Peak Angiogram Calculations from 4D Flow Imaging

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Introduction Cine 4D flow imaging allows not only for the assessment of cine velocity fields but also for the generation of angiograms. We have adopted this approach with a radially undersampled phase contrast acquisition, PC VIPR, to provide a non-contrast enhanced MRA alternative for patients with a contra-indication for CE MRA based on Gd injections [1]. We have adopted a modified complex difference (CD) algorithm for the derivation of the angiogram from the phase difference and magnitude data [2]. However, this approach can lead to signal drops and voids in areas with reversing flow when used with a radial acquisition. This work introduces a novel algorithm for the derivation of an angiogram based on dynamic CD images and its application to renal MRA.

Methods and Materials Our standard reconstruction uses the modified CD algorithm (1) where |V| represents the length of the velocity vector and Mag the magnitude of the voxel, both calculated as time average values from all radial projections. This average angiogram approach can lead to signal cancellations in vessels with reverse or pulsatile flow (see Fig 1). With temporally resolved velocity data, one can avoid this problem by creating an angiogram using only the peak velocity of a particular voxel within the cardiac cycle instead of the average velocity, ignoring all of the other values. While this peak angiogram approach will increase the background noise it should decrease signal degradations due to pulsatility (Fig 1). The two algorithms were compared in renal PC-VIPR scans acquired in 4 volunteers (average age = 34.0 years; 2 males; 2 females) and 6 patients (average age = 40.2 years; 1 male; 5 females). All studies were performed on a 1.5T system (GE Healthcare, Waukesha, WI) after obtaining IRB approval and written informed consent from all subjects. Scans were performed with the following parameters: imaging volume = 320 x 320 x 125-160 mm^3, readout = 256-320, 1.0-1.25 mm^3 acquired isotropic spatial resolution, V_{enc} of 40-100 cm/s, TR/TE/flip = 8.7ms/3.2ms/10º, retrospective cardiac gating and adaptive respiratory gating with a 50% acceptance window, reconstructed # of time frames = 16, scan time ~ 10 min. Signal levels were measured in the source images of both angiograms with ROI analysis of the renal aorta at three locations: at the renal bifurcation, 4.58 cm ± 0.70 cm superior (variation due to excitation slab constraints), and 5.0 cm inferior, using ImageJ (NIH, Bethesda, MD). Signal homogeneity was measured as the percent signal drop throughout the aorta.

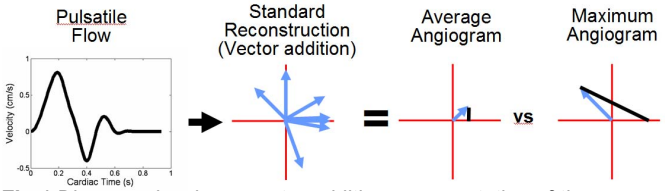

Fig 1 *Diagram showing a vector addition representation of the average and peak velocity values derived from a hypothetical flow profile.*

$$CD = \overline{Mag}\,\sin\left[\frac{\pi|\vec{v}|}{2V_{enc}}\right];\ |\vec{v}| < V_{enc} \quad (1)$$

Results Representative angiograms are shown in Figures 2 and 3. The signal dropped significantly less in the peak velocity reconstruction compared to the time averaged ($p < 0.05$, Student's t-test). Measured as the percentage of signal lost compared to the superior slice, the time averaged signals dropped 36.1% ± 25.9% compared to a drop of 24.2% ± 25.3% in the peak velocity angiogram.

Conclusions The amount of signal loss over the aorta was decreased in the peak angiograms, demonstrating an improved signal homogeneity over the course of the aorta as is seen in Figure 2 between the red arrows. The yellow arrows in Figure 2 show the increase in homogeneity within the aorta as seen in a single slice. While the difference in signal drop was not large, drastic improvements were seen in particular subjects, demonstrating the usefulness of this technique on a case by case basis. This is seen in Figure 3, where the iliac arteries (red arrows) are barely visible towards the bottom of the excitation slab in the time averaged angiogram, but remain visible in the peak angiogram. Several of the subjects showed signal losses in the infrarenal aorta in the average angiogram, which could lead to missed accessory renal arteries. It is important to note that in several of the subjects, there was little signal loss in the time averaged data, so the peak velocity reconstruction only degraded the image by increasing noise. However, a SNR analysis was challenged because of the uneven distribution of undersampling artifacts present in the individual time frames. A further improvement of the proposed algorithm is the use of a window of time frames to increase SNR while avoiding signal cancellations.

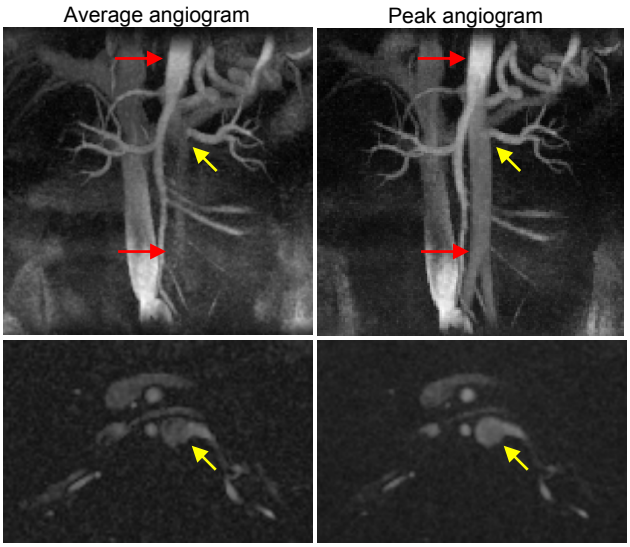

Fig 2 *Upper row: MIP images of a healthy volunteer obtained from the time average angiogram and the peak angiogram. Bottom row: Corresponding axial slice through the plane of the renal bifurcation.*

Acknowledgements We gratefully acknowledge funding by NIH grant 2R01HL072260-05A1 and GE Healthcare for their assistance and support.

References [1] D. Lum et al., Proc ISMRM 2008, 2891 [2] A. Anderson et al., Proc ISMRM 2008, 934.

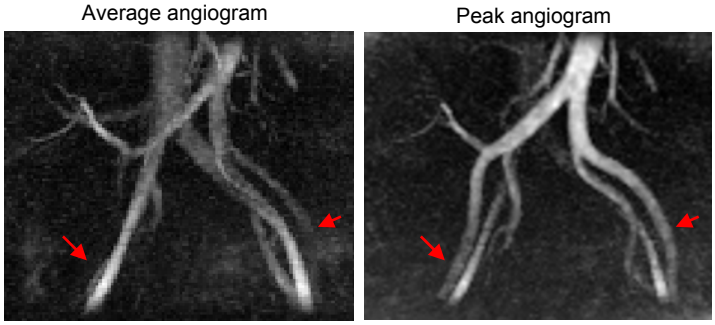

Fig 3 Coronal MIP of the time averaged and peak angiogram *in a patient with a kidney transplant,.*