Automatic segmentation of tendons in human skeletal muscles using DTI tractography derived tract-density maps

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Introduction: In Diffusion Tensor Imaging (DTI) studies of skeletal muscles, segmentation is performed manually, which is tedious and difficult in complex structures. Furthermore, muscle fiber tractography often results in fibers that continue along tendon or aponeurosis due to partial volume effects. This effect leads to overestimation of muscle fiber lengths and making it difficult to identify tendon insertion points and calculate pennation angles [1]. Muscle fibers spanning the entire length from tendon to tendon. This means the density of reconstructed fiber tracts within a skeletal muscles should remain constant over its volume, but increases at the tendons were they converge due to the partial volume effects. Therefore we hypothesized tract density differences can be used for automatic muscle segmentation to distinguish muscle from tendon.

The **aim** of the study was to develop a method for automatic muscle segmentation in humans, based on differences in tract density between muscle and tendon.

Methods: One healthy 27 year old male volunteer was scanned on a 3T scanner (Phillips Ingenia) using medium flexcoils. For the experiment we used DTI and T_1-weighted data in the calf using the following imaging parameters: **DTI:** SE-EPI; FOV: 240x156 mm^2; TE/TR: 49/5500ms; matrix size: 80x52; slices: 40; voxel size: 3x3x5 mm^3; SENSE: 1.5; partial fourier: 0.7; gradient directions: 15; bvalue: 400s/mm^2 Fat suppression: SPIR. **T1:** TSE; FOV 140x140 mm^2; TE/TR: 10/630 ms; matrix size 200x200; slices: 56; voxel size: 0.48x0.48x3 mm^3. The DTI data was processed using a custom-built toolbox for Mathematica 9.0 [2] and tractography was performed using the vIST/e toolbox [3]. First a whole volume seeding (1 per mm^3) was done with stop criteria: FA 0.01 to 1, fiber angle of 35 degrees per step of 0.2 voxel and a minimum fiber length of 1 cm. From these fiber reconstructions a tract-density (TD) map was created. TD values were normalized to muscle (TD muscle = 1).

Fiber tractography was performed for three muscles: the Gastrocnemius, the Soleus, and the Tibialis Anterior. Tractography was performed twice, once with conventional FA cutoff (min 0.15, max 0.5) and once based on the TD map. A threshold value of TD = 1.5 was used to distinguish muscle from tendon. Other stop criteria were identical: maximum angle of 10 degrees per step of 0.2 voxel and a minimum fiber length of 1 cm. For both sets the fiber lengths were extracted and the mean and standard deviation were calculated.

Results & discussion: The acquired TD maps and derived seeding volumes showed good visual agreement with anatomical data (figure 1 A to F). Regions of high TD corresponded to tendons (aponeurosis) visible on the T_1-weighted MRI and known locations of tendons. The use of the TD as a threshold for a tractography stopping criteria, prevented fibers from entering tendinous tissues (figure 1 G and H). As a comparison, fiber tractography with and without TD segmentation of the three muscles is shown in figure 2. Figure 3 shows histograms of the average fiber length of the Gastrocnemius, the Soleus and the Tibialis Anterior determined from conventional segmentation (bottom row) and from the TD segmentation (top row). The average fiber length based on TD segmentation (Fig 3, top) for the Gastrocnemius, Soleus and Tibialis Anterior (44mm, 33mm and 55 mm) compared well with literature (51mm, 44mm, 68mm), although it obviously depends on the subject [4]. Fiber lengths were significantly overestimated using the conventional threshold method. As a next step we will use the intersection of segmented fibers and the TD tendon volume for calculation of pennation angles in complex muscle anatomy.

Conclusion: We have showed the feasibility of automated muscle tendon and aponeurosis segmentation method based on tract density maps, which allowed for a more accurate determination of fiber length.

References: [1] P. Schenk et.al. J Anat 2013;223:61–8. [2] M. Froeling et. al. J Magn Reson Imaging 2012;36:237–48. [3] http://bmia.bmt.tue.nl/software/viste [4] S.R. Ward et. al. Clin Orthop Relat Res 2009;467:1074–82.

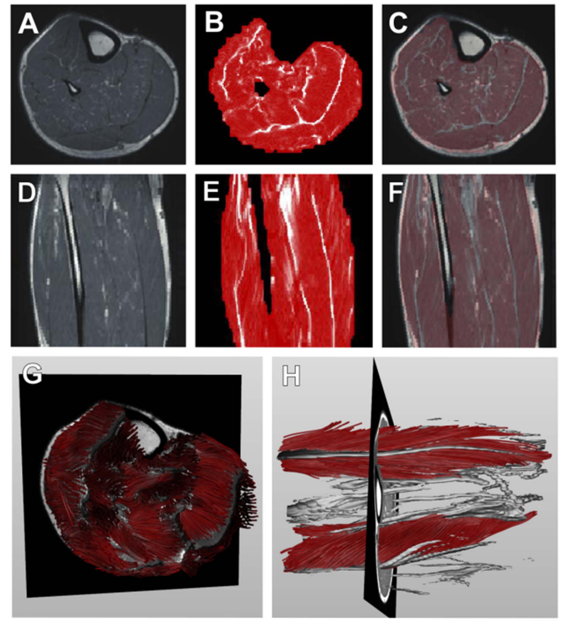

Figure 1: A-D) T_1-weighted image. B-E) Tract Density Maps. C-F) overlay TD map on T_1-weighted image. G) Whole volume fiber tractography and tendon volume. H) TD-based tractography of Tibialis Anterior and Soleus.

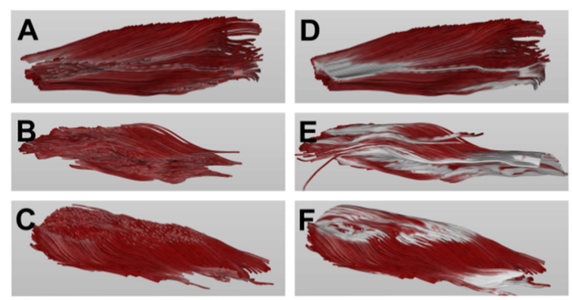

Figure 2: Fiber tractography of the Gastrocnemius (A-D), Soleus (B-E) and Tibialis Antrior (C-F) using TD (A to C) segmentation and normal (D to F) segmentation. Tracts are color coded for the tract density (red = low = muscle, white

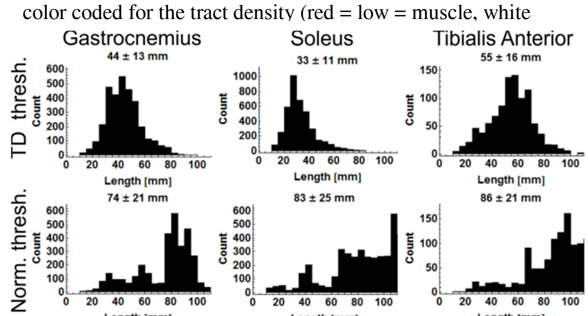

Figure 3: Histograms of the fiber length for three muscles based on tract density (top row) and normal (bottom row) segmentation