Multi-frequency Off-resonance Correction and Water/Fat Separation for Spiral Breast Imaging

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Introduction Lipid suppression is particularly important in breast imaging where glandular tissue is surrounded by fatty tissue. However, lipid suppression is sensitive to field inhomogeneities. Linear shimming on the scanner or linear off-resonance correction during reconstruction may be insufficient to correct for field variations, especially when scanning large volumes, such as in a bilateral breast exam. Spiral imaging allows for rapid acquisitions, but off-resonance manifests as blurring. Multi-frequency reconstruction allows the field to be corrected by an arbitrary function in all dimensions by choosing an optimal reconstruction frequency for each voxel [1,2]. We expand on this work, applying a multi-frequency reconstruction algorithm for 3-point water/fat separation using 3D stack-of-spiral breast images with multiple echo times.

Methods Three images are acquired with different echo times. Water and fat images are estimated using a least-squares three-point method assuming water is at resonance [2,3]. This process is repeated with different center frequencies (Δf), generating a set of water and fat images for each frequency. The least-squares residual image for each frequency can be used to evaluate the quality of reconstruction. A cost function is calculated independently for each voxel by summing the residual at the water frequency (Δf) and the fat frequency ($\Delta f - \Delta f_{cs}$) for each offset frequency. A field map is generated by choosing the offset frequency (Δf) that minimizes the cost function for each voxel, an extension to [2] that widens the spacing between minima (note Δf_{cs}=-220Hz at 1.5T). Figure 1 shows a representative cost function and the frequency that minimizes the sum of residuals. Finally, the image is reconstructed on a voxel-by-voxel basis using the center frequency corresponding to the value of the field map.

Images were acquired using a 3D stack-of-spiral acquisition with TE_1/ TE_2/ TE_3 = 1.0/2.6/4.2ms and TR = 22.8ms for Figure 2 and TR = 23.4ms for Figure 3 on a 1.5T GE Excite scanner using a four-channel breast coil (GE Healthcare, Waukesha, WI). We used a 9-interleave spiral, 20x20 cm FOV, 1.05x1.05mm^2 resolution in-plane, 32 slices, 3mm thickness, a 30° flip angle, linear shims, and a 23-second scan time.

Results Figures 2 and 3 show volunteer breast data reconstructed using a single center frequency for the entire image (a,c) and using different center frequencies for each voxel according to the local field inhomogeneity (b,d). The images generated using multi-frequency reconstruction demonstrate better fat/water separation, notably in the subcutaneous fat inferior to breast tissue, and reduced blurring due to off-resonance, especially near the chest wall and skin, as indicated by the arrows. Figure 3 (b,d) shows a dramatic improvement in the water/fat separation where there is a large inhomogeneity at the chest wall, as indicated by the arrows. The observed SNR does not differ significantly between the images and both the fat and water images reconstructed using the multi-frequency technique are in focus. Each data set was reconstructed in less than 30 minutes.

Discussion In this algorithm, the off-resonance correction is applied voxel-by-voxel, which allows for improved water/fat separation. *In vivo* data confirms that this method can be used to reduce image blurring due to off-resonance and improve water/fat separation in regions of poor field homogeneity. Multi-frequency reconstruction is computationally intensive, but allows for an arbitrary correction (i.e. not necessarily linear) [4], which is useful for cases with poor field homogeneity.

Conclusion We have demonstrated a simple procedure that incorporates water/fat separation and multi-frequency off-resonance correction for 3D spiral imaging. This algorithm should prove to be very useful in studies where the field inhomogeneity is considerable across the imaging volume and linear shimming and linear off-resonance correction are unlikely to sufficiently correct for the local gradients. This procedure simultaneously separates water and fat and corrects for field variations, resulting in improved water/fat separation.

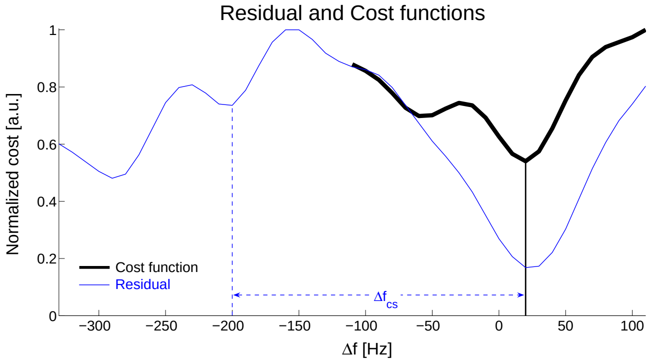

Figure 1 – Cost function showing the frequency that minimizes the sum of the residuals at the water and fat frequencies.

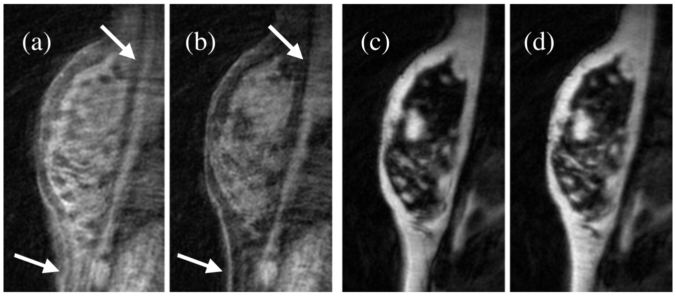

Figure 2

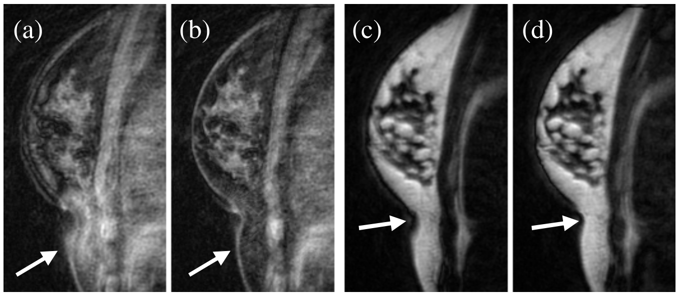

Figure 3

Figures 2 and 3: Breast data for normal volunteers
Single frequency water reconstruction: (a) water Δf = 0 Hz,(b) fat Δf = -220 Hz
Multi-frequency water reconstruction Δf_{cs} = 220 Hz: (a) water, (b) fat
The multi-frequency reconstruction images (b,d) show less blurring than the corresponding single frequency images (a,c). The arrows in Figure 3 show improved water/fat separation in the multi-frequency reconstruction.

References

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