DTI-based tractography in normal subjects and brain injury patients - Evaluation of different software packages

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**Aims and objectives**

Neuronal tissue consists of tightly packed and coherently aligned axons that are surrounded by glial cells and often organized in bundles. The movements of water molecules are therefore hindered to a greater extent in a direction perpendicular to the axonal orientation than parallel to it.

Diffusion tensor imaging (DTI) is a magnetic resonance technique that is sensitive to the diffusion of water in tissue and has become of great interest in the last years to reveal the anisotropy and orientation of white matter tracts of the brain in vivo. This information can then be used to delineate white matter pathways of the brain by employing fiber tracking algorithms. DTI has thus become an integral part of preoperative diagnostic imaging in many neurosurgical centers.

To-date there has been no general consensus on the optimal diffusion tensor acquisition protocol and different algorithms have been implemented, using either a deterministic or a probabilistic approach. Besides, the outcome of a DTI study might be strongly influenced by the parameters chosen for the seed generation and fiber propagation (curvature change and anisotropy thresholds).

In this work we compared different DTI software and evaluated the tumour effect on fibers.

**Methods and materials**

In this study diffusion-tensor MR imaging was performed on 25 healthy and 5 brain injured patients; none of the healthy patients had a neurologic or psychiatric disease or brain injury in his or her previous medical history.

We focused on corticospinal tracts and corpus callosum.

Patients were scanned in a supine position with a Philips Achieva 1.5 T scanner using a diffusion weighted echo-planar imaging sequence with 16 directions, whose parameters are reported in Table 1.

| TR (ms) | 9388 |
| TE (ms) | 70    |
| EPI factor | 59 |
| NSA | 3 |
| Acq. matrix | 112 x 110 |
| Acq. voxel (mm$^3$) | 2 x 2 x 2 |
| FAT SAT. | SPIR |
| b value (s/mm$^2$) | 0 - 800 |
A T1-weighted three-dimensional rapid gradient echo sequence was acquired for anatomic reference.

Images were analyzed with three different software packages: Philips FiberTrack module, DTI-Studio and FSL.

In all cases data were subjected to quality control before processing and corrected for eddy currents and motion artefacts; images were also registered to the reference volume at b=0.

The comparison was performed on a qualitative level through visual inspection of the fibers and quantitatively by a statistical analysis of apparent diffusion coefficient (ADC), fractional anisotropy (FA) and eigenvalues through ANOVA and t-test.

For Philips FiberTrack module different anisotropy thresholds (minimum FA between 0.15 and 0.5) and maximal angles (15 - 40 degrees) were tested. An automated 3D ROI was chosen for seed generation as to grant the reproducibility of the process. Data were interpolated with a 3 order polynomial fit. Experienced neuroradiologists were asked to evaluate the outcome of the analysis and the thresholds values they indicated as optimal were considered as standard settings in the software comparison.

The study of the corticospinal tract was performed choosing for seed generation either a single ROI in the internal capsule or two ROIs placed in the internal capsule and in the cortex.

FSL probabilistic fiber tracking algorithm was applied considering both one and two fibers per voxel. Group studies were also performed in order to obtain the tracts common to at least 80% of the subjects.

Results
The study performed with Philips FiberTrack module showed how the number and volume of tracts are strongly dependent on the thresholds chosen in the algorithm: we observed an evident reduction when minimal FA was increased and maximal angle was decreased (Fig. 1 and Fig. 2); the visual inspection was confirmed by statistical tests leading to p-values < 0.01.

**Fig. 1**: Analysis performed with Philips FiberTrack module and different anisotropy thresholds: a)FAmin = 0.2; angmax = 27°; b)FAmin = 0.5; angmax = 27°; c)FAmin = 0.15; angmax = 15°; d)FAmin = 0.15; angmax = 40°

**References**: Neuroradiology Department, S.Maria delle Croci Hospital, Ravenna, Italy
Fig. 2: a) FA as a function of minimal FA in corpus callosum; b) FA as a function of maximal angle in corticospinal tract

References: Department of Physics and Astronomy - University of Bologna, Postgraduate School in Medical Physics - Bologna/IT

According to the evaluation of experienced neuroradiologists, we chose 0.15 and 27° as the minimal FA and maximal angle for the software comparison.

As for the corticospinal tract, fibers obtained considering a single seed ROI and two ROIs were visually quite different (Fig. 3), the last method being more accurate in selecting
the proper fibers; statistical tests on FA, ADC and eigenvalues led to p-values between 0.01 and 0.05.

**Fig. 3**: Comparison between single ROI and 2 ROIs seed generation (analysis performed with Philips FiberTrack module)

**References**: Neuroradiology Department, S.Maria delle Croci Hospital, Ravenna, Italy

Results of FSL fiber tracking with one or two fibers per voxel were no statistically different, with p-values > 0.05 for all parameters considered in this study. Fig. 4 shows the results of group studies.
Fig. 4: FSL group analysis; fibers common to at least 80% of the subjects. a) corpus callosum; b) corticospinal tracts

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T-tests between Philips and DTI-Studio showed p-values > 0.05 for all parameters in corticospinal tract and < 0.05 for all parameters except #1 for corpus callosum.

FSL analysis led to higher ADC and lower FA values, with significative differences with the other software (Fig. 5).
Fig. 5: Example of software comparison: a) left corticospinal tract; b) corpus callosum

References: Department of Physics and Astronomy - University of Bologna, Postgraduate School in Medical Physics - Bologna/IT
In brain injured patients we measured reduced FA and increased ADC values around the lesion; different fibers orientation was observed too.

Fig. 6 is an example of analysis performed on a patient with a glioblastoma; the corticospinal tract is evidently interrupted.

![Image of example analysis](image1)

**Fig. 6**: Example of analysis on a patient affected by glioblastoma.

**References**: Neuroradiology Department, S.Maria delle Croci Hospital, Ravenna, Italy

**Images for this section:**
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Fig. 2: a) FA as a function of minimal FA in corpus callosum; b) FA as a function of maximal angle in corticospinal tract
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Fig. 5: Example of software comparison: a) left corticospinal tract; b) corpus callosum
Fig. 6: Example of analysis on a patient affected by glioblastoma.
Conclusion

This work has shown that the outcome of a DTI study is strongly influenced by the type of algorithm used for the fiber tracking, as well as the parameters chosen for the seed generation and fiber propagation.

The results of statistical tests between the DTI software considered in this study showed clearly that the differences in the displayed fiber bundles are relevant.

However, every program adopts modified versions of available algorithms and the modifications are hardly ever fully disclosed; besides it is not always possible to import/export seed ROIs between software, thus creating an additional uncertainty in the comparison.

Visual inspection of the fibers remains therefore the best way to evaluate the outcome of the different tools and the opinion of experienced neuroradiologists is mandatory in the choice of optimal parameters.

Considering these results, findings based on DTI tractography should be interpreted carefully. However DTI fiber tracking represents a promising non-invasive preoperative imaging tool, which is still being developed and needs to be refined further.

Personal information

References
