is increasingly applied in parts of the body other than the brain where fatty tissue is present[3-5]. The chemical shift (CS) between fat and water appears as variations in the phase maps that are not susceptibility-induced. These can lead to different contrast between fat- and water-based tissues in the susceptibility map for images acquired at different echo times. Therefore, for accurate QSM, it is essential to remove CS-induced phase variations. In this work, we compared a range of different fat-correction techniques in head-and-neck images of healthy volunteers in terms of field and susceptibility map quality, susceptibility of fatty fascia, and robustness to variable echo timing.

Methods

Multi-echo head-and-neck images were acquired in a healthy volunteer (Volunteer 1) on a 3T Philips Achieva (Best, NL) scanner using a 16-channel head-and-neck coil with parameters shown in Figure 1, Volunteer 1 (i). In-phase images[6] were also acquired in the same volunteer (Figure 1, (ii)). Fat-fraction and fat-corrected field maps were calculated for Volunteer 1 (i) using five different fat-correction techniques: one designed for QSM (SPURS[11]) and the rest from the 2012 ISMRM fat-water separation challenge[12] (Figure 2). A field map was also calculated from (ii) using non-linear field fitting[13-14] on the multi-echo complex images. A head-and-neck tissue mask was calculated by thresholding the inverse noise map[14-15]. Susceptibility maps were calculated from the in-phase field map and all field maps with reliable fat-fraction maps (Figure 2, yellow boxes) using: 1. Laplacian phase unwrapping[16] (except for the SPURS field map which was already unwrapped), 2. Projection onto Dipole Fields[17], 3. Iterative fitting with Tikhonov regularisation[15]. Two 3D ROIs were drawn manually (Figure 3, magnitude image) in the fatty fascia on the first-echo magnitude image of (i) in ITK-SNAP[18-19]. The same regions were segmented in (ii) by rigidly registering the first-echo magnitude images using NiftyReg[20] and applying the resulting transformation to the ROIs. The mean and standard deviation (SD) of the susceptibility in the ROIs were calculated in each case. SPURS and 3PD were also tested in head-and-neck images acquired in three more healthy volunteers using slightly different echo timings (Figure 1).

Results and Discussion

Figure 2 shows a comparison between the six fat-correction strategies. GOOSE failed to provide an accurate fat-fraction map. B0-NICE and IGCA estimated high fat-fraction in the water-based sternocleidomastoid muscle (red arrows), and low fat-fraction in the subcutaneous fat (blue arrows). Fat-fraction maps provided by 3PD and SPURS were similar and in accordance with the known anatomy. Moreover, the 3PD, SPURS, and in-phase acquisition field maps were also very similar. Figure 3 shows susceptibility maps calculated from these three field maps. All three susceptibility maps had very similar fat/muscle contrast (yellow/white arrows). The susceptibility values of fat measured in two ROIs containing fatty tissue (see magnitude image) are in good agreement for the three fat-correction strategies.

Figure 4 shows fat-fraction maps in four different volunteers, acquired with three different echo-timings (Figure 1), calculated using 3PD and SPURS. Both fat-correction techniques provided realistic fat-fraction maps in Volunteers 1 and 2 when the images were acquired with (i). However, these techniques failed for images of slightly different echo timings ((iii) and (iv)). Both algorithms include a step when the water and fat signals are determined in each voxel using region-growing methods that assume spatial smoothness. When this step fails, fat-water swaps can occur in the images (Figure 4, arrows). 3PD consistently failed for the (iii) echo timing, but performed well for (i) in both volunteers. According to the guidelines in Berglund et al.[7], the echo timing in (iii) is not suitable for accurate water-fat separation at 3T, but the timing in (i) is close to optimal. However, there is only a 0.2 ms difference in both TE_1s and ΔTEs between (i) and (iii). Consequently, a slightly different magnetic field or chemical shift could easily lead to similar errors. Therefore, 3PD cannot be expected to perform robustly in a multi-centre study. SPURS also failed for slightly different echo timings ((iii) and (iv)), therefore it is not robust to echo-timing either. In-phase imaging (ii) is a built-in option in most scanners. It suppresses CS effects on a voxel-by-voxel basis without performing any spatial, region-growing techniques. Therefore, it is a good candidate for robust fat-correction in head-and-neck images for accurate QSM.

Conclusions

We found in-phase imaging to be the most robust, fat-correction strategy for head-and-neck images. Future work will involve investigating the repeatability of head-and-neck susceptibility maps using in-phase imaging to suppress chemical shift effects.

Acknowledgements

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Figures

Figure 1: MRI acquisition parameters used to acquire multi-echo head-and-neck images in four healthy volunteers. (i) – (iv) were all 3D gradient recalled echo sequences with field of view = 22×24×24 cm, SENSE factor = 1.5×2×1 (RL-AP-HF), and flip angle = 18°.
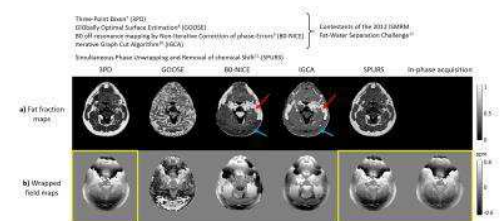

Figure 2: Comparison of six fat-correction strategies in Volunteer 1. Fat-fraction (a) and wrapped field maps (b) estimated using five different post-acquisition techniques and in-phase imaging are shown in the same transverse slice. The results of SPURS and GOOSE were rewrapped for ease of comparison. Note that fat-fraction maps cannot be calculated when in-phase acquisition is used. The arrows indicate the water-based sternocleidomastoid

muscle (red arrows), and the subcutaneous fat (blue arrows) in the B0-NICE and IGCA fat-fraction maps. Susceptibility maps were calculated from the field maps highlighted by yellow boxes.
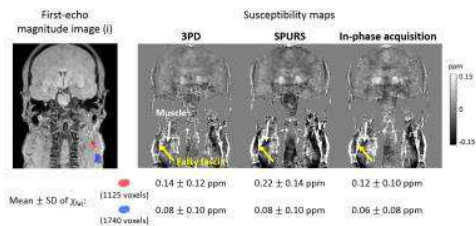

Figure 3: Susceptibility maps calculated from the 3PD, SPURS, and in-phase acquisition field maps of Volunteer 1. The arrows indicate the fatty fascia (yellow) and the surrounding muscle (white) in each map. Two fatty ROIs are shown in the magnitude image. The mean and standard deviation of susceptibility in these regions are displayed below each susceptibility map.
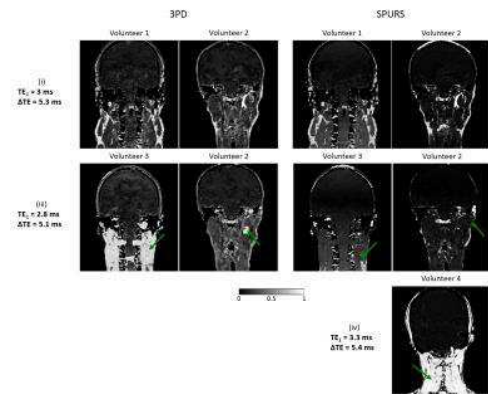

Figure 4: Fat fraction maps calculated in four different healthy volunteers using 3PD and SPURS. The echo timings are shown next to the images. The arrows indicate artifacts in the fat-fraction maps due to fat-water swaps.