Construction of a DTI atlas of the healthy human brain with diffusion full tensor information in ICBM-81 space: an application for studying the maturation of white matter

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Introduction

The availability of an appropriate diffusion tensor imaging (DTI) template and normative DTI data is essential for the interpretation of pathological white matter (WM) findings. Recently, it has been shown that incorporation of the full diffusion tensor information during coregistration and atlas generation improves the spatial and orientational alignment of DTI data (Van Hecke et al. 2007). As a consequence, an atlas that is used as a reference image for coregistration of DTI data should also contain this multi-component diffusion tensor information. In this work, we introduce such a population-averaged DTI atlas that contains the complete diffusion information. Because all diffusion information is present is this DTI atlas, fiber tractography can also be performed on the atlas. The tract reconstructions from this DTI atlas can be used as tract masks, which allows for semi-automated region-of-interest (ROI) analyses on individual DTI datasets that have been warped to the DTI atlas. To validate this method, we used these tract masks to assess WM maturation and asymmetry of children aged 4 months to 18 years.

Materials and Methods

The DTI atlas was generated using DTI data of 36 healthy volunteers (age range = 19-24 years). DTI data were acquired at 3T using a SE-EPI sequence with 45 directions of diffusion (b = 800 s/mm^2) and isotropic resolution of 2 mm. Analysis was performed using ExploreDTI, and in-house written tools. First, all DTI datasets were affinely coregistered to the ICMB81 template (Mori et al, 2008), after which the affinely warped DTI datasets were linearly averaged to yield an affine DTI atlas. The final DTI atlas – non-rigid-36subj-FullTensorInformation (NR-36subj-FTI) atlas, which is in ICBM81 space - was generated using non-rigid coregistration of the DTI datasets to the affine DTI atlas and subsequent linear averaging of the warped DTI datasets. Non-rigid coregistrations were performed based on a viscous fluid model, optimized for DTI images by Van Hecke et al (2007). On this NR-36subj-FTI atlas, we performed deterministic fiber tractography of 11 bilateral and 4 unilateral WM tracts using the ROI definition protocols of Wakana et al (2008) and Stieltjes et al (2003), which already have shown to be highly reproducible. To assess both intra- and inter-observer reproducibility, all tracts were reconstructed 3 times by 3 independent observers and kappa-values were calculated. Furthermore, tract masks were derived from the tract reconstructions and were used to extract mean FA- and MD-value for each tract in 42 individual DTI datasets of children (age range = 4 months-18 years). We studied WM maturation by assessing the effect of age on FA or MD using Pearson correlation tests WM asymmetry was evaluated by performing paired t-tests on the left and right mean FA- or MD-values obtained in the bilateral WM tracts after correction for age. Statistical threshold for significance was set at $p<0.05$ and Bonferroni correction was performed to account for multiple testing.

Results

Representative (color-encoded) slices through the atlas can be seen in figure 1B. As a reference the atlas of Mori et al (2008) is shown in figure 1A. Note that the atlas constructed in this study contains full tensor information, and that fiber tractography is possible (Fig 1C and D). All WM tracts could be reconstructed three times by all observers using the specified ROI definition protocols. High intra- and inter-observer reproducibility was found for all tracts (range of kappa-values intra = 0.51-1; range of kappa-values inter = 0.61- 0.96), except for the superior cerebellar peduncle (kappa-value intra = 0.51-0.73; inter = 0.49).

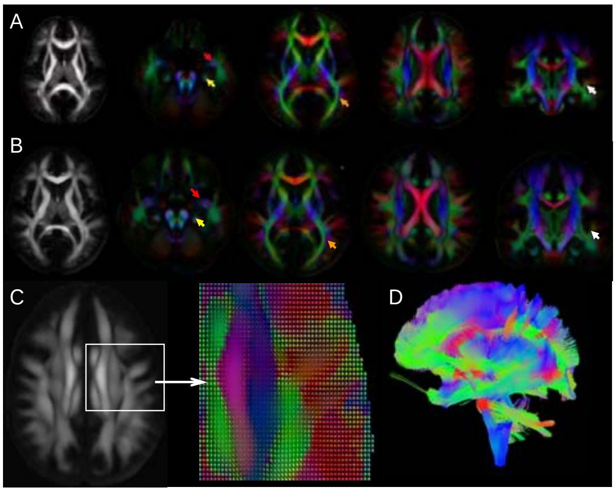

Figure 1: Representative axial slices of the ICBM81 template (A) and the NR-36-subj-FTI atlas (B) are shown, together with the diffusion ellipsoids (C) and a whole brain tractography of the NR_36subj_FTI atlas (D).

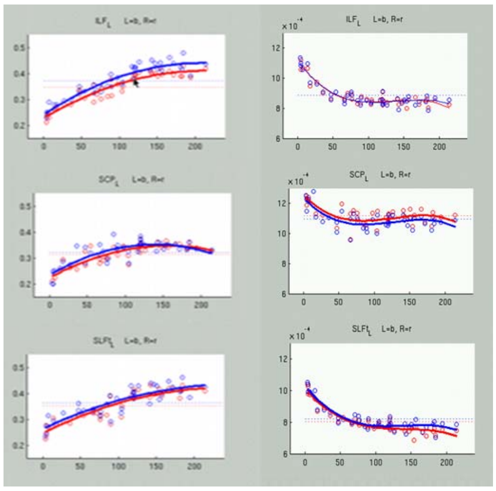

Figure 2: changes in FA (left column) and MD (right column) in 3 representative tract-masks (top: inferior longitudinal fasc., middle: superior cerebellar peduncle, bottom: superior longitudinal fasc.). Dots/lines in blue are for the left tract, red for the right tract. X-axis: age in months, Y-axis: FA/MD values.

Significant increase of FA and decrease of MD with age was found in all of the 26 tract masks (figure 2),. In 6 out of 11 bilateral tracts, a significant asymmetry of FA and MD was demonstrated.

Conclusion

In conclusion, we have developed a DTI atlas that contains the full diffusion information and which is in ICBM-152 coordinate space. Based on this atlas, 15 major WM tracts could be reconstructed with high reproducibility, which were subsequently used as tract masks to study WM maturation in a group of young children and adolescents. WM maturation observed here is in agreement with previous findings (Lebel et al, 2008). Tract masks offer another anatomical dimension of grouping voxels that belong to specific WM structures and are complementary to classical ROI evaluation. As such, they can be helpful in delineating how typical developmental trajectories are altered in individuals with developmental, cognitive and/or behavioural disorders.

References

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