Discriminating Brain Tumor Recurrence from Radiation-Induced Injury Using Diffusion Tensor Imaging

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Background and Purpose: Radiotherapy is a paramount therapeutic adjunct for patients with brain tumor. After radiation treatment, a considerable number of patients develop new lesions at or near the original tumor site. These lesions can be treatment–induced damage, tumor recurrence, or progressive tumor growth. The radiological differentiation of treatment effects from recurrent tumor is very difficult. Diffusion-weighted imaging (DWI) has been reported to be helpful in this regard by measuring differences in apparent diffusion coefficient (ADC) of enhancing lesions (1, 2). Our study was designed to explore the ability of diffusion tensor imaging(DTI) in assessing radiation-induced brain injury and brain tumor recurrence by measuring edema, the T2 signal intensity abnormality surrounding the lesions and areas adjacent to the edema that were negative on T2WI.

Methods: 16 patients were reviewed (8 males, 8 females, 7-53 years old, mean age 34 years) who developed new contrast-enhancing lesions with obvious edema 3-108 months after radiation treatment of the original tumor. Histological diagnoses of the original tumors in these 16 patients were astrocytic tumor (14 patients, 12/14 cases with high grade tumors, 2 patients with II grade), anaplastic ependymoma (1 patient) and medulloblastoma (PNET, 1 patient). The final differentiation between tumor recurrence and radiation injury of the new lesions found after radiotherapy was decided based on either histological findings or follow-up MR examinations and clinical conditions. In the patients who did not undergo surgical intervention, their lesions were considered to be radiation injury related if the enhanced lesions disappeared or decreased in subsequent MR examinations. Tumor recurrence was entitled if the enhancing lesions increased extensively on follow-up serial MR examinations, and the patients' clinical conditions deteriorated progressively during that period. Based on these criteria the group of recurrent tumor included 7 patients and the group of radiation-induced injury had 9 patients.

DTI was obtained using a single shot spin-echo echo planar imaging (EPI) technique along nine different directions with a b value of 0 and 1000 s/mm^2. The ADC and FA maps were calculated on a separate workstation. Initially, images were preprocessed to remove image distortion that arose from the EPI using MIAMI FUSE. Then the resulting images were entered into a tensor diagonalization written in MATLAB (The Mathworks, Natick MA). The region of interest (ROI) was placed according to contrast-enhancing T1WI and T2WI (using the imaging from DTI when b value is zero which is similar to T2WI), and then applied to ADC and FA maps to extract regional ADC and FA values. In each case 10 or 11 systematically-drawn ROIs of equal size (20 mm$^{2)}$ were defined on the following areas: edema including tract and non-tract white matter, T2WI-negtive white matter tracts adjacent to the edema and contralateral corresponding regions used as internal control. Mean ADC values and ADC ratios (ADC values in the lesions to ADC values of corresponding areas on the contralateral side), FA values and FA ratios (FA values in lesions to FA values of corresponding areas on contralateral side) were compared between the radiation injury versus tumor recurrence groups.

Results: The ADC ratios of edema in the recurrence group (mean ±SD, 1.48 ±0.27) showed significantly lower values (p <0.0001) than those of the radiation injury group (1.77±0.34). The ADC values of edema in the recurrence group (1.36±0.23×10^{-3}mm^2/s) and those of radiation injury group (1.32±0.21×10^{-3}mm^2/s) did not have significant difference (p=0.41). The ADC values of T2WI-negative white matter tract areas adjacent to the edema were normal in two groups compared with the internal controls. Although the FA values of tract and non-tract white matter of edema in two groups were both reduced compared with the internal control, the FA values and ratios did not show significant difference between the two groups. For T2WI-negative white matter tracts adjacent to the edema, the FA values were significantly lower in the recurrence group compared to the values found in the radiation injury group (0.23 ±0.04, 0.34±0.03, respectively, p =0.017). The FA ratios were also significantly lower in the recurrence group compared to the values found in the radiation injury group (0.72 ±0.14, 0.92±0.13, respectively p=0.0001).

Representative images from a tumor recurrence case and a radiation injury case were illustrated in Fig1-2, respectively.

Discussion: The ADC ratios in the edema in patients with radiation injury were higher than in those with tumor recurrence, but their FA values or ratios demonstrated no statistically significant difference. The higher ADC ratios in radiation-induced injury may be due to more increased water content in the edema areas. Note, our earlier study of ADC values within the newly enhancing lesion showed lower ADC in the radiation necrosis group compared to recurrent tumor group (3) consistent with examples in Figs 1 and 2.The FA changes within the edema surrounding recurrent tumor could be attributed not only to increased water content, but also the tumor infiltration(4). Abnormal FA values in the white matter tract with normal appearance on T2WI in patients with recurrent tumors may indicate that the DTI could be helpful in detecting occult white matter tract invasion(5) and FA measurement may be more sensitive than ADC.

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References:

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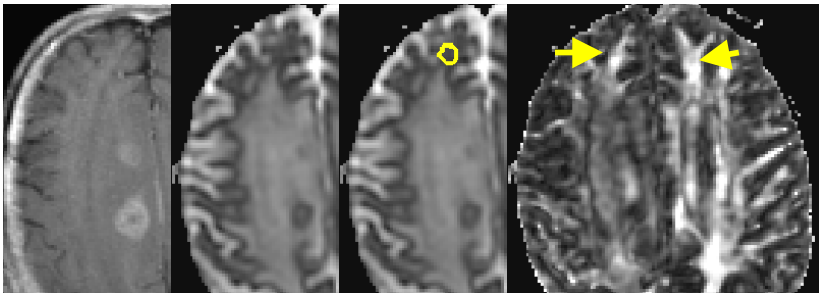

Fig1: radiation injury. From left to right: T1 post-contrast, ADC map, ADC map with ROI of the area adjacent to edema (circle) and FA map. The FA value of the ROI shown on the ADC map did not show hypointensity compared with contralateral side (arrows). The FA ratio in the ROI was 1.13. The averaged ADC ratio of edema was 1.68.

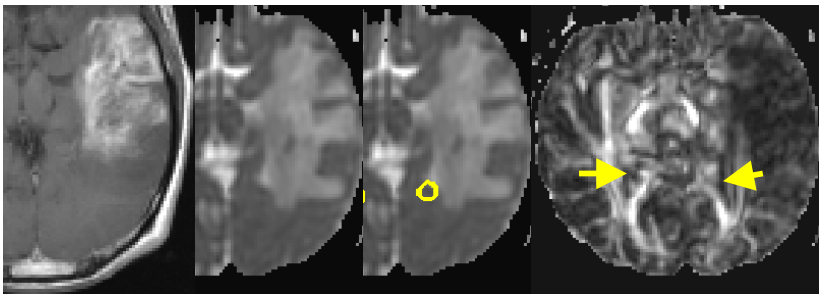

Fig2: tumor recurrence. From left to right: T1 post-contrast, ADC map, ADC map with ROI of the area adjacent to edema (circle) and FA map The FA value of the ROI shown on the ADC map showed hypointensity compared with contralateral side(arrows).The FA ratio in the ROI was 0.67. The averaged ADC ratio of edema was 1.48.