Tractography-Based Quantitation of Diffusion Tensor Imaging Parameters in White Matter Tracts of Preterm Newborns

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Purpose: MR diffusion tensor imaging (DTI) of preterm newborns offers a unique opportunity to noninvasively study the formation and development of white matter pathways [1]. DTI fiber tractography (DTT) enables 3D segmentation of axonal bundles, allowing quantitation of DTI parameters within specific WM pathways [2,3]. DTT has potential advantages over standard region of interest (ROI) methods for quantitation within a tract, including the ability to select only those voxels dominated by a particular fiber pathway of interest, and quantification at multiple locations along the tract. The semi-automated DTT method may also improve reproducibility of tract localization in serial studies and between different subjects. The purpose of this investigation was to establish the feasibility and reliability of quantitative diffusion tensor tractography for assessing white matter maturation in the premature brain by comparing DTT-based quantitation with standard manually placed ROI measurements of diffusion tensor parameters in the pyramidal tracts of preterm infants.

Materials & Methods: Nine newborns born prematurely at 25 - 34 weeks (median, 29 weeks) gestational age (GA) with no evidence of white matter injury on conventional MRI were studied with DTI. The median age at scan was 35 weeks (range, 33 – 39 weeks) with five infants receiving a second MR exam at or near term age. DTI was acquired at 1.5T using an MR-compatible incubator with a high-sensitivity neonatal head coil, with a 4.8min single-shot, multi-repetition echoplanar sequence; TR/TE = 7s/100ms, 3 NEX, 256 x 128 matrix, 360x180mm FOV, 3mm slice thickness, no gap [4]. Diffusion gradients were applied in 6 directions with b= 0 and 600s/mm^2. DTT was performed to segment bilateral pyramidal tracts, using a fiber-tracking algorithm [2] originating in the cerebral peduncle (CP) and filtering through the posterior limb of the internal capsule (PLIC) and precentral gyrus (PCG) (**Fig 1**). Voxels containing the resulting tracts were then used for quantitation of DTI parameters such as fractional anisotropy (FA) and directionally-averaged diffusion (D_{av}). DTT results were compared with standard manually placed ROI measurements at four corresponding locations along the tract. A single operator repeated all measurements for both the DTT and manual ROI measurement techniques to assess intra-observer repeatability of each method.
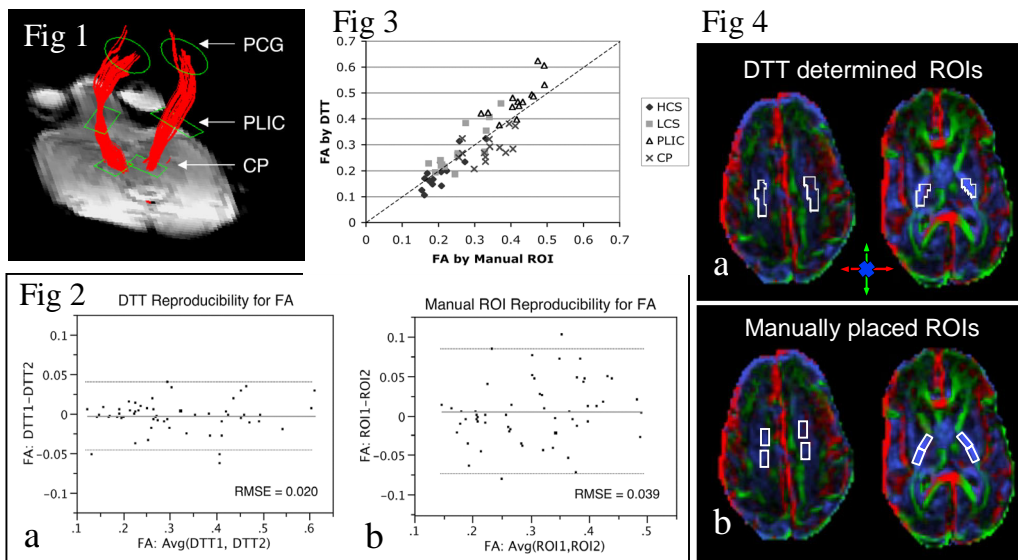

Fig 1

Fig 3

Fig 2

Fig 4

Fig 1. Pyramidal fiber tracts segmented by DTT in a preterm newborn at 33 wks GA.

Fig 2. Plots of difference vs. mean for repeated measures by a single operator, illustrates better repeatability of the DTT method (a) compared to manually-placed ROI method (b) for measuring FA.

Fig 3. Comparison of FA measures from both quantitation techniques in 4 anatomic locations along the pyramidal tract (HCS/LCS = high/low centrum semiovale) show good agreement, except for small systematic differences at the PLIC and CP (dotted line is line of equality).

Fig 4. Comparison of pyramidal tract ROIs chosen by DTT method (a) and manual placement (b) independently at two anatomic locations (left=HCS, right=PLIC) show good agreement. ROIs are shown overlaid on directionally-encoded color FA maps (red: left-right; green: anterior-posterior; blue:superior-inferior).

Results: The semi-automated DTT quantitation method demonstrated better reproducibility over manual ROI measurement for pyramidal tract quantitation and was less subject to intra-operator variability (p < 0.0001, Fisher test for equal variance), **Fig 2**. In general, the anatomic locations and measurements using the two techniques were in good agreement (**Fig 3, 4**). The pyramidal tracts had a median FA of 0.32 (range: 0.27 – 0.36) and median D_{av} of 1.12 mm^2/s (0.98 – 1.26). Both methods of quantitation yielded the highest FA values in the PLIC and lowest FA in the high centrum semiovale, and D_{av} values were highest in the high centrum semiovale and lowest in the PLIC. In addition to improved reproducibility, the semi-automated DTT method provided more detailed quantitation of DTI parameters at multiple slice locations along the pyramidal tract.

Discussion: These preliminary data suggest that DTT is feasible in premature newborns, provides more reliable tract measurements than manual ROI methods, and enables quantitation along the entire 3D trajectory of the tract for more detailed DTI assessment of white matter maturation.

References:

1) Miller SP, et al. JMRI 2001; 16:621-32.
2) Berman JI, et al. Proceedings ISMRM 2003.
3) Mori S, et al. Ann Neurol. 45:265,1999.
4) Partridge et al. NeuroImage 2004; 22(3):1302-1314.