

# Assessment of stiffness changes in the ex vivo porcine aortic wall using magnetic resonance elastography

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**Introduction:** Increased arterial stiffness has been found to be associated with increased morbidity and cardiovascular mortality in hypertensive patients [1,2]. Stiffening of large arteries results in various adverse hemodynamic consequences. As arterial stiffness has been established as a cardiovascular risk factor, it has also emerged as a potential target for intervention. The mechanics of the dynamic fluid-filled soft structure of the arteries are poorly understood and a major challenge for current techniques designed to assess arterial wall stiffness. Magnetic resonance elastography (MRE) is a noninvasive phase-contrast technique for estimating the mechanical properties of tissues by imaging propagating mechanical waves within the tissue. Prior studies have shown MRE has the potential to evaluate the elastic properties of vessel walls using measurements of mechanical wave propagation in the fluid near the vessel walls [3,4]. In this study, we hypothesize that changes in arterial wall stiffness itself, experimentally induced by formalin fixation, can be measured using MRE in ex vivo porcine aortas.

**Methods:** The stiffness of the aortic wall of five ex vivo porcine aorta specimens was measured with MRE. The aortas were filled with normal saline and were imaged with a gradient-echo MRE imaging sequence, a single-channel transmit-receive head coil, and an electromechanical driver applied to the vessel wall to generate mechanical waves within the aortas. The Young's modulus of the aortic wall was calculated by measuring the wavelength of the mechanical waves produced in the saline near the aortic wall from the acquired MRE images. Uniaxial tensile testing was also performed in all aortic samples to provide an independent measure of the Young's modulus. After an initial MRE scan and biomechanical testing, each individual aortic sample was immersed in 10% neutral buffered formalin for 6 days. The fixed aortic samples were reexamined using the same MRE protocol and biomechanical procedures. A paired Student's t-test was used to test for significant differences in the Young's moduli of the fresh and fixed aortas and a linear regression analysis was performed to compare the MRE and biomechanical testing modulus measurements.

**Results:** The propagating waves in the saline were well visualized in both fresh and fixed aortas. The mean Young's modulus from all fresh aortas using MRE was  $165.0 \pm 12.3$  kPa (range 149.2-176.8 kPa) while the mean stiffness of the fixed aortas was  $491.3 \pm 55.5$  kPa (range 392.7-522.6 kPa). There was a significant increase in the stiffness of the fixed aortas compared to the fresh aortas ( $p < 0.001$ ). Biomechanical testing also demonstrated a significantly higher stiffness in the fixed aortas compared to the fresh aortas ( $202.4 \pm 10.8$  and  $2240.0 \pm 406.8$  kPa, respectively,  $p < 0.001$ ). A strong linear relationship was revealed between the MRE and mechanical testing Young's moduli ( $r^2 = 0.972$ ,  $p < 0.001$ ).

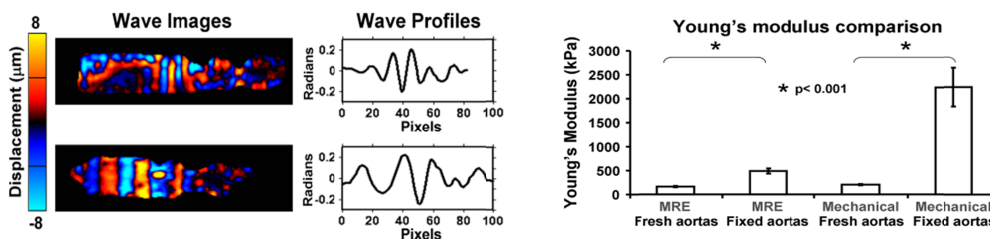


Fig. 2. The Young's modulus of fresh and fixed aortas obtained from MRE and mechanical testing.

Fig. 1. Wave images obtained with MRE in the fresh aorta (upper row) and the same sample after fixation (bottom). The wavelength of the propagating waves can be seen to be much longer in the fixed aorta. Wavelength is measured from line profiles.

**Discussion and Conclusion:** The results showed a highly significant difference between fresh and fixed aortic stiffness using both MRE and mechanical tensile testing. The substantial discrepancy between MRE and mechanical testing can be explained by the significant differences in the protocols and mechanical models used. This study has provided evidence of the effectiveness of using MRE to directly assess the stiffness change in aortic wall. The results offer motivation to pursue MRE as a noninvasive method for the evaluation of arterial wall mechanical properties without invasion of the artery itself.

**References:** [1] Laurent S, et al. Hypertension 2001;37:1236-41. [2] Laurent S, et al. Stroke 2003;34:1203-6. [3] Woodrum DA, et al. *Magn Reson Med*. 2006;56:593-600. [4] Woodrum DA, et al. *J Magn Reson Imaging*. 2009;29:583-7.