Multidimensional displacement analysis of the triceps surae muscle tendon complex during isometric contraction - A velocity-encoded MRI study at 3T

D. Shin[1], S. Ahn[1], J. Hodgson[2], R. Edgerton[1,2], and S. Sinha[3]

[1]Biomedical Engineering, University of California, Los Angeles, CA, United States, [2]Physiological Sciences, University of California, Los Angeles, CA, United States, [3]Radiology, University of California, San Diego, CA, United States

Introduction: One important prerequisite for the elucidation of structure-function relationship in the human muscular system is an accurate monitoring of its structural changes under a given loading condition. In routinely used isometric muscle contraction experiments of the lower leg, the common and often overlooked assumption is that the muscle movement is present mainly in the long axis of the leg. Though this is true to a large extent and much insight has been gained from it[1, 2], we investigated how much displacement is present in the direction orthogonal to the long axis. To that end, we have formulated an in vivo tissue tracking algorithm based on two-dimensional velocity-encoded phase-contrast MRI in order to track movement of soleus (SOL) and gastrocnemius muscles both in superior-inferior (SI) and anterior-posterior (AP) directions during submaximal plantarflexion starting from the upper medial gastrocnemius (MG) insertion region.

Materials and Methods: Two healthy subjects, i.e. S1, S2 (age: 30.0 ± 1.4 years, body mass: 73.7 ± 11.2 kg and height: 168.8 ± 5.2 cm, mean ± S.D.) were scanned - while performing 40% maximum voluntary contractions (MVC) synchronized to a sound cue - using a standard 2D FLASH PC sequence with VENC: 10 cm/s encoded in SI direction, TR/TE/FA: 13.3 ms/7.5 ms/20°, FOV: 160 mm x 320 mm, matrix: 128x256, 3 mm slice thickness, 290 Hz /pixel bandwidth, 3 views per segment, 2 averages in the retrospective gated mode to acquire 22 phases during 86 contraction cycles. The protocol was repeated for velocity encoding in AP direction with the identical sequence parameters. Trajectories of 20 seed ROIs (Fig. 1) uniformly placed along the aponeurosis-tendon complex were tracked in 2D using an in-house MATLAB-based algorithm. For each subject, the maximum range of AP displacement experienced by each ROI was extracted from the analysis (Fig. 2) and grouped according to muscle regions, i.e. MG region, proximal SOL, mid SOL, and distal SOL. Specifically, ROIs 1-4, 5-8, 9-14, 15-20 were assigned to MG, proximal SOL, mid SOL, and distal SOL, respectively.

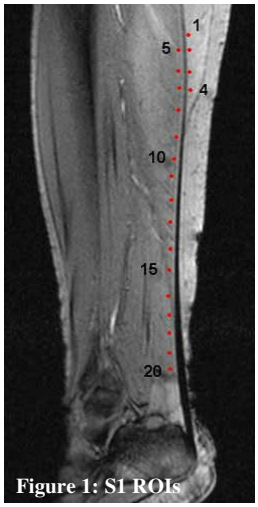
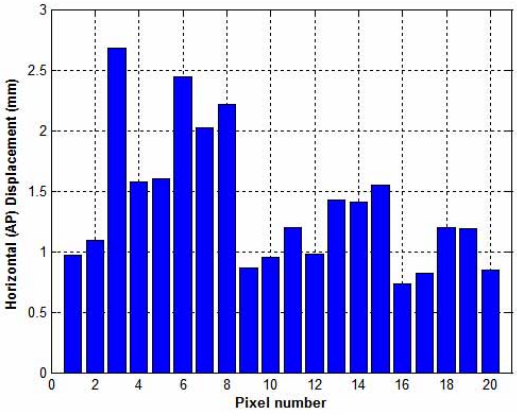


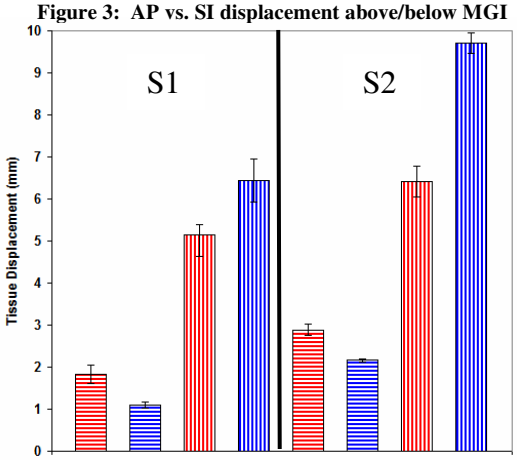
Figure 1: S1 ROIs

Figure 2: S1 AP Displacement



Results and Discussion: Analysis of the two dimensionally encoded velocity maps indicated significant AP displacement (up to 29.7% of SI) in triceps surae muscles during an isometric contraction at 40% MVC. The table below shows the average AP displacement in each muscle region for both subjects. Specifically, MG and proximal SOL, both located above MG insertion showed significantly larger mean AP displacement relative to their distal counterparts, i.e. mid-SOL and distal SOL for both subjects, highlighting the difference in the organization of muscle fibers in the upper MG region, which is bipennate in configuration. Consistent with this finding, the *combined* average AP displacement (horizontal shade in Fig. 3) of upper MG region (red in Fig. 3), i.e. MG and proximal SOL combined, was significantly higher ($p < 0.05$) than the region below (blue in Fig. 3), i.e. mid-SOL and distal SOL combined, for both subjects (S1: 1.83 ± 0.22 vs. 1.10 ± 0.08, S2: 2.88 ± 0.13 vs. 2.17 ± 0.03). In contrast, average SI displacement (vertical pattern in Fig. 3) in the upper region was significantly lower ($p < 0.05$) than the region distal to MG insertion showing the opposite trend.

Figure 3: AP vs. SI displacement above/below MGI



Muscle Region	S1	S2
MG	1.58 ± 0.78 mm	3.19 ± 0.29 mm
Proximal SOL	2.07 ± 0.36 mm	2.58 ± 0.10 mm
Mid-SOL	1.14 ± 0.24 mm	2.19 ± 0.12 mm
Distal SOL	1.06 ± 0.31 mm	2.15 ± 0.13 mm

Conclusion: Significant amount of tissue movement of the plantar flexors in the anterior-posterior direction as established in this experiment emphasizes the importance of two dimensional encoding of velocity during phase contrast data acquisition. In reference to 1D analysis, the 2D methodology provides much more realistic tracking of muscle morphology during isometric contraction. By extrapolation, 3D tracking would be the most physiologically accurate and desirable. We are attempting to solve in the near future, the concomitant technical impediment of reduced time-resolution of each phase by engineering improved MR acquisition pulse sequence schemes.

References: 1. Finni T et al. J Appl Physiol 95: 829-837, 2003. 2. Hodgson JA et al. J Morphol 267: 584-601, 2006.