Measuring human gastrocnemius pennation angle utlizing most likely pathway distributions in diffusion tensor imaging

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Introduction

The goal of this work is to demonstrate a new method for estimating muscle fascicle arrangement using a DTI-FT algorithm, named MetroTrac [1], that calculates a distribution of most likely connections between two regions of interest (ROIs). Recently diffusion tensor imaging with fiber tractography (DTI-FT) has been used for *in vivo* characterization of three-dimensional arrangements in mouse skeletal muscle [2] and humans [3]. Researchers have even verified fascicle arrangements estimated by DTI-FT methods with direct anatomical inspection within Sprague-Dawley rats [4]. We show the estimation of pennation angle within a distal section of the medial head of the human gastrocnemius muscle agrees on average with the previously used DTI-FT algorithm. However, we demonstrate the ability for the new algorithm to estimate fascicle arrangements within regions of the muscle that are not represented by the previous DTI-FT algorithm's results.

Methods

We acquired diffusion-weighted images in the calf of three healthy subjects (2 male, 1 female, ages 27-32). A single-shot echo-planar sequence was used to acquire axial slices for two b-values, b = 0 and b = 4000 s/mm^2 along 12 diffusion directions, in a 1.5T GE Signa LX scanner. The subjects were positioned supine with the ankle and knee in the neutral position, with a 5-inch surface coil positioned on the posterior side of the calf. To minimize B_0 inhomogeniety and gradient non-linearity effects on the diffusion measurements, we collected the images in five separate acquisitions, with each covering approximately 9*cm*. The images were acquired using a 20 *cm* by 20 *cm* FOV, 128 by 128 matrix size, and a 2.5 *mm* (skip 0.5 *mm*) through-plane resolution, and 6 acquisitions were collected and averaged for each slice. We also collected 3D-SPGR images at the same axial locations (256 by 256, 20 *cm* by 20 *cm* FOV, 3 *mm* slices) to identify anatomical structures.

The non-diffusion weighted component of the DTI data was automatically aligned to the T1 data using a mutual information algorithm [registration]. We confirmed that this registration technique aligns the DTI and T1 images to within a few millimeters. The section of medial gastrocnemius muscle was chosen such that it contained the anterior aponeurosis of the muscle, but not the posterior aponeurosis. The muscle was segmented manually using the T1 images. The streamlines tracing technique (STT) [5,6] algorithm was then seeded within the entire volume of the muscle segment placing two start points per voxel. Resulting STT tracts that did not intersect both the tendon ROI and a transverse ROI slice positioned at the belly of the muscle were discarded, as shown in Figure 1A. The remaining estimates were clipped to lie between the ROIs. MetroTrac produced distributions of likely connections between 32 voxels in the small tendon ROI and anywhere in the muscle belly slice ROI with 10k samples generated per voxel, Figure 1C.

Results

We measured the average pennation angle between a 20 *mm* fascicle portion and a plane approximation to the tendon segment. For the three subjects we estimated the pennation angle mean and standard deviation across the muscle to be 16±5°, 28±15°, 19±11° for STT and 19±8°, 25±8°, 18±9° for MetroTrac. These numbers are consistent with ultrasound and cadaveric measurements in the literature [7].

Discussion

Our results show that our new DTI-FT method for estimating fascicle pennation angle in human subjects is in agreement on average with the resulting estimates from previous DTI-FT methods, which were validated in small animal experiments [1]. Unlike previous methods we have also shown that are method is able to guarantee estimates from any position along the tendon to any other ROI and thus make estimates unrepresented by the previous methods.

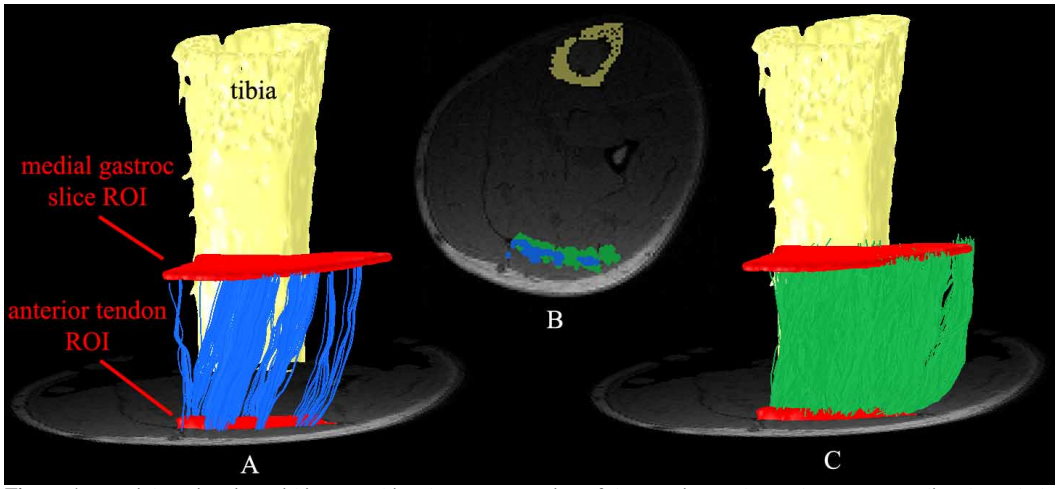

Figure 1. Fascicle estimation within one subject between a section of the anterior tendon and a transverse slice through the belly of the medial head of the gastrocnemius muscle. (A,C) The curves show the fascicle estimates from the STT (blue) and MetroTrac (green) algorithms. (B) This transverse image shows the intersection of the STT estimates near the tendon ROI as blue dots and the MetroTrac estimates as green dots with area approximately 4 *mm* per dot.

References

1. Sherbondy *et al.*, HBM, 2006.
2. Heemskerk *et al.,* MRM: 53:1333-1340, 2005.
3. Blemker *et al.*, ISMRM, 2005.
4. Damon *et al.,* MRM: 48:97-104, 2002.
5. Conturo *et al.*, PNAS, 10422-10427,199
6. Mori *et al.*, An Neurol, 45:265-269, 1999
7. Martin *et al.*, J. Anat, 2001.

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