

## High resolution mechanical imaging of the human kidney

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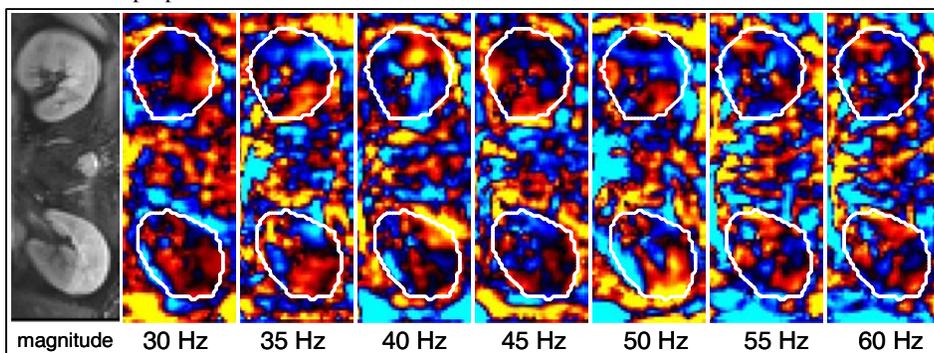
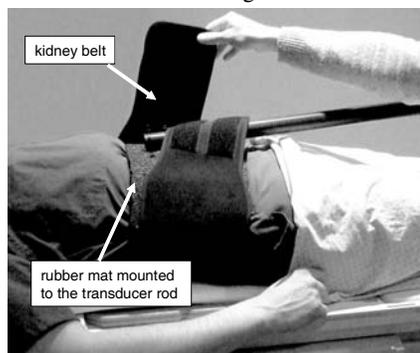
**Target audience:** Physicians interested in the diagnosis of renal diseases based on the mechanical properties of the kidneys.

**Background:** The noninvasive detection and quantification of renal fibrosis, especially in early stages, by the altered mechanical properties of the kidney could be beneficial for the diagnosis and therapy monitoring in a variety of chronic kidney diseases such as glomerulonephritis, obstructive nephropathy, interstitial nephritis, and cystic nephropathies.

**Purpose:** To test the feasibility and reproducibility of in vivo high-resolution mechanical imaging of the asymptomatic human kidney by three dimensional multifrequency MR elastography (3DMMRE).

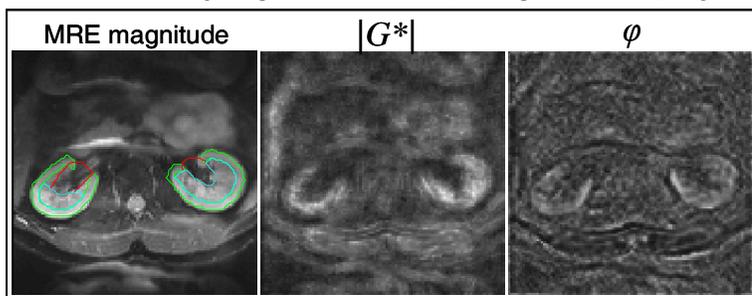
**Methods:** 9 volunteers were examined at 3 different physiological states of urinary bladder filling (normal state, full state, and empty state). Mechanical imaging was performed of the in vivo kidney using fast 3DMMRE and multifrequency dual elasto visco (MDEV) inversion. We analyzed the magnitude  $|G^*|$  and the phase angle  $\phi$  of the complex shear modulus by simultaneous inversion of full wave field data at 7 harmonic drive frequencies of 30, 35 .. 60 Hz. Details of the MDEV wave inversion algorithm are given in (1). The driver setup is shown in Fig.1. MRE sequence parameters: 10 transverse slices of  $2.5 \times 2.5 \times 2.5 \text{ mm}^3$  resolution, 8 wave dynamics, 3 wave field components, 2 averages to increase the SNR, TR = 1770 ms, TE = 55 ms, FoV =  $260 \times 260 \text{ mm}^2$ , matrix size  $104 \times 104$ ; parallel imaging with a GRAPPA factor of 2; motion encoding gradient frequency = 50.6 Hz and -amplitude = 30 mT/m; total scan time under 10 min for a full 3DMMRE examination (1680 images in total).

**Results:** An example of the complex-valued curl-field in a central image slice of one volunteer is shown in Fig.2. MDEV parameter maps in one slice are shown in Fig.3. Spatial averaging was performed in manually segmented regions of the kidney, the cortex (green), the medulla (blue), and the pelvis (red lines). The mean stiffness of the whole kidney was  $|G^*| = 1.83 \pm 0.25 \text{ kPa}$  and the phase angle  $\phi$  was  $0.82 \pm 0.08$ . Regional differences were observed in both  $|G^*|$  and  $\phi$  as shown in Fig. 4. The mean stiffness of the medulla was  $|G^*| = 2.67 \pm 0.52 \text{ kPa}$ , which is significantly higher than values measured in the cortex ( $|G^*| = 1.64 \pm 0.17 \text{ kPa}$ ,  $P < 0.001$ ) and the pelvis ( $|G^*| = 1.17 \pm 0.21 \text{ kPa}$ ,  $P < 0.001$ ). Similar differences were found for  $\phi$ , which was highest in the medullary region ( $0.89 \pm 0.12$ ), followed by the cortical region ( $0.83 \pm 0.09$ ,  $P = 0.001$ ) and the pelvis region ( $0.72 \pm 0.06$ ,  $P < 0.001$ ). Fig. 4 shows spatially averaged MRE parameters of all three anatomical regions at different states of bladder filling. No correlation between the different stages of bladder filling and viscoelastic properties was found.

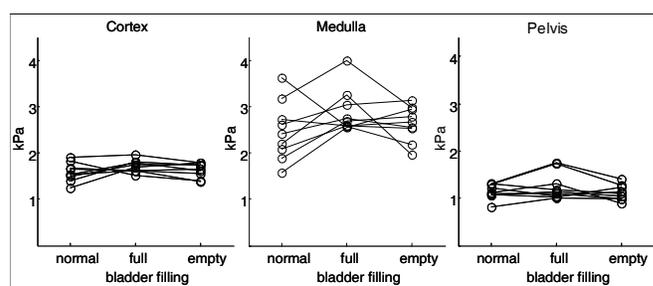


**Fig.1:** Driver setup. The transducer piston was connected to a nonmagnetic piezo-based driver.

**Fig.2:** Sections of transversal wave images (real part of 1 complex-valued curl component) at 7 drive frequencies (due to space limitations, images have been flipped by  $90^\circ$ ).



**Fig.3:** MRE Parameter of the kidney maps provided by MDEV inversion.



**Fig.4:** Regionally resolved  $|G^*|$  of the kidney at different physiological states.

**Discussion:** Mechanical parameter maps of the kidney were derived with a spatial resolution superior to that in previous work. While previous MRE studies of the human kidney achieved spatial resolutions from  $38$  to  $70 \text{ mm}^3$  (2-5), we were able to increase the resolution of wave images to under  $16 \text{ mm}^3$  and to stabilize the parameter reconstruction by including multifrequency wave patterns in a single inversion step. In agreement to (2), we found the stiffness of the kidney higher than that of liver and lower than that of the spleen (1). Furthermore, highest stiffness was seen in the medulla, followed by the cortex and the pelvis region which is in agreement to (3). However, our values are lower than renal elasticity values in the literature which requires further investigations with regard to factors potentially influencing MDEV inversion.

**Conclusion:** This study presents the first high resolution regional analysis of viscoelastic constants of the in vivo human kidney.

**Literature:** (1) Hirsch et al. *Magn Reson Med* 2013;doi 10.1002/mrm.24674. (2) Bensamoun et al. *Clinical imaging* 2011;35:284-287. (3) Rouviere et al. *J Magn Reson Imaging* 2011;34:880-886. (4) Warner et al. *Invest Radiol* 2011;46:509-514. (5) Korsmo et al. *Invest Radiol* 2013;48:61-68.