Quantitative DTI Fiber Tracking of White Matter Pathways in Premature Newborns

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Introduction: The pyramidal tract and the somatosensory radiation are among the first white matter tracts to mature and myelinate in the preterm human infant brain. Diffusion tensor imaging (DTI) of premature infants provides an opportunity to study the microstructural organization of these white matter pathways both prior to and during myelination. DTI fiber tracking enables the 3D segmentation of axonal bundles, even in unmyelinated white matter that is not yet visible on conventional MRI. In this study, a high-sensitivity neonatal head coil is employed in conjunction with an MR-compatible incubator, to perform high-resolution DTI of the premature infant brain. DTI fiber tracking is then used to delineate the pyramidal tract and somatosensory radiation, and quantify their microstructural changes during development.

Methods: Thirteen premature infants were imaged between 29 and 43 weeks gestational age (GA) at 1.5 T using an MR-compatible incubator with a custom designed neonatal head coil [1]. Six of the infants were serially scanned at two time points. DTI was acquired with a 4.8 minute single-shot, multirepetition echoplanar sequence and TR/TE = 7s/100ms, 3 NEX, 256 x 128 matrix, 360x180 mm FOV, and 3 mm slice thickness with no gap. Diffusion gradients were applied in 6 non-colinear directions with b= 600 s/mm^2 in addition to a b=0 s/mm^2 image.

Fiber tracks were constructed using software based on the FACT [2] algorithm, which follows the primary eigenvector in 3D continuous space from voxel to voxel. Tracks were launched from a starting region encompassing the posterior limb and the retrolenticular segment of the internal capsule. Resultant fiber tracks were filtered into motor and sensory components using two target regions drawn in the precentral and postcentral gyri, respectively. Fractional anisotropy (FA), directionally averaged diffusion coefficient (D_{av}), and the three eigenvalues (λ_1, λ_2, λ_3) were measured on a slice-by-slice basis, based on voxels through which the fiber tracks passed [3]. Measurements from the left and right sides of the brain were averaged for both the sensory and motor tracks. Tract-specific measures of FA, D_{av}, λ_1, λ_2, and λ_3 were obtained by averaging the slice-specific data along the internal capsule and centrum semiovale

Results: Pyramidal and somatosensory pathways were delineated in each case with DTI fiber tracking from the internal capsule through the central semiovale to the precentral and postcentral gyri (Figure). Graph 1 is a line histogram of the spatial heterogeneity of FA as a function of superior-inferior level typical for younger (<30 weeks) and older (>37 weeks) infants. FA peaks in the internal capsule and decreases as the tracts pass through the corona radiata. The mean tract-specific FA increased with gestational age while tract-specific measurements of D_{av}, λ_1, λ_2, and λ_3 all decreased ($p < 0.003$) with gestational age across all infants in both the pyramidal tract and the somatosensory radiation (Graph 2). The somatosensory pathways exhibited lower FA than the motor pathways ($p < 0.02$).

Discussion/Conclusion: DTI fiber tracking can detect and quantify microstructural changes in white matter pathways during preterm development. Myelination, decreasing water content, and increasing complexity of white matter architecture may cause the observed changes in DTI parameters with age. Younger infants exhibited a smooth decrease in slice-specific FA along the tracts from the internal capsule to the brain vertex. In older infants, maturation of crossing fibers from association and commissural pathways may reduce the slice-specific FA at the level of the centrum semiovale in both pyramidal and somatosensory projectional pathways. This pattern observed in the older infants is similar to that in older pediatrics and adults. FA measurements in this study are systematically higher than in studies using region of interest measurements not localized to specific tracts. Quantitative DTI fiber tracking is a powerful tool for the evaluation of developing axonal pathways during human brain development.

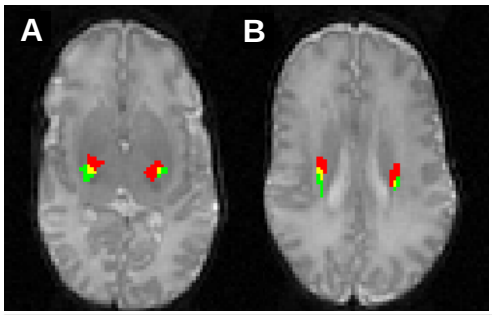
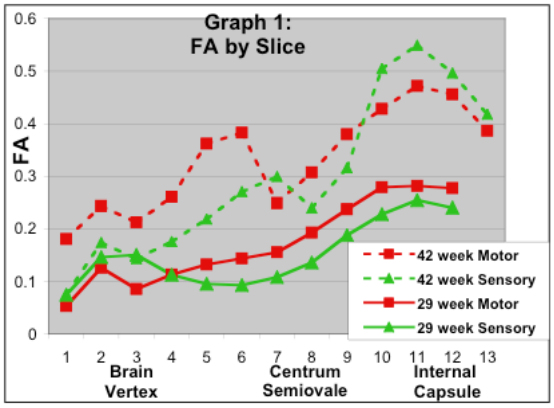
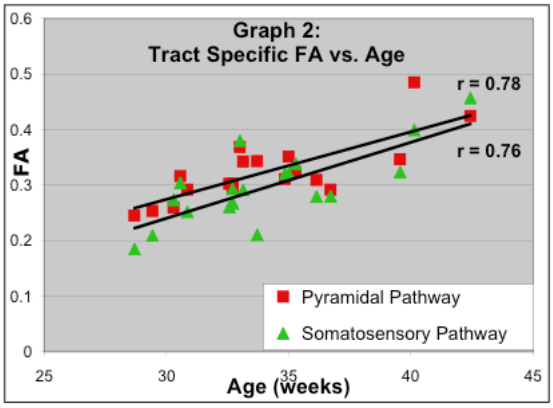


Figure: Fiber tracks in a 33 week GA infant at the a) internal capsule and b) centrum semiovale. Motor tracks are red, sensory tracks are green, and overlap is yellow.





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