A DTI Study of Glioma Infiltration Using Fractional Anisotropy and Fiber Coherence Index

X. J. Zhou[1,2], S. Yang[2,3], G. Srinivasan[2,4], H. H. Engelhard[5], and J. L. Villano[6]

[1]Departments of Neurosurgery, Radiology, and Bioengineering, Univ. of Illinois Medical Center, Chicago, IL, United States, [2]Center for MR Research, Univ. of Illinois Medical Center, Chicago, IL, United States, [3]Department of Radiology, Tongji Hospital, Shanghai, China, People's Republic of, [4]Department of Bioengineering, University of Illinois at Chicago, Chicago, IL, United States, [5]Department of Neurosurgery, Univ. of Illinois Medical Center, Chicago, IL, United States, [6]Department of Medicine, Univ. of Illinois Medical Center, Chicago, IL, United States

INTRODUCTION

Malignant glioma is one of the most lethal tumors that strikes adults in their prime. When a brain tumor is clinically suspected, MRI is the preferred radiological method to detect and characterize the disease [1]. The extent of tumor infiltration, however, does not typically correlate with the abnormality revealed by existing imaging techniques. The inability to define the extent of tumor infiltration has greatly limited our ability to design optimal radiation fields for radiation treatments, as well as to determine the extent of surgical resection.

It has been reported that glioma infiltration occurs preferentially along the white-matter fiber tracts [2]. With tumor invasion, the organized structure of a fiber tract can lose structural integrity, leading to changes in the diffusion properties of water molecules. Several DTI studies have focused on assessing tumor cell infiltration by measuring changes in scalar diffusion parameters, such as mean diffusivity, fractional anisotropy (FA), and their derivatives [3-5]. For high-grade gliomas where vasogenic edema is almost always present, these parameters offer rather poor specificity. A recent study indicated that the specificity may be improved by using an alternative parameter, called regional fiber coherence index (rFCI) [6]. However, limited evidence was provided based on a very small number (n=4) of patients. In this study, we have enrolled a total of 14 patients with either low-grade or high-grade gliomas and investigated the potential of using rFCI and FA for assessing tumor infiltration along the fiber tracts.

METHODS

Participants of the study included 14 adult patients with newly diagnosed glioblastoma multiforme (GBM; n=7; age range: 44-75 year old; mean age: 55 year old; female/male: 2/5) or low-grade gliomas (WHO grades I and II; n=7; age range: 19-56 year old; mean age: 40 year old; female/male: 5/2). All patients underwent clinically-indicated MRI scans performed on a 3.0 Tesla GE Signa HD scanner (General Electric Health Care Technologies, Waukesha, Wisconsin) with an eight-channel head coil. The MRI protocol included pre-contrast T1-weighted, T2-weighted, fluid-attenuated inversion recovery (FLAIR), and DTI axial imaging, and post-contrast T1-weighted 3D gradient echo imaging. The diffusion-weighted images of the DTI scan were acquired using a customized single-shot EPI pulse sequence with the following key data acquisition parameters: TR = 5225ms, TE = 85.7ms, FOV = 20cm, slice thickness = 5mm, slice gap = 0, number of slices = 20 , k-space matrix = 132×132, imaging matrix = 256×256, number of diffusion gradient directions = 27, b = 0, and 1000 s/mm^2, number of averages = 2, and the total data acquisition time = 5.03 min.

The set of diffusion-weighted images was transferred to a PC and processed using customized software (Diffusion Imaging Visualization Environment, or DIVE) developed using IDL (ITT Visual Information Solutions, Boulder, Colorado). For each patient in the high-grade glioma group, regions of interest (ROIs) were drawn by a radiologist in the fiber tracts suspected of tumor infiltration within 2-3 cm zone outside the gadolinium enhancement in the post-contrast T1-wighted images. This zone typically contained vasogenic edema. For the patients in the low-grade glioma group, ROIs were selected from the suspected fiber tracts at the edge of hyper-signal intensity area in the FLAIR images. For both groups, ROI selection was guided by the color-coded FA maps to avoid regions with crossing or branching fibers (Fig. 1). Additionally, we focused only on the relatively large fibers (>7mm) to reduce the adverse partial volume effect. At each ROI, FA and rFCI were computed, and the results were compared with the corresponding fiber tracts on the contralateral side, which served as controls.

RESULTS

Representative images for the high-grade and low-grade groups are shown in Fig. 1. For the high-grade group, a total of 53 ROI pairs (tumor side and contra-lateral side) were analyzed, and the results are summarized in Fig. 2a. Significant reduction in FA ($p < 0.0001$) was observed in the fiber tracts on the tumor side as compared to the controls. The ROIs with reduced FA exhibited significantly different rFCI values ranging from 0.74 to 0.99. For the low-grade group (totally 40 ROI pairs), the change in FA ($p < 0.0001$) was similar to what was observed in the high-grade group. The rFCI, however, showed little variation among the fibers on the tumor side (Fig. 2b).

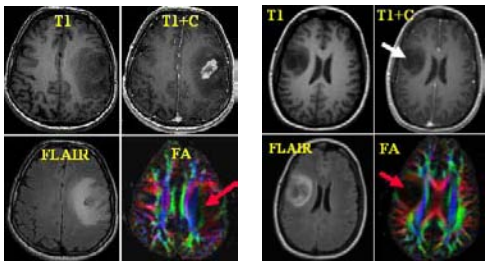

Fig. 1 Images of patients with high-grade (left) and low-grade (right) gliomas.

DISCUSSION AND CONCLUSIONS

The large variation among the rFCI values shown in Fig. 2a suggests that some ROIs may predominantly contain vasogenic edema which gives higher rFCI, while others may be largely infiltrated by tumor cells which produce a lower rFCI. Although a threshold value for rFCI is yet to be determined, these results, which are consistent with the observations reported in a previous study [6], indicate that rFCI can potentially improve specificity in separating fibers predominantly infiltrated with tumor cells from those largely affected by edema. The lack of the divergence in rFCI observed in Fig. 2b suggests that the fiber tracts may not contain significant tumor infiltration, even though FA values are reduced.

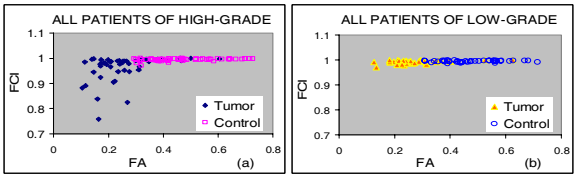

Fig. 2 Scatter plots of FA vs. rFCI for patients with high-grade (a) and low-grade (b) gliomas.

Although tissue biopsy is needed to serve as a gold standard to confirm the observations and further validate the hypothesis, the results in this study provide additional evidence suggesting that rFCI may be more specific to tumor infiltration than FA. With further validation, the improved specificity of rFCI, combined with the sensitivity of FA, may provide us with a new technique to track tumor infiltration in gliomas.

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