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ORIGINAL ARTICLE

Quantification of diffusion and anisotropy in intracranial epidermoids using diffusion tensor metrics and *p*: *q* tensor decomposition

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KEYWORDS
Diffusion tensor;
Anisotropy;
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Summary
Purpose: To quantitatively evaluate the diffusion tensor metrics *p*, *q*, *L* and fractional anisotropy in intracranial epidermoids in comparison with normal white matter in the splenium of the corpus callosum.
Methods: This retrospective study included 20 consecutive patients referred to our institute. All patients had a magnetic resonance imaging (MRI) study on a 1.5-Tesla MR system. A spin-echo echo-planar DTI sequence with diffusion gradients along 30 non-collinear directions was performed. The eigen values (λ_1, λ_2, λ_3) were computed for each voxel and, using *p: q* tensor decomposition, the DTI metrics *p*, *q* and *L*-values and fractional anositropy (FA) were calculated. The region of interest (ROI) (6 pixels each) was placed within the lesion in all the cases and in the splenium of the corpus callosum.
Results: The mean FA in the lesion and splenium were 0.50 and 0.88 respectively, with a statistically significant difference between them ($P < 0.01$). On *p: q* tensor decomposition, the mean *p*-value in the epidermoid was 1.55 ± 0.24 and 1.35 ± 0.20 in the splenium; the mean *q*-values

Abbreviations: FA, fractional anisotropy; CL, linear anisotropy; CP, panar anisotropy; CS, spherical anisotropy; *p*, isotropic component of diffusion; *q*, anisotropic component of diffusion; *L*, magnitude of diffusion; D, mean diffusivity; eADC, exponential apparent diffusion co-efficient; DTI, diffusion tensor imaging.

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in the epidermoid was 0.67 ± 0.13 and 1.27 ± 0.17 in the splenium; the differences were statistically significant ($P = 0.01$ and < 0.01 respectively). The significant difference between *p*- and *q*-values in epidermoids compared with the splenium of callosum was probably due to structural and orientation differences in the keratin flakes in epidermoids and white matter bundles in the callosum. However, no significant statistical difference in *L*-values was noted ($P = 0.44$).
Conclusion: DTI metrics *p* and *q* have the potential to quantify the diffusion and anisotropy in various tissues thereby gaining information about their internal architecture. The results also suggest that significant differences of DTI metrics *p* and *q* between epidermoid and the splenium of the corpus callosum are due to the difference in structural organization within them.

Introduction

Intracranial epidermoids are rare neoplasms that are derived from ectodermal inclusions during embryogenesis [1]. They represent about 1% of all intracranial tumors and commonly occur in extra-axial locations like the cerebellopontine angle, basal cisterns and rarely within the ventricles [2]. The imaging features of epidermoids on conventional magnetic resonance imaging (MRI) sequences have been reported by many authors [3–5]. These lesions are characteristically hyperintense on trace images of diffusion-weighted imaging (DWI). Initially, it was thought that the diffusion is restricted in these lesions which may be responsible for this signal intensity. Subsequently, two studies were published evaluating the diffusion tensor imaging (DTI) in epidermoids [6,7]. Both these studies showed that diffusion is facilitated in epidermoids compared with the normal white matter. The authors further proposed that planar anisotropy and T2-shine through could be the reasons for diffusion trace hyperintensity. Quantitative DTI using the metrics *p*, *q* and *L* has gained importance in the evaluation of various neurological disorders. These metrics can quantify the magnitude of diffusion and have the potential to be tissue signatures. In this study, we utilized the DTI metrics *p*, *q*, *L* and fractional anosotrophy (FA) to quantify the diffusion and anisotropy in epidermoids. In addition, we have attempted to study the relation of the DTI metrics with planar anisotropy which helps us to understand the predominant pattern of diffusion and microstructural properties of epidermoids.

Materials and methods

This retrospective study included 20 consecutive patients (12 histopathologically proven epidermoids and 8 patients with imaging findings typical of epidermoid who were managed conservatively). Our Institutional Ethics Committee approved the study. Of the 12 patients with histopathological diagnosis, 10 patients were included from a previous study [7]. All patients underwent an MRI examination performed on a 1.5-Tesla MR system (Avanto TIM; Siemens, Erlangen, Germany) using a 12-channel phased array head coil. In addition to routine T1, T2 and fluid attenuation inversion recovery (FLAIR) sequences, a spin-echo echo-planar DTI sequence with diffusion gradients along 30 non-collinear directions was performed. The parameters for DTI included TR 3500 msec, TE 105 msec, matrix size 192 × 192, FOV 230 mm^2, slice thickness 5 mm with a 1.5-mm gap, averaged twice, and with a b-factor of 0 and 1000 seconds/mm^2. The analysis was performed by two neuroradiologists (BT and KS) in consensus using the same software package provided by the vendor on a separate workstation (Leonardo; Siemens, Erlangen, Germany) in all patients. For DTI analysis, three regions of interest (ROI) of uniform size (6 pixels) were placed within the lesion and then averaged (Fig. 1). For comparison, similar ROIs were placed in the splenium of the corpus callosum. Both the splenium and epidermoids were shown to have high fractional anisotropy values and hence, the splenium was selected for comparison [6,7]. The eigen values (λ_1, λ_2, λ_3) were computed for each voxel and then mean diffusivity (D), FA, linear anisotropy (CL), planar anisotropy (CP), spherical anisotropy (CS) and exponential ADC values (eADC) were calculated (Fig. 2). Using the following formulae, the DTI metrics *p*, *q* and *L* values were calculated [8].

$$\text{Linear Anisotropy (CL)} = \frac{\lambda 1 - \lambda 2}{\lambda 1 + \lambda 2 + \lambda 3} \quad (1)$$

$$\text{Planar Anisotropy (CP)} = \frac{2(\lambda 2 - \lambda 3)}{\lambda 1 + \lambda 2 + \lambda 3} \quad (2)$$

$$\text{Spherical Anisotropy (CS)} = \frac{3\lambda 3}{\lambda 1 + \lambda 2 + \lambda 3} \quad (3)$$

$$\text{Mean diffusivity (D)} = \frac{\lambda 1 + \lambda 2 + \lambda 3}{3} \quad (4)$$

$$\text{Anisotropic diffusion } (q) = \sqrt{(\lambda 1 - D)^2 + (\lambda 2 - D)^2 + (\lambda 3 - D)^2} \quad (5)$$

$$\text{Isotropic Diffusion } (p) = \sqrt{3}D = \frac{\lambda 1 + \lambda 2 + \lambda 3}{\sqrt{3}} \quad (6)$$

$$\text{Magnitude of diffusion (L)} = \sqrt{p^2 + q^2} \quad (7)$$

Using *p: q* tensor decomposition, fractional anisotropy can also be represented as:

$$\text{FA} = \sqrt{\frac{3}{2}}\frac{q}{L} \quad (8)$$

Statistical analysis

Student's *t*-test was used to estimate the statistical significance for difference in these parameters between the tumor and normal white matter in the splenium. A ''*P*'' value of less than 0.05 was considered to indicate a statistically