MR Elastography as a Method to Determine the Mechanical Properties of Fresh and Formalin Fixed Porcine Hearts

Ria Mazumder[1], Bradley Dean Clymer[1], Richard White[2,3], and Arunark Kolipaka[2,3]

[1]Department of Electrical and Computer Engineering, The Ohio State University, Columbus, OH, United States, [2]Deparment of Radiology, The Ohio State University, Columbus, OH, United States, [3]Deptarment of Internal Medicine, Division of Cardiology, The Ohio State University, Columbus, OH, United States

Targeted Audience: Biomedical engineers and biomechanical engineers.

Purpose: Formalin fixed cardiac muscles are an integral part of ex-vivo cardiac research [1]. Formalin fixation alters the mechanical properties of the heart muscle, by changing its stiffness value. The standard quantitative measurement of stiffness is done by performing mechanical testing on myocardial strips. Magnetic resonance elastography (MRE) is a novel phase-contrast technique used to determine the spatial stiffness maps of soft tissues non-invasively. The purpose of this study is to determine the variation in stiffness of the left ventricular (LV) myocardium before (fresh) and after formalin fixation.

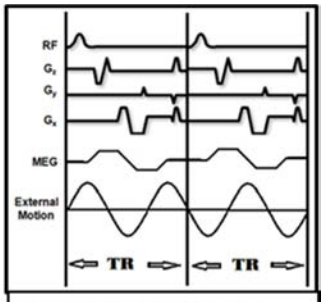

Fig1: GRE based MRE pulse sequence

Methods: *Ex-vivo* cardiac MRE was performed on 4 porcine hearts before and after formalin fixation on a 3T MRI scanner (Tim Trio, Siemens Healthcare, Erlangen, Germany). After the animals were euthanized, their hearts were dissected and stored in ice for 5 hours. A balloon was inserted into the LV to inflate the hearts. Then MRE was performed. A rapid gradient-echo (GRE) based MRE sequence [Fig1] was used to acquire multi-slice short axis views of the heart covering the entire LV. Mechanical waves were introduced into the heart by a pneumatic driver system. Post scanning, fresh hearts were fixed in formalin for 10 days and re-scanned using the same imaging parameters. Imaging parameters included TE=21.4ms; TR=25ms; slice thickness=2mm; $\alpha=16^{o}$; matrix=128x128; FOV=256x256mm^2; slices=42, 45; isotropic resolution of 2x2x2mm^3; mechanical vibration frequency=60Hz; 4 MRE time offsets; and motion encoding gradients of 16.67ms duration (60Hz) was applied in all the three directions (x, y, z) to encode the in-plane and through plane motion. These wave images were masked to obtain the LV myocardium and processed using custom built software (MRE Lab, Mayo Clinic, Rochester, MN) to obtain the stiffness maps. A 2D weighted direct inversion [2] was performed by applying a directional filter in 8 directions to remove the reflected waves and also a band-pass filter was used to remove the longitudinal motion. The mean stiffness values from all the slices before and after formalin fixation was reported. Student's t-test was performed to determine the significant difference in stiffness value between the fresh and formalin fixed hearts.

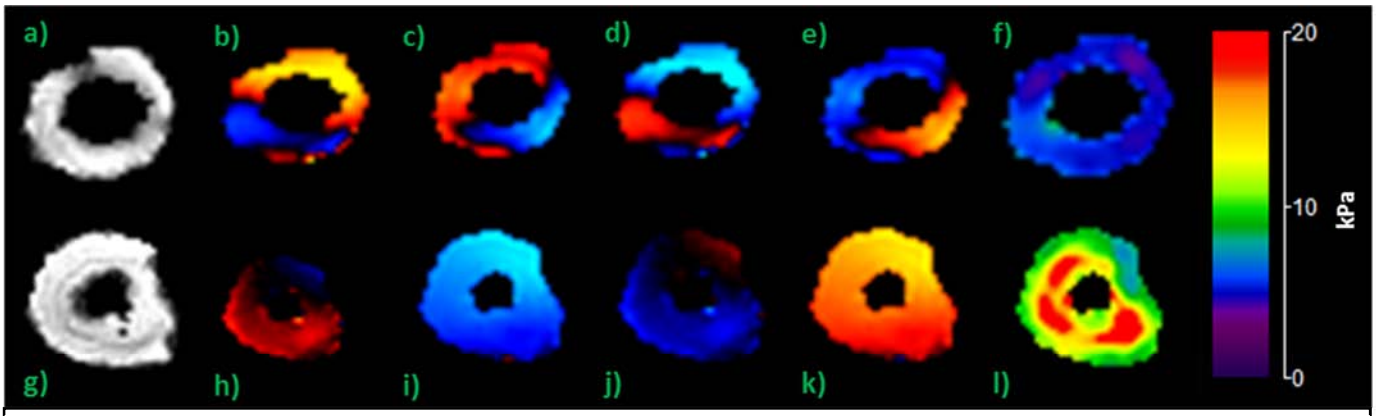

Fig 2: 1st Row: Images obtained from fresh heart. **2nd Row:** Images obtained from formalin fixed heart. **1st Column:** Magnitude image; **Columns 2-5:** Wave images displaying the four phase offsets; **6th Column:** Stiffness maps obtained from direct inversion algorithm.

Results: Figure 2 represents the magnitude image, wave images and the corresponding stiffness maps for one of the hearts before and after formalin fixation. The mean stiffness values obtained from all the four hearts before and after fixation are shown in Figure 3.

Discussion: We have demonstrated non-invasive spatial estimation of myocardial stiffness using MRE. Furthermore, we have showed that formalin fixed LV myocardium was significantly (p-value=0.009) stiffer than the fresh hearts. However, in one of the pigs the stiffness of the fresh heart was 9.02 kPa as compared to others (mean stiffness 4.92 kPa). This increase in stiffness is because of the variation in inflation pressure between the fresh hearts.

References: 1. Sosnovik et al. JCMR 2012, **14**:70
2. Manduca, A., et al., Medical Image Analysis, 2001. **5**(4): p. 237-254.

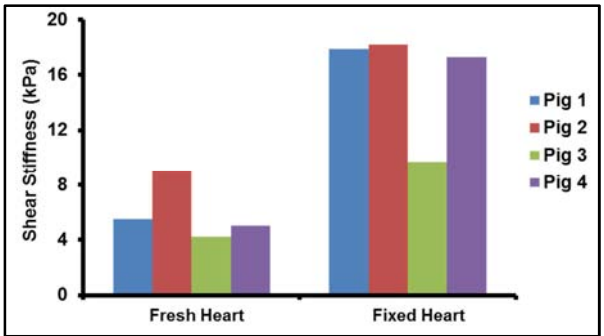

Fig 3: Graph representing the stiffness variations in the four fresh and formalin fixed hearts.