Time-Dependent Wall Shear Stress Measurement in Middle Cerebral Artery (MCA) using Bi-Exponential Curve Fitting of Phase Contrast MR Angiography

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INTRODUCTION: Vascular wall shear stress (WSS) is believed to play a critical role in the processes of atherosclerosis[1,2]. WSS could be used to assess vascular disease initiation and proliferation processes. Advancement of PC-MRA technique enabled *in vivo* evaluation of arterial WSS. However, MR velocity measurements are more sensitive to partial volume effects (PVE) on edge pixels, especially at times in the cardiac cycle when velocities are high and it is very hard to determine a boundary condition, especially in low resolution 1.5T MRI. A previous study for evaluating WSS used boundary nodes by 2D third-order Lagrangian elements [3]. In this study, we sought to develop a method suitable for time-dependent measurements of WSS in the M1 segment of the MCA with robust lumen segmentation and PVE suppression.

MATERIALS AND METHODS: Phase contrast MR angiogram (PC-MRA) images of M1-MCA segment were obtained on perpendicular plane to its direction with FOV 26.5 x 14 cm, Matrix 256 x 192, Slice thickness 3mm, TR/TE=11.88~12.92/5.74~5.95, at 12 discrete time points during cardiac cycle. All the MR images were 10 times magnified by Lanczos interpolation and MR density was converted into velocity using velocity encoding (VENC) information. Automatic lumen segmentation using Otsu thresholding method was performed. Velocity profiles were extracted in each slice of the PC-MRA images and a bi-exponential curve with wall boundary outliers was fitted to the profile to suppress PVE. The boundary outliers were determined by minimization of RMSE between the fitted curve and original data. The Lumen cross-sectional area of MCA and WSS were evaluated at all time points of the cardiac cycle and their temporal changes including luminal diameter, luminal area change, color-coded WSS on MRI were measured. All software was implemented based on Matlab 2009a ™.

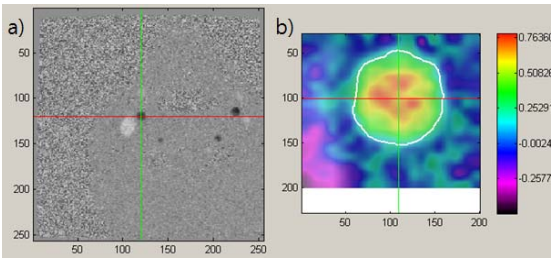

Figure 1 selected vessel on PC-MRA (a) and vessel segmentation (white) with velocity color coding on a magnified image (b).

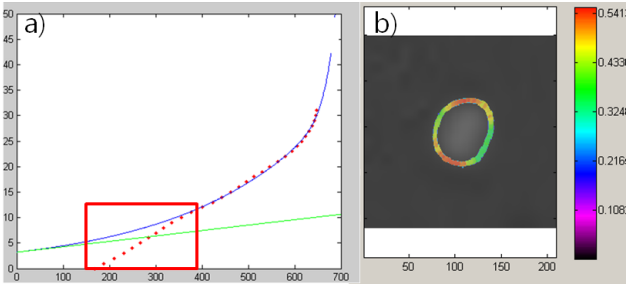

Figure 2 Bi-exponential curve fitting (blue line) with outliers and wall shear stress calculation by differentiate at 0 (green line) (a) and WSS map (unit; Pa) (b). Red spots inside a red box in Figure 2a represent partial volume effect, magnified by interpolation

RESULTS: Figure 1 shows the PC-MRA and selected vessel segmentation on 10 times magnifies images by Lanczos interpolation and Otsu thresholding. In Figure 2, typical pattern of PVE inside a red box was shown. A bi-exponential curve fitting with boundary outliers (blue line) was performed and WSS was evaluated by differentiation at 0 (green line) in Figure 2a. Figure 2b represent WSS map on the vessel boundary. Figure 3 shows WSS maps on the cardiac cycle. Temporal crossectional area changes showed about 25 % increase on end systolic phase than end diastolic. The measured range of WSS is about 4.41~ 6.402 Pa.

DISCUSSION AND CONCLUSION: Lanczos interpolation with low-pass filter kernel characteristics preserve velocity profiles derived from PC-MRA images. Lumen segmentation using Otsu thresholding combined with bi-exponential curve fitting of the velocity profile compared favorable to simple thresholding and active contour methods regarding the suppression of PVE. In conclusion, Lanczos interpolation, Otsu thresholding and bi-exponential curve fitting of velocity profile and evaluation of the gradient at the edge pixels can be combined to a sequential semi-automated analysis of PC-MRA images. Results include anatomical information and physiological wall parameters with robust lumen segmentation and PVE suppression.

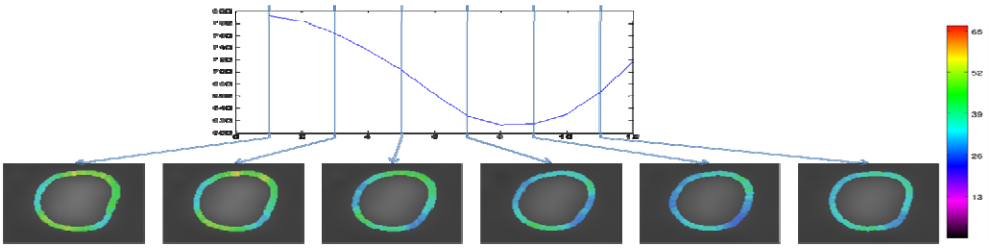

Figure 3 WSS maps (Pa) on the cardiac cycle (lumen area (mm^2) vs time)

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