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VALIDITY OF PATIENT-SPECIFIC COMPUTATIONAL HEMODYNMAICS FOR NONINVASIVE QUANTIFICATION OF BLOOD FLOW

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Summary: *Patient-specific computational hemodynamics (PSCH) based on CT/MRI images has emerged as a powerful noninvasive technique to quantify hemodynamics in blood vessels for potential assistance of vascular disease assessment and treatment planning. In this work, we study the validity of the unique PSCH technique we recently developed using unified lattice Boltzmann method (LBM) for 4-D (time+space) in vivo hemodynamics based on time-of-flight (TOF) MR angiography (MRA) for morphological vessel geometry and electrocardiogram (ECG) gated phase contrast (PC) imaging for velocity profiles at inlet and outlet of the vessel. The validation is carried out through comparisons of PSCH vs. MRA for velocity distributions on representative transverse planes. Five volunteers were recruited to participate in the study. For each volunteer, one high resolution TOF MRA image and 10 coarse resolution ECG gated PC images are acquired for the PSCH. Both vertebral and carotid arteries are studied for the validation. The comparisons of velocity contours show good agreements between PHCS outputs and MRI measurements, implying (1) the PSCH is reliable for noninvasive quantification of vessel hemodynamics and (2) the integration of PSCH of flow, pressure, and wall shear stress (WSS) into diagnostic MRI of vascular diseases is promising.* This work is supported by IU Health Research Fund.

Background Vascular diseases are serious medical conditions that can lead to disability, amputation, organ damage, and even death. According to CDC (Centers for Disease Control and Prevention), in 2010, the total costs of cardiovascular diseases in the United States were estimated to be $444 billion. Treatment of these diseases accounts for about $1 of every $6 spent on health care and it is likely to become even greater as the US population ages. It has been long know that blood hemodynamics is a major contributing factor for the development of vascular diseases [1] because the interaction between an internal blood flow and wall deformation often underlie biological function or dysfunction of an artery. Nevertheless, the quantification and analysis of *in vivo* blood hemodynamics remains challenging. Radiological imaging can accurately identify morphological abnormality of a blood vessel and may noninvasively quantify the flow, it does not assess important underlying functional data including the dynamic interaction between the blood flow and vessel/plaque wall. Thus the role of the imaging in assessing the overall risk and predicted outcomes of vascular disease is limited. Recently, patient-specific computational hemodynamics (PSCH) in human subject has emerged as a powerful technique to noninvasively reveal flow, pressure and wall shear stress (WSS) distribution. Corresponding parametric analysis is expected to provide the necessary functional information to promote a deeper understanding of vascular diseases, laying the groundwork for future improvements

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in patient care and clinical decision making. The attractive advantages of PSCH include the low cost of facility, personnel, and supplies, the short and flexible time cycle, and the direct human subject results with full human subject protection. Radiological evaluation and animal model experimentation cannot compete with these advantages and achieve similar results with the same investment. We have developed a unique PSCH technique, named ***InVascular***[2], using mesoscale lattice Boltzmann method (LBM)[3,4] and GPU parallel computing[5,6]. In this work, we validate the reliability of InVascualr for PSCH.

Methodology A group of five healthy volunteers was recruited to participate in the study. For each volunteer, one high resolution time-of-flight (TOF) magnetic resonance angiogram (MRA) image and 10 low resolution electrocardiogram (ECG) gated phase contrast (PC) images were acquired. As shown in Fig. 1, image processing of MRAs (a) results in the vessel geometry and 10 velocity slices (b). The geometry and velocity profiles at inlet and outlets are fed into InVascular for PSCH. For each artery, the InVascular numerically quantifies the velocity and pressure fields as well as WSS distribution on the inner wall of the artery. We compare the velocity profiles (slices 2-9) obtained from PSCH with MRI measurement.

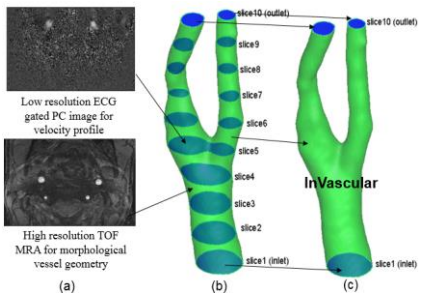

Fig. 1 Image extraction (a ⇒b) and feed PSCH for geometry and velcoity (b ⇒c)

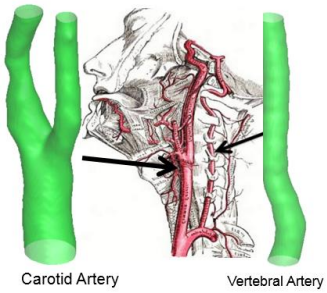

Fig.2 Carotid and vertebral arteries segmented from MRI images.

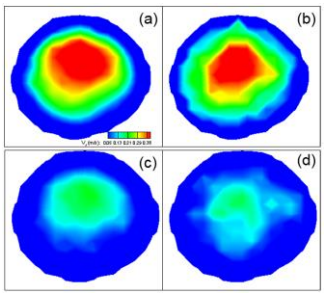

Fig. 3 Velocity contours of PSCH (a,c) vs. MRI (b,d) at systole (a,b) and diastole(c,d)

Results and Conclusion Both vertebral and carotid arteries of each volunteer are studied (Fig. 2). Comparisons of velocity contours on different transverse planes in arteries are found in good agreement with MRI measurements. Figure 3 shows one representative comparison of PSCH quantification (left column) vs. MRI measurement (right column) at peak systole (top row) and end of diastole (bottom role). We conclude that PSCH is reliable to quantify in vivo velocity filed and the integration of PSCH of flow, pressure, and wall shear stress (WSS) into diagnostic MRI of vascular diseases is promising.

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