Relationship between Diffusion Entropy and Axonal Density in Human Brain

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INTRODUCTION: Although conventional diffusion tensor MRI (DTI) based on Gaussian model has become an important clinical measurement in detecting WM changes, it could produce large errors in detecting WM with crossing axons. Also, the dynamic range of Gaussian DTI is very low in the anatomic brain structures with low axonal density, such as grey matter. To overcome the weakness of Gaussian DTI, diffusion entropy measurement was performed in current study to investigate the relationship between diffusion entropy and axonal density in human brain. Our data indicated that diffusion entropy is significantly correlated with axonal density.

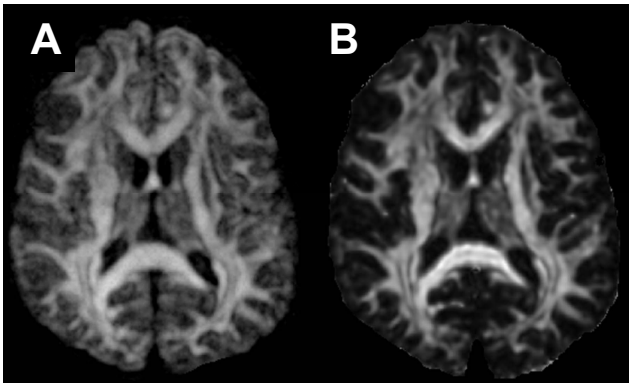
MATERIALS AND METHODS: Ten healthy subjects with no history of neurological or psychological history disorders participated in this study. MRI measurements were performed with a GE 3T MRI system. Q ball based DTI was acquired using pulsed gradient spin-echo echo-planar sequence with 55 diffusion directions of b = 1500 s/mm^2. Shannon's entropy is evaluated via

$$H(X_i) = -\sum_{x_i \in k} p(x_i) \log p(x_i) \qquad (1)$$

where $P(x_i)$ is the probability that X_i is in the state x_i, and $P(x_i)$ log $P(x_i)$ becomes

0 when $P = 0$. Entropy was processed using in-house software written in Matlab. The Gaussian DTI was analyzed using DTI Stadio[1]. FA and entropy values were measured in white matter, fiber crossing region, gray matter (different locations) and cerebro-spinal fluid (CSF) regions. The axonal densities from the same ROIs were evaluated using a combined Nissl- and silver-staining method in human histological sections. Percentage of axons in the field was used to represent axonal density.

RESULTS: Entropy revealed enhanced dynamic range of contrast compared with FA (Fig 1A and B). Gray matter regions are more visible in the entropy map than in FA map. Compared with FA, the relative values of entropy with respect to corpus callosum were approximately triple in gray matter and double in frontal white matter. Entropy also exhibited significant correlation (r=0.91, p=0.012) with axonal density measured in different brain structures. Unlike FA, entropy is less affected by axonal orientation and is more weighted by axonal density.



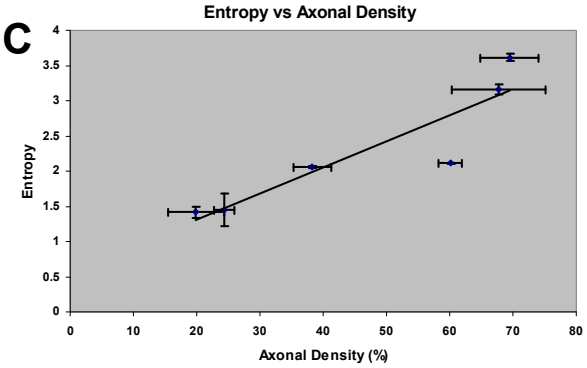


Fig. 1 The entropy (A) and FA (B) maps from the same slice of a represent normal volunteer exhibited an enhanced dynamic range of contrast in entropy compared with FA map. Fig 1C represents relationship between entropy and axonal density.

Discussion: Diffusion entropy exhibits better dynamic range and distinction between different structures of gray matter without making any assumptions or modeling during the diffusion process. Our data demonstrate that entropy strongly (R=0.89) depends on axonal density rather than axonal orientation and is potentially a very useful measurement for detecting brain structure changes during neurological diseases and recovery.

REFERENCES:

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