Reduction of the Transient Oscillations in Alternating-TR SSFP

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Introduction: Steady-state free precession (SSFP) sequences are attractive because of their high SNR-efficiency. The use of alternating repetition times (ATR) has been proposed to shape the SSFP profile e.g. for fat suppression [1]. However, the oscillatory response during the transient period to steady state is more complicated than that of balanced SSFP and may lead to significant artifacts. In this work, several strategies for catalyzing i.e., speeding up the transition to the steady state, ATR sequences are evaluated in terms of the resulting oscillation amplitudes.

Methods: The RF excitations in ATR are spaced apart by TR_1 and TR_2 as displayed in Fig. 1.a and the amount of precession is different in the two intervals. This adds nulls to the spectrum as shown in Fig. 1.b and increases transient oscillations compared to balanced SSFP imaging. The uneven spacing between the excitations creates an asymmetric signal profile, making it difficult to suppress oscillations well over a broad range of frequencies. Instead, a narrower set of frequencies in the [-100, 100] Hz range can be attempted.

A simple approach is to align the magnetization to its steady-state direction using a single pulse before the sequence starts [1]. This method works only for a small range of frequencies around the resonance for ATR. Alternatively, the ATR sequence itself can be comprised of a set of linearly increasing [2] or Kaiser-Bessel windowed [3] flip angles. A Shinnar-Le Roux (SLR) design [4] can be used for faster catalyzation. It consists of a series of RF pulses separated in time by Δt, a design parameter.

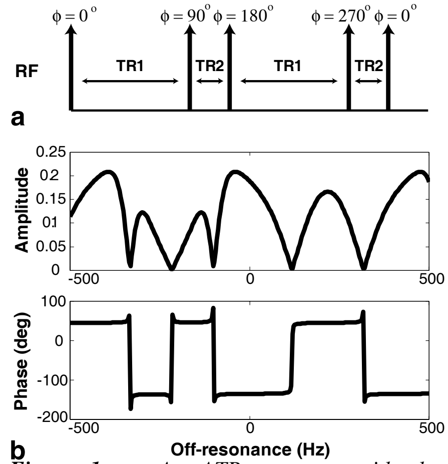

Figure 1. ***a:*** *An ATR sequence with the parameters: $\alpha=60^o$, $TR_1/TR_2=3.45/1.15$ ms and $(0\text{-}90\text{-}180\text{-}270)^o$ phase cycling.* ***b:*** *The resulting transverse magnetization for T1/T2 = 1000/200 ms.*

Results: The catalyzing sequences were tested for the ATR sequence shown in Fig. 1, assuming T1/T2 = 1000/200 ms (arterial blood). The single-tip pulse has a flip angle of $2\alpha/3$, a phase of 225^o. The linear and Kaiser-Bessel ramps lasted 18.4 ms. The SLR design had 10 pulses for a total of 11.5 ms. In this case, Δt was chosen to be 1.15 ms as TR_1/TR_2 is an integer, TR_2 = 1.15 ms and the magnetization profile is periodic with $1/TR_2$. The simulated transient responses are shown in Fig. 2. The SLR design achieves the most robust suppression of the oscillatory response. The oscillation amplitudes resulting from the catalyzation methods were simulated with respect to T1/T2 and TR_2/TR_1. There were no significant variations with T1/T2. The mean amplitude of oscillation as a function of TR_2/TR_1 is displayed in Fig. 3. The SLR sequence, redesigned for each TR_2/TR_1, outperforms other methods for a wide range of TR_2/TR_1 values. A 3D ATR acquisition of a water phantom with centric phase encoding and a linear shim along the readout direction, was preceded by several catalyzation sequences, as displayed in Fig. 4. The relatively short SLR design approaches the catalyzation performance of a longer duration, 90 ms, Kaiser-Bessel design.

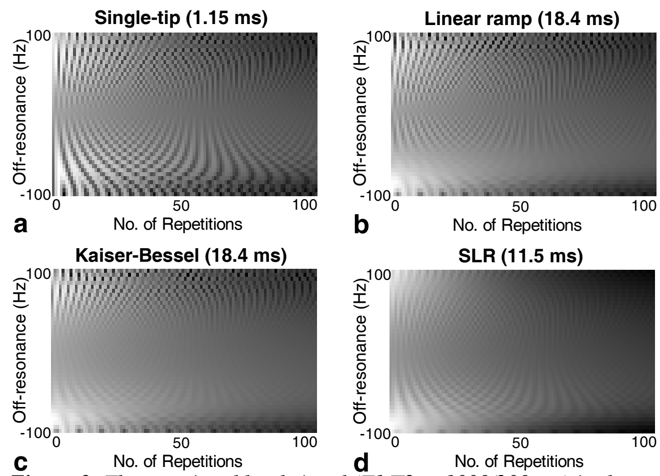

Figure 2. The transient blood signal (T1/T2 = 1000/200 ms) is shown as a function of off-resonance and the number of RF excitations for ***(a)*** *single-tip,* ***(b)*** *linear ramp,* ***(c)*** *Kaiser-Bessel ramp and* ***(d)*** *SLR designs. The SLR design has the smoothest transient response.*

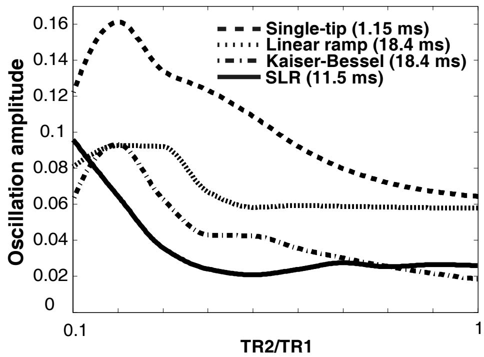

Figure 3. The mean oscillation amplitude as a function of TR_2/TR_1 is displayed single-tip, linear ramp, Kaiser-Bessel ramp and SLR designs.

Conclusion: A fast and robust catalyzation sequence will allow ATR imaging to be combined with techniques such as magnetization preparation. In cases where the catalyzation time has to be short, the SLR design gives the most robust catalyzation. However, if it can be afforded a long train of Kaiser-Bessel windowed pulses is a good choice as it is simple to design and works well.

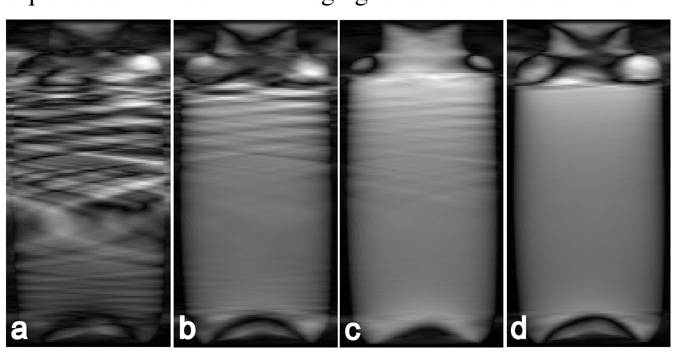

Figure 4. *A water bottle with T1/T2 = 1850/1850 ms was used for a 3D ATR acquisition with centric phase encoding and a linear shim to create a ±110 Hz frequency variation along the readout (vertical) direction. The encoding matrix was 192x96x44 with a 1 mm in-plane resolution and a 2 mm slice thickness. The results are shown for* ***(a)*** *single-tip (1.15 ms),* ***(b)*** *linear ramp (18.4 ms),* ***(c)*** *SLR (11.5 ms) and* ***(d)*** *Kaiser-Bessel (90 ms).*

References:

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