Blood Velocity Imaging using Spiral Phase Contrast with Complex Difference Processing

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Abstract: We measured through-plane blood velocity in the ascending aorta with spiral phase contrast MRI (SPC-MRI) processed using complex difference methods. The relatively long TRs required to minimize the saturation of blood-pool spins in complex difference processing provide sufficient time for acquisition of spiral interleaves. Furthermore, spiral sampling of k-space has demonstrated good image quality in the presence of motion with efficient k-space coverage. Complex difference processing of phase contrast data subtracts out the signals from stationary tissue which both eliminates partial volume effects and allows for a drastic reduction of imaging FOV. Blood velocities measured with complex difference and phase difference methods are compared for both full FOV and reduced FOV cases.

Introduction and Theory: Single projection real-time volumetric flow imaging can be used to measure flow rate rapidly in areas where there is no overlapping of vessels in the projected direction [1]. However, there are overlapping vessels around the heart which make using single projection measurements of flow untenable. Using spiral sampling, one can resolve the flow for each pixel instead of only the integration of the flow onto a single projection. Complex difference processing of phase contrast data has the advantage of eliminating the partial volume effects from voxels that contain both flowing spins (blood) and stationary tissue [2] and also subtracting out the signals from stationary tissue. We investigate the accuracy of the complex difference processing for the measurement of flow velocity by comparing it with the phase-difference SPC-MRI. The phase of the transverse magnetization is the sum of background phase (Φ_b), which is a combination of the RF coils, off-resonance, unbalanced gradient phases due to eddy currents and the velocity encoded phase (Φ_v)

$$\theta(x,y) = \Phi_b(x,y) + \Phi_v(x,y) = \Phi_b(x,y) + \gamma M_1 v_z(x,y)$$

Where M_1 is the encoded first moment and $v_z(x,y)$ is the velocity of the spin and γ is the gyromagnetic ratio. Complex difference signal can be expressed as:

$$\Delta s(x,y) = \kappa(x,y)\,|M_+(x,y)|\,\{\exp(i\theta_2(x,y)) - \exp(i\theta_1(x,y))\}$$

In which $\kappa(x,y)$ is coil sensitivity map and $M_+(x,y)$ is the excited transverse magnetization. With the assumption of uniform excitation and non-varying background phase inside the vessel one can express the velocity inside the vessel as follow:

$$V_z(x,y) = \frac{2V_{enc}}{\pi}\sin^{-1}\left(\frac{\Delta s(x,y)}{2\kappa(x,y)\,|M_+(x,y)|\exp(i\Phi_b)}\right)$$

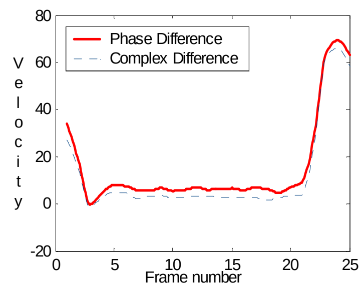

Figure1. Complex difference velocity measurement (cm/s) vs. phase difference processing

The background phase correction is achieved by calculation of the measured phase inside the vessel from the spin density image derived from the same acquisition. The imaging parameters were selected such that the spin-density value inside the vessel can be calculated from the magnitude image; this measurement also includes the sensitivity map of the coils in the region.

Method: A flow sensitive spiral phase contrast sequence was developed in which the refocusing pulse is combined with the bipolar gradient. Images were acquired on a GE Signa CV/i 1.5T MR imaging system (GE, Waukesha, WI) and an 8-channel cardiac phased array coil (Nova Medical, Wakefield, MA). Two low resolution single-shot images with different echo times were acquired at the beginning of the cardiac scan for off-resonance map calculation and correction using the linear field map for subsequent cardiac phases [3]. Peripheral gating was used in all experiments. Normal volunteers were imaged with informed consent as approved by the NHLBI IRB. The spiral sequence consisted of 16 interleaves with spatial resolution of 2.04 mm. Field of views (FOVs) of 35 cm and 15 cm were prescribed for large and small FOV experiments, respectively. To keep the TR and spatial resolution constant between two experiments, the number of interleaves is reduced to 5 in small FOV experiment. The imaging parameters were as follows: TR = 24.8, $\alpha=30^0$ BW=±125, slice thickness=3 mm, V_{enc}=300 cm/s.

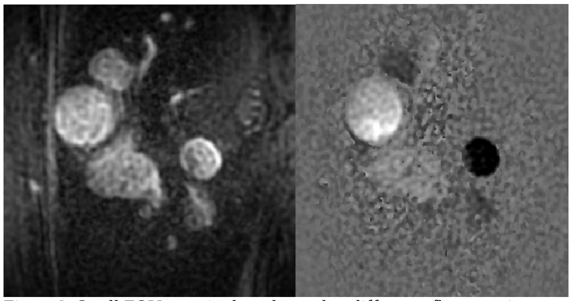

Figure 2. Small FOV magnitude and complex-difference flow map image

Results: FIG 1 shows the velocity of the blood flow through an axial slice in ascending aorta above the bifurication of pulmonary artery, comparing the complex difference vs. phase difference. FIG 2 shows the flow in a small FOV image processed with the complex difference with corresponding magnitude image.

Discussion: Blood velocities measured with a spiral phase contrast technique with complex-difference processing agreed with those measured with conventional phase-difference processing. Subtraction of the stationary tissues, particularly those from fat and tissues distant from the blood flow of interest, allowed small field of views (15 cm). Reduced field of view requirements can be used to reduce the total acquisition time or to increase spatial resolution in the same imaging time.

References:

[1] Thompson RB, et. al. MRM, In press.
[2] Polzin JA, et al.**,**JMRI. 1995 Mar-Apr;5(2):129-37
[3] Irarrazabal P, et al. Magn Reson Med, 1994; 35(2), 278-82.