The Effect of Diffusion Tensor Imaging SNR on Skeletal Muscle Tractography

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Introduction

Diffusion tensor imaging (DTI) of skeletal muscle coupled with tractography has been used successfully to visualize muscle fiber structure [1]. Restricted diffusion in the tissue allows for muscle fibers to be tracked using the first eigenvector of the diffusion tensor. Various deterministic methods of tractography have been proposed and implemented for tracking axons in the brain [2,3,4,5], and the systematic application of the same methods in skeletal muscle has only recently been documented [8]. Errors in tractography arise from errors in computing the eigenvectors from noisy DTI data, and can accumulate as the individual tract length becomes longer, leading to potentially large deviations from the anatomical muscle fibers. Therefore, attempts have been made to understand the effects of noise on DTI [6] and tractography [7], and it is necessary to investigate these effects, since there is generally low SNR in the DTI acquisition of skeletal muscle because of low T2 and high T1. When attempting to utilize deterministic fiber tracking in the muscle in a quantitative way, it is important to understand how SNR affects tractography to be able to estimate the reliability of the results. Therefore, this work focuses on investigating the effects of DTI SNR on tractography in skeletal muscle by comparing a few geometrical parameters of the reconstructed tracts from various tracking algorithms.

Methods

DTI Acquisition: Four healthy subjects were imaged in the supine position with legs in a relaxed state, placed parallel to the magnetic field, feet first. DTI was collected on the left calf of two of the subjects, and the left thigh of the other two. All data was collected on a 3T full-body Siemens Trio scanner (Siemens Medical Systems, Erlangen, Germany). Diffusion-weighted images were acquired using a single-shot twice-refocused spin-echo EPI sequence with the following parameters: TR/TE = 3000/71 ms, FOV = 25x25 cm^2, slice thickness = 10 mm, matrix = 76x76, and seven axial slices. Diffusion weighted gradients were applied along 30 non-collinear directions with a nominal b-value of 550 s/mm^2. Water excitation was performed using a spatial-spectral RF pulse to remove the signal contribution from fat. Two of the DTI scans had 30 averages (scan time ~ 45 min) and the other two had 10 averages (scan time ~ 15 min). These acquisitions were chosen so as to get a range of SNR values for comparison. By varying the number of DTI averages used for tractography, different SNR levels were achieved (i.e. doubling number of averages increases SNR by $\sqrt{2}$). The overall range of the SNR analyzed was 6-78.

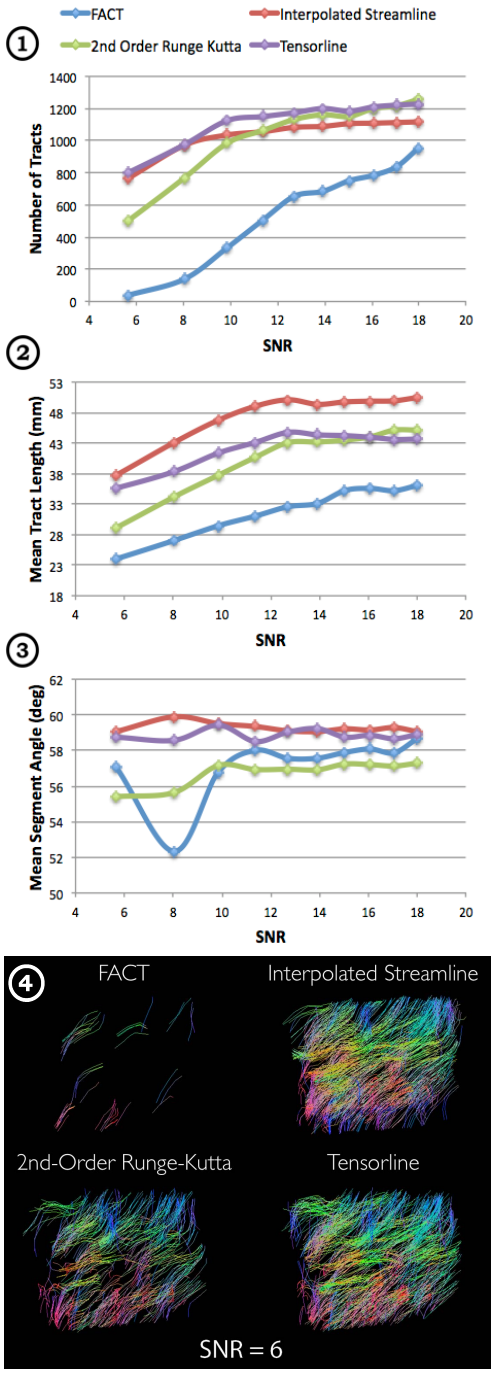
Tractography: Tractography was performed in the gastrocnemius medialis (in the calf) and vastus lateralis (in the thigh) muscles with *Trackvis* software [9] using four deterministic tractography methods: FACT [2], Interpolated Streamline (with 0.5 mm step size) [3], 2nd-order Runge-Kutta [4], and Tensorline [5]. The stop criterion for the tract was an orientation change between points greater than 40 degrees, in order to properly reflect muscle anatomy. A B-spline filter was applied to smooth the tracts, and a minimum tract length of 20mm was used for all the methods in an attempt to eliminate spurious tracts. A region of interest (ROI) was hand-drawn containing the entire muscle being studied, and all data outside the muscle was removed.

Results and Discussion

The metrics used for comparison were number of tracts drawn, mean tract length (mm), and the angle of each tract segment relative to the z-direction. Figures 1-3 indicate that the measures from a single method start to converge at high SNR. These results are consistent both across subjects and for different muscles, showing the same convergence rate for each method. It should be noted however that the tractography methods converge to different values of the measures. This is a limitation of quantifying results from deterministic tractography that has not yet been explored in terms of quantifying results. FACT, compared to the other three methods, seems to be affected the most by noise, as seen in Figure 4, and is because the step size is based on the voxel size, which is fairly large in the case of skeletal muscle. On the other hand, the interpolated streamline method calculates the tensor after each 0.5 mm step by interpolating from the neighboring voxels, similar to applying a regularization filter to the data before tractography, and is, not surprisingly, the least susceptible to noise.

Conclusion

For our specific parameters, interpolated streamline consistently converged at SNR~15, Tensorline and Runge-Kutta at SNR~20, and FACT at SNR~40. These values are not abolute; they will vary with different voxel sizes and tractography parameters. As attempts to quantify the accuracy of deterministic tractography multiply, the choice of tractography method and minimum SNR required for the DTI should be important parameters in the design of any DTI protocol for skeletal muscle.



Figures: (1-3) Plots of various metrics vs. SNR for the vastus lateralis of one subject (10 averages). (4) Tractography of vastus lateralis using the four methods and only one DTI average (SNR = 6).

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