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High-resolution mechanical imaging of the kidney

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ABSTRACT

The objective of this study was to test the feasibility and reproducibility of *in vivo* high-resolution mechanical imaging of the asymptomatic human kidney. Hereby nine volunteers were examined at three different physiological states of urinary bladder filling (a normal state, urinary urgency, and immediately after urinary relief). Mechanical imaging was performed of the *in vivo* kidney using three-dimensional multifrequency magnetic resonance elastography combined with multifrequency dual elastovisco inversion. Other than in classical elastography, where the storage and loss shear moduli are evaluated, we analyzed the magnitude $|G^*|$ and the phase angle φ of the complex shear modulus reconstructed by simultaneous inversion of full wave field data corresponding to 7 harmonic drive frequencies from 30 to 60 Hz and a resolution of 2.5 mm cubic voxel size.

Mechanical parameter maps were derived with a spatial resolution superior to that in previous work. The group-averaged values of $|G^*|$ were 2.67 ± 0.52 kPa in the renal medulla, 1.64 ± 0.17 kPa in the cortex, and 1.17 ± 0.21 kPa in the hilus. The phase angle φ (in radians) was 0.89 ± 0.12 in the medulla, 0.83 ± 0.09 in the cortex, and 0.72 ± 0.06 in the hilus. All regional differences were significant ($P < 0.001$), while no significant variation was found in relation to different stages of bladder filling.

In summary our study provides first high-resolution maps of viscoelastic parameters of the three anatomical regions of the kidney. $|G^*|$ and φ provide novel information on the viscoelastic properties of the kidney, which is potentially useful for the detection of renal lesions or fibrosis.

1. Introduction

Proper renal function is essential for whole body homeostasis such as the excretion of nitrogenous byproducts, the regulation of electrolytes and extracellular fluid volume, as well as the maintenance of the body's acid–base balance. With their endocrine function the kidneys also coordinate long-term blood pressure regulation. End-stage renal failure is associated with conditions such as serious electrolyte imbalance or increased acid levels and anemia, and affected patients may require long-term hemodialysis or a kidney transplant (Wolfe et al., 1999). The incidence and prevalence of diabetes and hypertension-associated chronic kidney disease (CKD) are on the rise (El Nahas, 2005; Coresh et al., 2007).

CKD such as glomerulonephritis, obstructive nephropathy, interstitial nephritis, and cystic nephropathies are invariably accompanied by renal fibrosis as a result of an excessive accumulation of extracellular matrix through the activation of fibroblasts and myofibroblasts (Cho, 2010; Wynn, 2008).

The noninvasive detection and quantification of these fibrotic changes, especially in early stages, by the altered mechanical properties of the kidney could be beneficial for the diagnosis and monitoring the response to treatment. So far, in vivo ultrasound elastography has been successfully used in allograft kidney transplants (Arndt et al., 2010; Sommerer et al., 2013). A correlation between the grade of fibrosis and renal stiffness parameters as shown by Arndt et al. (2010) and Sommerer et al. (2013) was not observed by Grenier et al. (2012) and remains a matter of debate. The penetration depth of ultrasound-based elastography, however, is restricted due to the high absorption rates of both ultrasound signal and transient shear waves (Sandrin et al., 2003), limiting the accessibility of the *in vivo* kidney, especially in obese patients.

These restrictions only partially apply to magnetic resonance elastography (MRE) (Muthupillai and Ehman, 1996) where the maximum diagnostic depth is less constrained due to the lower damping rate of continuously excited time–harmonic shear waves at very low frequencies between 25 Hz and 60 Hz. MRE has been proven sensitive to hepatic fibrosis and is increasingly integrated into diagnostic liver examinations in the routine clinical setting

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