Velocity Selective Prepared Non-Contrast Enhanced MR Angiography using Phase Sensitive Reconstruction

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Introduction: There has been renewed interest in non-contrast enhanced MR angiography (NCE-MRA), particularly of the peripheral arteries in patients with compromised renal function. Among various approaches, motion sensitized driven equilibrium (MSDE) based NCE-MRA has shown considerable promise.[1] These approaches include multiple acquisitions with different MSDE preparations, which are then subtracted to achieve the final angiogram. The empirical settings of the MSDE gradients used with these approaches combined with possible patient motion between the acquisitions can potentially lead to incomplete background signal and venous signal suppression. An alternative approach using velocity selective preparation (VSP) with minimal to no background signal in a single acquisition has been previously proposed,[2] however, the velocity encoding used with these approaches lead to venous signal contamination. In this work, we present a phase sensitive reconstruction combined with VSP that can determine the flow direction and can potentially differentiate arterial and venous signals with background signal suppression in a single acquisition.

Theory: VSP uses magnetization preparation using a 90^o_x-180^o_y-90^o_y RF pulse train with velocity encoding gradients applied between the RF pulses. Figure 1 shows a schematic of the spin behavior experiencing the VSP. The static spins (red arrow) accumulate same amount of phase between the 90^o_x-180^o_y and 180^o_y-90^o_y and are aligned along the initial orientation (i.e. y-direction). However, the moving spins (blue and green arrows) accumulate phase depending upon their direction and velocity (i.e.) arteries and veins accumulate different phase in opposite directions. Hence, at the end of the VSP, the static spins are oriented along the transverse plane while the moving spins in the opposite direction are oriented along the longitudinal direction (+z and –z). Spoiler gradients applied immediately after the VSP destroys the static signal while preserving the signal from the moving spins. A phase sensitive acquisition that follows immediately can measure the signals and the directions of the moving spins.

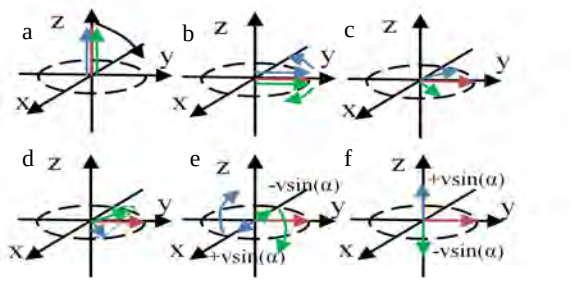

Figure 1. Schematic of the magnetization evolution during VSP (Red arrow represents a static spin; blue and green arrows represent moving spins in opposite directions). α represents the phase accumulation.

Methods: A VSP module was implemented in a 2D balanced steady state free precession (bSSFP) acquisition. To minimize the sensitivity to B_0 and B_1 inhomogeneities, an adiabatic pulse (BIR-4 with flip angle (FA) 90^o) based VSP was used. All experiments were performed on a 3 T Ingenia scanner (Philips Healthcare, The Netherlands). The method was first validated in a flow phantom consisting of tubes with flow in opposite directions submerged in a static water bath (fig. 2a). The imaging parameters were: TR/TE = 3.1/1.56 ms; matrix size = 220×216; voxel size = 1.1×1.1×4 mm^3; centric phase encoding. The flow was set to 4 cm/s as measured by phase contrast and the corresponding v_{enc} was set to 15 cm/s. An additional image without VSP gradients and BIR-4 FA 0^o was acquired to estimate the phase for phase sensitive reconstruction.[3] Subsequently, the method was tested on the lower legs of 2 normal volunteers with IRB approval and written informed consent. The acquisition was cardiac triggered to peak systole with the following parameters: coronal orientation; TR/TE = 3.0/1.5 ms; FOV = 334×167 mm^2; resolution = 1.1×1.1 mm^2; 10 mm slice thickness; centric phase encoding and a v_{enc} of 15 cm/s.

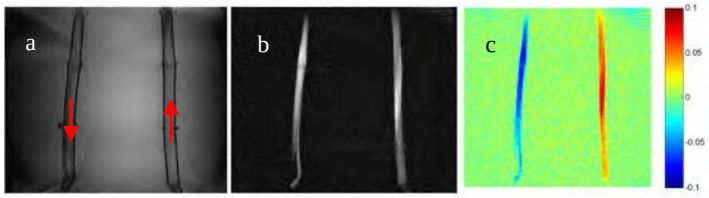

Figure 2. Flow phantom images: (a) reference image acquired using FA 0^o BIR-4; (b) magnitude image acquired with VSP; (c) phase sensitive image depicting flow direction.

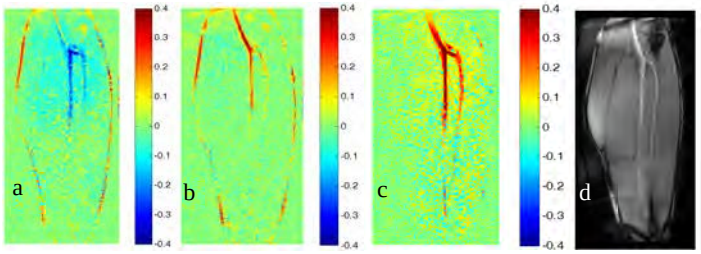

Figure 3. Normal volunteer study. Phase-sensitive reconstructed images acquired with VSP using a) positive gradient, b) negative gradient, and c) subtracted image between b and a. (d) reference image used for phase sensitive reconstruction.

Results: Fig. 2b shows the magnitude image of the flow phantom using the proposed VSP, with essentially no background signal. Using the phase information from the reference image (fig. 2a), phase sensitive reconstruction allowed estimation of the flow direction (fig. 2c). Similarly, the direction of the popliteal arteries was also estimated using the phase sensitive reconstruction in the normal volunteer (fig. 3a). When the VSP was applied with gradients in the opposite direction, the phase sensitive reconstruction appropriately determined the direction of the arterial flow (fig. 3b). A subtraction between the two images provided the angiogram with good background signal suppression (fig. 3c).

Discussion: The phase sensitive acquisition and reconstruction combined with velocity selective preparation allows the separation of flow depending upon the direction with minimal background signal suppression. The background signal in the human studies, particularly fat, has not been completely suppressed with VSP and future implementation with chemical-shift acquisitions should minimize this signal. Further optimization of the velocity encoding gradients combined with 3D bSSFP acquisitions should allow the separation of arteries and veins with minimal background signal in a single acquisition.

Reference: [1] Fan Z et. al., MRM 62 (2009); [2] Korosec FR et. al, MRM 30 (1993); [3] Kellman P et. al., MRM 47 (2002).