Multifrequency MR Elastography on human thigh muscle in relaxation and in contraction

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Introduction: Magnetic Resonance Elastography (MRE) is a phase contrast based MRI technique which enables to deduce the mechanical properties of in vivo tissues by analyzing the propagation of viscoelastic shear waves [1]. Using a superposition of multiple excitation frequencies the viscoelastic behavior of tissue can be measured over a spectral range in one single experiment [2]. A multifrequency MRE study on human liver has shown the good applicability of the two parameter springpot model for characterizing liver tissue rheology [3].

Problem: In previous MRE studies on in vivo human skeletal muscle the viscoelastic parameters were evaluated at one specific frequency [4-5]. Here, a significant increase in stiffness was measured in a contracted thigh muscle compared to a relaxed thigh muscle [5]. However, there are no reports in literature about a correlation between muscle contraction and the α-parameter of the springpot model which is a measure for the structural composition of the basic rheological elements in a material [6].

Objective: In this study the quadriceps femoris muscles of four male volunteers were examined by multifrequency MRE in relaxation and in contraction. The viscoelastic parameters were determined according to the rheological springpot model.

Methods: The quadriceps femoris muscles of four male volunteers (mean age: 38.8 ± 5.6 a) were examined in relaxation and in contraction by multifrequency MRE in the isotropic plane. The number of experiments per volunteer and condition of the muscle varied between 1 and 3. Shear waves were introduced into the muscle by a rod transducing the vibrations of a loudspeaker to a buckle which was fixed around the thigh. The excitation signal was a superposition of the frequencies 25 Hz, 37.5 Hz, 50 Hz and 62.5 Hz with an amplitude ratio of 1, 4, 8 and 16 respectively (relative to the 25 Hz-vibration). All measurements were performed in a 1.5T scanner (Siemens Sonata, Germany) using a single-shot spin-echo echo planar imaging (EPI) sequence upgraded with a motion encoding gradient (MEG) in slice-select direction (MEG frequency f_G = 50 Hz, number of MEG cycles N = 1, TR = 0.5s). Scalar wave images in a transversal slice were calculated by subtracting phase images acquired with reverse MEG. Temporally resolved wave propagation was captured by shifting the trigger in 20 equal time steps over an 80 ms interval. After Fourier-transformation the complex shear moduli *G(x,y,f)* were calculated from the corresponding complex wave images *U(x,y,f)* by a 2D-inversion of the Helmholtz equation. *G(x,y,f)* was averaged over the muscle region for obtaining *G(f)*. Using the springpot model (η set to 1 Pa s) the independent viscoelastic parameters α and μ were fitted and for each subject mean values in relaxation and in contraction were evaluated from the individual follow-up experiments.

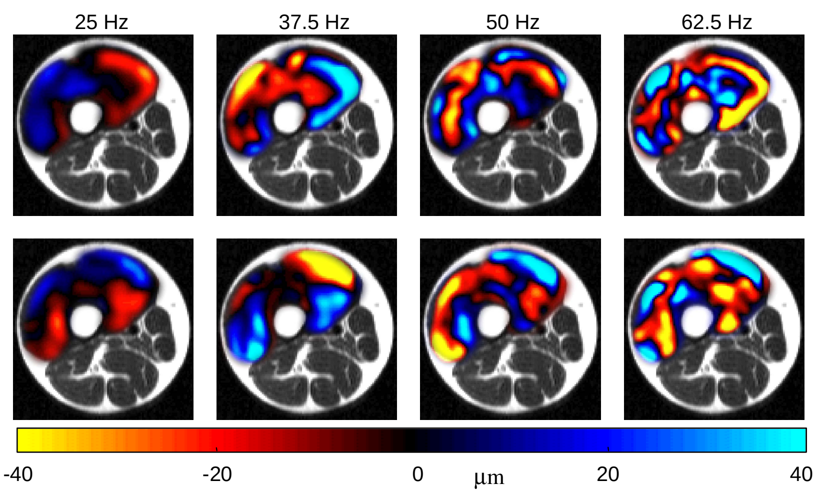

Figure. 1: Multifrequency MRE experiment on the quadriceps femoris muscle of one volunteer in relaxation (top row) and in contraction (bottom row). Complex wave images *U(x,y,f)* (real part) are displayed for the four excitation frequencies. All wave images are superposed on transversal T2-weighted magnitude images (FoV: 150mm x 150mm) for anatomical orientation.

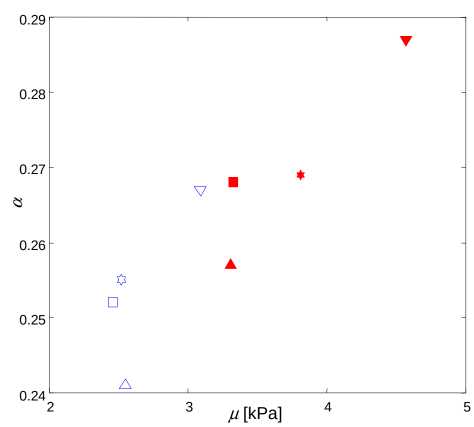

Figure 2: Viscoelastic parameters according to the springpot model in the quadriceps femoris muscle. Each symbol corresponds to one volunteer. The individual mean values are illustrated in relaxation (blue, blank) and in contraction (red, filled).

Results: Fig. 1 shows a multifrequency MRE experiment on the quadriceps femoris muscle of one volunteer. In relaxation and in contraction all driving frequencies were introduced well into the muscle. It is already obvious by a visual inspection that the wavelengths in the images corresponding to identical frequencies are longer in contraction than in relaxation which indicates a higher stiffness in the contracted muscle. This observation is approved by the mean individual viscoelastic parameters in relaxation and in contraction which are displayed in fig. 2. The values of μ and α are higher for all volunteers in contraction. A linear correlation between the increase of α and μ is indicated in figure 2. The interindividual mean values (±SD) of the differences between contraction and relaxation are $\Delta\alpha$=(0.017±0.003) and $\Delta\mu$=(1.10±0.34) kPa.

Conclusion: In this study an increase in stiffness of the quadriceps femoris muscle due to contraction was measured by multifrequency MRE. Both independent parameters of the rheological springpot model correlated significantly with the condition of the muscle. This is an indication that muscle contraction is associated with a structural reordering of the tissue building blocks.

References: [1] Muthupillai et al., Science 269, 1854-1857 (1995); [2] Klatt et al., Phys Med Biol 52, 7281-7294 (2007); [3] Klatt et al., Roefo (2008), in print; [4] Papazoglou et al., MRM 56, 489-497 (2006); [5] Bensamoun et al., JMRI 27, 1083-1088 (2008); [6] Schiessel et al., Macromolecules 28, 4013-4019 (1995).