Improvements in quantitative magnetic susceptibility mapping at using additional low resolution scans

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Introduction. Phase images measured with gradient echo sequences are very sensitive to changes in the local magnetic field and can be used to identify regions with different magnetic susceptibilities. This information is useful for a number of neurodegenerative diseases (e.g. Alzheimer's disease) [1]. However a change in the local magnetic susceptibility leads to a non-local change in phase. Therefore, it is hard to find the underlying susceptibility distribution from phase images alone. In this abstract we use the Fourier based relation between phase and susceptibility [2,3] to calculate high resolution susceptibility maps. The relation between susceptibility (χ) and phase (φ) is given by the following:

$$\chi = \mathrm{FT}^{-1}\left\{ \mathrm{FT}\left(\frac{\varphi}{-\gamma B_0 TE}\right) \times \left(\frac{1}{\frac{1}{3} - \frac{k_z^2}{k_x^2 + k_y^2 + k_z^2}} \right) \right\}$$

where k_x, k_y and k_z are distances from the origin in reciprocal space, the direction of B_0 being along k_z. This method of calculating χ on a pixel-by-pixel basis fails when the denominator of the second term goes to zero. This problem can potentially be resolved by measuring data at multiple orientations with respect to B_0. However, this either increases the data acquisition time significantly, and might therefore not be applicable to clinical cases, or limits the spatial resolution. Therefore, we propose a method which uses one high resolution data set, and two reduced data sets with two small rotations of the object being imaged.

Methods. In order to test the proposed method, we have simulated phase maps with three different orientations (-10°,0° and +15°, with respect to the B_0 field, for a long, thin bar with χ = 1 ppm surrounded by an infinite medium with χ = 0 ppm. Susceptibility maps were calculated from these phase maps using the equation above while excluding data points where the second term of the equation was larger than a threshold of 10 (determined empirically). When calculating susceptibility maps based on multiple orientations, the data points of the individual orientations were averaged only if they exceeded the threshold, otherwise they were discarded. This technique was repeated for a combination of two low resolution images and one high resolution image in which case the high resolution data was weighted correspondingly higher in the average. In vivo experiments were performed on a 7 T Achieva MRI scanner (Philips Healthcare, Best, The Netherlands) using a 16 channel Nova Medical receive head coil. A 6 minute high resolution coronal 3D gradient echo scan was used with the following parameters: TR /TE /α = 35 ms / 20 ms / 15°, 0.5 x 0.5 x 0.8 mm^3 resolution, SENSE factor 4 (2x2), followed by two fast (<1 minute) lower resolution scans (1.5 x 1.5 x 2 mm) with the subject's head rotated at an angle of ~5° and 12° with respect to the main magnetic field. The data were zero-filled to obtain the same matrix size used for the high resolution scan. Phase images were co-registered based on registration parameters determined for the modulus images in terms of rigid body rotation and translation. The registered phase images were then unwrapped by applying a high-pass filter, before the final susceptibility map was produced.

Results and Discussion. Figure 1 shows the results of the simulations, a-c show the characteristic striping artifact resulting from removal of data points in which the second term of the equation is above the threshold. The susceptibility maps are produced from images with a data matrix of 128 x 128. The direction of the bar is into the paper and the white arrow depicts the direction of the magnetic field. In (a) the bar is perpendicular to Bo, and in (b) and (c) it is rotated by 10° and -15° respectively. The artifacts can effectively be removed by combining the results from the three orientations as shown in figure 1d. If the images corresponding to (b) and (c) are acquired at lower resolution (32x32) and zero-filled, then the combination produces figure 1e, which still contains some striping artifact, but the quality is considerably improved compared to using only a single orientation.

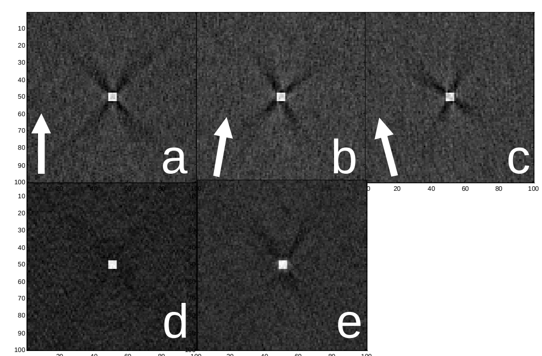

*Figure 1: Susceptibility maps based on the simulated phase behavior of a bar with added Gaussian noise. **a-c)** resulting maps from different orientations with respect to B_0. **d)** Combining information from a-c. **e)** Combining and one high resolution and two low resolution phase maps.*

Figure 2 shows a first example of in-vivo data. The image on the left is the susceptibility map using only one orientation high-resolution data set (400 x 400). The image on the right is the combination of the high-resolution with two lower resolution images (180 x 180, zero-filled to 400 x 400) acquired with the subject rotating his head. These very preliminary data show that it is possible to significantly reduce the artifacts, without having to increase the scan time considerably.

Conclusion. Preliminary results of in-vivo brain data showed that artifacts in magnetic susceptibility maps can be reduced considerably by the incorporation of additional low resolution scans acquired with a small rotation (< 15°) of the subject's head within the receiver coil.

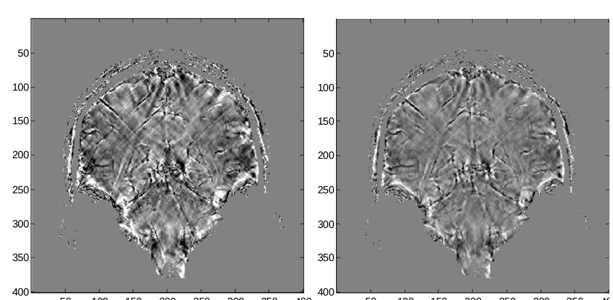

Figure 2: Susceptibility maps The left image is calculate using only high resolutio data at a single orientatioı The image on the right use two other orientation lo resolution data. Data is scale between ± 0.5 ppm (black t white)

References.

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