Fully Automated Shimming for High Lipid Regions using Phased Arrays at 3T

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Introduction: For the brain, a variety of automated non-iterative shimming methods using phase evolution derived B_0 maps have been reported. These methods assume a single chemical species contributes to the image. Although this is true within the brain, lipid contributions from skin, bone marrow and structural fat, may approach or exceed the concentration of water in other organs. In these instances, standard B_0 mapping methods cannot be used due to contributions arising from the lipids. Further, most modern MRI systems utilize phased arrays for detection, requiring that the mapping routines account for varying sensitivity and phase reference from the different receiver coils. To overcome these limitations we have developed a method which is compatible with phased arrays and allows arbitrarily long evolution periods to maximize the accuracy of the B_0 map acquired from organs outside of the brain. To demonstrate the method we have applied it to shim the human calf at 3T on a Siemens Trio system.

Methods: The measured signal from a gradient echo measurement of arbitrary delay can be written as

$$A_{msd}\exp(-i\phi_{msd}) = A_w\exp(-i\phi_w) + A_f\exp(-i(\phi_{wf} + \phi_w))$$

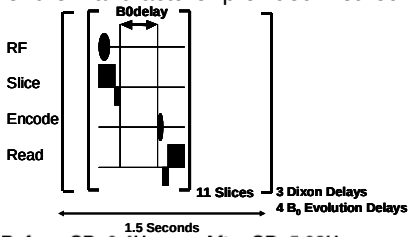
where A_w and A_f are the amplitudes of the water and fat signals, ϕ_w is the phase due to the B_0 field and ϕ_{wf} is the phase due to the chemical shift difference between fat and water. To correct for the presence of phase evolution in the B_0 maps due to the chemical shift of lipids, a 3 point Dixon image is embedded in the multi-point B_0 mapping sequence (Figure 1). Using A_w and A_f, as determined from the three point Dixon images, a phase map due to B_0 inhomogeneity, ϕ_w, can be determined for any arbitrary echo time. The maps of ϕ_w then represent just the effect of B_0 inhomogeneity, identical to that seen if only a single species, water, were present. Highly accurate maps can then be calculated using multiple evolution time delays (Figure 1).

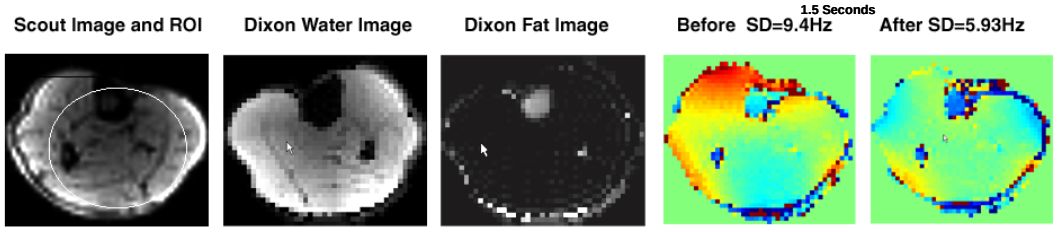
When using multiple receivers, the absolute phase will vary depending upon location and receiver. Spatial variability in the SNR of each receiver can degrade the accuracy of the phase measurement when signals from spatially distant coils in the group are averaged or summed with those from more proximal coils. To eliminate this effect the SNR of each imaging pixel from each receiver was determined and those with the largest SNR were used on a pixel by pixel basis. Thus the final B_0 map is constructed from a "patchwork" of the most sensitive coils for any specific location.

B_0 maps of the human leg were acquired on a Siemens 3T Trio system using an 8 coil leg coil. The data was acquired using a gradient echo readout using 7 delays, 3 forming the Dixon maps (with additional evolution delays of 0, 1.2 and 2.4ms $1/2\Delta_{water\text{-}fat}$) and 4 evolution delays, 1, 2, 4 and 8ms which were used to calculate the B_0 map. The data was acquired using an 11 slice acquisition (2mm thick, 2mm gap) with 64x64 resolution over a FOV of 192x192cm. For these studies a TR of 1.5S was used, resulting in an acquisition time of 96sec (64 encodes x 1.5S). All 1st and 2nd order shims were used in the optimization.

Results: Displayed below (Figure 2) are the water and fat images reconstructed from the Dixon images along with the B_0 map obtained prior to shimming indicating the regions where the lipid and water signals dominate. The target ROI shown in white, containing both bone marrow (lipid dominates) and muscle (water dominates) was selected for shimming. The leg was initially shimmed using the clinical shim routine, resulting in a standard deviation of 9.34Hz over the selected ROI. A map was then acquired using our method and corrections were calculated, predicting that the σB_0 could be improved to 5.34Hz. The calculated corrections for 1st and 2nd order shims were applied and a second map was acquired. The single adjustment resulted in resulted in σB_0=5.93Hz, in good agreement with the predicted homogeneity and a 37% improvement in homogeneity over the manufacturer provided method.

Figure 1(right) Pulse sequence for B0 mapping. Figure 2 (below) Scout image showing ROI, Dixon water and fat images and B0 maps acquired before and after shimming. The full color scale for the B0 maps is ±60Hz.





Conclusions: The developed method allows regions where lipids dominate to be included in the calculation of automated shimming. This provides for significant improvement (37%) over that of the standard shim routines provided by the manufacturer and single pass adjustment of the shims. The method is compatible with phased array coils and easily implemented on commercial scanners. With increasing field strength available (7T) methods to provide robust and rapid shimming of regions outside the brain will be critical for spectroscopic imaging and other applications requiring good B_0 homogeneity.