Fiber Tracking of Extraocular Muscles In Vivo

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Introduction

Only few studies have investigated fiber tracking based on diffusion tensor imaging (DTI) or diffusion spectrum imaging (DSI) in various muscle tissues: human tongue (in vivo) [1], beef tongue (ex vivo) [2–4], human uterus (ex vivo) [5], human calf muscle (in vivo) [6]. While lacking the ability to resolve intravoxel crossing fibers, DTI tractography may have the capacity to resolve intervoxel crossing and non-crossing fibers at scales which are relevant since they coincide with the practical dimensions of mechanical deformation. In the current study we sought to investigate the feasibility of fiber tracking of human extraocular muscles in vivo based on diffusion tensor imaging. Imaging of extraocular muscles is particularly intricate because of the small size of the muscles compared e.g. to calf muscle, the low signal-to-noise ratio compared to e.g. brain tissue, as well as eye motion and susceptibility artifacts.

Methods

Imaging was done on a 3 T MR scanner (Siemens TIM Trio, Siemens Medical Solutions, Erlangen, Germany) using a custom-made 2-channel coil. The circular coil elements of 60 mm diameter were placed over the eyes so that the subjects were able to fixate on a marker at the top of the scanner bore during the scan. EPI diffusion tensor imaging scans were performed on two subjects with the following imaging parameters: TR = 3.5 s, TE = 78 ms, 20 slices, matrix size 64x64, 192 mm FoV, 3 mm isotropic voxel size, bandwidth 2440 Hz/px, 10 non-diffusion-weighted volume, 60 diffusion-weighted volumes with a b-value of 400 s/mm^2, resulting in a scan time of 4:09 min:s.

Fiber tracking and visualization were performed using custom-made programs written in C++ using VTK. The fiber tracking algorithm is based on the Fiber Assignment by Continuous Tracking (FACT) algorithm [7]. Fibers were seeded in one spherical region of interest (ROI) behind each eyeball so that all but the inferior oblique eye muscles were found from these ROIs. Shown fibers were limited to a length of more than 21 mm to exclude short erroneous fibers.

Results and Conclusion

Use of the 2-channel surface coil resulted in a strong increase in SNR compared to the standard head coil. Due to the focal coil sensitivity profile it also allows small field-of-view acquisitions without image wrap. Four of the six extraocular muscles i.e. superior rectus, inferior rectus, medial rectus, and lateral rectus could be depicted and are mostly separated from each other (Fig. 1 & 2). However, differentiation between superior rectus, superior oblique and levator palpebrae superioris was difficult and these muscles could not be separated from each other reliably at the given spatial resolution. To clarify the presentation, inferior oblique was not included in the seed ROI and therefore not shown. Higher spatial resolution is needed to enable clear separation of all muscles as well as show more details. Likely, the optic nerve is not shown in the fiber tracts because it is more easily affected by eye motion.

We conclude that diffusion tensor imaging and fiber tracking of human extraocular muscles in vivo is feasible. However, higher spatial resolution is required to better depict and separate the muscles. The ability of DTI tractography to resolve extraocular muscles in vivo should allow the application of this imaging technique for the development of novel image guided surgery.

Acknowledgments

References

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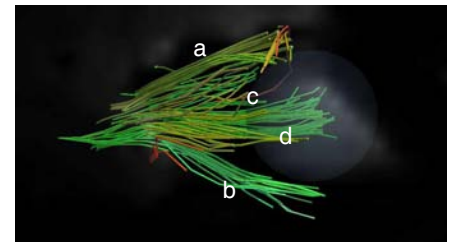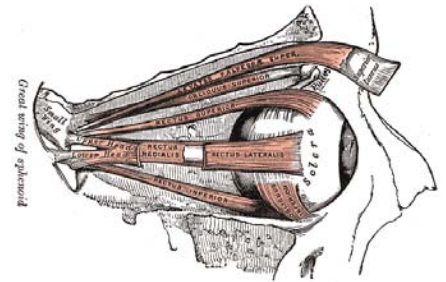[8] Gray, H. Anatomy of the Human Body. Philadelphia: Lea & Febiger, 1918.

Figure 1: Muscles of the right orbit (top)[8] and fiber tracking results of the same muscles (bottom). View is from right. Marked muscles are superior rectus (a), inferior rectus (b), medial rectus (c), and lateral rectus (d). Location of eyeball is symbolized in fiber tracking view.
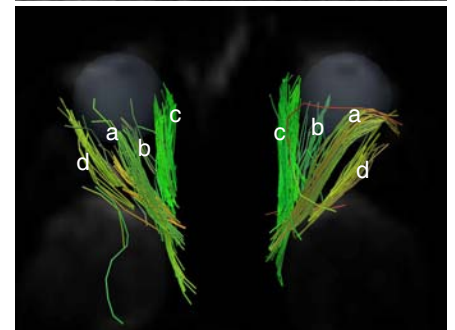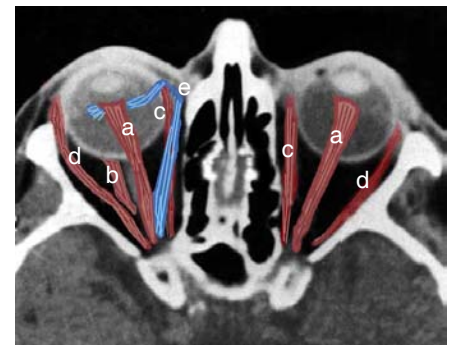

Figure 2: Transverse CT scan with schematic coloring of the muscles of both orbits (top) and fiber tracking results of the same muscles (bottom). View is from top. Marked muscles are superior rectus (a), inferior rectus (b), medial rectus (c), lateral rectus (d), and superior oblique (e). Location of eyeballs is symbolized in fiber tracking view.