Combined T2-Prep and Outer Volume Suppression Preparation Sequence for Coronary Angiography

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Target Audience: MR engineers, scientists and clinicians interested in RF pulse design, cardiac imaging, or coronary angiography.

Purpose: Enhancement of blood-myocardium contrast and suppression of the volume outside the heart are desired for coronary magnetic resonance angiography (MRA). For these purposes, several RF preparation sequences such as T2-Prep [1][2] and outer volume suppression (OVS) [3][4] have been designed. These two preparation sequences could be played separately in series to achieve both T2-Prep and OVS. However, it is advantageous to apply these two preparations simultaneously so that the time between preparation sequence and image readout is minimized, and also specific absorption rate is reduced. In this work, a novel preparation sequence that simultaneously achieves T2-Prep and OVS is designed and tested for coronary MRA.

Methods: The proposed magnetization preparation sequence is shown in Figure 1. A nonselective 90° adiabatic pulse (BIR-4) [5] is first applied, followed by two identical 180° adiabatic full passage (AFP) refocusing pulses. Finally, a 2D -90° RF spiral pulse brings the T_2-weighted magnetization within a selective circular or elliptical region back to the longitudinal direction. The BIR-4 pulse is designed with a hyperbolic tangent amplitude of $\beta = 10$ and a tangent frequency modulation of $\tan(\lambda) = 50$ [5]. The AFP is designed with hyperbolic secant amplitude and modified hyperbolic tangent frequency modulation ($\mu = 2.5$, $\beta = 980$). The spiral pulse has a phase matched with the transverse magnetization phase at the echo of the second AFP, which maximizes the tip-up in the passband and minimizes the tip-up in the outer volume [2].

The proposed sequence can be applied between the fat-saturation module and imaging module of the coronary MRA sequence (Fig. 2). The two AFP refocusing pulses prevent excessive T_1 recovery of the fat signal, resulting in a longitudinal magnetization of 0.025 M_0 for fat at the end of the preparation sequence according to Bloch simulation.

Results: Bloch simulation shows that the proposed sequence achieves good suppression of the volume outside a circular passband while enhancing the blood-myocardium contrast by factor of 1.5 using a 20-ms T2-Prep time. The performance remains nearly the same within the off-resonance range of [-100, +100] Hz and B_1 scale range of [0.8, 1.2] (Fig. 3). Figure 3 (a)-(c) simulate blood with $T_1 = 1000$ ms, $T_2 = 230$ ms.

Phantom data were acquired with a single-slice Cartesian sequence to demonstrate the performance. Signals from the outer volume were suppressed to the noise level and signals from the T_2 phantom displayed expected T_2 weighting (Fig. 4). *In vivo* 3D cones coronary MRA [6] was performed with and without the proposed preparation (FOV = 28x28x14 cm^3, spatial resolution = 1.2x1.2x1.25 cm^3, diameter of OVS passband = 12 cm). The proposed preparation substantially reduced outer volume signals (3.77 to 0.39 measured in chest wall) while enhancing blood-myocardium contrast (0.30 to 0.49 in relative blood-myocardium contrast ratio defined as $(S_{blood}-S_{myo})/S_{blood}$) (Fig. 5).

Conclusion: We have developed a simultaneous T2-Prep and OVS preparation sequence and tested its feasibility in phantoms and *in vivo*. This sequence induces T2 weighting to improve blood-myocardium contrast while suppressing outer volume signals, which can facilitate scan acceleration by reducing the imaging FOV. Another potential advantage in free-breathing coronary MRA is that the respiratory motion artifacts from structures outside the heart (e.g., chest wall) can be reduced.

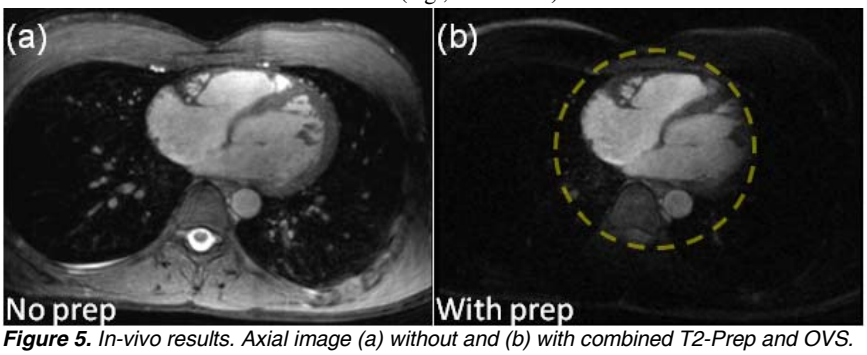

Figure 5. *In-vivo results. Axial image (a) without and (b) with combined T2-Prep and OVS. Yellow dash line denotes the OVS passband.*

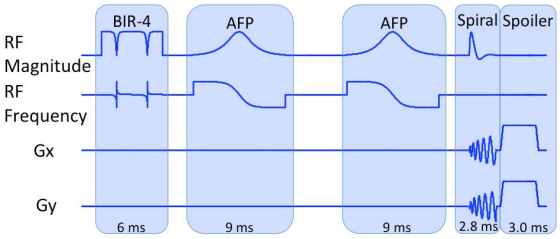

Figure 1. *Pulse sequence diagram.*

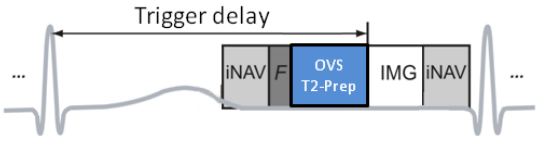

Figure 2. *Timing diagram of coronary MRA sequence. iNAV: navigators. F: fat saturation. IMG: imaging.*

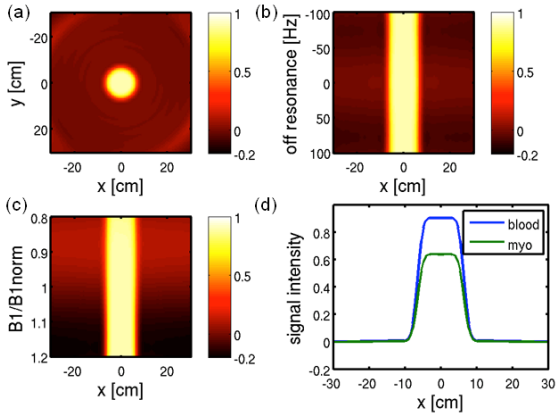

Figure 3. *Simulation results. (a) Spatial profile. (b) Off-resonance sensitivity. (c) B_1 sensitivity. (d) Signal of blood and myocardium. (b)-(d) at y = 0.*

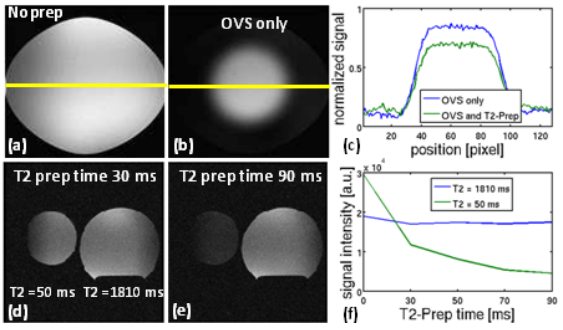

Figure 4. *Phantom scans.* ***TOP:*** *Phantom (a) no prep and (b) with OVS only. (c) Center signal (yellow line) normalized to image w/o prep.* ***BOTTOM:*** *T_2 phantoms with OVS and (d) 30 ms and (e) 90 ms T2-Prep. (f) Comparison of signals with 0 to 90 ms T2-Prep times.*

References: **[1]** Brittain JH, *et al.*, MRM 33: 689–696, 1995; **[2]** Nezafat R, *et al.*, MRM 61:1326–1335, 2009; **[3]** Pisani L, *et al.*, MRM 57: 297–307, 2007; **[4]** Smith TB, *et al.*, MRM 67: 1316–1323, 2012; **[5]** Staewen RS, *et al.*, Invest Radiol 1990;25:559–567; **[6]** Wu HH, *et al.*, MRM 69:1083–1093, 2013.