Fiber Connection Density Map Based on Diffusion Tensor Image Data

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Introduction DTI is a highly useful complementary imaging modality that yields information about the brain's white matter, which otherwise appears homogeneous in anatomical MRI data. In DTI, fiber tracts are traced based on the assumption that the preferential direction of the local Brownian thermo motion of water molecules coincides with the underlying fiber orientation. Many effective measurements related to white matter fiber tracts have been developed from DTI data, including fractional anisotropy (FA) mapping, trace mapping, and iso-mapping; each of the measures may play a role in fiber tractography. Yet connectivity information is not presented in an FA map: an area of brighter intensity indicates a higher probability that fiber tracks exist in that location; however it does not necessarily indicate a greater density of fiber tracts when compared with dimmer regions. For example, in Fig. 1, the brighter intensity of the region inside the circle does not indicate a higher density of fibers, but rather, it indicates well-oriented tissue and therefore a higher probability of underlying fiber bundles. While the tracked fibers in a 3D representation can be intuitively manipulated, fiber tracts in the brain as a whole are difficult to visualize and to investigate effectively because of the vast number of neural fibers. Our FCD-map surmounts this difficulty: it presents a normalized measurement of the connection density of neural fiber tracts by embedding connectivity information with a tractography algorithm and by reducing the 3x3-matrix dimensionality at each voxel in the DTI data to that of an intensity value in the FCD-map. In fact, researchers have been looking for methods to measure fiber connection density [1,2], to help their diagnosis in clinical practice or hypnotic research.

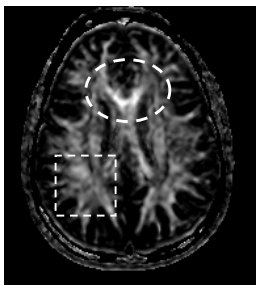

Fig 1. FA map

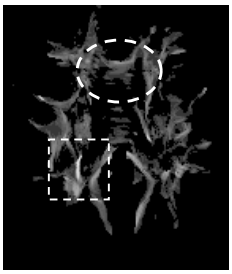

Fig 2. FCD map

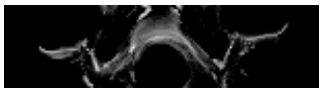

Fig 3. Magnified axial view of FCD-map of a CC portion

Methods **Data**: *In vivo* human data were acquired using a 1.5T Philips Gyroscan NT system. A single-shot EPI sequence with a SENSE parallel imaging scheme (SENSitivity Encoding, reduction factor R=2.5) was used for DTI data acquisition, with an imaging matrix of 96× 96 and a field of view of 240×240 mm (nominal resolution 2.5 mm), which was then zero-filled to 256×256. Axial slice thickness was 2.5 mm parallel to the anterior–posterior commissure line. A total of 50 to 55 slices covered the entire brain and brainstem leaving no gap. The diffusion weighting was encoded along 30 independent directions and the b-value was 700 mm^2/sec. Five additional images with minimal diffusion weighting (b=33 mm^2 /sec) were also acquired. **Algorithm:** We applied the fiber tracking algorithm presented in [3] to the entire brain. Starting from each voxel, the tracking algorithm identified all fibers within the brain that were longer than a length threshold of 20. The R-threshold [3] for terminating tracking was set at 0.1, and a transition C-threshold [3] of 45^0 was used. We then merged identified fiber tracks to guarantee that individual fibers would be presented only once. Finally, we counted the number of fibers that passed through each voxel, and we generated a relative measurement of fiber connection density by normalizing the counts to a scale of 0 to 1.

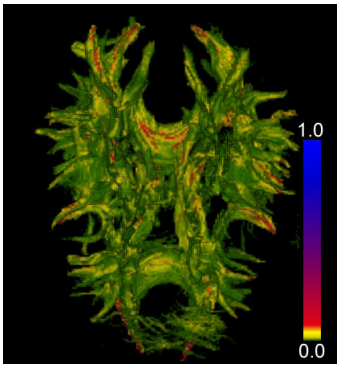

Fig 4. Volume rendered axial view

Results The corpus callosum (CC) regions are typically the brightest in FCD maps, but not always. In Fig. 2, the FCD map of the same individual and section location featured in Fig. 1 shows that regions with a high fractional anisotropy measurement may not necessarily bear the densest fiber connections: the region in the square is not as well oriented as the one in the circle (Fig. 1), yet according to our tracking results, it contains more fiber connections (Fig 2). And although the CC regions appear similar in the FA map (Fig.1), they appear quite dissimilar in the FCD map: the upper layer of the CC is about 4.2 times as dense as the lower part, and the brightest spot in the square region is about 4 times as dense as the brightest spot in the circle region. Fig. 3 shows a magnified view of one CC region where one can see different levels of fiber connection density. Fig. 4 shows a 3D volume-rendered view of the same subject's FCD map.

Discussion Because of the huge number of neural fibers and the coarse resolution of DTI, tracking every individual fiber in the brain remains intractable. Still, based on DTI data, the tracking algorithm can trace the major fiber pathways. The algorithm [3] tracks pathways starting from each voxel in the brain, allowing us to reconstruct all fibers passing through selected seed voxels. The resulting FCD map depends on the choice of tracking algorithm; nevertheless, under the criteria we have established, all fibers have the same possibility of being identified. The number of reconstructed fibers connected with a particular voxel is proportional to the degree of probable connection with other brain regions. Therefore, the number of identified fiber connections in a voxel is a reasonable index of the density of fiber connections at that voxel. Although it would be impossible to count the number of fibers that physically exist in reality, our method provides a normalized measure of the density of fiber connections relative to other brain regions.

References

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[3] D Xu, et al., *NeuroImage*, November, 2002, Vol. 17, pp. 1131-1143