MAPPING NEUROMUSCULAR ACTIVATION PATTERNS USING MAGNETIC RESONANCE ELASTOGRAPHY OF SKELETAL MUSCLE

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Target Audience

Medical physicists, rheologists, scientists studying neuromuscular activation and skeletal muscle physiology.

Purpose

Magnetic Resonance Elastography (MRE) enables measurement of the mechanical and viscoelastic properties of a tissue volume *in vivo*. MRE of skeletal muscle has been used to study muscle disease [1] and muscle damage [2], as well as the difference between contracted and relaxed states [3] [4]. However, previous MRE studies have presented only a global average value of stiffness for a ROI encompassing a whole muscle or muscle group. With a new MRE image processing software pipeline, MRE-J [5], we created pixel by pixel maps of multiple muscle viscoelastic properties in a transverse section through the thigh, allowing for the study of inter- and intra-muscle viscoelastic characteristics for all the muscles of a limb.

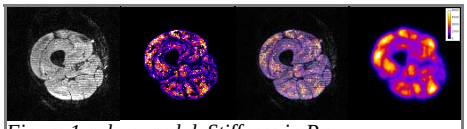

Figure 1 a, b, c, and d. Stiffness in Pa.

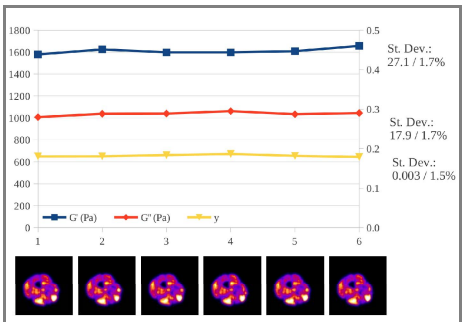

Figure 2

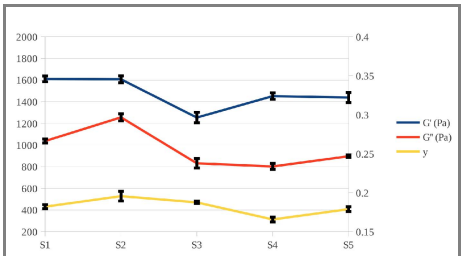

Figure 3

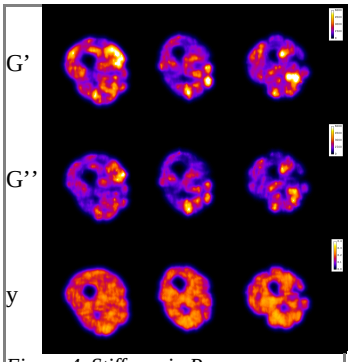

Figure 4. Stiffness in Pa.

Methods

Time series of six consecutive images were acquired in five subjects in an acquisition protocol described elsewhere [6]. Images were unwrapped, decomposed and inverted in MRE-J to create maps of the storage modulus *(G')*, the loss modulus *(G")*, and a solid/liquid characterization constant $y = \arctan(G''/G')/\pi$ [7]. Individual muscles within the images were masked in *ImageJ* (US National Institutes of Health), and median values of *G'*, *G''*, and *y* were recorded for each muscle.

Results

Figure 1a shows the EPI anatomy magnitude scan, while Figure 1b shows the corresponding elastogram. These images contain no smoothing, anatomical or other masking, filtering or interpolation. Figure 1c is an overlay of Figure 1 (a) and (b) to highlight the anatomical specificity of the elastogram, and Figure 1d shows the same image as Figure 1 (b) after application of a Gaussian smoothing kernel.

Figure 2 shows the consistency across multiple scans of an individual subject, for *G'*, *G''* and *y*. The scans themselves are present along the X axis. Figure 3 shows mean values (as points) and standard deviations (as error bars) for all time series scans of the five subjects. Mean standard deviation across all subjects and values was 2.4%. Analysis of variance of *G'*, *G''*, and *y* by subject showed significant differences $p < .001$ in each case, with $F(4, 25) = 118.1$, 174.2, and 61.38 respectively.

Maps of varying resting state viscoelastic properties in the thigh muscles of three subjects are shown in Figure 4. Regions with high tone in the resting state are easily identifiable: *vastus medialis* in leg 1 (median 2139 Pa vs. 1696 Pa image median), *sartorius*, *gracilis* and *semitendinosus* in leg 2 (median 1382 Pa vs. 1199 Pa image median), and *adductor magnus* in leg 3 (median 2569 Pa vs. 1335 image median).

Discussion

The inversion maps yielded clear depictions (i.e. pixel by pixel maps) of the viscoelastic properties of all anatomical regions and features of the thigh. We were able to characterize *G'*, *G''* and *y* through each individual muscle, with nulls only at anatomical discontinuities in the tissue such as bone, vein and fascial compartments. A Gaussian smoothing kernel preserves anatomical specificity while making muscle belly results more uniform. The stiffness values are in line with other MRE literature such as [4] and [2] and consistent across multiple scans.

Conclusion

MRE muscle viscoelasticity maps allow quantitative mapping of neuromuscular activation patterns as represented by tissue mechanical properties. The maps are consistent across multiple acquisitions and show individual specificity of resting state activation. The ability to map these patterns through a transverse limb slice potentially represents a new protocol for the evaluation and targeting of therapies and training regimens. In future work we will use this new muscle mapping technique to study the time course of topical treatments on muscle viscoelasticity.

References

[1]Ringleb et al, JMRI 2007;25 [2]Green et al., NMR Biomed 2012;25 [3] Jenkyn et al. J Biomech 2003;36 [4] Klatt et al., Phys Med Biol 2010;55 [5] Barnhill et al. 2012 ImageJ Conf Proc [6] Kennedy et al. ISMRM 2012 Abst 5569 [7] Sinkus et al. MRM 2007;58