Evaluation of Wall Shear Stress in Spontaneously Hypertensive Rats by Phase-Contrast MRI

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Introduction:

With advantages of non-invasive, phase-contrast magnetic resonance imaging (PC-MRI) is a unique technique to measure the velocity of blood flow. Wall shear stress (WSS) derived from PC-MRI, used to provide insights into the blood rheology, is of high interest [1]. It has been proposed that vessels with atherosclerosis are associated with lower WSS [2]. The frequent occurrences of atherosclerotic plaques are in regions of curvature, bifurcation, and branching of vessels. In addition, hypertension may also intensify the occurrence of atherosclerosis. Rats with native hypertension (spontaneously hypertensive rat, SHR) are an excellent animal model to go further study on the atherosclerosis [3]. In this work, we investigated hemodynamic patterns of common carotid arteries (CCA) in the rat model by measuring WSS with PC-MRI.

Materials and Methods:

Four SHR (male, weight=310~350 g) and five normotensive Wistar Kyoto (WKY) (male, weight=320~355 g) rats at ages of 16 weeks were anesthetized with 1.5% Isoflurane. All images were acquired in a 7T animal MRI scanner (Bruker ClinScan 70/30) with gradient strength of 630mT/m. To make sure that the through-plane velocity was measured, 3D time of flight (TOF) angiography was performed for localization (TR/TE/θ=20msec/3.46msec/90°, matrix size=256×256, and FOV=40×40mm). PC-MRI was conducted after the TOF sequence by the prospective ECG triggering. A 2D single-slice time-resolved PC-MRI were performed as following parameters: TR/TE/θ=15.55msec/4.51msec/30°, matrix size=256×256, slice thickness=2 mm, number of average=10, and FOV=40×40mm. To evaluate spatial differences in WSS, the PC-MRI was performed at two levels, including middle and bifurcation (Fig. 1). WSS was calculated based on the following equation:

$$WSS = \eta \, dv/dr$$

where η is the viscosity of fluid, v is the velocity of fluid, and r is the vessel radius. Two parameters were extracted from each WSS function: temporal averaged WSS (WSS_{avg}) and systolic WSS (WSS_s). The WSS_{avg} was the average WSS over all cardiac cycle and WSS_s was the maximum WSS over the cardiac cycle.The velocity profile and WSS parameters were extracted by an analysis tool computed on Matlab [1].

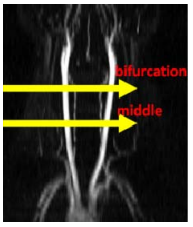

Figure 1. The coronal view of TOF MRA for localization. The PC-MRI was performed at two levels: middle and bifurcation.

Results:

The group averaged WSS for both SHR and WKY in middle and bifurcation were plot as a function of cardiac phases in Fig. 2. The WSS parameters were compared in Fig. 3. For SHR, WSS_{avg} was significantly reduced in bifurcation when compared to that in middle (P<0.05). In systolic phase, the differences of WSS_s in two locations were more significant (P<0.01). On the contrary, there was no statistically significant difference between middle and bifurcation for WKY (normal control). With the hypertension as a risk for developments of atherosclerosis, SHR also exhibit the significantly lower WSS_s when compared to WKY (P<0.05).

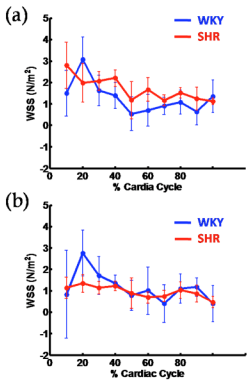

Figure 2. Group averaged WSS for both WKY and SHR in middle (a) and bifurcation (b) of CCA.

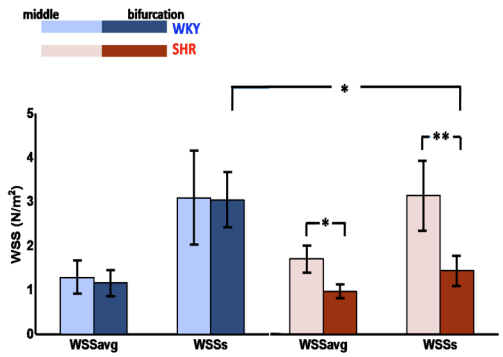

Figure 3. The comparison of WSS parameters. For SHR, WSS_{avg} and WSS_s were significantly lower in bifurcation than in middle. In addition, SHR also exhibit significantly lower WSS_s when compared to WKY. (* indicated P < 0.05, ** indicated P<0.01)

Discussion and Conclusions:

In this study, the WSS of the CCA of hypertensive rat model was measured by PC-MRI for the first time. The PC-MRI study for rat model was seldom utilized due partly to the fact that worse spatial resolution may result in errors in velocity estimation. Tang et al. [4] showed that at least 16 voxels must cover the cross section of the vessel to ensure the measurement error to within 10%. In this study, the cross section of the CCA covered at least 25 voxels, which meets the need of the accurate estimation. SHR is characterized by the genetic hypertension and reaches an established stage of hypertension development at the age of 12 weeks. According to early work by Simon *et al*, it suggested that hypertensive state would be accompanied by the decrease in WSS_{avg} as well as WSS_s in brachial artery for human [5]. By using the state of the art gradient system, higher resolution was achieved to avoid errors in velocity estimation. Therefore, we successfully demonstrate that the WSS_{avg} and WSS_s were significantly decreased in bifurcation of CCA in SHR. These phenomena were not observed in the normal control group of WKY rats. In conclusion, this preliminary study demonstrated the feasibility and sensitivity of *in vivo* WSS measurements in rat model. The PC-MRI can distinguish the WSS difference between SHR and WKY, and even between different levels of CCA. It could also be a potential translational model for non-invasive longitudinal studies, which would be valuable for drug developments of atherosclerosis.

References:

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