Journal of the Neurological Sciences 375 (2017) 43–51

Contents lists available at ScienceDirect

Journal of the Neurological Sciences

journal homepage: www.elsevier.com/locate/jns

Axial MR diffusion tensor imaging and tractography in clinical diagnosed and pathology confirmed cervical spinal cord astrocytoma

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ARTICLE INFO

Article history:
Received 24 July 2016
Received in revised form 12 January 2017
Accepted 13 January 2017
Available online 14 January 2017

Keywords:
Diffusion tensor imaging
Diffusion tensor tractography
Astrocytoma
Cervical spinal cord

ABSTRACT

Objective: To evaluate the diffusion tensor imaging (DTI) and diffusion tensor tractography (DTT) features of cervical spinal cord astrocytoma.
Methods: Eleven patients with cervical spinal cord astrocytomas and 10 healthy volunteers were recruited in this study. Conventional magnetic resonance imaging (MRI) and axial DTI were performed on a 3.0T MRI system. Apparent diffusion coefficient (ADC), fractional anisotropy (FA), axial diffusivity (AD), and radial diffusivity (RD) values for the lesions were measured. DTT was performed using the principal diffusion direction method.
Results: ADC values of the lesions and the normal-appearing tissue around the tumour (NATAT) on T2-weighted imaging (T2WI) increased. The ADC values of the lesions were higher. The FA values of the lesions and the NATAT decreased significantly, with the lesions having lower FA values. The RD value (1.36 ± 0.49) of the tumours was significantly higher than those found in the healthy controls, but similar for the AD value (1.84 ± 0.56). There were no differences in ADC or FA values between lesions and NATAT in McCormick Type I vs. Type II patients. Based on the DTT, 7 patients with solid mass tumours were classified as Type I. One patient with a solid mass, 2 patients with cystic degeneration inside the lesions, and 1 patient with a cyst around the mass were classified as Type II.
Conclusions: FA values of the cervical spinal cord astrocytoma decreased, but the ADC values increased. DTI was sensitive for the evaluation of pathological changes that could not be visualized on T2WI. Our preliminary study indicates that DTT can be used to guide operation planning, and that axial images of DTT may be more valuable.

1. Introduction

Intramedullary spinal cord neoplasms are rare lesions and account for 2–4% of all central nervous system tumours [1]. These lesions represent approximately 20% of all spinal tumours in adults and up to 35% of all spinal tumours in children [2,3]. Gliomas account for 80% of all intramedullary tumours and are further subdivided into astrocytomas (60–70%) and ependymomas (30–40%) [4]. Astrocytomas are the second most common intramedullary tumours in adults (30–35% of all tumours) and are the most common in children (90% of all tumours) [5–7]. They primarily occur in the cervical spine and often involve multiple spinal segments.

Conventional magnetic resonance imaging (MRI) is the most widely used tool for the diagnosis of intramedullary spinal cord neoplasms and for their follow-up. Conventional MRI can visualize the extent of intramedullary spinal cord tumour and differentiate between its cystic and solid components. Using gadolinium-enhanced MRI and considering the patients' clinical features, most clinicians can correctly diagnose intramedullary spinal cord neoplasms. However, one disadvantage of the existing system is that it cannot visualize fibre tracts and their relationships to spinal cord tumours. Diffusion tensor imaging (DTI) has traditionally been employed in the brain and recent investigations have evaluated its role in the spinal cord in the settings of degenerative changes [8–10], trauma [11,12], and neoplasms [13–16]. DTI and diffusion tensor tractography (DTT) are non-invasive methods that can visualize the directions and integrities of white matter tracts and their relationships to intramedullary tumours. In our experience, spinal

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http://dx.doi.org/10.1016/j.jns.2017.01.044
0022-510X/

cord DTI image quality is highest in the cervical region, as it has the largest cross-section and has suitable anatomical structures surrounding the spinal cord.

Because cervical spinal cord astrocytomas are rare and due to the limitations of DTI technology, few DTI studies of intramedullary spinal cord neoplasms, including astrocytomas, have been reported. Only one report focused on the sagittal DTI of spinal cord astrocytomas from 5 patients has been published [13]. With the development of DTI technology, it is now possible to perform axial DTI, which can provide more information regarding the relationship between tumours and white matter tracts. Amenability to quantitative analysis is another advantage of DTI. Regions of interest (ROI) can be placed at specific columns, and the apparent diffusion coefficient (ADC), fractional anisotropy (FA), axial diffusivity (AD), and radial diffusivity (RD) values can be obtained for quantitative analysis. To evaluate the DTI and DTT features of cervical spinal cord astrocytomas, patients with cervical spinal cord astrocytomas were recruited into our study and axial DTI was performed. To the best of our knowledge, this is the first systematic report of axial DTI for the study of cervical spinal cord astrocytomas.

2. Methods

2.1. Subjects

Eleven patients clinically diagnosed with cervical spinal cord astrocytomas were recruited into the study. The study was approved by our Institutional Review Board. All of the volunteers signed informed consent and approved the publishing of the data as a research paper. Inclusion criteria included clinical diagnosis with cervical astrocytoma based on clinical features, conventional MRI, gadolinium-enhanced MRI, and follow-up; normal cognition and agreement to undergo a complete MR scan; the absence of exogenous implants; no history of epilepsy; and no history of heart or lung disorders. Exclusion criteria included dyspnoea, claustrophobic syndrome, and serious motion artefacts. Neurological deficits were classified according to the McCormick Grade Score [17]. Ten healthy volunteers were recruited as controls.

2.2. MR data acquisition

MR examinations, including conventional MRI and research DTI protocol, were performed on a 3.0T MRI system (Philips Achieva 3.0T TX) equipped with a 16-channel neurovascular array at the Center for Biomedical Imaging Research (Tsinghua University, Beijing, China). The head of the patient was fixed to the table using padding and a strap. Patients were asked to keep still and avoid swallowing as much as possible during image acquisition. The imaging protocol began with the acquisition of a sagittal T2-weighted preview. The conventional MRI consisted of 1) a T1-weighted sagittal turbo spin-echo (TSE) sequence (repetition time [TR], 550 ms; echo time [TE], 6.3 ms; section thickness, 3 mm), 2) a T2-weighted sagittal TSE sequence (TR, 3034.2 ms; TE, 90 ms; section thickness, 3 mm), 3) an axial T2-weighted fast field echo (FFE) sequence (TR, 700 ms; TE, 22.6 ms; section thickness, 3 mm), and 4) a T1-weighted 3D (T1-weighted turbo field echo; TR, 9158.7 ms; TE, 80.3 ms; section thickness, 2 mm; voxel size, $0.99 \times 1.0 \times 2.00\ mm^3$). The images were obtained from the tentorium cerebelli to the T4 vertebral level.

For axial DTI, a single-shot echo planar imaging sequence was used with the following parameters: TR, 9158.7 ms; TE, 80.3 ms; matrix size, 112×112; field of view, $224 \times 224\ mm^2$; section thickness, 3 mm; and voxel size, $2.0 \times 2.0 \times 3.00\ mm^3$. Diffusion gradient encoding was performed in 32 directions with $b = 800\ s/mm^2$ and with an additional measurement without a diffusion gradient ($b = 0\ s/mm^2$). Two vertical saturation bands were used. One was positioned ventrally over the trachea to limit flow effects and motion due to swallowing. The other saturation band was set dorsally to suppress signals from non-spinal cord tissues that were close to the surface coils and produced high-intensity signals. Manual shimming was estimated within a parallel-epiped closely fitting the cervical spinal cord. The research DTI sequence duration was 11 min and 23 s.

2.3. MR data analysis

DTI data were transferred to a post-processing system (Philips Extended MR workspace 2.6.3.2) for analysis. Before performing the tensor estimation, a Philips correction procedure named Diffusion Registration was applied to the DTI dataset to correct distortions related to eddy currents induced by the large diffusion-sensitizing gradients. ADC, FA, AD, and RD values were measured at the lesions (within the mass and avoiding cysts) and the normal appearing tissue around tumours (NATAT) on T2WI. In addition to the 2D parametric FA colour-encoded maps, 3D white matter fibre tracts were created using the principal diffusion direction method, typically using an FA threshold value of 0.18, an angulation threshold of 27°, and a fibre length of 10 mm.

2.4. Regions of interest (ROI)

In the patients, the ADC and FA values were calculated on a voxel-by-voxel basis using the most accurate axial b0 image. ROIs were placed within the solid lesions and avoided cysts. ROIs at the lesions were 4–12 voxels depending on the sizes of the tumours, whereas ROIs at the NATAT on T2WI were 2–4 voxels. In healthy volunteers, 4 ROIs were placed at the lateral, dorsal, ventral funiculi, and the grey matter of the C2 vertebral level spinal cord. To avoid partial volume effects caused by the cerebrospinal fluid, all ROIs were placed in the spinal cord. λ_1, λ_2, and λ_3 were obtained at single voxel in the dorsal funiculi. RD and AD values were then calculated as follows: $AD = \lambda_1$ and $RD = (\lambda_2 + \lambda_3) / 2$.

2.5. Statistical analysis

Data were analysed using statistical software (SPSS version 20.0). Continuous data were reported as means ± standard deviations (SDs). The Kolmogorov-Smirnov test was used to evaluate whether the ages of the subjects in the two groups were consistent with a normal distribution. The Fisher exact probability test was used to test the sexual distribution between patients and controls. Independent *t*-tests were used for comparisons of ADC, FA, AD, and RD values. Linear regression was used to test for correlations between FA and ADC values. P values < 0.05 were considered significant.

3. Results

3.1. Epidemiology and clinical data

Eleven patients (male:female ratio, 7:4) clinically diagnosed with cervical spinal cord astrocytomas were recruited (Table 1). The patients were aged 32.9 ± 11.0 years. Ten healthy volunteers (male:female ratio, 5:5) were recruited as controls. The controls were aged 27.4 ± 4.2 years. The ages and sexual distribution of the two groups were similar ($P = 0.17$ and 0.67, respectively). Conventional MRI showed that 8 patients had solid mass tumours, 2 patients had cystic degeneration in the lesions, and 1 patient had a cyst around the mass. Gadolinium-enhanced MRI showed a slight enhancement of the tumours in patients with solid mass tumours and cystic degeneration in the lesions, with an obvious enhancement of the mass in the patient with a cyst around the mass. Ten patients were clinically diagnosed with astrocytoma, the patient (number 3) with a cyst around the mass was clinically diagnosed with ependymoma before the surgery. This patients had an astrocytoma WHO II confirmed by a post-surgery pathological study. Two patients (numbers 1 and 2) with solid tumours underwent surgery. During the operation, no clear boundary was determined and astrocytoma WHO II was confirmed by a post-surgery pathological test. Five of the 8 patients with solid mass tumours accepted tentative high dose