Contrast Enhancement using Slice Selective Composite Continuous Rotation Adiabatic Pulses

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Introduction: Slice selective adiabatic full passage (AFP) pulses can generate nonlinear phase dispersion across the selected slice (1, 2). One potential application of this property is to produce enhanced imaging contrast in comparison to the conventional spin-echo (SE) sequence (T_2 contrast). In a preliminary study, enhanced contrast in comparison to the SE sequence was observed for nickel(II) doped water phantoms with short T_2 using a customized localization by adiabatic selective refocusing (LASER) (3) pulse sequence, where a pair of slice selective AFP pulses separated by a time delay were employed to produce the echo. However, the nonlinear phase dispersion and consequently imaging contrast could be further enhanced using a series of selective composite continuous-rotation AFP (CRAFP) pulses in the LASER sequence. The purposes of this study was to compare the contrast produced by the LASER sequence using CRAFP pulses to that generated by a spin-echo diffusion weighted (SEDW) imaging sequence. The contribution of $T_{2\rho}$ contrast (4) was also examined using the LASER sequence containing composite non-continuous-rotation AFP (NCRAFP) pulses.

Methods: Imaging experiments were performed on a 4T Varian whole body MRI with a Siemens Sonata gradient coil using a birdcage transmit/receive radio frequency coil (7.7 cm ID). CRAFP pulses were constructed by alternating the frequency sweep direction of adjacent AFP pulses such that cumulative nonlinear phase dispersion was achieved. A phantom was constructed using two bound tubes containing nickel(II) doped (2 and 21 mM, respectively) deionized water to form two compartments (A and B, respectively) of different transverse relaxation time constant T_2 (413 ms and 52 ms, respectively). The contrast across a single 5 mm slice was calculated by dividing the difference of the average signal intensities (SI) between the two compartments by the reference SI, which was the average SI of A measured by the SE sequence. The amplitude and the duration of the diffusion gradients (G_{diff}) in SEDW were set to the same values as those of the slice selection gradient (G_z) in LASER. To examine the $T_{2\rho}$ contrast contribution, the phantom was also imaged using the LASER sequence containing NCRAFP pulses (i.e., a series of AFP pulses with the same frequency sweep direction for every AFP pulse). For all measurements, FOV = 7 cm, TE/TR = 100 ms/ 2 s, and matrix size = 64 x 64. The nonlinear phase dispersion generated by the CRAFP pulses as compared to the linear phase dispersion produced by the SEDW sequence was also modeled using typical experimental parameters (n (the number of CRAFP pulses) = 1, 5; T (pulse width of one AFP pulse) = 2.5 ms; $G_{diff} = G_z$ = 1.876 G/cm; z (spin position in z-direction) = -2.5 to +2.5 mm; δ (duration of G_{diff}) = 10 ms; Δν (bandwidth of the AFP pulse) = 4 kHz).

Results: The modeling results (Fig. 1) indicated that the nonlinear phase dispersion produced by the CRAFP pulses is asymmetric across the slice, and that the average magnitude of the nonlinear phase dispersion generated by five CRAFP pulses exceeds the average linear phase dispersion produced by the SEDW sequence across the slice. Sample images acquired using SEDW and LASER are shown in Fig. 2. In comparison to SEDW (Fig. 3), the image contrast was significantly enhanced by LASER using the CRAFP pulses when the effective pulse width (T_{eff}) (i.e., n times T) was increased to 12.5 ms (900° CRAFP pulse), which was consistent with the model prediction. The contrast generated by the NCRAFP pulses was higher than that generated by SEDW but lower than that produced by the CRAFP pulses at long T_{eff}.

Figure 1

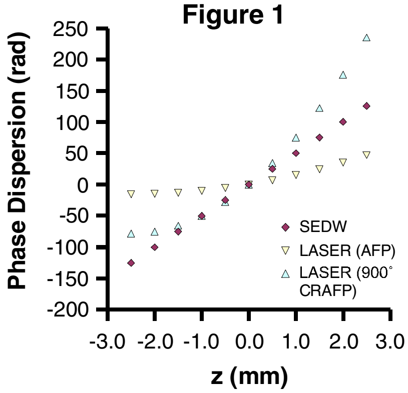


Figure 2

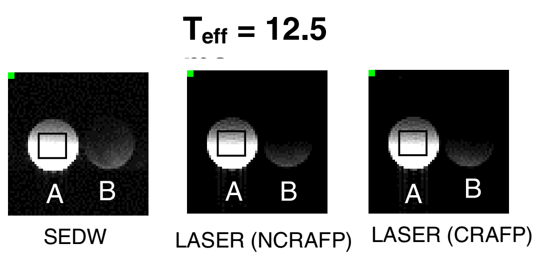
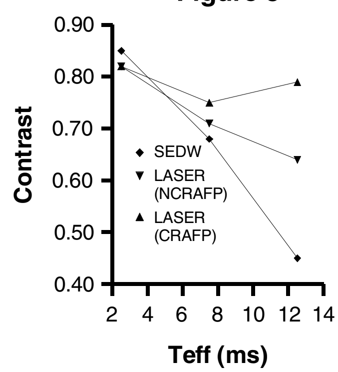


Figure 3



Discussion: Nonlinear phase dispersion and imaging contrast can be significantly enhanced by CRAFP pulses as shown by the modeled and experimental results (Figs. 1 and 3). Experimental results further demonstrated that the enhanced contrast produced by LASER is associated with the nonlinear phase dispersion generated by the adiabatic pulses (Fig. 3) and cannot be explained by the $T_{2\rho}$ contrast. This result demonstrates the enhanced sensitivity of slice selective CRAFP pulses to magnetic susceptibility with potential applications for enhancing imaging contrast in the presence of paramagnetic agents.

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