Investigation of Neonate Brain Development Enabled by Tract-Oriented Quantification

M. Maddah[1], A. U. Mewes[2,3], H. Als[2], G. McAnulty[2], E. L. Grimson[1], and S. K. Warfield[2]

[1]Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Cambridge, MA, United States, [2]Computational Radiology Laboratory, Harvard Medical School and Children's Hospital, Boston, MA, United States, [3]Institute of Radiology, Charite, Berlin, Germany

Introduction:

Investigation of early brain development is of great scientific and clinical importance. Prematurely born infants are vulnerable to brain injuries and early detection of abnormalities may help their treatment and care. Diffusion tensor MRI enables visualization and quantification of white matter pathways well before other imaging techniques. However, studies performed so far have not fully benefited from the potentials of this modality. Prior work on neonate DTI analysis has been limited to the comparison of scalar diffusion parameters, such as fractional anisotropy (FA), in manually defined regions of interest (ROIs) [1, 2]. Such approaches are sensitive to the accuracy and reproducibility of specifying the ROI by the experts. Errors in defining the ROIs are especially important in analyzing neonate DTI due to the limited resolution and SNR. More importantly, spatial patterns of the tract maturation are lost in the quantitative analysis. Tract-oriented analysis, wherein the fiber tract acts as a common coordinate system, enables unambiguous quantification of the spatial information. To our knowledge, this is the first tract-oriented analysis of the neonate DTI data where mapping of the fiber pathways to the common coordinate system is performed rigorously. Dubois et al. [3] proposed a similar approach, wherein the quantitative parameters are either reported at manually selected landmarks along the fiber pathways or averaged over the whole fiber bundle.

Material and Method:

Very low birth weight infants born below 30 weeks postmenstrual age underwent structural and diffusion MRI at approximately 32 weeks and approximately 42 weeks postmenstrual age. Imaging was carried out without sedation and with informed consent utilizing a protocol approved by the institutional review board. Whole brain DTI required 10 minutes of scanning time on 1.5 T GE scanner with 31 directions, 6 baseline images, and (0.7, 0.7, 1.5) mm resolution. Manual outlining of ROIs for tractography was performed in 3D Slicer. An Expectation Maximization algorithm was used to cluster the trajectories in a mixture model framework and to obtain the point correspondence between the trajectories in each cluster. The common coordinate system is obtained as proposed in [4] by constructing a distance map from each cluster center. The parameters of interest are averaged over all trajectories that belong to a cluster and plotted along the common coordinate system.

Results:

Clustered white matter trajectories for cortico-spinal, cingulum, and uncinate fasciculus are shown in Fig. 1 (a)-(c) and (d)-(f) at two time points of 32 and 42 weeks postmenstrual age for one of the subject. FA-colored trajectories clearly show the spatial patterns of the tract development, especially in the cortico-spinal tract. Box-plots of the FA variation along the tract arc length of the superior part of the cingulum, which is proven to be a challenging tract in quantitative analyses [3], and at the above two time points are shown in Fig.2. As can be clearly seen, only the posterior part of the tract exhibits a significant increase in the fractional anisotropy. Whereas tract-oriented analysis shows 76% increase in the mean FA (from 0.17 to 0.30) in the posterior part of the superior cingulum, ROI-based analysis on the entire superior cingulum shows only 18% FA increase (from 0.22 to 0.26).

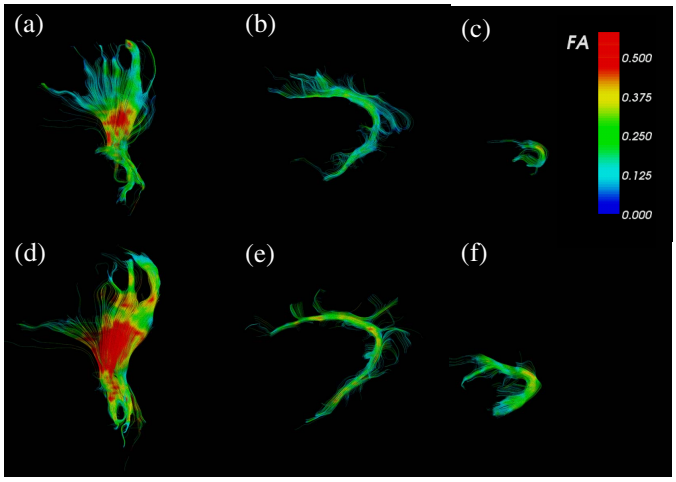

Fig. 1 FA-colored trajectories from (a), (d) cortico-spinal, (b), (e) cingulum and (c), (f) uncinate fasciculus at 32-wk (up) and 42-wk (down) postmenstrual age. Spatial patterns of the tract development are clearly seen.

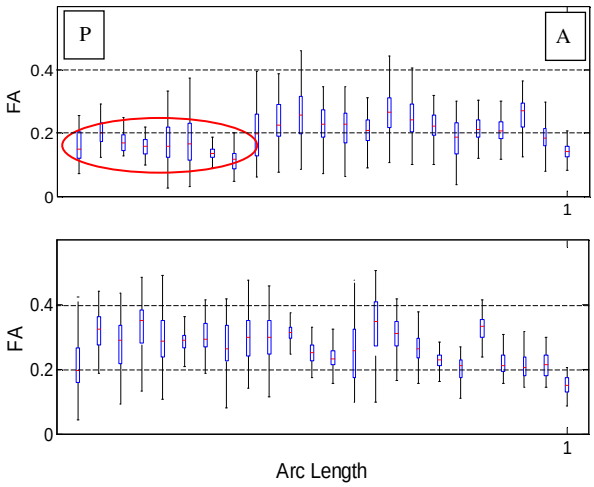

Fig. 2 Box-plot of the FA variation along the tract arc length for the superior part of the cingulum and at 32-wk (up) and 42-wk (down) postmenstrual age. Only the posterior part shows a significant FA increase. ROI-based analysis fails to detect such spatial dependencies.

Conclusion:

Tract-based quantitative analysis reveals developmental differences that are not identified by ROI-based methods. Spatial patterns of the tract development are clearly observed once the parameters of interest are plotted along the tract arc length. Comparison across different subjects or at different time points are easily achieved by mapping the corresponding cluster centers. The proposed approach opens new possibilities for more accurate analysis of neonate brain development.

Acknowledgment: This work is supported in part by NIH grants P41 RR013218, U54 EB005149, U41 RR019703, P30 HD018655, R01 RR021885, R01 GM074068, R01 EB008015, R03 CA126466, and R01 HD046855, by a research grant from CIMIT, and grant RG 3478A2/2 from the NMSS.

References:

[1] H. Huang, et al.White and gray matter development in human fetal, newborn, and pediatric brains, Neuroimage, 27-38, 2006.
[2] J. Berman, et al. Quantitative diffusion tensor MRI fiber tractography of sensorimotor white matter development in premature infants. Neuroimage, 862-871, 2005.
[3] J. Dubois, et al. assessment of early organization and maturation of infants' cerebral white matter fiber bundles: A feasibility study using quantitative diffusion tensor imaging and tractography, Neuroimage, 1121-1132 (2006).
[4] M. Maddah, et al., Probabilistic clustering and quantitative analysis of white matter fiber tracts, IPMI, 372-383, 2007.