Effect of Voxel Size, Image Orientation, VENC and TE on Phase Contrast Measurements in Turbulent Stenotic Jets

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Introduction: Aortic stenosis (AS) can give rise to high velocity jets of more than 400cm/s. Phase contrast (PC) has the potential to accurately diagnose lesion severity; however, AS jets are often very turbulent and intravoxel dephasing can introduce significant errors in peak velocity and flow. In an *in-vivo* investigation of moderate to severe AS patients we found that PC measurements of stroke volume (SV) were systematically lower than SV obtained from volumetric measurements (Figure 1a). *In-vitro* experiments in a pipe of aortic diameter were able to reproduce these errors. Shortening TE, (Figure 1b) was shown to increase signal and improve accuracy; however, the relative influence of factors contributing to the signal loss and errors remains uncertain [1-3].

Purpose: To investigate, using up-to-date gradient hardware, the influence of voxel size [1], velocity encoding (VENC) [2], and orientation of the jet relative to the image plane [3], all of which have previously been found to cause signal loss and intravoxel dephasing in high velocity turbulent jets.

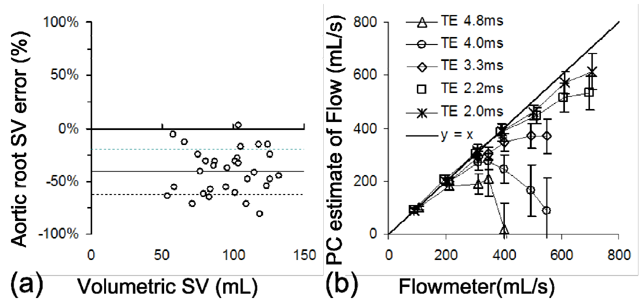

Figure 1(a) SV from summation of PC aortic velocities underestimates volumetric SV, it occurs when there is low signal. These errors were reproduced in-vitro (b) and it was found by shortening TE the signal intensity and the accuracy of PC improve.

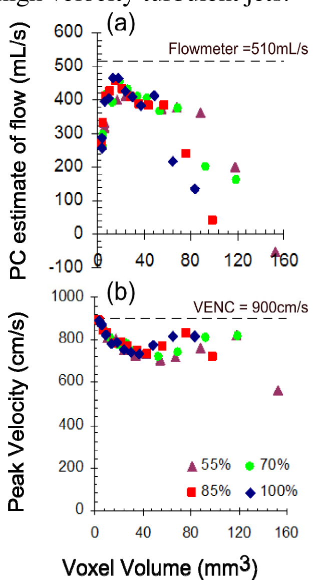

Figure 2 (a) PC flow and (b) peak velocity as a function of voxel volume and phase resolution.

Method: An experimental phantom consisting of a straight PVC pipe with an internal diameter of 28mm and a 12mm concentric circular constriction created a stenotic jet. Water was pumped through a closed circuit at constant flow rates ranging from 100-700mL/s. An electromagnetic flow meter with an accuracy of 1% provided the gold standard measurement of flow. All experiments were conducted on a Siemens 1.5T Avanto scanner (gradient strength 40mT/m with slew rate 170T/m/s) using a modified retrospectively gated velocity encoding sequence with an artificial ECG for triggering.

In-plane resolution was varied from 0.78-3.91mm by varying FOV and matrix size, and in-plane isotropy was varied by decreasing the phase resolution from 100% to 85%, 70% and 55%. The effect of VENC was studied at flow rates of 200 and 300mL/s, at VENCs of 350-999cm/s and 550-999cm/s respectively. Image orientation relative to the jet was investigated by rotating the image plane in the axial-sagittal direction by 1^0, 2^0, 3.5^0, 5^0, 7^0, 10^0; at three different TE/TR values (msec) of 3.6/52.05, 2.8/45.65, and 2.0/39.25; and at two flow rates, 300 and 500mL/s. Where appropriate, other image parameters were held constant at TE/TR 2.8/45.65msec, flip 30^0, matrix size 192x132, FOV 300mm, slice thickness 5.5mm, VENC 900cm/s and a flow rate of 500mL/s.

Results: Figure 2a shows the highest accuracy occurred with a voxel volume of 13.5-19mm^3 and in-plane resolution of 1.5-1.8mm. More isotropic voxels gave slightly better results. Peak velocity was highly dependent on voxel size but not shape (Figure 2b). VENC had minimal effect on flow and peak velocity accuracy. The accurate estimate of flow was conserved as the image plane was orientated oblique to the jet; however, Figure 3 shows that peak velocity is reduced over and above what was expected from the cosine(θ) relationship. This dependence of the peak velocity estimate on orientation is removed at shorter TEs.

Discussion: Flow in a jet is complex; velocities in the jet converge before and diverge after the vena contracta. Intravoxel dephasing could occur if the velocity distribution of the spins, due to in-plane motion, is too large. This would increase at more oblique orientations to the jet's high velocities, figure 3. Shortening TE reduces the time available for the velocity distribution intravoxel dephasing to occur improving the PC velocity estimate.

Increasing in-plane resolution aims to reduce the distribution of velocities causing intravoxel dephasing. Figure 2 shows that the balance point between too few spins (insufficient signal) and too many spins to get reliable estimate of flow with PC velocity occurs at a voxel volume of 13.5-19mm^3.

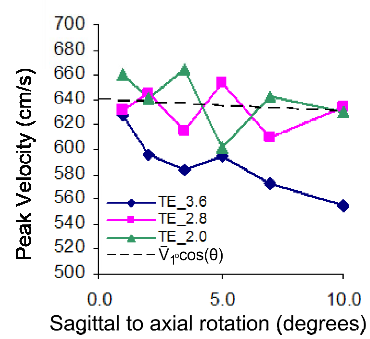

Figure 3 Peak velocity as a function of image orientation relative to the jet for flow rates of 500mL/s.

Conclusions: Flow errors were most sensitive to TE, and more effort should be made to reduce this parameter in clinical studies. Typical clinical values of voxel size had the least flow error. The effect of image orientation on velocity estimates was reduced at short TE.

1. Nayak KS, Magn Reson Med 2003;50(2):366-372. **2.** Hamilton CA, J. Magn Reson Imaging 1994;4(5)752-755 , **3.** Kilner PJ, Circulation 1993;87(4) :1239-48