Quantification of Aortic Stiffness across the Cardiac Cycle Using Magnetic Resonance Elastography: Reproducibility Study

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Target Audience: Biomedical researchers, MRE researchers, cardiovascular and radiology physicians

Purpose: The measurement of arterial stiffness has long been an important parameter for determining the severity and risk involved with many cardiovascular diseases[1]. It has been shown that arterial stiffness varies across the cardiac cycle and has different effects in disease progression during systole when compared to diastole[2]. Previous studies have also shown that pressure-loading conditions are different for different disease states, which affects arterial stiffness across the cardiac cycle[3]. It is therefore important to have an accurate measurement of stiffness across the entire cardiac cycle in order to account for these variations and develop an efficient method of arterial stiffness quantification. Magnetic resonance elastography (MRE), a non-invasive MRI-based technique, has recently been applied to measure aortic stiffness[4]. The aim of the study is to determine MRE-derived shear stiffness (μ_{MRE}) of the abdominal aorta throughout the cardiac cycle.

Methods: An In-vivo abdominal aortic MRE was performed on 4 healthy volunteers of ages ranging from 20-33 years. All imaging was performed on a 3T-MRI Scanner (Tim-Trio, Siemens Healthcare, Germany). All the volunteers have been scanned twice in order to test the reproducibility of the MRE-derived stiffness measurements. The volunteers were positioned in the supine position and placed head first in the scanner. 70Hz mechanical waves were introduced into the aorta using a pneumatic driver system as shown in figure 1[2]. A 2D multi-slice segmented, retrospective cardiac-gated, gradient recalled echo-MRE cine sequence was performed to acquire wave data in the sagittal slices of the abdominal aorta. The imaging parameters included: TE/TR = 9.52/14.3 ms, # of segments = 8 (+/– motion encoding) matrix = 128x64, FOV = 40 cm^2, α = 25°, 8 cardiac phases, slice thickness = 6 mm and a motion encoding gradient of 120Hz was applied separately in the x, y, and z direction to encode the motion. Sagittal images were masked to delineate abdominal aorta (Figure 2) and MRE wave images were analyzed with MRE-Lab (Mayo Clinic Rochester, MN) to obtain 3D stiffness (μ_{MRE}) values of the abdominal aorta[5]. Standard bSSFP short-axis cine imaging of the left ventricle was performed to determine trigger times for end-diastolic and end-systolic phase, which were then matched with data from the multi-slice aortic MRE scan to determine stiffness at the aforementioned points in the cardiac cycle.

Results: Figure 2 (a) shows the sagittal magnitude image with the red contour used for segmenting the abdominal aorta; (b-e) corresponding snap shots of wave propagation in one of the volunteers; f & g are the MRE-weighted stiffness maps from three encoding directions for both (f) end-diastolic phase (2.5±0.9 kPa) and (g) end-systolic phase (3.1±0.7 kPa) using a local frequency estimation inversion algorithm. Figure 3 shows a plot μ_{MRE} stiffness values at various points in the cardiac cycle for the same volunteer with higher stiffness values at end-systole and lower values at end-diastole. Furthermore, figure 3 also shows the plot of μ_{MRE} stiffness value acquired from reproducibility scan for the same volunteer; where the dashed line indicates first scan and bold line indicates the second scan. The variation in stiffness values between the reproducibility scans in a volunteer was within 1 standard deviation at all cardiac phases. Figure 3 shows a bar graph of mean μ_{MRE} stiffness values from four volunteers at end-systole and end-diastole.

Conclusion: The initial results of this study demonstrate reproducibility and the feasibility of determining μ_{MRE} stiffness values during the cardiac cycle. The results also show a variation in μ_{MRE} stiffness values throughout cardiac cycle where stiffness values were observed to be lower in diastole when compared to systole. However, additional data is warranted to establish the stiffness values of the aorta during the cardiac cycle.

References: ***1.*** *Agabiti-Rosei et al. Vasc Health Risk Manag. 2009; 5:353-60.* ***2.*** *Hermeling E et al. J Hypertens. 2012; 30(7):1489-91; author reply1491-2.* ***3.*** *Yang E et al. J Am Soc Echocardiogr. 2013; 26(8):901-909 e1.* ***4.*** *Kolipaka A et al. JMRI 2012; 35(3):582-86.* ***5.*** *Manduca A et al. Med Image Anal. 2001 Dec; 5(4):237-54.*

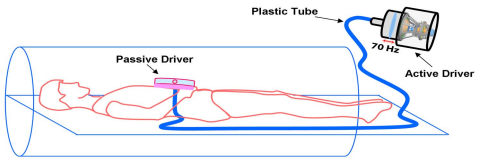

Figure 1: Passive driver is placed on the abdomen. Sound waves are non-invasively transmitted to the driver and into the volunteer. These waves are imaged by MRE and used to calculate stiffness.

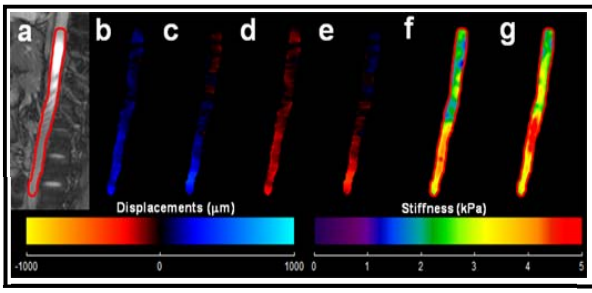

Figure 2: **(a):** Sagittal magnitude image with contour (red) outlining aorta. **(b-e):** Wave propagation at four points in time. **(f, g):** Weighted stiffness maps from x, y, and z encoding directions with a mean μ_{MRE} of 2.5±0.9 kPa and 3.1±0.7 kPa for end-diastole and end-systole respectively.

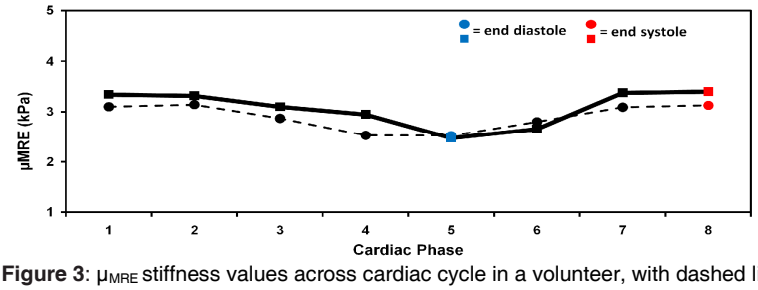

Figure 3: μ_{MRE} stiffness values across cardiac cycle in a volunteer, with dashed line represents first scan and bold line the second scan.

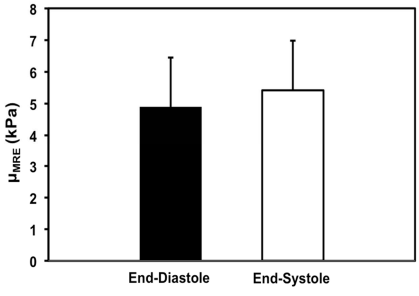

Figure 4: Bar graph of mean MRE-derived shear stiffness values (μ_{MRE}) at end-diastole and end-systole from all four volunteers.