Evaluation and accuracy of arterial wall shear stress measurement using a rapid 3D phase contrast acquisition technique

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INTRODUCTION

Wall shear stress (WSS) is the viscous drag of flowing blood on the vessel wall [1]. Low and oscillatory WSS has been associated with plaque formation [2]. Therefore a non-invasive method of measuring WSS *in-vivo* in a reasonable scan time would be useful. We have applied Phase contrast-Vastly undersampled isotropic projection (PC-VIPR), a rapid 3D projection based method [3] for assessment of WSS. PC-VIPR is capable of acquiring large 3D volume data with isotropic spatial resolution in a single acquisition and allows measurement across the vessel in any direction. The objective of this study is to demonstrate the feasibility of measuring WSS using 3D PC-VIPR. Phantom and *in-vivo* experiments were performed to compare 3D PC-VIPR WSS results with 2D PC WSS.

MATERIALS AND METHODS

Experiments were performed on a 1.5T MR scanner (Signa LX; GE Medical Systems, Milwaukee, WI) using 2D PC and 3D PC-VIPR sequences. For the phantom study, a 1 M long tube with an internal diameter of 8.0 mm was surrounded by 2% agar gel. Tubing was connected to a Cole-Parmer pump supplying copper sulphate doped water with a T1 of approximately 400 msec, from a reservoir housed outside the scan room. Typical parameters used for 2D PC were TR/TE/Flip = 29 ms/8.5 ms/15º, FOV = 80 x 80 mm, matrix 512 x 512 and NEX= 10. The parameters used for PC-VIPR were TR/TE/Flip = 14.3 ms/4.2 ms/10º, FOV = 180x180x180 mm, matrix 512x 512x512, and scan time = 14 minutes. The effects of spatial resolution and undersampling for PC-VIPR were studied for WSS estimates in the tube phantom where the analytical result is known. Thus far a single healthy human volunteer study was performed using retrospectively gated 3D PC-VIPR compared to Cartesian cine 2D PC placed perpendicular to the internal carotid artery. The parameters used for cine 2D PC were FOV= 24x24 cm, matrix 256x256, and scan time = 2 minutes. The parameters used for PC-VIPR were FOV= 24x24x24 cm, matrix 256x256x256 and scan time = 8 minute with 1300 projections per cardiac phase. The flow [4] in the carotid arteries was expected to be approximately laminar therefore a parabolic fitting method described by Oyre *et al* was used to estimate WSS.

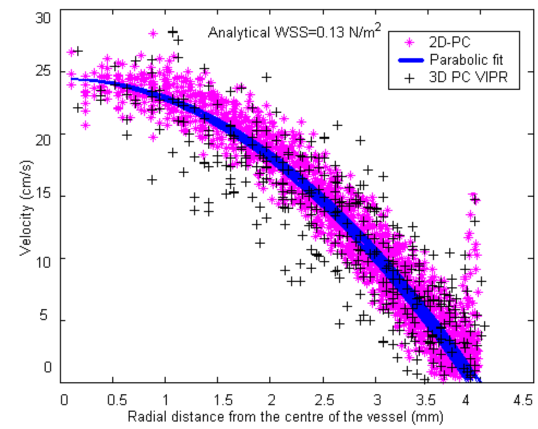

Figure 1 - 3D PC-VIPR velocity profiles matches the 2D PC profile. The WSS values for both were 0.12 N/m^2. Laminar flow is present in circular vessels, which allows an analytical measurement of WSS. The solid blue line indicates the parabolic fit curve.

RESULTS AND DISCUSSION

The phantom experiment allowed analytical calculation of WSS and also demonstrated that 3D PC-VIPR WSS measurements matched with 2D PC. The velocity profiles match perfectly for 3D PC-VIPR and 2D PC (Figure 1). However, for practical applications shorter scan times and larger voxel sizes must be used. The phantom experiments suggest that a resolution of 0.7mm is adequate to measure WSS within 5% for a T1 of ~ 0.4 s (Figure 2). Another factor likely to affect the accuracy of WSS estimates is the degree of azimuthal undersampling. As few as 2,500 projections (~6minutes for 10 cardiac phases) are enough to reduce errors in WSS estimates below 5%. Although preliminary, the WSS measurements from the *in-vivo* study show that 3D PC-VIPR performs comparable to 2D PC (Figure 3). The parameters used for WSS *in-vivo* are in the range where error is 10-20%. Increasing the scan time on the order of 14 minutes will reduce the errors in situations where needed.

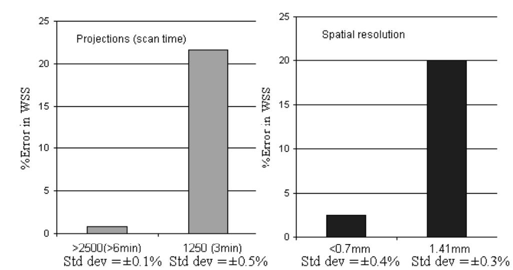

Figure 2 – The percent error in WSS due to azimuthal undersampling and spatial resolution in PC-VIPR. The errors are measured with respect to the analytical value (WSS = 0.13 N/m^2).

CONCLUSIONS AND FUTURE WORK

We have demonstrated the feasibility of measuring WSS in phantom studies and *in-vivo* using 3D PC-VIPR. 3D PC-VIPR is a promising technique for measuring WSS and flow in the carotid arteries due to its capability of 3D volume acquisition in a single exam, isotropic spatial resolution, reduced scan time and the ability to measure across vessels in any orientation. The parametric method of Oyre [5] works well for circular vessels having a laminar flow profile. We are currently developing a non-parametric model for WSS measurements in arteries with complex geometry. Further *in-vivo* studies investigating WSS measurements in the carotid bifurcation are in progress.

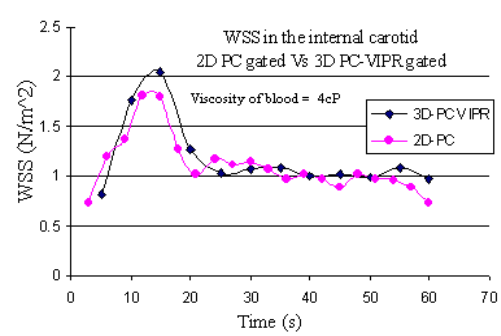

Figure 3 - WSS in the right internal carotid artery of a healthy volunteer for 3D PC-VIPR gated and 2D PC gated shows comparable results.

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