Wall Shear Stress of Swine Model with Induced Carotid Artery Stenosis

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OBJECTIVES
Low and/or oscillatory shearing stress at a vessel wall is regarded as a risk factor of the evolution of atherosclerotic plaques [1]. In vivo hemodynamic study concurrent with temporally-resolved histo-pathological investigation has inherent difficulties especially, at the stage of formation and development of atherosclerotic lesions. In this study to estimate wall shear stress for comparison with histological results, stenosis at swine carotid artery was artificially induced by surgical partial ligation. Advanced atherosclerotic plaques were developed in a proximal portion to the stenosis. Concurrently, high-resolution MR phase contrast (PC) was performed to estimate the temporal and spatial distribution of wall shear stress within small and deeply positioned swine carotid vessel. Doppler velocimetry was used to measure and compare blood flow with MR measurement.

METHODS AND MATERIALS
Common carotid arteries were surgically ligated to cause 80% stenosis in 13 Yucatan swine. All animals were then fed with a high-fat and high cholesterol diet till the formation of advanced atherosclerotic plaques was verified. 3T and 1.5 T Siemens scanners were used for high-resolution MR PC imaging to quantify flow velocity. Standard 2D RF-spoiled gradient echo sequence was used for image acquisition with TR/TE= 10.7/5.6 msec, flip angle 90 degrees. Imaging matrix was 320×320 mm, slice thickness 2.2 mm, with 2.2×2.2 mm in-plane resolution. Intense intravascular Doppler guide wire (FloWire, VOLCANO) with 12 MHz piezoelectric ultrasonic transducer and a real-time spectrum analyzer (Flomap, Cardiometrics) were used for the measurement. Intravascular Doppler guide wire was advanced through a 5F sheath (FloWire, VOLCANO) with 12 MHz piezoelectric ultrasonic transducer and a real-time spectrum analyzer (Flomap, Cardiometrics) were used for the measurement.

RESULTS AND DISCUSSIONS

Though surgical ligation was performed to create a concentric stenosis, vessels near the stenosis developed, varying in shape which in turn, affected blood flow. In the figure above, results of wall shear stress color-maps (+ 3.1 Pascal in the model A) at the systole, superimposed onto the magnitude image, are shown. Doppler traces and temporal distributions at two regions, distal and proximal, are shown for swine model A and B. The distal region to the stenosis showed highest instantaneous wall shear stress (3 ～ 8 Pascal) which demonstrates increased blood flow passing after the stenosis. It also showed high average wall shear stress and little oscillation (mean (Pascal)/OSI: 1.49± 0.10 in model A and 0.71/0.08 in model B). On the other hand, the proximal region to the stenosis showed low and/or oscillating shear stress (mean (Pascal)/OSI: 0.63±0.18 in model A and -0.06/0.47 in model B) where advanced atherosclerotic plaques were developed. MR-PC measurement of the flow in the swine model was validated by Doppler velocimetry which demonstrated good agreement between two methods. Estimation of wall shear stress at the stenosis was not feasible due to a small vessel dimension at the given imaging resolution.

CONCLUSION
Low and/or oscillating wall shear stress was observed at the proximal region to the stenosis induced by surgical ligation during atherosclerotic plaque formation in the swine model. The distal region to the stenosis showed relatively high wall shear stress with little oscillation, depending upon the vessel geometry. Calculated wall shear stress based on PC-MRI datasets was consistent with Doppler velocimetry measurement. High resolution MR-PC imaging in conjunction with the swine model may be beneficial to providing an in-depth understanding of the hemodynamic effects on the evolution of atherosclerotic lesions.

REFERENCES