Application of Geometrical Diffusion Tensor Imaging on Acute Ischemic Cerebral Infarction

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Introduction:

Fractional anisotropy is (FA) one of the most popular indices in describing the anisotropic diffusion of cerebral vascular diseases such as ischemic cerebral infarction [1] on diffusion tensor imaging (DTI). However, it could only describe the degree of anisotropy of diffusion without further characterizing the geometric orientation of the diffusion. The concept of geometric diffusion using the linear (Cl), planar (Cp) and spherical (Cs) coefficients in healthy human brain was firstly introduced by Alexander et al. [2]. And, it has been extended to analyze the aging brain by Liu et al. [3]. Whether these geometric coefficients are superior to the traditional approach in ischemic cerebral infarction or not has not been investigated up to date. In this study, we aim to measure the geometric diffusion coefficients and compare to FA in acute ischemic infarction on DTI.

Materials and Methods:

MR scanning: All MR examinations were performed using a 1.5T MR system (Siemens Vision; Erlangen, Germany) with a single-channel circularly polarized head coil. Axial MR images were acquired using a spin-echo echo-planar imaging sequence. The diffusion-sensitizing gradients were applied along six directions (b = 707 s/mm2) plus one reference image (b = 0 s/mm2). Imaging parameters were as follows: TR/TE/NEX = 5000/100/2, FOV= 24 cm, section thickness = 5 mm (no intersection gap), and matrix size = 128 $\times$ 128.

Data analysis: The diffusion tensor was calculated on a voxel-by-voxel basis by using the known relationship with the b matrix. The elements of the diffusion tensor D (Dxx, Dyy, Dzz, Dxy, Dxz, Dyz) from the encoded diffusion coefficients were derived as described by Basser et al. [4]. Eigenvalue decomposition of each voxel tensor was performed to determine the principle ordered eigenvalues, λ1, λ2, and λ3. The diffusion anisotropy can be represented by fractional anisotropy (FA),

$$FA = \sqrt{\frac{3}{2}\frac{(\lambda_1-\bar{\lambda})^2+(\lambda_2-\bar{\lambda})^2+(\lambda_3-\bar{\lambda})^2}{(\lambda_1{}^2+\lambda_2{}^2+\lambda_3{}^2)}} \qquad where \quad \bar{\lambda} = \frac{\lambda_1+\lambda_2+\lambda_3}{3}$$

The shape of the diffusion tensor can be characterized by a combination of linear, planar and spherical measures:

$$C_L = \frac{\lambda_1-\lambda_2}{\lambda_1+\lambda_2+\lambda_3} \qquad C_P = \frac{2(\lambda_2-\lambda_3)}{\lambda_1+\lambda_2+\lambda_3} \qquad C_L = \frac{3\lambda_3}{\lambda_1+\lambda_2+\lambda_3}$$

All the metrics fall in the range 0~1, and they sum to unity: CL + CP+ CS= 1.

Subjects: This study enrolled 21 patients (64.95 ± 8.61 years) with cerebral infarction within 1~4 days after onset. Three gray-white-matter (GWM) pairs, including posterior limb of internal capsule and globus pallidus (IC_GP), corona radiata and caudate nucleus (CR_CN), subcortical white matter and superficial gray matter (SCWM_SGM) of infarctions were specified by manual drawing of polygonal ROIs based on T2W, FA and DW images by a 5-year experienced neuroradiologist (Fig. 1). The corresponding contralateral hemisphere served as control group. The values of FA, Cl, Cp and Cs in ROI were calculated. Statistical analysis was performed with Student's t-test between stroke and control groups.

Results:

The infarction group showed statistical significant decrease of FA value than the control group (IC 32.8%, CR 27.7%, SCWM 27.4%, GP 25.8%, CN 12.5% and SGM 6.7%) (Fig 2a). In the white matter, the Cl value decreased to a larger degree as compared to FA (IC 46.5%, CR37.5% and SCWM 41.3%) (Fig 2b). In the gray matter, the decrease of the Cp value also exceeded the decrease of FA at GP (31.8%), and CN (26.9 %) (Fig. 2c). The change of Cs values was reciprocal to the FA values, showing increase of the Cs value significantly in the infarction group (IC 44.6%; CR21.2%; SCWM 14.4%; GP 12.3%; CN 5.6%; SGM 1.4%).

Discussion:

Our study shows an overall tendency of decreased anisotropy on FA, Cl and Cp indices and increase of isotropy on Cs of the infracted brain. The linear coefficient is superior to FA in depicting white matter infarction. And, the planar coefficient is more sensitive than FA in gray matter infarction. The change of diffusion indices varies in different anatomic locations. We shortly conclude that geometric DTI coefficients may play a role in evaluating acute ischemic cerebral infarction as well as FA and even better.

References:

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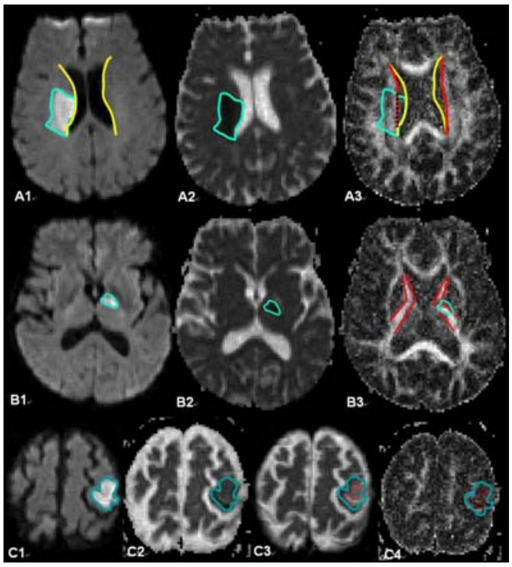

Figure 1. Illustration of ROI drawing in (CR-CN), IC-GP (B), and SCWM-SGM (C) pairs.

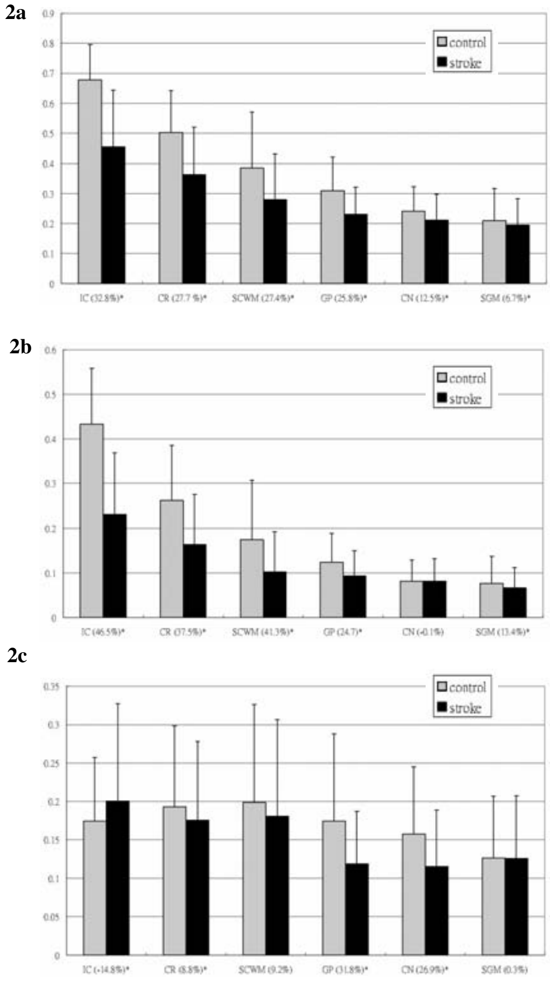

Figure 2. Diffusion indices including (a) FA, (b) CL and (c) CP of the stroke lesions. The X axis represents the specific location of IC, CR, SCWM, GP, CN, and SGM. * represents P value < 0.01.