Calculation of Muscle Fiber Orientation and Length in the Human Soleus by Diffusion Tensor Imaging

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Abstract: It has recently been shown that muscle fiber length and orientation can be measured using diffusion tensor magnetic resonance imaging. We hypothesize that this technique can be applied to human subjects using clinical systems, and that changes in fiber length and orientation during muscle contraction can be obtained. We measured the fiber length, pennation angle, eigenvalues and fractional anisotropy in the human soleus during rest and contraction. Our results demonstrate that DT-MRI is a sensitive method for non-invasively measuring muscle fiber architecture.

Introduction: Fiber tracking using diffusion tensor magnetic resonance imaging (DT-MRI) has been used successfully in visualizing white matter neuron bundles in the human brain [1]. This technique has been extended to skeletal myofibers and shown to reliably determine fiber geometry and orientation in vivo [2]. The purpose of this project is to demonstrate the use of fiber tracking in determining fiber orientation and length in the human soleus during rest and contraction.

Methods: Six healthy volunteers were laid supine in a 1.5 T Siemens Sonata. DT-MRI was performed on the calf muscle region of the left leg during rest and while maintaining 3 kg load. The ankle was set at 0° (foot perpendicular to the bed of the MR scanner) during rest, and at full extension during contraction (plantar flexion direction). A single-shot EPI sequence was used with a TR/TE of 4700ms/120ms. FOV, matrix size, slice thickness, and number of slices were 22.3x25.5 cm^2, 256x224, 4mm, and 50, respectively. The package of slices were centered at approximately 12.5 cm below the tibial head. Diffusion encoding was used in six directions with a single b value of 400 s/mm^2. Total scan time, which includes both rest and exercise, was approximately 20 minutes. Fiber tracking of skeletal myofibers was performed by determining the eigenvector associated with the principle eigenvalue. An interpolation function was used to determine the diffusion tensor at points between pixels. A fifth-order Runge-Kutta algorithm with a step-size of 0.1 (~100μm in-plane) was used for the tracking program, and stop constraints (such as low anisotropy and a large change in path direction) were employed. Fiber length, pennation angle (angle between the directions of the muscle fiber and force vector), eigenvalues, and fractional anisotropy were calculated from the individual tracks and averaged overall all tracks. All calculations were performed using MATLAB (The Mathworks, Inc., Natick, MA).

Results: The pennation angle during rest and contraction is depicted in Figure 1. During contraction, the mean pennation angle increase was 46 % ($P<0.05$) from rest values. Conversely, fiber length decreased by -33 % ($P<0.1$). These results are similar to those obtained in the literature using ultrasonography [3]. The eigenvalues and fractional anisotropy showed negligible differences between rest and contraction. The eigenvalues, though statistically not different between rest and contraction, did show an increasing trend during contraction. This is consistent with literature findings [4].

Discussion: The present study demonstrates that changes in fiber length and orientation due to contraction can be measured using DT-MRI on a clinical system. This method also provides a means for simultaneously calculating the diffusion properties of the same muscle fibers. It was expected that maintaining a 3 kg load isometrically for the limited scan duration (approximately 10 min) would induce only a minimal amount of fatigue. This was evident by the non-statistical increase in the eigenvalues. Thus, the changes seen in the fiber length and pennation angle are due to rotation at plantar flexion of the foot along the ankle joint.

References:

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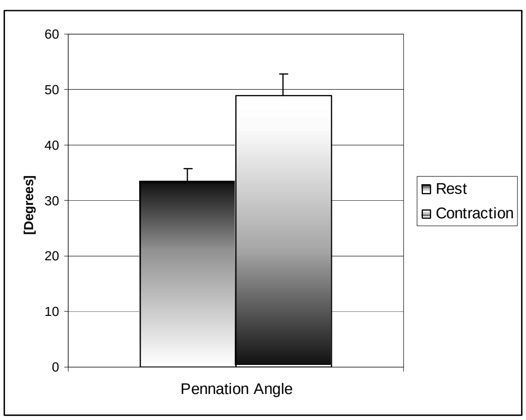

Figure 1: Pennation angle measured during rest and contraction.

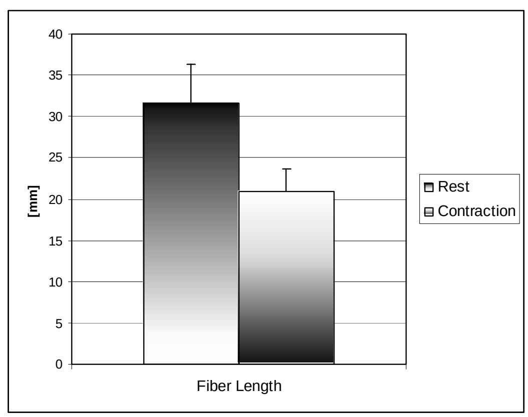

Figure 2: Fiber length measured during rest and contraction.