Introduction Spiral imaging allows for rapid image acquisition, but is extremely sensitive to off-resonance, which manifests as blurring. Linear shimming is not able to correct for the degree of B_0 inhomogeneity typical in breast imaging. Multi-echo imaging takes advantage of phase accrual at different echo times to determine the chemical composition of the acquired signal. In order to accurately decompose a signal into its components, it is necessary to know the off-resonance experienced by the spins. We use low-resolution spectra to estimate the field, which is an extension of the elegant three-point method [1]. Knowing the B_0 field, we can improve water/fat separation with a multi-frequency reconstruction for spiral breast imaging.

Methods Using images from three echo times, we can create a low-resolution spectrum. In the extreme case, we can take a three-point FFT in time to generate a three-point spectrum [1]. We can choose echo times so that we get three spectral peaks separated by the chemical shift frequency of water and fat (*i.e.*, $e^{(-i2\pi\ \Delta TE\ f_{cs})}$ corresponds to $2\pi/3$ phase). The signal in breast imaging is dominated by fat and water, so the third spectral frequency is 'blank,' and we expect it to be zero when we are on resonance. We zero-pad and perform an N-point FFT to create an interpolated spectrum. By finding the frequency that minimizes the spectrum, we can determine the off-resonance frequency for each voxel. This spectral residual method is compatible with any water/fat decomposition method. Here, we can reconstruct the data on a voxel-by-voxel basis using a multi-frequency reconstruction for spiral imaging.

We scanned one normal volunteer using a 3D stack-of-spiral acquisition at 1.5T ($TE_{1,2,3}$ = 1.0, 2.6, 4.2ms, TR = 22.8ms, 40° flip angle, 22-second scan time) and 3T ($TE_{1,2,3}$ = 1.2, 2.0, 2.8ms, TR = 21.4ms, 20° flip angle, 23-secon scan time) using a four-channel breast coil. We used a 9-interleave spiral, 20x20cm FOV, $1.1\text{x}1.1\text{mm}^2$ resolution in-plane, 32 slices, 3.6mm thickness, and linear shims.

Results We present *in vivo* data that shows improvement in water/fat separation and deblurring when compared to a single frequency reconstruction. The 1.5T data (Figure 2) shows an example where water/fat separation fails at the inferior edge of the breast (arrow); some fat signal is incorrectly placed in the water image. Our multi-frequency reconstruction correctly decomposes the data into water and fat images. Both the 1.5T and 3T data (Figures 2,3) demonstrate improved image quality due to deblurring. In both cases, there is such severe blurring at the superior edge of the breast that the skin is not clearly visible (circles). Our reconstruction improves both the appearance of the skin and the edges between fat and glandular tissue.

Discussion This algorithm may provide a promising method for estimating the B_0 field variation for multi-echo imaging. *In vivo* data demonstrate the utility and feasibility of using this method clinically. The spectra can be calculated quickly and provide a robust measurement of the main field inhomogeneity.

Taking the Fourier transform of the zero-padded data is equivalent to demodulating the data at various off-resonance frequencies and summing the signals in time to find the composite signal as a function of Δf. While the latter method takes into account the effects of blurring in spiral imaging, calculating the cost function in this way is very computationally intensive, approximately equal to the time it takes to reconstruct the images for multi-frequency reconstruction. We assume that the field map changes more slowly than the blurring, so we believe that this simplified reconstruction is reasonable, and the quality of the field maps generated supports our assumption.

This spectral cost function also provides a sharper minimum than a least-squares method, which is inherently quadratic. We expect a zero-crossing at the 'blank' frequency with slope ≈ 1; taking the magnitude of the spectrum produces a sharp minimum, which makes determination of the field map more robust when compared with least-squares residuals [2,3].

Conclusion We demonstrate a simple method of calculating the field map using low-resolution spectra as cost functions for each voxel, which can be used to improve image reconstruction. By efficiently calculating the field map, we can further reduce reconstruction time, such as by using localized demodulation/gridding kernels [4,5].

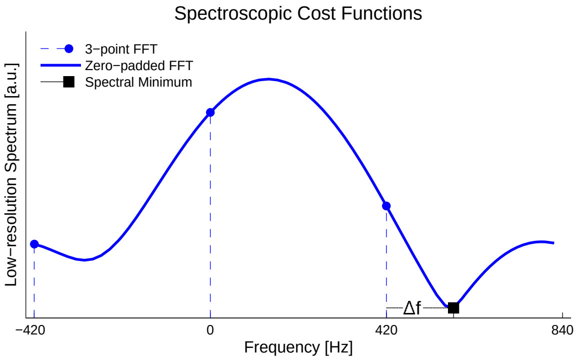
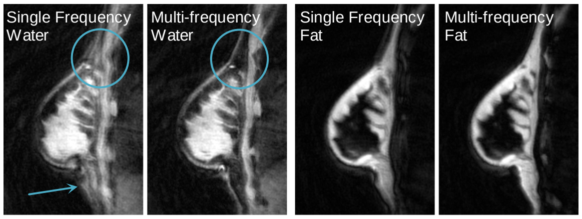


Figure 1: *Low Resolution Spectrum (3T data)*

The three points indicated by the circles correspond to the fat, water, and 'blank' frequencies. By finding the frequency that minimizes the spectrum (black square), we can determine the off-resonance at that voxel ($\Delta f = f_{cs} - f_{min}$). This Δf can then be used to perform multi-frequency reconstruction.



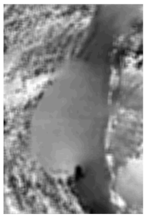
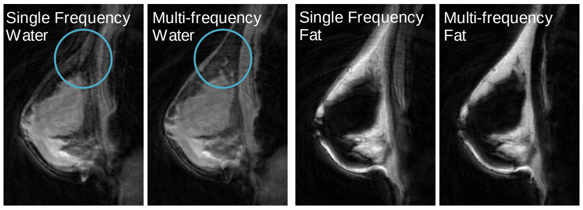


Figure 2: 1.5T *Breast Data, Normal Volunteer*

The field map to the left was used to reconstruct the multi-frequency water and fat images shown above. The multi-frequency reconstruction images demonstrate improved water/fat separation (arrow) and less blurring (circle).



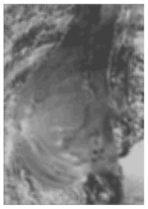


Figure 3: *3T Breast Data, Normal Volunteer*

The field map to the left was used to reconstruct the multi-frequency water and fat images shown above. The multi-frequency reconstruction images show improved image deblurring while maintaining water/fat separation and apparent contrast and SNR.

References

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