Developing 3D Wavefield Renal MR Elastography: Primary Hyperoxaluria Pilot Study

Scott A. Kruse[1], Kevin J. Glaser[1], Jun Chen[1], Dawn S. Milliner[2], Sudhakar K. Venkatesh[1], and Richard L. Ehman[1]

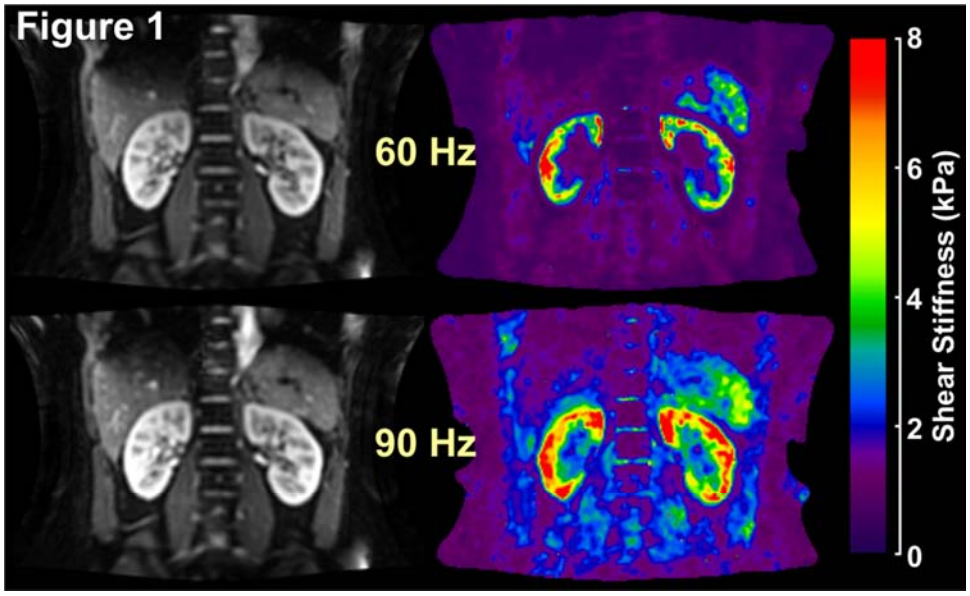
[1]Department of Radiology, Mayo Clinic, Rochester, Minn., United States, [2]Division of Nephrology and Hypertension, Mayo Clinic, Rochester, Minn., United States

Purpose: Previous studies that have explored the potential of MRE to characterize disease in native kidneys have been limited to 2D wavefield approaches [1-3]. The assumptions about wave propagation that are needed for reliable 2D MRE, such as discussed in [4-5], are poorly applicable to renal imaging. The purpose of this study was to develop and test the feasibility of a 3D wavefield MRE protocol for assessing kidneys in situ. A second goal of the work was to conduct pilot studies of an optimized protocol in a small series of patients with primary hyperoxaluria, a condition in which there is clinical need for more effective noninvasive tools for assessing the extent of parenchymal disease.

Methods: All image acquisitions were performed on a 1.5-T MRI scanner (GE, Signa HDxt) with an 8-channel phased-array torso coil. The study was conducted with IRB approval and informed consent. 4 normal volunteers and 5 patients with primary hyperoxaluria were enrolled in the study. The subjects were imaged in the supine position and placed feet-first in the scanner. An active driver source driven at 60 & 90 Hz provided motion to two soft, pillow-like, acoustic-pressure-activated drivers placed against the body wall, one under each kidney. An elastic belt was used to secure the drivers to the body wall. A 2D multislice, single-shot, flow-compensated, spin-echo, echo-planar MRE sequence was used to collect 3D vector wave images [6]. Volumes were acquired in the coronal, axial, and oblique orientations to evaluate the effectiveness of each orientation as there could be differences in acquisition time and image quality due to the different number of slices required to cover the kidneys in different directions and changes in flow, respiratory, susceptibility, and off-resonance artifacts associated with the different orientations. Imaging parameters included field of view (FOV) = 36-45 cm, slice thickness = 3 mm, image acquisition matrix = 96x96 (reconstructed to 256x256), 24-36 interleaved slices, 3 time offsets, 6 motion-encoding directions ($\pm$X, $\pm$Y, $\pm$Z), TR/TE = 1000-1500/45-50 msec, parallel imaging acceleration factor = 2, motion sensitivity = 12 μm/radians, receiver bandwidth = ±250 kHz, and SI or RL frequency-encoding direction as appropriate. A 6.45-msec, 3.2 G/cm, zeroth-moment-nulled motion-encoding gradient was used on each side of the spin-echo refocussing pulse to encode the motion. This sequence was performed with a 16-24 second breathhold per time offset (3 total).

The data was analyzed by taking the curl of the displacement vector/wave images. 3D spatio-temporal directional filtering [7] with 20 evenly spaced 3D directional filters incorporating a fourth-order Butterworth bandpass filter with cut-off frequencies of 0.001 and 64 cycles/FOVx was applied to reduce the effects of wave interference. Elastograms were calculated for each directionally filtered dataset with a 3D direct inversion algorithm [8] and combined with a wave-amplitude-squared weighted sum. The elastograms were analyzed by manually drawing regions of interests (ROIs) in each slice that included the entire renal parenchyma, while excluding areas with inadequate wave amplitude.

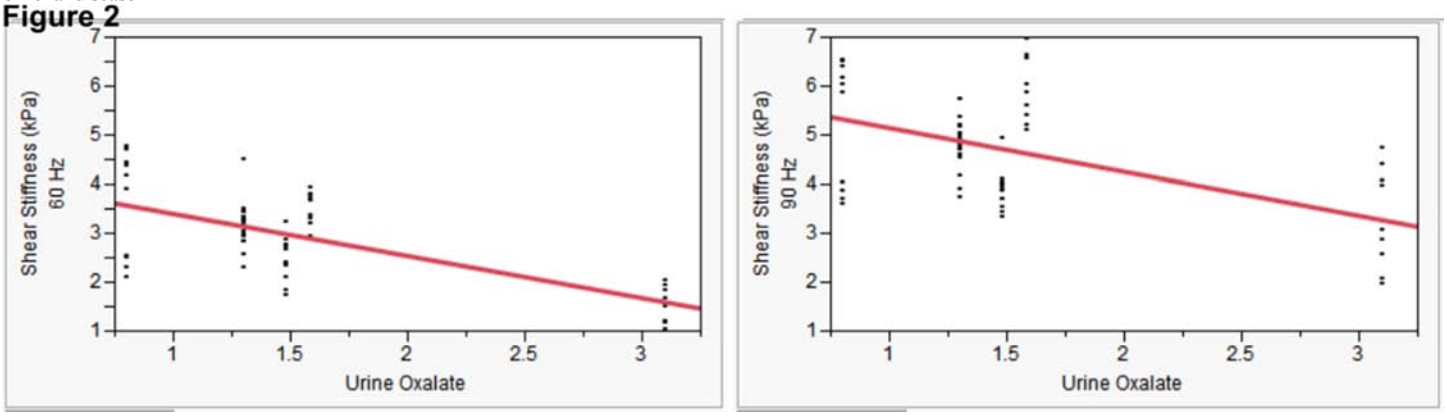
Figure 1



Results: Figure 1 shows MR magnitude and stiffness images at 60 & 90 Hz in a normal volunteer. The mean renal parenchymal stiffness measured in the right and left kidneys in a series of 4 volunteers, at 60 Hz, without known renal disease was 2.99 $\pm$ 1.08 kPa. A subset of 2 volunteers was also scanned at 90 Hz. The mean renal parenchymal stiffness was 6.16 $\pm$ 0.57 kPa. There was no significant difference in the stiffness of the right and left kidneys. After protocol optimization was completed, a pilot study of 3D wavefield MRE was conducted in a series of 5 patients with primary hyperoxaluria. As illustrated in figure 2 (each point is an ROI, 2 per slice, 1 for each kidney), the results provide preliminary evidence of a trend of decreased parenchymal stiffness with increasing urinary oxalate levels.

Discussion and Conclusion: The results confirm that it is feasible to implement a full 3D wavefield MRE protocol for quantitatively assessing the mechanical properties of native renal tissues, in situ. The protocol provides a basis for further studies to evaluate the potential of MRE to contribute to the noninvasive evaluation of renal disease.

Figure 2



References: [1] Venkatesh SK, et al. Proc. ISMRM. 2008. #461. [2] Bensamoun SF, et al. Clin Imaging. 2011 Jul-Aug; 35(4):284-7 [3] Rouvière O, et al. JMRI. 2011 Oct; 34(4):880-6. [4] Yin M, et al. MRI. 2008 Jul; 26(6):770-80. [5] Baghani A, et al. J Acoust Soc Am. 2009 Sep; 126(3):1541. [6] Yin M, et al. JMRI. 2013. Oct; 38(4):809-15. [7] Manduca A, et al. Medical Image Analysis. 2003. **7**: 465-473. [8] Manduca A, et al. Med Image Anal. 2001. Dec; 5(4):237-54.