Signal and Contrast Properties of Very-Long Spin-Echo Trains for 3D T2-weighted Turbo-Spin-Echo Imaging

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Introduction: Spin-echo trains with a duration on the order of 1 second, achieved by using variable-flip-angle refocusing RF pulses that yield a prescribed signal evolution for selected relaxation times, have recently been shown to permit single-slab, high-resolution 3D T2-weighted turbo/fast spin-echo (TSE) imaging of large volumes, such as the whole brain, in clinically acceptable acquisition times [1,2]. Although these techniques appear very promising for routine clinical applications, the basic signal and contrast properties of such long, variable-flip-angle echo trains for T2-weighted imaging have not been described. The goal of this work was to perform a theoretical analysis of the basic characteristics of variable-flip-angle spin echo trains, including the signal, signal-to-noise efficiency and contrast as function of the echo-train duration.

Methods: The basis for our analysis is a three-part prescribed signal evolution that begins with a 5-echo exponential decay, which provides a smooth transition from the initial longitudinal magnetization [3]. The signal level is uniform during the second portion of the evolution, which extends just beyond its center to 53% of the total duration. For the final portion of the evolution the signal decays exponentially with a time constant equal to 0.29 of the total duration. The full-width at half maximum for the point spread function corresponding to this prescribed signal evolution is 1.44, equal to that for the slightly different prescribed signal evolution described in ref. 2. It was assumed that the center of *k* space is acquired at the center of the evolution.

Using methods described in previous studies [2,4], the refocusing RF-pulse flip angles required to achieve the prescribed signal evolution were calculated for echo-train durations between 200 and 1000 ms, assuming T1 = 1000 ms, T2 = 100 ms, echo spacing = 4 ms and TR = 2500 ms plus the echo-train duration. The resulting variable-flip-angle series were then used to calculate the signal evolutions for four other pairs of relaxation times (T1/T2 = 500/50, 500/100, 2000/100, 2000/200 ms) representative of a range of soft tissues encountered in vivo.

For the reference relaxation times (T1/T2 = 1000/100 ms) and the four other pairs, "contrast-equivalent" TE values (TE_{eqv}) were calculated as described by Busse et al [2] and Weigel et al [5]. For given relaxation times and variable flip angles, TE_{eqv} is the echo time for a conventional (180° refocusing RF pulse) spin-echo train that would yield the same contrast as observed with the variable-flip-angle pulse sequence for which, depending on the values of the flip angles, the center of *k* space may be acquired at a time following the excitation RF pulse that is much longer than TE_{eqv}. Finally, for the range of echo-train durations considered, the signal-to-noise efficiency (SNR/sqrt(TR)) was calculated for the prescribed signal evolution (T1/T2 1000/100 ms) and for an ideal 180° echo train with echo times equal to the corresponding TE_{eqv} values for the prescribed signal evolution.

Results and Discussion: Figure 1 shows the signal intensity at the center of *k* space for the prescribed signal evolution (T1/T2 1000/100 ms) and for an ideal 180° echo train with the same duration. As expected, T1 contributions to the signal for the prescribed evolution result in substantially higher signal levels for all echo-train durations. Figure 2 shows TE_{eqv} as a function of the echo-train duration for the five pairs of relaxation times considered. At durations less than about 400 ms, the TE_{eqv} values are similar for all tissues, consistent with the observations of Weigel et al [5] for TRAPS. However, at longer durations, substantial differences develop between the tissues. Figure 3 compares the signal-to-noise efficiency for the prescribed signal evolution to that for an ideal 180° echo train with echo times equal to the corresponding TE_{eqv} values. For echo-train durations shorted than 950 ms, the prescribed signal evolution is more efficient, indicating that the variable-flip-angle approach is superior for accelerating the acquisition compared to using a conventional 180° echo train combined with another means to shorten the imaging time such as a half-Fourier acquisition or parallel imaging.

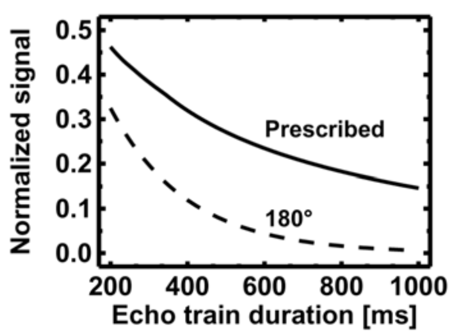

Fig. 1. Signal intensity at the center of *k* space for the prescribed signal evolution (solid) and an ideal 180° echo train (dashed).

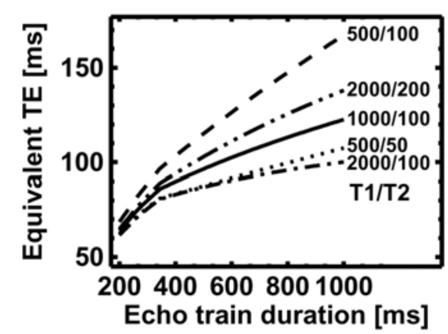

Fig. 2. Contrast-equivalent TE vs. echo train duration for the five pairs of relaxation times considered.

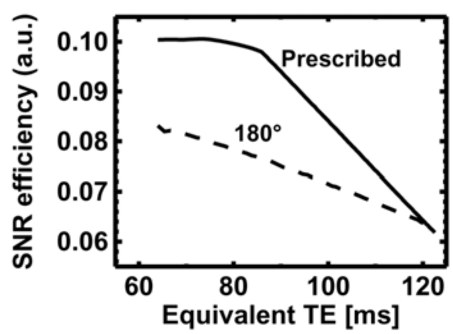

Fig. 3. SNR efficiency vs. contrast-equivalent TE for the prescribed signal evolution (solid) and an ideal 180° echo train (dashed).

Conclusions: We have described basic signal and contrast properties of long, variable-flip-angle echo trains for T2-weighted turbo/fast spin-echo imaging. For echo-train durations greater than about 400 ms, the contrast-equivalent echo time is predicted to show a significant dependence on the relaxation times, which means there is no echo time for which the contrast in a conventional spin-echo image will appear essentially identical to that in the variable-flip-angle image. Additional studies will be required to determine if this property is an advantage or disadvantage of the variable-flip-angle technique. For echo-train durations up to 950 ms, the prescribed-signal-evolution method demonstrates higher signal-to-noise efficiency than a 180° echo train, confirming that the variable-flip-angle technique is an effective approach for accelerating 3D T2-weighted turbo/fast spin-echo imaging.

References:
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