Effect of Anisotropic Smoothing on DT-MRI-based Fiber Tractography in the Medial Gastrocnemius Muscle

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Target Audience: Muscle biomechanists and imaging scientists interested in quantitative muscle MRI or post-processing of diffusion tensor imaging data.

Purpose: Diffusion tensor magnetic resonance image- (DT-MRI) based fiber tracking allows non-invasive estimation of three-dimensional muscle structure, such as muscle fiber pennation angle, length, and curvature, and direct comparison with other MR data (e.g. structural, perfusion). Pennation angle (the angle formed between the fiber and the local aponeurosis surface tangent) is related to force production[1], and fiber count and length can be used to characterize states of atrophy. Changes in these metrics related to muscle damage and repair have the potential for use in both assessing disease progression and/or response to treatment. Challenges to DT-MR imaging in leg muscle include low signal (related to the short T2 of muscle) and fat suppression (due to the substantial layer of fat surrounding even healthy muscle). These factors deleteriously impact image quality and consequently introduce error in estimation of the diffusion tensor eigenvectors that are used for fiber propagation. Therefore, it is desirable to find a postprocessing approach that would improve fiber tracking (e.g. increase the number of successfully tracked fibers) without over smoothing and introducing errors (e.g. influencing pennation angle). Anisotropic smoothing implemented with a Craig Sneyd scheme prior to estimation of the diffusion tensor has been shown to efficiently reduce noise in DT-MRI data of human brain[2]. The goal of this study was to assess the effect of anisotropic smoothing on fiber tract measures, including pennation angle, fiber length, and fiber number in the medial gastrocnemius (MG) muscle in healthy subjects using DT-MRI.

Methods: Healthy adult volunteers (n=6) participated in this study, which was approved by the local Institutional Review Board. Written, informed consent was obtained from each subject. MRI data were acquired using a 3T Achieva/Intera scanner and SENSE cardiac coil (Philips Healthcare). DT-MRI parameters: TR/TE=4000/55 ms; FOV=192x192 mm; voxel size=1.5x1.5x6 mm^3; NEX=5; b-value=485 s/mm^2; 15 diffusion encoded directions; 24 slices. The DT-MR sequence was optimized to increase SNR and to mitigate fat shift artifact. Each stack of 12 DT-MR images was registered using an inline tool provided by Philips. All data were processed using MATLAB (The Mathworks). The diffusion tensor and the associated eigenvectors and fractional anisotropy (FA) values were determined on a voxel-wise basis from either unsmoothed (0%) or anisotropically smoothed (5%, 10%, 15%) DT-MR data. Using itk-snap (www.itksnap.org)[3], the MG boundary was segmented. The location of each aponeurosis was traced over the 20 most distal slices of the segmented muscle and was discretized into a rectangular mesh. Fiber tracts were initiated from the aponeurosis mesh nodes and were propagated based on principal eigenvector orientation if 1) the tract remained within the muscle boundary; 2) the FA value was within 0.05-0.35 for the present voxel; and 3) the angle between two adjacent eigenvectors was <20°. Repeated measures ANOVA was used to determine statistical significance ($p<0.05$) between smoothing levels.

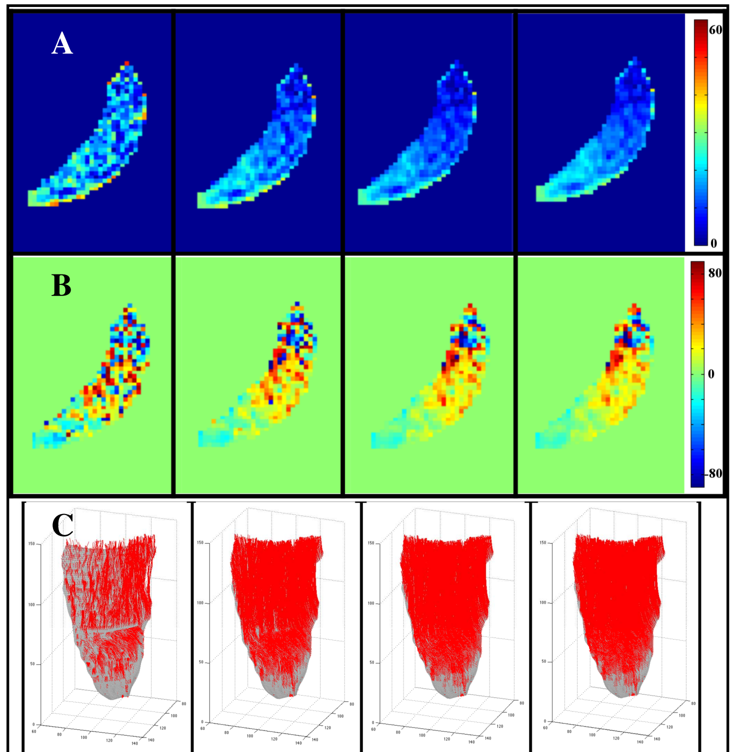

Figure 1: A) Polar angle (θ) of the principal eigenvector for 0%, 5%, 10%, 15% smoothing (left to right). B) Azimuthal angle (φ) of the principal eigenvector for 0%, 5%, 10%, 15% smoothing (left to right). C) Fiber tracks (red) on aponeurosis mesh (grey) for 0%, 5%, 10%, 15% smoothing (left to right).

Results: Smoothing of the DT-MR data removed local heterogeneity in the diffusion tensor eigenvector as demonstrated by the polar (θ) and azimuthal angle (φ) of the principal eigenvector (Figure 1A, B). Anisotropic smoothing significantly increased the number of fibers tracked and the mean fiber tract length; however, there were no significant differences between 5%, 10%, and 15% smoothing levels (Table 1; Figure 1C). Anisotropic smoothing at 5% did not impact mean pennation angle; however, the 10% and 15% levels of smoothing significantly decreased pennation angle from the unsmoothed calculated angles (Table 1).

Table 1. Mean and (standard deviation) values for pennation angle, number of fibers, and fiber length. * indicates statistical difference ($p<0.05$) from unsmoothed (0%) data.

	0%	5%	10%	15%
Pennation Angle (°)	20.1 (4.0)	19.5 (3.5)	19.3* (3.2)	19.3* (3.2)
Number of fibers	1270 (740)	2657* (713)	2828* (510)	2815* (509)
Fiber length (mm)	18.6 (5.0)	34.0* (4.4)	35.4* (3.5)	35.4* (3.5)

Discussion: Anisotropic smoothing of DT-MRI data was chosen to improve fiber tractography by minimizing influence of noise wile preserving physiologic features related to function. A smoothing level of 5% preserves pennation angle while increasing the number and length of fiber tracts.

Conclusion: A modest level (5%) of anisotropic smoothing will preserve physiological features of fiber tracts while improving fiber tractography. This approach will be useful in applications assessing muscle structural changes related to disease progression or response to therapy in patient populations.

References

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