Fat Correction for Susceptibility Mapping in the Head and Neck

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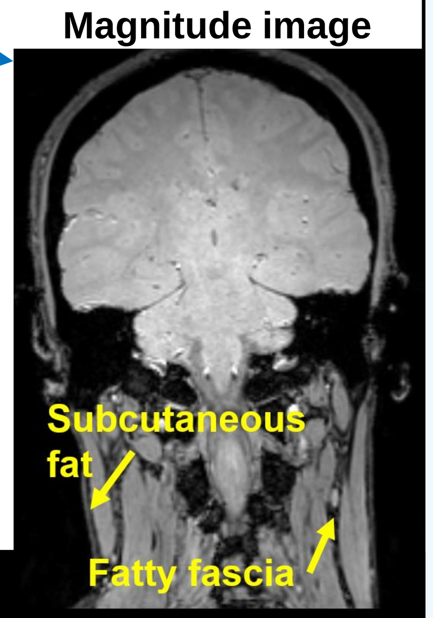
Introduction

- Magnetic Susceptibility Mapping (SM) is a recently developed MRI technique with emerging clinical applications[1]. It calculates magnetic susceptibility (χ) maps from MRI phase images[2]
- SM is increasingly applied in parts of the body other than the brain (like the head-and-neck) where fatty tissue is present[3-4]
- The chemical shift (CS) between fat and water appears as variations in the phase maps that are not χ-induced. These can lead to different contrast between fat and water in the χ map for images acquired at different echo times (Figure 2, bottom row, arrows). For accurate SM, it is essential to suppress CS-induced phase variations
- There are a number of strategies for fat correction (FC) in phase images. However, there is no established value for the χ of fat in the literature

Magnitude image

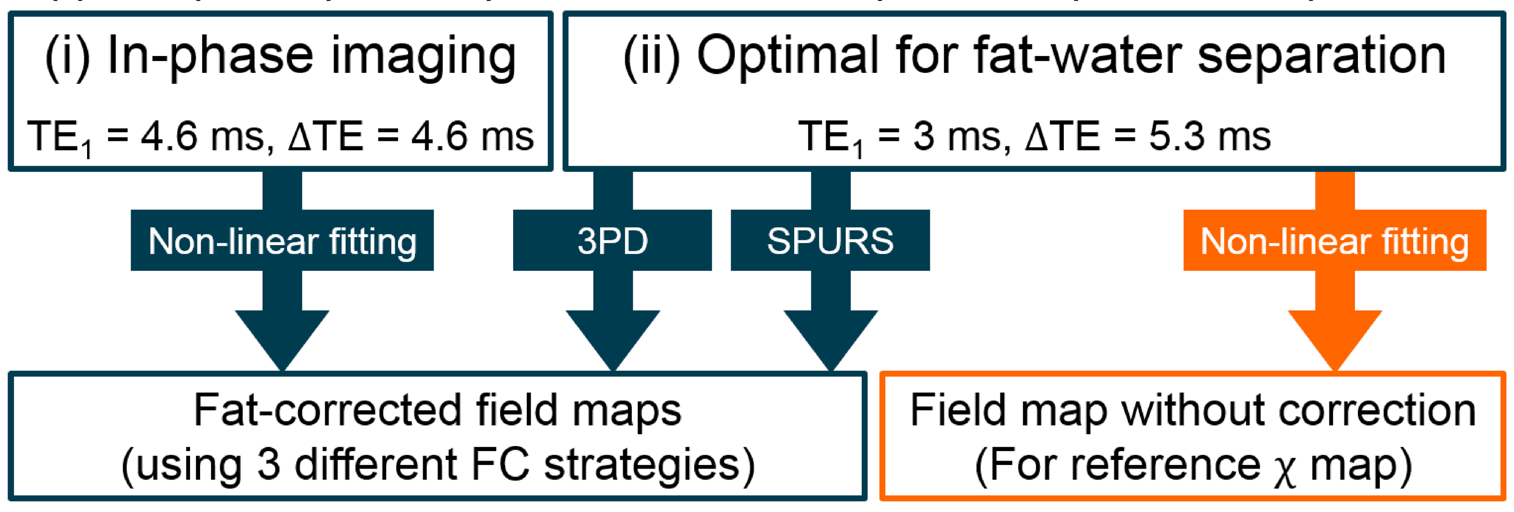


Aims:

1. To compare χ maps of the head-and-neck using three different fat-correction (FC) strategies: In-phase imaging[5], the 3-point Dixon method[6] (3PD), and Simultaneous Phase Unwrapping and Removal of chemical Shift[7] (SPURS)
2. To investigate echo-time dependence of the χ contrast using 3PD

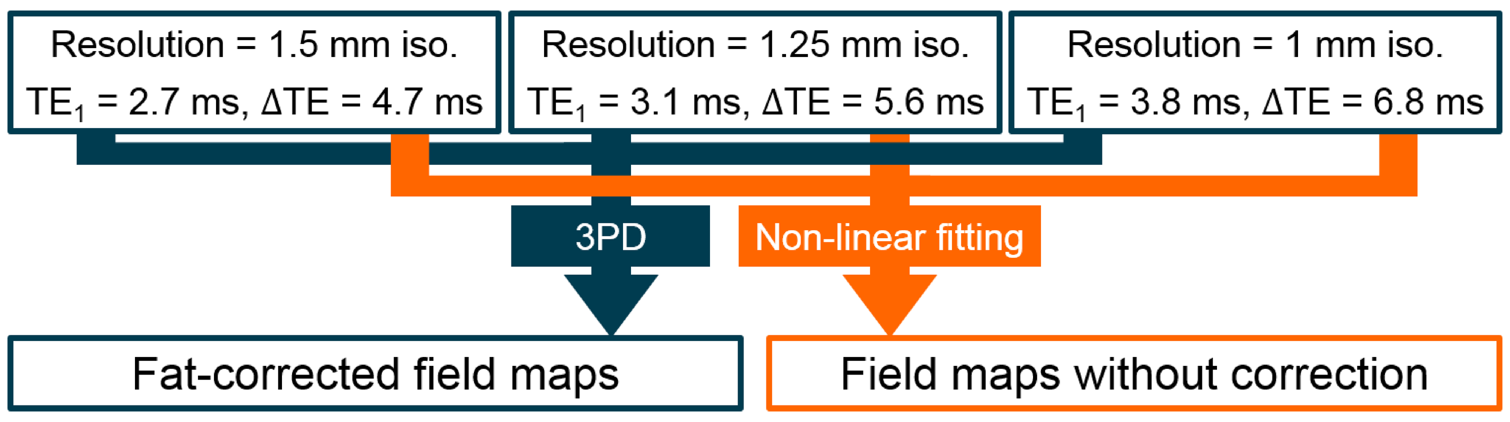
Methods

Multi-echo head-and-neck images were acquired in a healthy volunteer on a 3T Philips Achieva scanner using a 3D gradient-echo sequence and a 16-channel head-and-neck coil, with field-of-view = 24×24×22 cm (orientation = AP-RL-FH), SENSE factor = 2×1.5×1, 1 mm isotropic resolution, 4 echoes and a flip angle of 18°. Two different echo timings were used: (i) for in-phase imaging (TR = 21 ms) and (ii) for optimal post-acquisition fat-water separation[6] (TR = 23 ms):



Fat-corrected field maps were calculated from (i) using non-linear fitting[8], and from (ii) using either 3PD, or SPURS. We selected these FC strategies, because in-phase imaging is an available option on most clinical scanners, 3PD was the winner of the ISMRM fat-water separation challenge[9], and SPURS is a FC technique specifically designed for SM. A brain mask was obtained using the FSL Brain Extraction tool[10] and a fatty region (1125 voxels) was manually segmented on the magnitude image (Figure 1, red overlay).

We also acquired a set of SM-optimised, multi-echo head-and-neck images in a healthy volunteer on the same scanner using a 3D gradient-echo sequence and a 16-channel head-and-neck coil, with field of view = 24×20×24 cm (orientation = AP-RL-FH), SENSE factor = 2×1×1. Three different isotropic resolutions and, consequently, three different echo timings were used (TR = 29–34 ms):



We calculated field maps from all three using both 3PD (with fat correction) and non-linear fitting (without fat correction). Again, a fatty region (629 voxels) was manually segmented in the highest-resolution magnitude image (Figure 2, red overlay). This ROI was segmented in the other two images by rigidly registering the magnitude images with the highest-resolution magnitude image, and applying the transformation to the ROI.

Susceptibility maps were calculated from all field maps using:

1. Laplacian phase unwrapping[11] ($\sigma = 10^{-10}$)
2. Background field removal using Projection onto Dipole Fields[12]
3. Susceptibility calculation by iterative fitting with Tikhonov regularisation[13]

The mean and standard deviation of the χ in the fatty ROIs were calculated in each case. Root mean squared differences (RMSDs) between the fat-corrected images and the reference χ map (calculated from (ii)) in the brain were also calculated for the three different FC strategies.

References

[1]Eskreis-Winkler et al., NMR in Biomedicine, 2016
[2]Shmueli et al., MRM 62(6), 2009
[3]Hernando et al., JMRI, 40(5), 2014
[4]Dimov et al., MRM, 73(6), 2015
[5]Disler et al., AJR, 169(5), 1997
[6]Berglund et al., MRM, 63(6), 2010
[7]Dong et al., IEEE Trans Med Imaging, 34(2), 2015
[8]Liu et al., MRM 69(2), 2013
[9]The 2012 ISMRM Fat-Water Separation Challenge: http://challenge.ismrm.org/node/18
[10]Smith, Human brain mapping 17(3), 2002
[11]Schweser et al., MRM 69(6), 2013
[12]Liu et al., NMR in Biomedicine 24(9), 2011
[13]Kressler, IEEE Trans Med Imaging 29(2), 2010

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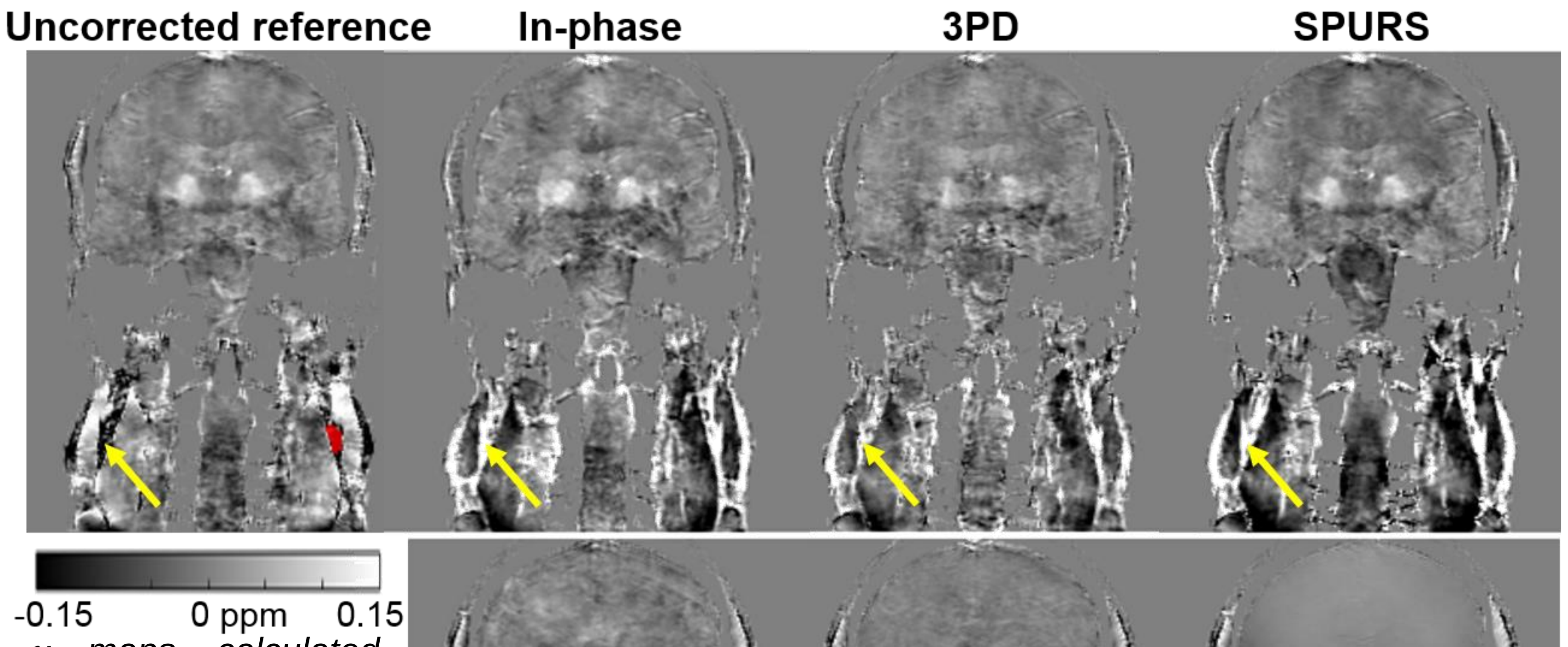
Results and Discussion



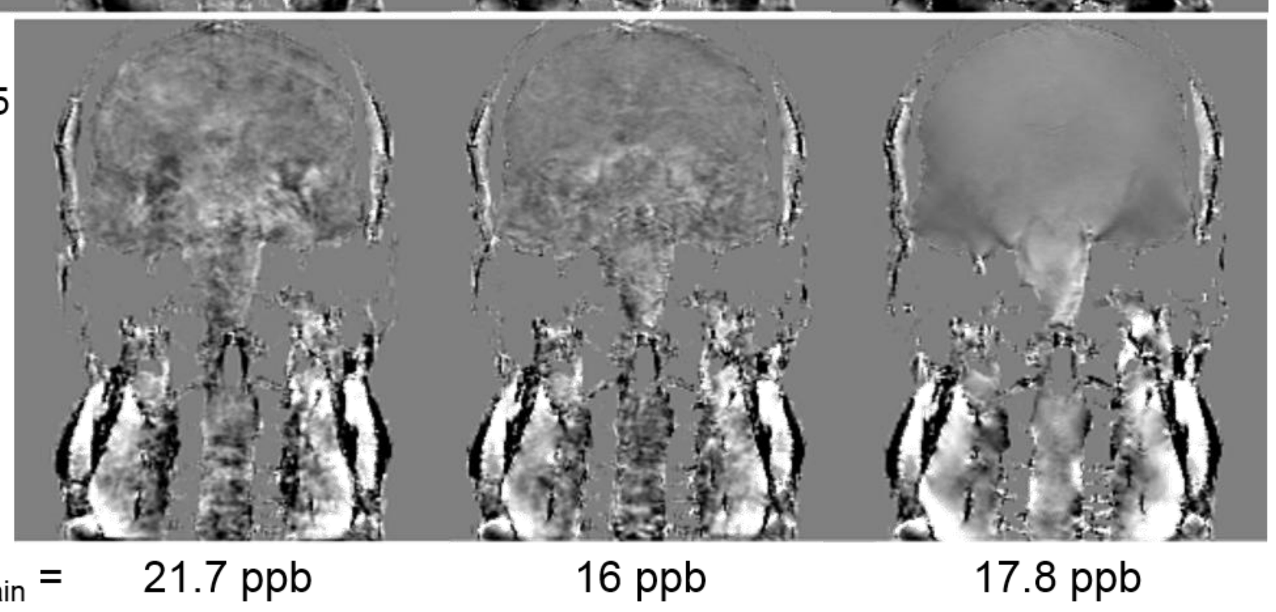


Figure 1: *χ maps calculated without FC or using one of the three different FC strategies (top row). The manually segmented fatty region is highlighted in red. Difference images between the corrected and uncorrected χ maps are also shown (bottom row) along with RMSDs in the brain.*

- All three FC strategies reversed the χ contrast between fatty and water-based tissues relative to the reference image (Figure 1, arrows) and provided very similar susceptibility maps (Figure 1, top row). This implies that these calculated susceptibility maps are accurate
- RMSD values (Figure 1, bottom row) were very small in each case because of the lack of fatty tissue in the brain. There was a slightly higher difference (both visually and numerically) in the brain for the in-phase χ map as this was calculated from (i) as opposed to (ii) and then rigidly co-registered to the reference χ map (calculated from (ii)). 3PD provided the smallest RMSD, but fewer anatomical features were visible in the difference between the SPURS result and the reference χ map in the brain
- The χ of fat in the ROI was also very similar for the three FC strategies (Table I, top row)

Reference	In-phase	3PD	SPURS
-0.16 ± 0.14	0.12 ± 0.10	0.14 ± 0.12	0.22 ± 0.14

	TE_1 = 2.7 ms, ΔTE = 4.7 ms	TE_1 = 3.1 ms, ΔTE = 5.6 ms	TE_1 = 3.8 ms, ΔTE = 6.8 ms
Corrected	0.14 ± 0.11	0.14 ± 0.09	0.09 ± 0.08
Uncorrected	0.09 ± 0.07	-0.06 ± 0.10	0.06 ± 0.08

Table I: *Mean ± standard deviation of χ (in ppm) in the fatty ROIs. The top and bottom row correspond to the χ maps of Figure 1 and 2 respectively.*

- Fat correction (using 3PD) provided χ maps with very similar contrast for the three different echo timings (Figure 2, top row, yellow arrows)
- The contrast in the χ maps calculated without correction largely depended on the echo timing (Figure 2, bottom row, yellow arrows)
- χ of fat was similar for the three echo timings after fat correction, but was very different for the uncorrected χ maps (Table I, bottom row)
- All these results imply that 3PD performed accurate fat-correction
- The χ of fatty tissue in the highest-resolution image calculated after FC was substantially lower than in the other two fat-corrected maps. Moreover, this χ map was generally more noisy due to the small voxel size (Figure 2, blue arrow), and contained additional artifacts introduced by 3PD because the echo timings were not optimal for FC (Figure 2, green arrow)

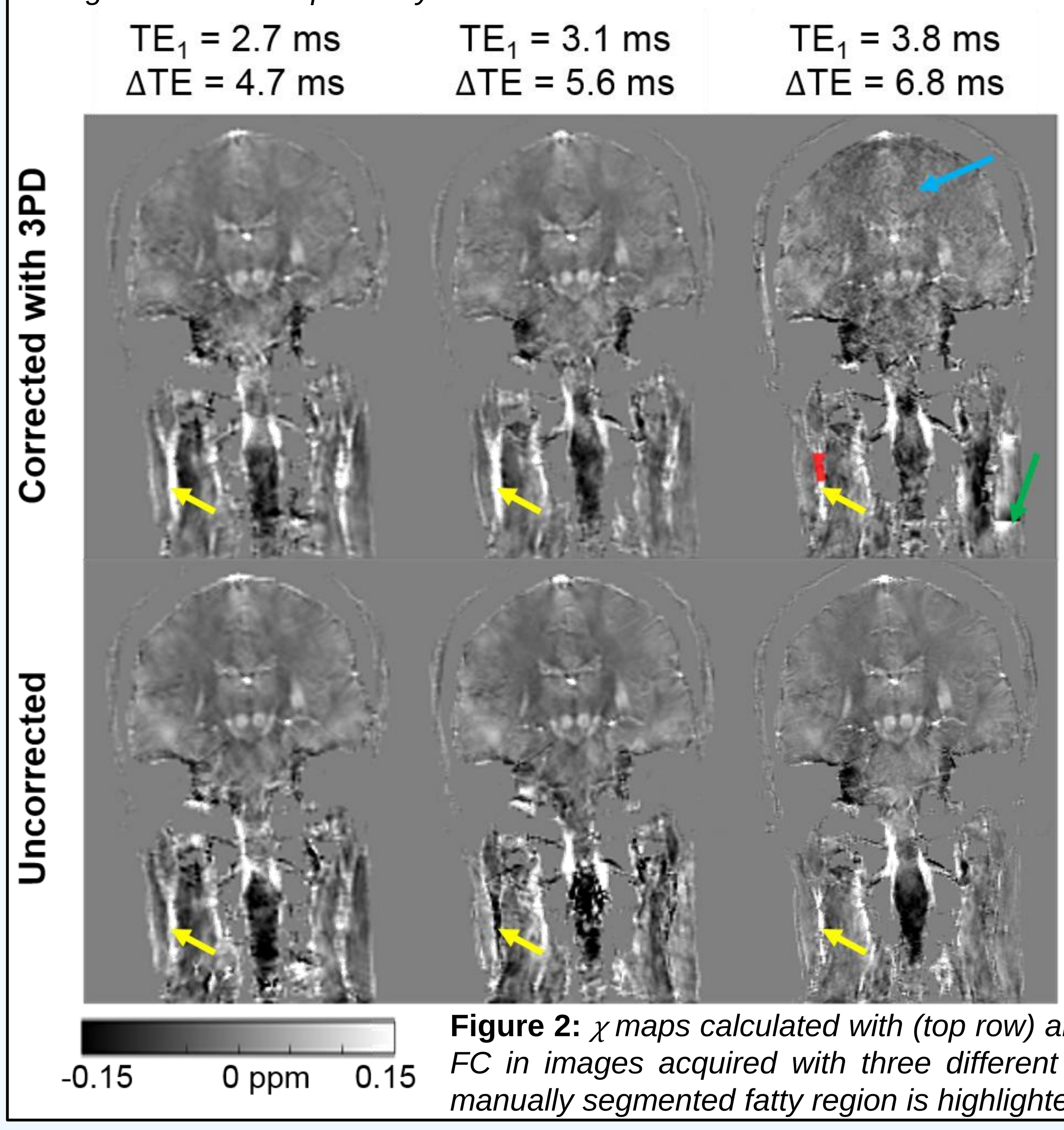


Figure 2: *χ maps calculated with (top row) and without (bottom) FC in images acquired with three different echo timings. The manually segmented fatty region is highlighted in red.*

Conclusions

- All three fat-correction strategies provided very similar susceptibility maps and mean susceptibilities within the segmented fatty region
- The contrast and the susceptibility of fatty tissue in the fat-corrected images were very similar for three different echo timings, even though these were very different in the images calculated without correction
- These results imply that the techniques used in this study performed accurate fat correction
- The susceptibility difference between the corrected and the reference maps in the brain was very small for all three FC strategies as expected
- The highest-resolution susceptibility map calculated with FC was generally more noisy and contained artifacts introduced by the 3PD method
- Future work will assess the robustness of each of these FC strategies to motion and across subjects

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