Optimized fat suppression for elliptical centric k-space ordering

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Introduction: Elliptical centric k-space ordering [1] has become the method of choice in MR angiography for selective acquisition of the arterial phase after administration of Gd contrast. It minimizes venous contamination and has been shown to be robust to motion and pulsatile flow artifacts. In a number of contrast enhanced MRI applications, however, notably in the breast and liver, fat suppression is often required to delineate small vessels, tumours and to improve contrast. This is especially true for abdominal scans where subtraction-based methods perform poorly due to motion artifacts. The use of a fat saturation pulse every TR is prohibitively expensive on scan time (typically doubles or trebles the scan time) and is, hence, unsuitable for MRA and dynamic MRI. In conventional centric acquisitions, this can be tackled using the SPECIAL scheme where fat saturation pulses are played intermittently [2,3] for a set of phase encodes. The phase encodes are ordered such that the null point coincides with the acquisition of central k-space data. In the case of elliptical centric k-space ordering, this method leads to severe ghosting due to the modulation of central k-space data as the fat magnetization recovers during the data acquisition segment. A novel strategy was developed for achieving magnetization preparation in elliptical centric ordered sequences by varying the rate of application of the prep pulse according to an energy cost function.

Theory: We used the fact that the energy of radial k-space (k_r) reduces significantly as one moves away from the center of k-space to devise an optimized fat suppression technique. The intensity of the fat signal is proportional to its magnetization value and the "energy" corresponding to the k-space value acquired. The basic idea is to slowly decrease the rate with which fat suppression pulses are played out as k_r is increased. An initial scheme was chosen and the cost function calculated which yielded a new scheme and this process was iterated until convergence occurred and the cost function minimized. In practice, we found that for the abdomen and the breast, the same set worked across volunteers suggesting that the dominant signals came from the central annulus of elliptically ordered k-space.

Methods: MATLAB was used for phantom simulations and optimization of the fat saturation pulse play-out rates. An elliptical annulus representing the abdomen enclosing smaller elliptical annuli (kidneys) was used as a model and k-space data was generated. A custom Bloch equation simulation tool was used to calculate the recovery of the fat signal following the fat inversion pulse and rf excitation pulses. An energy cost function was derived from the fat magnetization signal and the k-space energy ($|I(k)|^2$ and then minimized to yield the optimal play-out rates. For reducing the search space, we restricted the k-space to three annular regions and obtained the optimal rate for each annulus using iterative method described above. Human subjects (in accordance to IRB-approved protocols) were imaged on a 1.5 T GE Signa CV*i* (Waukesha, WI) scanner. A 4-channel phased array breast coil/torso coil was used for breast/abdominal acquisitions, respectively. An elliptical centric 3D spoiled GRE sequence was used for imaging. The breast imaging was typically performed with 0.1mol/kg Gd contrast injection. Typical optimized values used were k_r = 0.1, 0.3 and 0.6 for the normalized annuli widths with repetition rates for fat suppression once every 5, 15 and 40 TRs for the three regions. As expected the central annulus width and play-out rate had the biggest impact on fat suppression. The numerical simulations provided a valuable starting point to further optimize the fat suppression on the volunteer scans.

Results: The simulation results are shown in Figure 1 which compares the central annulus of the phantom. Our optimized technique (B) shows considerably less ghosting and better suppression than the conventional SPECIAL (A). Figure 2 compares the two methods on an abdominal scan. Fig. 2b depicts the ghosting and poor fat suppression when fat sat pulses are applied at a uniform rate of one per 16 TRs. Fig 2c depicts the proposed optimized fat sat scheme using rates of 5,15 and 40 per TR depending on kr. Excellent fat suppression was achieved with no perceptible ghosting. The scan time increased from 16s to 20s. We applied this fat suppression scheme to the breast where the quality of fat suppression required is more stringent. Figure 3 shows slices from the left and right breast of a patient with a tumour demonstrating excellent fat suppression with elliptical centric encoding. Fat sat playout rates were 8,16 and 24 per TR depending on kr.

Conclusion: We have developed an efficient and effective fat saturation strategy for elliptical centric acquisitions that yields optimal fat suppression without increase in scan time over conventionally ordered fat saturation schemes. The idea can be applied to other magnetization preparation schemes such as IR and T_2 prep to improve image contrast in elliptical centric acquisitions. While we used the same scheme for all volunteers, a water suppressed fat scout image can be obtained and the optimization performed on the fly to further improve contrast on an individual basis.

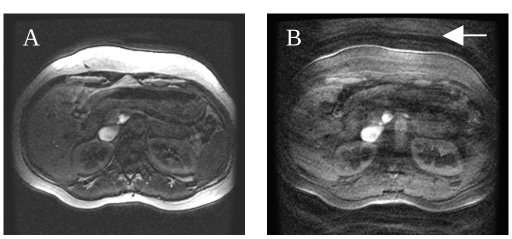

Figure 2. Comparison of SPECIAL fat sat (B) with our optimized scheme (C). Note dramatic reduction in ghosting compared to (B) and the improved contrast compared to the non-fat suppressed image (A).

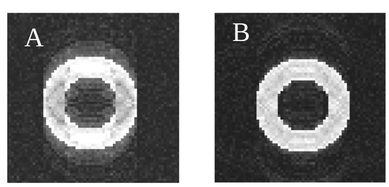

Figure 1. Comparison of simulation results of SPECIAL fat sat with our optimized scheme. The central small annulus is shown zoomed. Note the reduced ghosting and higher fat suppression in B.

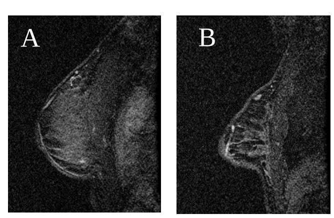

Figure 3. Comparison of SPECIAL fat sat (A) with our optimized scheme (B) in the left and right breast of a patient with breast cancer. Note the degree of fat suppression and absence of ghosting

References:

1. Wilman et al. MRM 1998; **40**: 24-35. 2. Foo, et al. Radiology 1994; **191**: 85-90. 3.. Foo et al. JMRI 1993; **3**: 611-6.