Calalyzing the Refocused TSE Echo Train Facilitates Phase-Detection for Fat-Water Separation

Introduction: The refocused turbo-spin-echo (rTSE) sequence achieves flow-independent, non-contrast angiograms by blending the advantages of the TSE sequence with the balanced Steady State Free Precession (bSSFP) sequence [1]. Unlike standard TSE sequences, the rTSE sequence suffers from spurious echo artifacts which enter the latter parts of the echo train. In particular, fat suppression remains an issue with this sequence due to fat's short T_1, which causes any fat that experiences an imperfect refocusing pulse (due to B1 inhomogeneity) to display a bright signal by the time the center echo is acquired. This fat signal cannot be removed by chemical suppression pulses or water-only excitation pulses since the origin of the signal is within the echo train itself. An alternative approach is fat/water separation, rather than fat suppression. Here, we show that the phase detection technique proposed by Hargreaves et al [2] for bSSFP fat/water separation is also applicable to rTSE, provided the phase transition region at the beginning of the echo train is bypassed.

Theory: The fat separation technique proposed in [2] for bSSFP sequences utilizes the predictable difference in phase between fat and water that arises in steady state to separate water and fat. Since the rTSE sequence is essentially a bSSFP sequence run with 180-degree alpha pulses, any tissue that experiences a less-than-perfect 180-degree pulse will behave as if it were in a bSSFP sequence. However, since the rTSE sequence acquires signal during what would be termed the transient period for bSSFP, we cannot directly apply the phase detection technique to rTSE images. Figure 1a shows the phase evolution for spins across a range of frequency values that experience an imperfect 160-degree refocusing pulse in the standard rTSE sequence. For fat, located around -220 Hz at 1.5T, there is a transient period during which the phase switches rapidly in a somewhat chaotic manner. Therefore, we can skip acquisition of the first few echoes in the standard rTSE sequence and be reasonably certain the phase behavior of the spins has settled into their final state, allowing for phase detection and fat-water separation.

The approach outlined above will work reasonably well, provided the phase of the spins has settled down prior to data acquisition. However, the phase transition point is a function of frequency and flip angle, often requiring more skipped-echoes than strictly necessary to ensure steady phase. A better approach is to treat the rTSE sequence even more like a bSSFP sequence and, instead of applying a single 90-degree excitation pulse, apply a series of pulses to catalyze the spin-echo-train, forcing the phase behavior into the steady state more quickly (Fig. 1b). The magnitude of the signal is still in the transient (not shown). A number of echoes must still be skipped to account for the ramp, but this number is known and does not change based on frequency or flip angle.

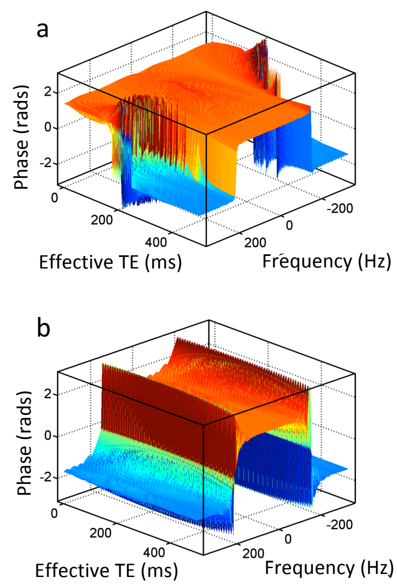

Figure 1. Phase evolution for spins experiencing an imperfect refocusing pulse during an rTSE echo train. a) Standard and b) Catalyzed sequence.

Methods: A volunteer was scanned on a Siemens 1.5 T Avanto scanner with both the standard and catalyzed versions of the rTSE sequence. Sequences had identical scan parameters: TR/TE 3000/150 ms, field of view 325x157x144 mm, echo spacing 4.6 ms (to put the fat signal squarely in the middle of the negative phase plateau), used a single surface coil for reception, and applied chemical fat saturation prior to excitation to suppress fat in the initial portion of the echo train. The catalyzed sequence used a 15-pulse linear ramp from 0-to180-degrees, and for fair comparison, both sequences skipped acquisition of the first 16 echoes. Images were processed in the manner described by [2] in Matlab to separate water-only and fat-only images. Briefly, after system phase correction, the sign of the real part of each pixel value determines whether it belongs in the water-only or fat-only image.

Results: Figure 2 shows the results when using the two rTSE sequence variants to separate water and fat for non-contrast angiography of the calf. Fat-only and water-only images are easily separated from the standard image in both cases, but the non-catalyzed skipped-echo sequence has better background suppression, likely due a stimulated echo effect arising from muscle in the early parts of the echo-train because of the ramped pulses.

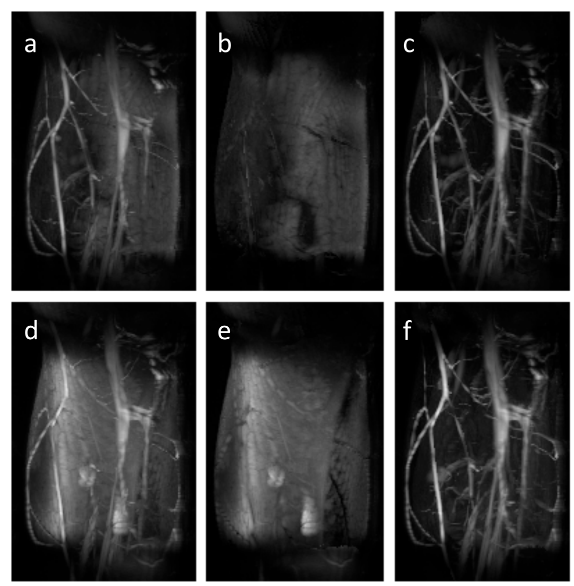

Figure 2. MIPs of the calf of a normal volunteer. Standard sequence with first 16 echoes skipped (a), fat-only MIP (b), and water-only MIP (c). The catalyzed sequence (d) can also be separated into fat- (e), and water-only images (f).

Discussion and Conclusion: To apply phase sensitive fat/water separation in rTSE imaging, a simple skipped-echo or catalyzed-TSE approach is required to avoid the ill-defined phase transition region at the beginning of the echo train. Despite better background suppression when using the simple skipped-echo approach in this one case, the catalyzed sequence should provide more consistent results, as the number of skipped echoes remains constant.

References: [1] Fielden, et al. ISMRM (2009) #1877.
[2] Hargreaves, et al. MRM (2003) 50:210-213.

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