Acceleration-Selective Magnetic Resonance Angiography

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TARGET AUDIENCE: MR researchers and technicians interested in MR angiography.

PURPOSE: Velocity-selective magnetization preparation has been shown to provide high angiographic contrast for non-contrast-enhanced (NCE) MR angiography (MRA) in the lower extremities[1]. Acceleration-sensitive excitation was introduced to improve the differentiation between arterial and venous flow, but relied on suppression of arterial flow based on intravoxel dephasing, requiring subtraction of two acquisitions for angiographic contrast[2]. In this work, we design a new acceleration-selective (AS) magnetization preparation pulse sequence that generates positive arterial contrast directly without the need for subtraction, and demonstrate its application for lower extremity MRA in healthy volunteers.

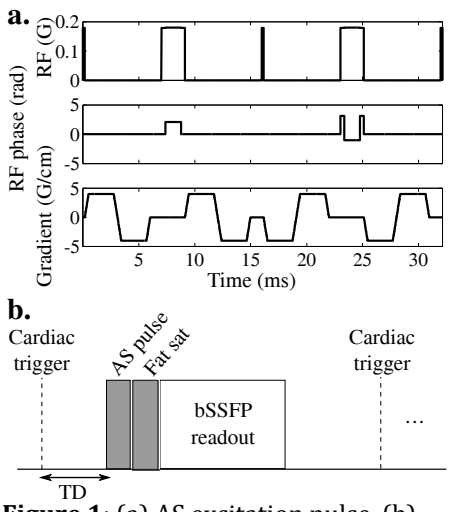

Figure 1: (a) AS excitation pulse. (b) Timing diagram of AS MRA sequence.

METHODS: AS pulse design: Fig. 1 shows the AS pulse and its inclusion in the angiographic sequence. The AS pulse (Fig. 1a) is designed by interspacing RF sub-pulses between a series of tri-lobed gradients with nulled first and zeroth moments but non-zero second moment, so as to provide acceleration-dependent selectivity without spatial or velocity selectivity. The RF sub-pulse areas determine the flip angle of non-accelerating spins. To reduce off-resonance frequency and B_1 sensitivity, $90_0360_{120}90_0$ and $90_{180}360_{300}90_{180}$ refocusing pulses are inserted halfway between each tri-lobed gradient[3,4], which requires inverting the sign of each gradient lobe that sees odd-numbered refocusing pulses prior to it. A 1 ms delay was inserted before each RF pulse to allow for eddy current decay. Bloch simulations of the resultant longitudinal magnetization as a function of acceleration and off-resonance frequency for T_1=1070 ms and T_2=40 ms (approximate for 1.5T muscle) are shown in Fig. 2a. Spins with acceleration in [-1, 1] m/s^2 (static tissue and venous blood, which has minimal acceleration) are excited by 110° and nulled at the readout time, while spins with acceleration in [2, 8] and [-8, -2] m/s^2 (arterial blood) are left mostly intact at the end of the AS pulse. Unlike with velocity-selective preparation, the acceleration direction can be positive or negative, so the profile can be centered at zero.

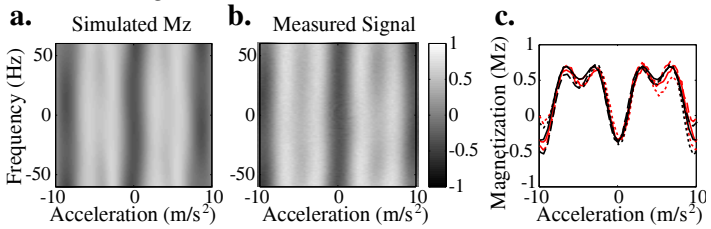

Figure 2: (a) Bloch simulated excitation profile as a function of acceleration and off-resonance frequency for muscle at 1.5T. (b) Phantom (T_1/T_2 = 107/98 ms) measurement of the excitation profile. (c) Comparison of simulated and measured excitation profiles for the phantom in (b). Red/black = measured/simulated, solid/dashed/dotted = 0/-60/60 Hz.

Phantom study: A phantom was used to measure the AS excitation profile. The gradient lobes in Fig. 1 were replaced with gradient blips in X to simulate acceleration over spatial position, and a constant gradient was played in Y to simulate off-resonance frequency. After the AS pulse, a 90° pulse and 2DFT readout imaged the longitudinal magnetization.

Imaging methods: All scans used a GE Signa Excite 1.5T scanner with the body transmit coil. The phantom study used a receive head coil, and in vivo studies used an 8-channel cardiac receive coil. The sequence is initiated by a peripheral cardiac trigger followed by a trigger delay (TD), the AS pulse, a fat saturation pulse, and then a 3DFT balanced SSFP readout (Fig. 1b). Two images were acquired with different TDs: at peak and decreasing systolic flow (80/135 ms), as determined by a PC flow MRI scan. Imaging parameters were: coronal scan orientation, 1.1x1.0x1.3 mm^3 resolution, 30x30x9.1 cm^3 FOV, FA=80°, TR=4.9 ms.

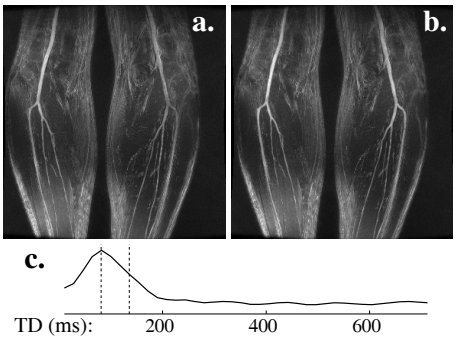

Figure 3: Targeted MIP NCE AS MRA for (a) TD=80 ms, (b) TD=135 ms, corresponding to peak and decreasing systolic flow given by a PC flow MRI (c), show that TD=135 ms has better angiographic contrast.

RESULTS: Figs. 2b-2c show the measured and simulated signals for the phantom validation study. The measured signals closely match the simulated profiles, as a function of both acceleration and off-resonance frequency. Figs. 3a-3b show in vivo NCE AS MRA targeted MIPs as a function of the trigger delay, with TD=135 ms exhibiting better artery-background contrast.

DISCUSSION/CONCLUSION: We have demonstrated a new MRA method that uses acceleration selectivity to create angiographic contrast directly without the need for subtraction. With acceleration-selective preparation, nulling times can be chosen for optimal background suppression. By incorporating refocusing pulses into the AS sequence, we have mitigated the effect of off-resonance frequency variation on the images. While other refocusing pulses may be used, we found that the $90_0360_{120}90_0$ pulse with MLEV phase cycling produced the best images when B_1 variations are also a concern.

REFERENCES: [1] Shin *et al.*, MRM 70:1229-40, 2013. [2] Priest *et al.*, MRM 72:699–706, 2014. [3] Levitt *et al.*, Progr NMR Specgtrosc 18:61-122, 1986. [4] Shaka AJ, *et al.*, JMR 77:606–612, 1988.