Arterial Wall Stiffness Variations Along the Canine Aorta using Pulse Wave Imaging with Validation in vitro

Danial Shahmirzadi1, Ronny X. Li1, William W. Qaqish1, Elisa E. Konofagou1,2
Department of Biomedical Engineering, Columbia University, New York, NY, USA
Department of Radiology, Columbia University, New York, NY, USA

Introduction: The aortic stiffness has been proposed as an independent indicator of cardiovascular disease. Existing methods to estimate the aortic stiffness are either invasive, e.g. catheterization, or yield global (inaccurate) measurements, e.g., applanation tonometry. Pulse wave imaging (PWI) is an ultrasound-based method aiming at noninvasive and regional estimation of pulse wave velocity (PWV); a highly correlated parameter to the wall stiffness through the Moens-Korteweg equation. This study reports the assessment of PWI for measuring the regional wall stiffness along the canine aorta in vitro. Materials and Methods: Aortas (total length L=187.5±45.96 mm; n=2) from mongrel male dogs were freshly excised from the thoracic (post-arch) to the suprarenal abdominal region and kept immersed in phosphate-buffered saline (PBS) during in vitro imaging and testing. A normalized coordinate system was set on each aorta describing each axial location (x) normalized by the total length, i.e. x/L=0 for the thoracic and x/L=1 for the abdominal. A peristaltic pump (Manostat Varistaltic, IL) was connected to the aorta providing sinusoidal flow. A Sonix Touch (Ultrasonix Medical, BC) ultrasound system with a 10 MHz linear array operating at 642 fps and 32-beam density was used to acquire the RF signals and estimate the wall displacement at several locations along the aorta using a 1D cross-correlation technique. The information was used to generate spatio-temporal plots and estimate the PWV as the slope of the linear regression. The PWV estimates, together with density, radius and thickness measurements, were used to estimate the Young’s modulus based on the Moens-Korteweg equation. After completion of the PWI, the same locations used for imaging were also used to extract rectangular specimens of width w=7.63±1.32 mm and length L=14.55±1.83 mm (n=14) in the circumferential direction. The Instron® 5848 Microtester (Instron, MA) was used to perform tensile cyclic testing up to a strain of at the rate of . However, in order to operate within the similar strain range as in the PWI, only the slope of the stress-strain curve up to modulus and used to validate the PWI estimates. All in vitro protocols were completed within 24 hours post-mortem. Results and Discussion: Figure 1 shows the regional spatio-temporal plots obtained in eight different axial locations along the aortic specimen. The plots also show the wave foot and the linear fit in each case. The PWV values show a decrease from the thoracic to the descending aorta followed by a slight increase at the suprarenal level (results now shown). Figure 2 shows the results of the wall Young’s modulus both as measured by the mechanical testing and estimated by the PWI. The PWI method is found to underestimate the mechanical testing measurements despite the fact that the qualitative shape of the wall modulus variation was accurately captured consistently. The discrepancy between the PWI and mechanical testing measurements could be attributed to the different boundary conditions in the PWI setup compared to mechanical testing including the use of the simplistic Moens-Korteweg equation in the former and the use of small, sectioned specimens in the latter as well as differences in the loading state, strain range and existence of residual stress between the two methodologies. Conclusion: Reliable implementation of the noninvasive PWI method can be of paramount significance in estimating the change in wall stiffness in vivo and enhancing the prognostic techniques. In this study, the PWI was successfully implemented in different regions along the canine aorta in vitro and was shown able to detect similar qualitative spatial changes and lower variability than mechanical testing. Acknowledgements: NIH R01-HL098830.