The Virtual 180: Application to High Field Fast Spin Echo Imaging

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Introduction: High field human MRI systems have potential for rapid or high resolution imaging; however, intense RF power deposition prohibits successive high flip angle pulses, essentially precluding traditional multi-slice fast spin echo (FSE) with 180° refocusing angles. In a method called TRAPS [1], 180° refocusing pulses are applied while collecting the center of k-space to provide high signal levels; refocusing angles are reduced during acquisition of the periphery of k-space to curtail overall RF power deposition. Unfortunately, this method requires long echo trains and short echo spacings to smoothly modulate flip angles. Despite considerable power savings, it remains unfeasible at high field strengths, where even a limited number of 180° refocusing pulses generate excessive RF heating for high duty cycle multi-slice imaging. In this work we demonstrate that the signal response typically associated with 180° pulses may be achieved temporarily, without high flip angle pulses. We demonstrate this "virtual 180° echo", which requires less RF power than one generated by an actual 180° pulse, provides a desirable signal response and permits short echo train TRAPS for high resolution multi-slice imaging of the human brain.

Methods: Flip angle modulation schemes have been proposed to smoothly and quickly reduce the refocusing angles immediately following excitation [2, 3]. These approaches can be employed, in reverse, to drive magnetization back into the 180° coherence state, creating an intense virtual 180° echo, without high flip angles. This echo state may be maintained with subsequent 180° pulses or, as shown here, flip angles may be rapidly ramped back down to conserve RF power. For proof of principle, we employ Hennig *et al.*'s 1-ahead algorithm to initially reduce flip angles to 60°, then their 3-ahead algorithm [2] to form the virtual 180° echo and return the flip angles to 60° (see Fig. 1). Echo amplitudes were simulated with the extended phase graph algorithm. Multi-slice images (0.83 x 0.83 x 3.5 mm^3, TR=4.7 s, TE=54 ms, ESP=9 ms, ETL=12, slices=32) were obtained using the described flip angle scheme with the virtual 180° echo encoded as the contrast dominant echo. Images were obtained from a 4.7 T whole-body imaging system controlled by a Varian Unity Inova console. Maximum gradient strength was 3.5 G/cm with 300 μs rise time. We employed a 27 cm birdcage RF coil (XL resonance, Canada) for transmit and a closely coupled 4-element array coil (PulseTeq, United Kingdom) for signal reception. Short term RF power remained below 3 W/kg.

Results and Discussion: Figure 1 displays a short echo train TRAPS refocusing angle scheme and simulated echo amplitudes; a virtual 180° echo is formed following the 6^{th} RF pulse. This echo, a transient response to a rapid flip angle ramp, has signal amplitude nearly equivalent to that of a train of ideal 180° pulses. This echo train used only 25% of the RF power required by a train of 180° pulses, and permits efficient multi-slice imaging, as shown in Fig. 2. Images display conventional T_2 weighting, as expected from a TRAPS like sequence. While we present a specific example, numerous flip angle modulation schemes can form a virtual 180. A single mean flip angle transition pulse [4] can replace the three pulse ramp used here; also, computational algorithms may be employed to tailor the signal response for a more desirable point spread function.

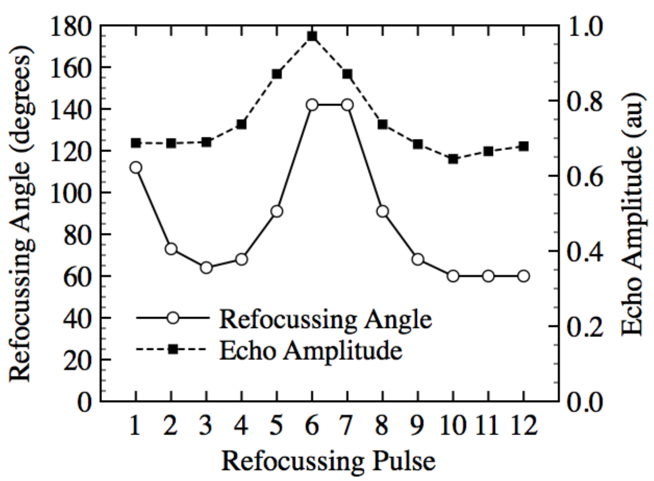

Figure 1: Refocusing angles and simulated relaxation-free echo amplitudes. A virtual 180° echo is formed following the 6^{th} RF pulse.

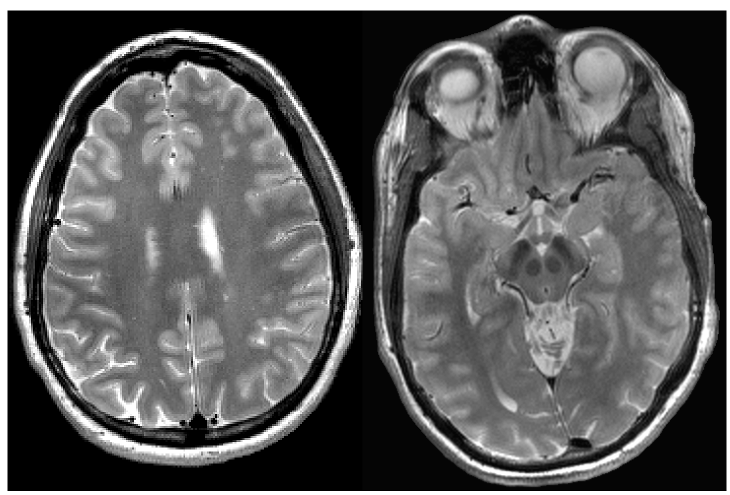

Figure 2: Virtual 180° TRAPS images acquired at 4.7 T. The absence of high flip angles permits multi-slice imaging at high field, yet retains the signal characteristics of high flip angles.

Conclusion: We have demonstrated that the signal response associated with a 180° refocusing pulse may be achieved with a series of reduced flip angle pulses. When this echo is encoded into the center of k-space, we obtain a short echo train TRAPS sequence suitable for high field imaging, where fewer and lower flip angle pulses are needed; this is also ideal for very high resolution imaging, where long echo spacings (and short trains) are required for spatial encoding.

References: **[1]** Hennig, J. et al., (2003) Magn Reson Med 49(3) 527-535. **[2]** Hennig, J. et al., (2004) Magn Reson Med 51(1) 68-80. **[3]** Alsop, D. C., (1997) Magn Reson Med 37(2) 176-184. **[4]** Lebel, R. M. et al., (2007) Magn Reson Med 57(5) 972-975.