Assessment of Kidney Stiffness in a Swine Model of Renal Arterial Stenosis with 7-D MR Elastography

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Introduction: MR Elastography (MRE) is an MRI-based technique for quantitatively assessing the mechanical properties of soft tissues by visualizing propagating shear waves in tissues (1). Ideally, the MRE acquisition would involve obtaining displacement data for 3 dimensions in space, 3 cyclic displacement directions (x, y, and z) at each point in space, and at multiple time points in the wave cycle. The acquisition time required for such a 7-dimensional imaging task *in vivo* can be lengthy. When simple wave propagation patterns can be generated in large organs like the liver, it may suffice to acquire only 2-D wave field data (2). However, when smaller and more complex structures are evaluated, it is in general necessary to acquire 7-D MRE data, due to the complexity of wave propagation. The goal of this study was to develop a practical 7-D EPI-based renal MRE protocol and to test the following hypotheses: 1) 7-D MRE provides renal parenchymal stiffness measurements that have similar mean values but a smaller standard deviation than 2-D measurements for the same kidney in a porcine model of acute renal arterial stenosis (RAS); 2) 7-D MRE is sufficiently sensitive to detect expected reactive stiffness changes in the contralateral kidney in an experimental animal model of renal artery stenosis.

Materials and Methods: Four swine were implanted with stents that induced proliferative changes in the renal arterial wall of varying degree. One animal was used as a control. Fluoroscopic angiography was used to determine the degree of stenosis and hemodynamic changes. At ten weeks, 7-D MRE and 2-D MRE with 3-D sensitization were used to assess renal tissue stiffness. MR exams were all implemented on a 3.0 T whole-body GE imager (Signa, GE Healthcare, Milwaukee, WI, USA), using a 8 channel torso coil. Animals were imaged in a supine position, with a 19-cm cylindrical passive pneumatic driver placed against their posterior body wall. Continuous vibrations at 90 Hz generated shear waves throughout the tissues of the abdomen. A spin echo based EPI MRE sequence with flow compensation was used to collect 7-D wave images with following parameters: 2 shots, TR/TE = 1200/94.6 ms, Matrix = 96x96x24, 4 phase offsets through one cycle of motion, 3 pairs of tetrahedral trapezoidal motion encoding gradients along the x, y and z directions. 2-D MRE wave images along the x, y and z motion directions were also acquired to study the evolution of stiffness changes in the kidney with RAS, reported separately. Quantitative elastograms of the contralateral kidney were obtained using the local frequency estimation inversion algorithm (3) with 8/20 directional filters (4) for 2-D and 3-D respectively. At the time that this abstract was written, a total of 5 animals had been evaluated.

Results: Fig.1 illustrates coronal and axial MIP (maximum intensity projection) images of the 3-D renal elastograms for the untreated (contralateral) kidneys of the experimental animals. The bottom captions illustrate the induced RAS extent for each individual animal. Figure 2 shows a comparison of the 7-D MRE technique and the 2-D technique in one of the animals. There was no significant difference in mean cortex stiffness in each animal, as measured by these two techniques. However, the standard deviations of the cortex stiffness measurements obtained from 7-D MRE were substantially lower than those from 2-D MRE results ($SD_{7-D} = 0.25\sim0.41$ kPa versus $SD_{2-D} = 0.40\sim1.00$ kPa). Compared with the control animal, the shear stiffness of the renal cortex tissue was found to increase significantly in the contralateral kidneys ($p < 0.0001$) of the severe (75~95%) RAS animals. The average shear stiffness value of the contralateral cortex in all RAS animals was significantly higher than that of the normal kidneys (5.12 ± 0.61 kPa versus 4.01 ± 0.20 kPa), as illustrated in Fig.3.

Fig.1

Maximum Intensity Projection (MIP) Elastograms of Contralateral Kidneys
Coronal / Axial
0% Control   20% RAS   75% RAS   85% RAS   95% RAS

Fig.2

7-D EPI MRE Result (96x96x24x4x3)
2-D GRE MRE Result (256x96x1x4x3)

Fig.3

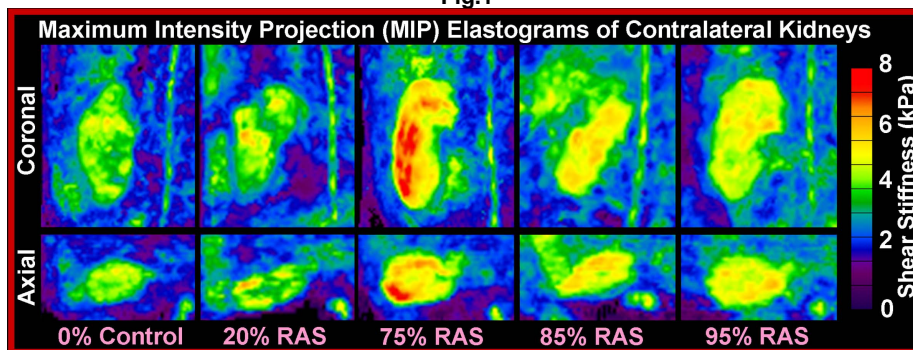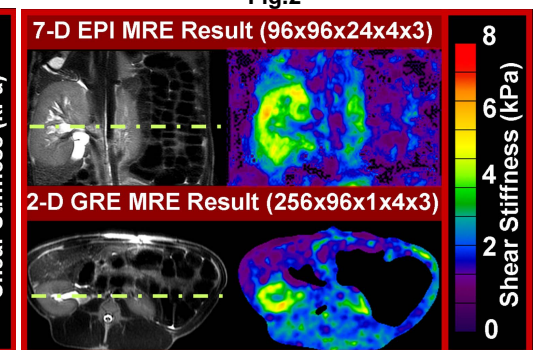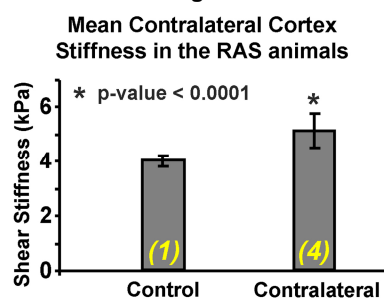Mean Contralateral Cortex Stiffness in the RAS animals
* p-value < 0.0001

Discussion: The result show that a 7-D wave acquisition protocol provides more consistent stiffness values for renal MRE than a 2-D protocol. This reflects the ability of the 7-D acquisition and inversion to account for wave propagation patterns that cannot be represented appropriately in a 2-D model. The improved consistency of the 7-D protocol was helpful in demonstrating the observed post RAS changes in the stiffness of contralateral kidneys in this animal model. We speculate that the observed changes in renal stiffness are a reflection of a compensatory increase in renal blood flow, causing increased tissue turgor. More research will be needed to confirm and explain these results.

Conclusions: The results show that MRE is a promising technique for quantitatively assessing the mechanical properties of renal tissue in a RAS swine model *in vivo*. The preliminary results provide motivation for further development of 7-D MRE techniques.

References:
[1] Muthupillai, R. Science 269(5232): 1854-7
[2] Yin, M. Clin Gastroenterol Hepatol. 2007 Oct; 5(10): 1207-1213
[3] Manduca, A. Med Image Anal 2001, 5(4): 237-54.
[4] Manduca, A. Med Image Anal 2003, 7(4): 465-73