Estimation of Abdominal Aortic Aneurysm Stiffness using MR Elastography: Is Stiffness Superior to Diameter?

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Target Audience: Diagnostic radiologists, interventional radiologists, vascular surgeons

Purpose: Abdominal aortic aneurysms (AAA) tend to enlarge over time and, if not repaired, can rupture - an event that has a high mortality rate[1]. Currently the "gold standard" for assessing the risk for rupture is AAA diameter; surgical or endovascular aneurysm repair is recommended when the diameter exceeds 5.5 cm. However, previous studies have reported that many smaller AAAs (<5 cm) ruptured while many larger AAAs (>5 cm) remained stable[3].This suggests that AAA size may not be the only predictor of AAA rupture. It is known that changes in AAA wall stiffness can reflect extra-cellular matrix integrity, a key factor in the pathophysiological development of AAA and a predictor for risk for rupture[4]. Recently, a non-invasive, magnetic resonance (MR)-based method known as MR elastography (MRE) has been applied to determine the wall stiffness of the aorta[5]. Our hypothesis is that AAA wall stiffness is independent of AAA diameter, and the aim of this pilot study is to evaluate MRE-derived AAA wall stiffness (μ_{MRE}) relative to AAA diameter.

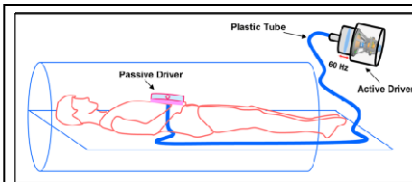

Figure 1: Passive driver is placed on the abdomen. Sound waves are non-invasively transmitted to the driver and into the volunteer. These waves are imaged by MRE and used to calculate stiffness.

Methods: In-vivo aortic MRE was performed on 10 patients (ages 36-78 years) with AAA measuring between 3.0-6.2 cm. All imaging was performed using a 3T-MRI scanner (Tim-Trio, Siemens Healthcare, Germany). The volunteers were placed head-first supine position into the scanner and 60Hz mechanical waves were introduced into the aorta using a pneumatic diver as shown in Figure 1[6]. A gradient echo-MRE sequence was performed to obtain wave data on a center sagittal slice of the aorta covering the AAA. The imaging parameters included: TE/TR = 21.3/25ms, matrix = 128x64, FOV = 36x36 cm^2, α = 16˚, slice thickness = 5 mm and a motion encoding gradient of 60Hz applied separately in the x, y, and z direction to encode motion. Then, MRE wave images were analyzed using MRE-Lab (Mayo Clinic Rochester, MN) to obtain the stiffness of the aorta[6]. Regions of interest were drawn within the AAA region to report the mean MRE-derived stiffness.

Results: Figure 2a-e shows a magnitude image with a red contour outlining the abdominal aorta and snapshots of wave propagation through the tissue in one of the patients; figure 2f shows the corresponding weighted stiffness map with a mean stiffness of 21.1 kPa at the AAA region with an aneurysm diameter of 5 cm. Figure 2g-l shows magnitude images of aortas for three separate AAA patients, aneurysm diameters of 5.0 cm, 4.5 cm, and 3.0 cm, and their stiffness maps with mean stiffness values at the aneurismal region of 10.3 kPa, 28.1 kPa, and 12.2 kPa, respectively. Figure 3 shows a plot of MRE-derived AAA stiffness as a function of AAA diameter, with a poor linear correlation of R^2 = 0.005.

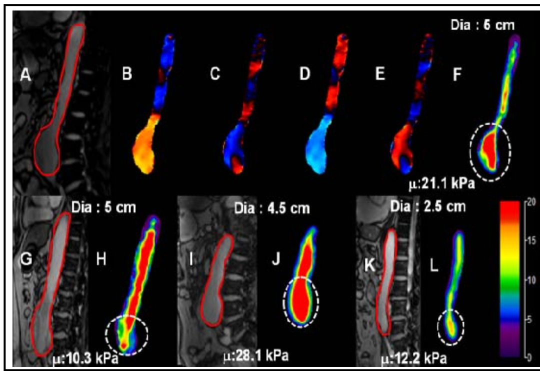

Figure 2: (a): Sagittal magnitude image with contour (red) outlining aorta. (b-e): Wave propagation at four points in time. (f): Weighted stiffness map with a mean 2D μ_{MRE} value of 21.1±4.2 kPa at the area of aneurysm. (g-l): Sagittal magnitude images with stiffness maps for three volunteers with aneurysm diameters of 5.0 cm, 4.5 cm, and 3.0 cm and μ_{MRE} values of 10.3 kPa, 28.1 kPa, and 12.2 kPa, respectively.

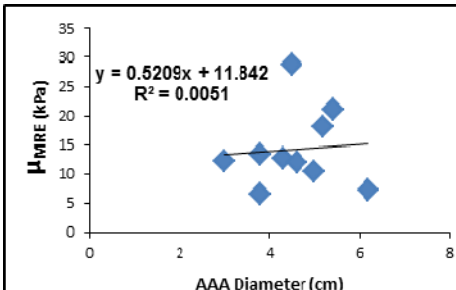

Figure 3: Relationship between AAA stiffness vs diameter.

Discussion: AAAs are clinically followed according to their size with serial CT scans. The results from this study suggest that in addition to AAA size, aortic stiffness may be an important biomechanical factor to consider when evaluating the probability of rupture. AAA progression has been speculated to have an initial phase of increasing wall stiffness as elastin fails and collagen predominates, followed by a phase of decreasing wall stiffness due to subsequent collagen failure[7]. Indeed, AAA's have been shown to rupture at lower stiffness values[8]. The fact that in our study there was no relationship between aortic stiffness and AAA diameter suggests that each patient's aneurysm has a distinct progression and natural history which may not be predicted by the diameter alone. In addition, the biomechanical changes within the aortic wall - so important in determining an aneurysm's risk of rupture - also cannot be assessed using size alone. In the future, a more personalized approach to AAA management using MRE-derived aortic stiffness might be warranted to better assess the risk of rupture. Though more studies are necessary to determine the relationship between enlarging AAAs and the corresponding changes in aortic stiffness, MRE provides a valuable tool when studying biomechanical changes in the aorta.

References: **1.** Patel MI et al. J Am Coll Surg. 1995 Oct;181(4):371-82. **2.** Chaikof EL et al. J Vasc Surg 2009;50:S2-S49. **3.** Nicholls S et al. J Vasc Surg. 1998; 28(5):884-8. **4.** Vorp DA et al. Arterioscler Thromb Vasc Biol 2005;25:1558-1566. **5.** Kolipaka A et al. JMRI 2012; 35(3):582-86. **6.** Manduca A et al. Med Image Anal. 2001; 5(4):237-54. **7.** MacSweeney STR et al. Br J Surgery 1994;81:935-941. **8.** Vorp D et al. Ann NY Acad Sci. 1996; 800:274-6.