A new transducer-free MR elastography method for voxel-based mapping of aortic stiffness in vivo

Rachel Clough[1], Jordi Alastruey[1], Abdelali Ghazouani[1], Louis Vilgrain[1], Simon Lambert[1,2], and Ralph Sinkus[1]

[1]*Division of Imaging Sciences and Biomedical Engineering, King's College London, London, London, United Kingdom,* [2]*Centre for Inflammation Research, INSERM U1149, Clichy, Ile de France, France*

INTRODUCTION: Aortic stiffness is one of the most important risk factors in the development of cardiovascular disease. [1] Augmentation of systolic blood pressure increases the workload of the heart and over time this results in left ventricular hypertrophy, myocardial ischemia, and degenerative changes in the arterial system, leading to premature death. [2] Early detection of arterial stiffening is important to better identify those at higher risk and to modify their clinical course by using appropriate medical and behavioral interventions. Measurement of arterial stiffness using pulse wave velocity (PWV) is the current reference standard among non-invasive modalities. However, this technique can only provide either very localized (single slice) or spatially-averaged measurements of stiffness. Magnetic resonance elastography (MRE) in contrast is able to provide a high-resolution voxel-based map of tissue stiffness. MRE using an external mechanical transducer has previously been used to non-invasively assess the viscoelastic properties of soft tissue by imaging the propagation of shear waves. The aim of this study was to develop a free-breathing MRE sequence with shear waves generated by the closure of the aortic valve, an intrinsic source of mechanical waves, for the assessment of aortic elasticity *in vivo*.

METHODS: MR images were acquired on a 3T scanner (Philips Healthcare) with a 32-channel coil in 5 healthy volunteers (median age: 28 (23-31) years). **MRE:** Data were acquired using a free-breathing, ECG-gated CINE gradient echo sequence with motion encoding gradients (MEG) at 165Hz and an amplitude of 60mT/m (slice: oblique-sagittal, FOV=300x240mm^2, ST=8mm, acq spatial res=1.17x1.94mm^2, TR/TE=8.8/6.9ms, FA=15°, acq time=1:39(min:sec)). A pencil beam navigator located at the dome of the diaphragm was used to minimise respiratory motion artefacts (window=5mm). Data were acquired with and without motion-encoding for comparison. **PWV:** Data were acquired using a free-breathing ECG-gated balanced fast field echo (slice: transverse positioned at the level of the pulmonary artery, transecting the ascending aorta, FOV=350x300 mm^2, ST=10mm, acq spatial res=1.2x1.2 mm^2, TR/TE=5.0/3.0ms, FA=15°, 100 cardiac phases, NSA=3, VENC=150-175cm/s, SENSE=2, acq time=5:05(min:sec)). **Time of aortic valve closure:** Data were acquired in breath-hold using an ECG-gated balanced fast field echo sequence (FOV=320x320mm^2, ST=10mm, acq spatial res=1.5x1.5mm^2, TR/TE=3.0/1.5ms, FA=45°, 60 cardiac phases, acq time=21sec). **Image analysis:** MRE phase images were analysed along a line placed within the aortic wall (*Fig.1 A,B*). This resulted in waterfall images showing the MRE phase along that line (*x-axis in Fig.1 C,D*) as a function of acquisition time during the cardiac cycle (*y-axis*). The time of the phase distortion originating from the propagating shear wave was compared with the time of closure of the aortic valve from CINE imaging. The MRE phase-profile at the time of valve-closure was then fitted to a sinus in order to extract the apparent shear wavelength λ. The apparent shear wave speed Cs was calculated from the MRE data via the measured apparent wavelength λ using the following equation: **$Cs=\lambda*\nu$** (ν=165Hz being the frequency of the MEG) (*Fig. 1D*). The PWV was calculated using the Q-A loop method [3] and compared to the MRE values.

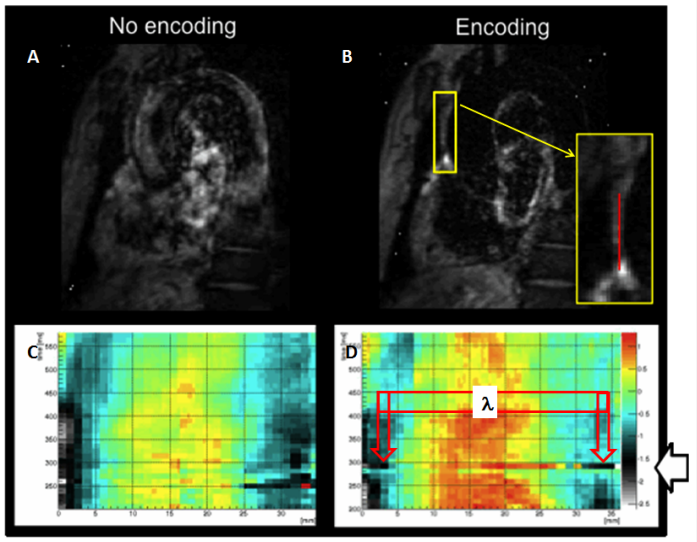

Figure 1. A,B: *Magnitude images of the MRE scan at the time of valve closure. The inset in B shows the aortic wall and the line (red) along which MRE phase data were analyzed.* ***C,D****: MRE phase data shown as waterfall diagrams (x-axis=space along red line in B, y-axis=time point of acquisition during cardiac cycle. Motion encoded data demonstrated a phase change at the time of valve closure (*white arrow*). The apparent wavelength λ was estimated from a sinus fit to the phase profile at the time of valve closure.*

RESULTS: Assessment of aortic valve closure (*Fig. 2*) was possible in all volunteers, and occurred ~375ms (277-420) after the R-wave. Motion encoded images demonstrated a phase change at the time of the valve closure (*Arrow, Fig. 1 B*). Phase data acquired without the MEG did not show similar findings (*Fig. 1 A*). The median shear wave speed was 4.29m/s (3.47-4.95). The data from the 5 volunteers showed good correlation (*Fig. 3*) and no proportional bias (bias = -0.26m/s) compared with the PWV reference standard.

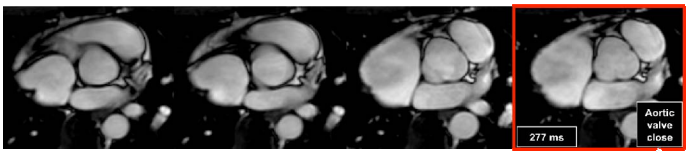

Figure 2. *Aortic valve closure was assessed using high-resolution cine imaging. The timing of the valve closure was subsequently related to the phase change on the motion encoded images.*

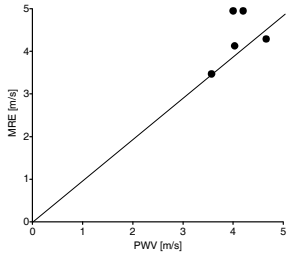

Figure 3. *There was good correlation between the MRE and PWV data.*

CONCLUSION: We have successfully developed a new free-breathing MRE sequence which is able to accurately characterise aortic stiffness *in vivo* using shear waves generated by aortic valve closure. The benefits of this technique compared with MR pulse wave velocity measurements are that a high-resolution voxel-based stiffness map of the entire aorta can be produced in a single free-breathing scan. This technique has a clinically acceptable acquisition time and represents an emerging method for patient-specific cardiovascular disease risk stratification.

REFERENCES: 1. Laurent S et al. Hypertension 2001;37:1236-1241. **2.** Oliver JJ et al. Arterioscler Thromb Vasc Biol. 2003; 23:554-566. **3.** Alastruey J. J Biomech. 2011; 44:885-91