On-resonant binomial pulse preparation for magnetization transfer contrast enhanced coronary vein imaging

C. T. Stoeck[1,2], D. C. Peters[1], Y. Han[1], K. V. Kissinger[1], B. Goddu[1], L. Goepfert[1], W. J. Manning[1,3], S. Kozerke[2], and R. Nezafat[1]

[1]Department of Medicine (Cardiovascular Division), Beth Israel Deaconess Medical Center and Harvard, Boston, MA, United States, [2]Institute for Biomedical Engineering, University and ETH Zurich, Zurich, Switzerland, [3]Department of Radiology, Beth Israel Deaconess Medical Center and Harvard Medical School, Boston, MA, United States

INTRODUCTION Magnetization transfer (MT) has been used in various clinical applications to enhance tissue contrast in MRI [1, 2]. MT contrast enhancement can be established by either continuous wave off-resonant [3], pulsed off-resonant [4] or pulsed on-resonant [5] radio frequency (RF) irradiation. Application of pulsed off-resonance RF irradiation in coronary vein MRI has been shown recently [6]. Application of an MT pre-pulse yields improved visualization of coronary veins by suppressing myocardial signal while maintaining blood signal. In this study, we sought to investigate the use of an optimal binomial pulse for on-resonant magnetization transfer sequences. Numerical, phantom and *in vivo* studies were performed to optimize the on-resonance MT sequence parameters. A comparative study of the optimal on-resonance vs. off-resonance sequence was performed to evaluate each sequence in coronary vein imaging.

MATERIALS AND METHODS The parameters including repetition, flip angle and order of a binomial on-resonant MT sequence were optimized by numerical simulation of the coupled Bloch equations and a subsequent phantom validation in 4%, 8% agar and water. In a pilot study, nine healthy adult subjects were imaged in a left ventricular (LV) two chamber view using a 2D gradient echo imaging sequence. With the optimal candidate parameters obtained in the initial numerical and phantom data, MT contrast enhancement was then achieved using binomial pulses with order of 1 to 3, total flip angles of 60°, 120°, 240°, 480° and 720° as well as 2 to 8 pulse repetitions. The binomial pulses were block shaped with maximal allowable amplitude. For comparison, images were acquired with off-resonant MT-preparation using the same pulse parameters as on-resonant pulses with an offset frequency of 500Hz and duration of 20ms. Relative contrast to noise ratio (rCNR) was measured between left ventricular (LV) blood pool and myocardium.

In a subsequent study, the optimal parameters were used for 3D small-slab targeted imaging of the coronary vein anatomy. Seven healthy subjects were imaged with the following imaging parameters: TR/TE/α: 6ms/1.87ms/30°, FOV of 270×270×30 mm^3 with a spatial resolution of 1×1×3mm^3 reconstructed to 0.5×0.5×1.5 mm^3, 20 slices with 15 phase-encode lines per hear-beat. MT-contrast was enhanced using 8 repetitions of either a second order binomial pulse with α_{tot}=240°, a first order binomial pulse with α_{tot}=720° or an off-resonant pulse with a frequency offset of 500Hz and α_{tot}=720°. CNR was measured between the coronary sinus (CS) blood and the myocardium. Measured CNR was normalized to the values obtained from images without MT (rCNR). All Images were acquired on a 1.5T Philips Achieva System (Philips Healthcare, Best, the Netherlands) and approved by IRB.

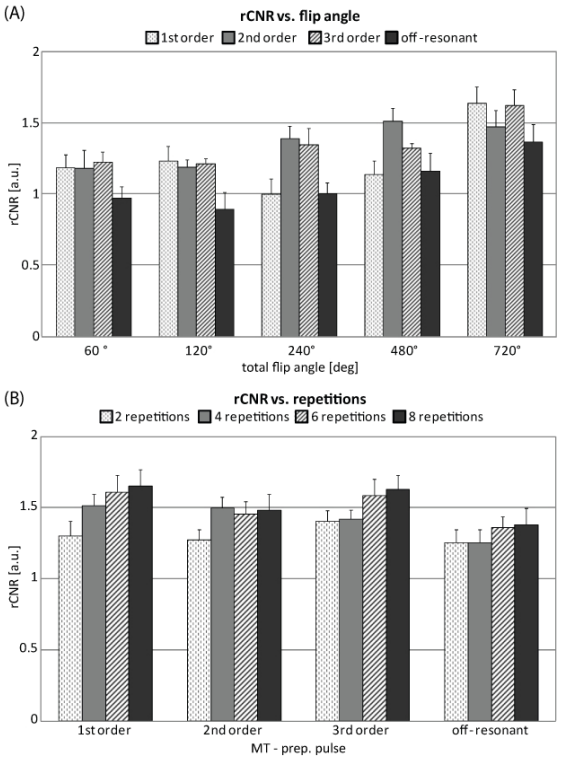

Figure 1 The rCNR between left ventricular blood and myocardium is shown as function of the applied flip angle (A) and the amount of pulse repetitions (B). Contrast enhanced values were plotted against non-contrast enhanced values. rCNR values were obtained by linear regression.

RESULTS Our initial numerical and phantom data were used to evaluate the impact of each parameter (data not shown) and were used in the subsequent *in vivo* studies. Figure 1 shows the *in vivo* rCNR measured in the pilot 2D study between LV blood and myocardium as a function of (A) total flip angles and (B) pulse repetitions. In A, eight pulse repetitions were used for each flip angle while in B a total flip angle of 720° was used for each repetition. In the low flip angle range (60°-120°) contrast was not enhanced more than 22% by on-resonant MT preparation. In the intermediate range of flip angles (240°-480°) second order on-resonant binomial pulses dominate the other MT preparation pulses, yielding a contrast enhancement of 39% (240°) and 51% (480°). Using the largest flip angle applied in this study (720°) first order pulses yield the highest contrast enhancement (64%). Off-resonant MT-preparation fails using flip angles in the lower range of 60° to 240°. In order to create a satisfying amount of contrast, multiple pre-pulse repetitions are needed. Figure 2 shows an example slice from a 3D coronary vein data-set acquired (A) without any MT pre-pulse, (B) with eight second order binomial pulse with α_{tot}=240°, (C) eight first order binomial pulse with α_{tot}=720° and (D) eight off-resonant pulses with α_{tot}=720° and frequency offset of 500Hz. rCNR was measured to be 1.4±0.2, 2.2±0.1, and 2.0±0.2 for the low flip angle second order pulse, high flip angle first order binomial on-resonant pulses and the off-resonant pulses respectively.

DISCUSSION We investigated an on-resonant MT preparation sequence that can be used for cardiovascular imaging, particularly coronary vein MRI. First order preparation pulses with large flip angles yield similar enhancement as off-resonant MT preparation. Furthermore, at lower flip angles second order on-resonant MT-preparation pulses outperform off-resonant and on-resonant first order binomial MT, which can be of benefit if the total flip angle is limited due to limitations in energy deposition.

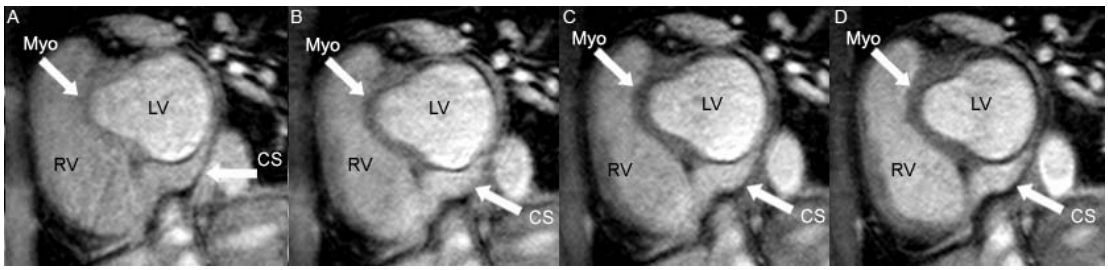

Figure 2 A single slice taken from the 3D targeted small slab coronary vein acquisition is shown. (A) represents the non-contrast enhanced reference image. Contrast enhanced images show the effect of eight repetitions of second order pulses with α_{tot}=240°(B), first order pulses with α_{tot}=720° (C) or off-resonant pulses with α_{tot}=720° and 500Hz offset (D). The arrows point to the coronary sinus (CS) and the myocardium (Myo).

REFERENCES

[1] Wolff SD, Balaban RS MRM 1989;10(1):135-144
[2] Henkelman RM et al. NMR Biomed 2001;14(2):57-64
[3] Schneider et al. JMRI 1993;3(2):417-423
[4] Wolff SD, Balaban RS. Radiology 1994;192(3):593-599
[5] Hua J, Hurst GC JMRI 1995;5(1):113-120
[6] Nezafat R et al. MRM 2007;58(6):1196-1206