Evaluation of Renal Parenchymal Disease in a Rat Model with Magnetic Resonance Elastography

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Introduction

Palpation is an important tool used by physicians to diagnose disease by assessing the mechanical or elastic properties of tissue. Magnetic Resonance Elastography (MRE) is a noninvasive imaging technique that measures and quantifies mechanical tissue properties [1,2]. It uses phase contrast MRI to image propagation of applied acoustic shear waves in tissue. The resulting wave images are processed to yield a quantitative map depicting the elastic modulus of tissues in the region of interest [3].

MRE permits mechanical assessment of structures that are inaccessible to palpation, and by providing quantitative measurements, it may represent a useful new method of tissue characterization. The purpose of this work was to investigate the potential of MRE to characterize the kidney and specifically to investigate diseases involving glomerular and interstitial processes. Previous work has demonstrated the feasibility of renal MRE using ex vivo animal kidney specimens [4-6]. In vivo imaging of kidneys poses new challenges such as adequately illuminating a retroperitoneal structure with shear waves and more familiar challenges such as respiratory motion.

Here we report the results of a feasibility study of the use of MRE to assess the mechanical properties of renal parenchyma in an animal model in vivo. This model is of interest, because once a suitable MRE technique validated in normal animals, it will be possible to study animals with a number of different induced renal parenchymal disease processes, such as nephrocalcinosis, glomerulonephritis, and amyloidosis.

Methods

Imaging of mechanical waves was performed on a 1.5T whole-body MR imager and has been previously described in detail [1,2]. Following anesthetization of rats, a Delrin (acetal homopolymer) rod connected to an electromechanical driver was used to apply shear waves at 300 Hz in the kidney.

In addition to standard imaging gradients, the MRI sequence incorporated oscillating, motion-sensitizing gradients that were synchronized with the acoustic shear waves. The sequence provided images that effectively represented quantitative snapshots of tissue displacements caused by propagating mechanical waves. The wave images were processed through a series of algorithms that generated a local spatial frequency estimate map of the shear waves in tissue. This map was then used to create a shear modulus map. [3]

Results

After acquiring MRE data, quantitative shear modulus maps were computed from the wave image data sets (Figure 1). The elastogram demonstrated that the shear modulus of parenchymal tissue is consistent across the kidney.

Figure 1: A) Shear wave image at 300 Hz, with a maximum displacement of 58 microns. B) Corresponding T2-weighted FSE image. C) The resulting shear modulus map indicates that parenchymal tissue is 3.5 kPa, for the region shown.

Renal elastography studies were performed in five animals. Each animal was scanned multiple times at 300 Hz. Figure 2 illustrates the mean shear modulus of cortical tissue, for each animal. Mean shear modulus from individual animals ranged from 2.7 to 4.8 kPa. Mean for all animals was 3.9 kPa (95% CI: 3.3 to 4.4 kPa).

Discussion

The consistency of elastic modulus measurements was greater in the same animal than among different animals. The minimal intra-animal variability suggests excellent precision of the MRE technique in this application. The larger inter-animal variability may reflect true differences between animals. For example, the elastic properties of renal cortex may vary between animals due structural differences that are present. Physiological variables may also be important, since blood pressure, glomerular filtration rate, and intravascular volume could all conceivably alter renal shear modulus in vivo.

While on the same order of magnitude, the renal cortical shear modulus measurements in this study differ from those obtained in a prior study, where MRE of fresh ex vivo porcine kidney determined a cortical shear modulus of 1.67 kPa at 300 Hz [4,5]. It is not unexpected that without metabolism, blood pressure, and tubular function, the mechanical properties of ex vivo kidney tissue are substantially different from the in vivo condition.

Conclusion

In summary, MRE-based quantitative measurements of the shear modulus of renal cortical tissue were highly consistent in each animal. Larger variations in these measurements between different animals may reflect systematic, intrinsic, or transitory physiologic differences (such as hydration status), and this topic will require further study. This study demonstrates the feasibility of MRE for assessing the rheomechanical properties of renal tissue in vivo in an animal model and provides a basis for ongoing MRE studies of renal tissue affected by disease processes.

References