Single Phase Image Reconstruction for MR Elastography

K. Uffmann[1], M. E. Ladd[1]

[1]Department of Diagnostic and Interventional Radiology, University Hospital Essen, Essen, Germany

Introduction

MR Elastography (MRE) represents an innovative method to measure the stiffness of skeletal muscle [1, 2]. For dynamic MRE image acquisitions a periodic mechanical excitation is required, which is synchronized to the motion sensitizing gradients of the sequence for phase contrast acquisitions. To determine the entire elasticity tensor typically eight phase images with different phase offsets between mechanical oscillation and motion sensitizing gradients have to be acquired with gradient orientations along all three spatial orientations [3]. With the assumption of pure transverse wave propagation and isotropic elasticity the shear modulus can be determined utilizing phase image acquisitions with gradients oriented only parallel to the mechanical excitation. For an examination of elasticity changes with higher temporal resolution (less than a minute), a reconstruction method is needed to determine elasticity from just one phase image. In this study a new method allowing for shear modulus reconstruction with only one phase image was analyzed with simulated data and tested on phase images acquired in a Agar gel phantom and in vivo.

Methods

For the calculation of the shear modulus from a phase image the wave vector representing the propagating sinusoidal phase change has to be determined. Due to reflections and refraction multiple waves interfere at one local point. For the following reconstruction method it is assumed that this results in one sinusoidal transverse wave $\vec{u}_{eff} = \vec{A}\cdot\sin\left(k_{eff_1}\vec{x} + k_{eff_2}\vec{y} + \alpha\right)$ in each pixel. With the Laplacian operator $\Delta = \sum_i \frac{\partial^2}{\partial x_i^2}$ applied to the wave $\vec{u}_{eff}$ the total wave vector can be determined with $k_{tot} = \sqrt{\sum_i k_{eff_i}^2} = -\sqrt{\left|\Delta\vec{u}_{eff} / \vec{u}_{eff}\right|}$. The shear modulus then is calculated with $\mu = \rho\left(2\pi f \cdot k_{tot}^{-1}\right)^2$, where f is the excitation frequency and ρ is the tissue density.

The algorithm was tested on images with simulated sinusoidal patterns with different wave vectors ([0 1000] m^{-1}), wavelengths ([0 1.5·FOV]), and amplitudes ([0 pi]) with a wave vector of 167.6 1/m. For all these tests constant white noise (σ = 0.6) was added. An additional test was performed by varying the noise level (σ ∈ [-0.5 0.5]). As the noise was generated with random numbers, the test results represent the average of 500 repetitions.

Additionally the algorithm was applied to an image containing sinusoidal wave patterns with a wavelength in a centric rectangular representing a shear modulus of 18.8 kPa in the rectangle and 8.3 kPa in the surrounding area (Fig. 5). The reconstruction was performed assuming a tissue density of 1000 kg/m^3, an excitation frequency of 142.9 Hz, a field of view (FOV) of 200 x 150 mm^2 and a matrix of 256 x 192.

Finally the algorithm was applied to a phase image (Fig. 7) acquired in a two compartment phantom (1 and 2 % Agar gel concentration). Additionally, results of the reconstruction of phase images acquired in an relaxed (Fig. 9) and stressed (Fig. 10) biceps muscle of one volunteer are shown.

Results

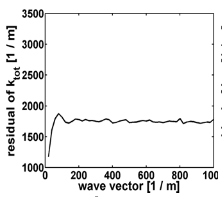

Fig. 1

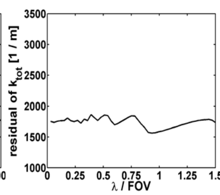

Fig. 2

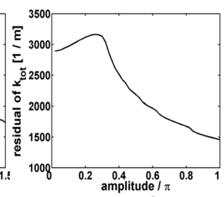

Fig. 3

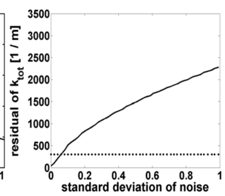

Fig. 4

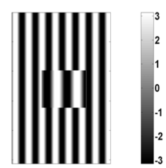
Fig. 5

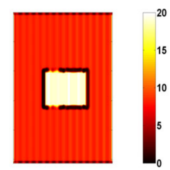
Fig. 6

Fig. 1 to 4 show the residual of the wave vector determined by the reconstruction of test images with different wave vectors, wavelengths, amplitudes, and noise, respectively. All graphs represent the results of an average of 500 repetitions. The dashed horizontal line in Fig.4 represents the true wave vector. Fig.6 shows the shear modulus reconstructed from the simulated phase image shown in Fig. 5. The data yields a mean shear modulus of 18.8 kPa in the centered rectangle and 8.4 kPa in the surrounding area. Strong deviations arise at edges or steep changes.

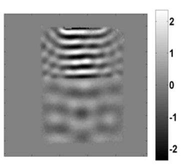
Fig. 7

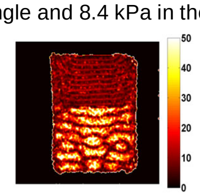
Fig. 8

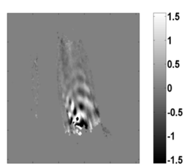
Fig. 9

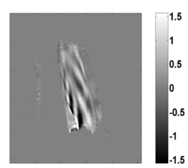
Fig. 10

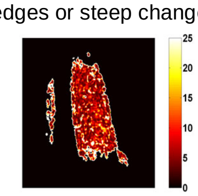
Fig. 11

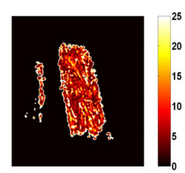
Fig. 12

Fig. 8 shows the shear modulus of the phantom of Agar gel with 1% concentration in the upper and 2% concentration in the lower part. Mean shear moduli of 8.9 kPa and 22.8 kPa could be measured, respectively. Fig. 11 and 12 show the shear modulus reconstructed from the phase images acquired in the biceps relaxed (Fig. 9) and under load (Fig. 10). The mean shear modulus yields a difference of 1.5 kPa.

Discussion

The presented reconstruction method is able to determine spatial elasticity variations. The residual depends on the amplitude, while less influenced by wave vector variations and the wavelength-to-FOV-ratio. The increase of noise level raises the residual to a multiple of the real wave vector value. Thus the reconstruction is only able to depict changes of the shear modulus qualitatively. As the algorithm only requires one phase image, which can be acquired in less than a minute, time depending elasticity changes can be examined. It is still required to compare this approach to other algorithms for single image reconstruction, e.g. the local frequency estimation [4, 5].

References

1. M. A. Dresner et al., JMRI 13: 269-276 (2001) / **2**. K. Uffmann et al, Proc. Intl. Soc. Mag. Reson. Med., 10 (2002), p. 7 / **3**. R. Sinkus et al, Phys. Med. Biol. 45: 1649-1664 (2000) / **4**. A. Manduca et al, SPIE 2710: 616-623 (1996) / **5**. J. Braun et al., MRI 19: 703-713 (2001)