European Journal of Radiology Open 3 (2016) 153–161

Contents lists available at ScienceDirect

European Journal of Radiology Open

journal homepage: www.elsevier.com/locate/ejro

Fiber tracking: A qualitative and quantitative comparison between four different software tools on the reconstruction of major white matter tracts

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ARTICLE INFO

Article history:
Received 22 May 2016
Received in revised form 22 June 2016
Accepted 23 June 2016

Keywords:
Deterministic tractography
Fiber tracking
Diffusion tensor imaging
Magnetic resonance imaging

ABSTRACT

Purpose: Diffusion tensor imaging (DTI) enables in vivo reconstruction of white matter (WM) pathways. Considering the emergence of numerous models and fiber tracking techniques, we herein aimed to compare, both quantitatively and qualitatively, the fiber tracking results of four DTI software (Brainance, Philips FiberTrak, DSI Studio, NordicICE) on the reconstruction of representative WM tracts.
Materials and methods: Ten healthy participants underwent 30-directional diffusion tensor imaging on a 3T-Philips Achieva TX MR-scanner. All data were analyzed by two independent sites of experienced raters with the aforementioned software and the following WM tracts were reconstructed: corticospinal tract (CST); forceps major (Fmajor); forceps minor (Fminor); cingulum bundle (CB); superior longitudinal fasciculus (SLF); inferior fronto-occipital fasciculus (IFOF). Visual inspection of the resulted tracts and statistical analysis (inter-rater and betweensoftware agreement; paired *t*-test) on fractional anisotropy (FA), axial and radial diffusivity (Daxial, Dradial) were applied for qualitative and quantitative evaluation of DTI software results.
Results: Qualitative evaluation of the extracted tracts confirmed anatomical landmarks at least for the core part of each tract, even though differences in the number of fibers extracted and the whole tract were evident, especially for the CST, Fmajor, Fminor and SLF. Descriptive values did not deviate from the expected range of values for healthy adult population. Substantial inter-rater agreement (intraclass correlation coefficient [ICC], Bland-Altman analysis) was found for all tracts (ICC; FA: 0.839–0.989, Daxial: 0.704–0.991, Dradial: 0.972–0.993). Low agreement for FA, Daxial and Dradial (ICC; Bland-Altman analysis) and significant paired *t*-test differences ($p < 0.05$) were detected regarding between-software agreement.
Conclusions: Qualitative comparison of four different DTI software in addition to substantial inter-rater but poor between-software agreement highlight the differences on existing fiber tracking methodologies and several particularities of each WM tract, further supporting the need for further study in both clinical and research settings.
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1. Introduction

Diffusion-weighted magnetic resonance imaging (DW-MRI) is based on the random coherent motion of water molecules, utilizing it as a contrast mechanism in order to quantify the anisotropic diffusion corresponding to the anatomical structure of the human brain [1]. In the brain, diffusion is restricted by the various tissue structures and can therefore be used to investigate its microstructure.

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http://dx.doi.org/10.1016/j.ejro.2016.06.002
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Diffusion tensor imaging (DTI) [2] constitutes a formal description of the aforementioned relation. In regions where the principal diffusion direction concurs with the major eigenvector of the diffusion ellipsoid [3], following the local orientation allows in-vivo reconstruction of fiber bundles [4–6] via various single-tensor tractography approaches [7] (Fiber Assignment by Continuous Tracking (FACT), Streamline, TENsor Deflection (TEND) algorithms).

However, the traditional single-tensor DTI-based tractography, which is mainly extracting all the directional information about the fiber from the major eigenvector, has been proven limited. In this case, DTI orientation estimates have a direct anatomical meaning only in regions where there is no fiber crossing/kissing/fanning/branching and only a single bundle of parallel axons runs through a voxel of the image. When more complex patterns are observed, such as within-voxel fiber crossing, the correlation of the model estimates to the anatomical gold standard is less straightforward [4,8]. More sophisticated approaches have therefore been developed.

The emergence of numerous models and fiber tracking techniques during the past decade raises the need for a comprehensive and quantitative comparison between different software and, thus, different implemented tracking methodologies. In the present study, we compare, on both qualitative and quantitative way, the fiber tracking results of four different DTI software: Brainance (*Advantis Medical Imaging, Eindhoven, The Netherlands*), Philips FiberTrak (*Philips, Best, The Netherlands*), DSI Studio [9], NordicICE (*Nordic NeuroLab, Bergen, Norway*).

2. Material and methods

2.1. Study design

Ten healthy right-handed volunteers (4 males) aged between 22 and 42 years old (M = 31.50 years; SD = 7.09 years) were included in the study. All participants gave their informed consent to be scanned for the research purpose of the study, which were done in accordance to the declaration of Helsinki and had been approved by the Local Ethical Committee. Inclusion criterion was age older than 18 years old. Exclusion criteria were (a) presence of any neurological condition affecting central nervous system (CNS); (b) severe psychiatric illness or other systemic disease; (c) psychoactive drugs or other medication that could affect CNS; (d) alcohol or drug abuse; (e) known structural pathology in the MRI and (f) standard contraindications for MRI. Neurological conditions, severe psychiatric illness or other systemic diseases were excluded based on interview of each participant before scanning, including detailed assessment of each participant's available medical records for excluding possible medication treatment with known effects on CNS. The absence of any brain pathology was further confirmed by experienced radiologists based on participants' MRI scanning.

2.2. MR imaging acquisition

All participants underwent brain MRI examination on a 3T system (Achieva TX; Philips, Best, The Netherlands) using an 8-channel SENSE head coil.

2.2.1. 3D T1-weighted acquisition

The T1-weighted sequence was acquired using a three-dimensional sequence (time of repetition (TR): 9.9 ms, echo time (TE): 3.7 ms, flip angle: 7°, voxel-size $1 \times 1 \times 1$ mm, sagittal slice orientation, matrix size 244×240).

2.2.2. DTI acquisition

DTI acquisition included an axial single-shot spin-echo echo-planar imaging sequence with 30 diffusion encoding directions and the following parameters: TR: 7299 ms, TE: 68 ms, flip angle: 90°, field of view: 256×256 mm, acquisition voxel size: $2 \times 2 \times 2$ mm, sensitivity encoding reduction factor of 2, two b factors with 0 s/mm^2 (low b), and 1000 s/mm^2 (high b) with two b factors averaged per b value, in order to ensure better signal-to-noise ratio (SNR). The acquisition consisted of 70 slices and the scan time was 8 min 40 s.

2.3. DTI tractography analysis

The following WM tracts were examined as representative of projection, commissural, and associative WM fibers: corticospinal tract (CST); forceps major (Fmajor); forceps minor (Fminor); cingulum bundle (CB); superior longitudinal fasciculus (SLF); inferior fronto-occipital fasciculus (IFOF).

For the tract reconstruction we used four different fiber tracking software available to the raters, whose description can be found below:

2.3.1. Brainance DTI suite (Advantis Medical Imaging, Eindhoven, The Netherlands)

Brainance DTI software suite is a cloud-based tool developed by *Advantis Medical Imaging* towards a more efficient, robust and anatomically accurate fiber tractography and quantification result. In *Brainance*, a new fiber tracking methodology has been developed and implemented, mostly based on the principles of the deterministic logic, which is highly accurate in the final 3D reconstruction of the fiber bundles in comparison to the anatomical gold standard.

2.3.2. FiberTrak package (Philips, Best, The Netherlands)

FiberTrak is a DTI software package developed by Philips which implements the Fiber Assignment with Continuous Tracking (FACT) algorithm in order to reconstruct the fiber pathways.

2.3.3. DSI studio (http://dsi-studio.labsolver.org)

DSI Studio is a non-commercial software for diffusion MR images analysis. The provided functions include reconstruction, deterministic fiber tracking (TEND algorithm) and 3D visualization.

2.3.4. NordicICE (Nordic NeuroLab, Bergen, Norway)

The *NordicICE* Diffusion/DTI Module generates diffusion maps from MR diffusion imaging studies from all major MR vendors. It also includes the feature of reconstructing fiber tracts (Fiber Tracking) in the CNS and can quantify fiber statistics such as fractional anisotropy (FA), apparent diffusion coefficient (ADC) and more. The parametric values that are shown correspond to the selected output maps that were generated during the DTI analysis.

During the selection of the region-of-interest (ROI) in all the aforementioned software, a multiple ROI approach was applied for the reconstruction of the CST according to well-known anatomical landmarks. We selected three primary ROIs on axial slices: (a) the bundle of fibers running in the rostrocaudal axial in the anterior pons; (b) the posterior limbs of the internal capsule; and (c) the precentral gyrus. Fmajor, Fminor, CB, SLF and IFOF tracts were reconstructed according to previously published protocols [10]. All reconstructed fibers that are transpassing all ROIs were included. The fiber tracking procedure was performed with the thresholds of minimum FA value at 0.15, and maximum angle at 27°. Mean FA, axial (Daxial) and radial (Dradial) diffusivities were calculated by each software, except for *NordicICE* where only mean FA measurements were performed for the reconstructed fiber bundles due to the available software release limitations.

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