Relationship analysis of axial and radial diffusivities may be helpful in discriminating tumor-infiltrating edema from pure vasogenic edema

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Target audience
Neuroradiologists, Neurosurgeons

Purpose
Diffusion tensor imaging(DTI) might be useful in distinguishing pure vasogenic edema and edema with tumor infiltration. However, results of current studies were conflicting. The changes induced by tumor infiltration may be covered by severe increase of extracellular volume of edema. Commonly used metrics, such as mean diffusivity(MD) and fractional anisotropy(FA), are non-specific in characterizing the two pathological changes. During the maturation of white matter, the reduction of diffusivities parallel to the white matter axons, the major eigenvalue, $\lambda_{/\!/}$, is inconsistent with the two minor eigenvalues(1). This gives us an inspiration that analysis of the relationships between $\lambda_{/\!/}$ and $\lambda_{\perp}$ in edema may help to reveal the integrity of myelin and characterize the two types of edema. This study compared the relationships of $\lambda_{/\!/}$ and $\lambda_{\perp}$ in pure vasogenic edema and edema with tumor infiltration.
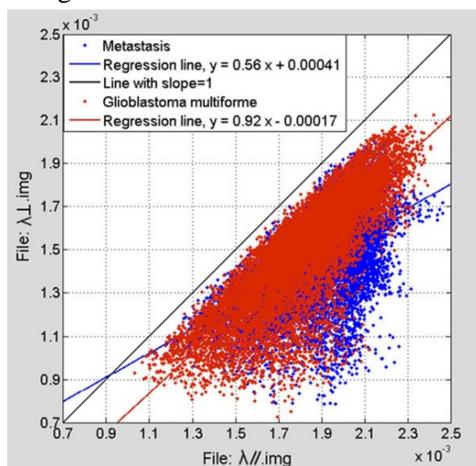

Fig.1: Scatterplot of $\lambda_{/\!/}$ and $\lambda_{\perp}$ of peritumoral edema. Each point represents one pixel in edema. Red points are generated from edema outside of a glioblastoma multiforme, blue points generated from edema outside of a metastatic tumor. Regression coefficients of red points is 0.92, and higher than 0.56 of blue points.
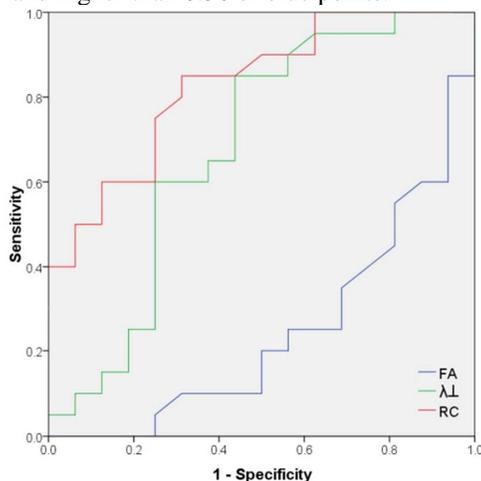
Methods
Thirty-six patients with solitary brain tumor(8 meningiomas, 8 metastasis and 20 malignant gliomas) accompanied with peritumoral edema were enrolled in this study. DTI were acquired with a 3-Tesla MR imaging system (Signa HDXT; General Electric Medical Systems, Waukesha, WI), and the following parameters were used: TR and TE were 8000 ms and 86 ms, respectively; thirty directions; b values 0/1000 s/mm^2 were employed; the in-plane resolution was 128×128 and interpolated to an image matrix of 256×256; slice thickness was 5mm with no gaps. Raw data were processed with DtiStudio software (version 2.4, Johns Hopkins University, Baltimore, MD, USA) and maps of principal eigenvalues ($\lambda 1$, $\lambda 2$ and $\lambda 3$), FA and MD were available. ROIs were drawn to contain areas of high T2 signal intensity outside of tumor core in every plane. We employed MATLAB 2007 (Math Works Inc., Natick, MA, USA) to generate scatter plots of $\lambda_{/\!/}$($\lambda_{/\!/}$=$\lambda 1$)and $\lambda_{\perp}$($\lambda_{\perp}$=($\lambda 2$+ $\lambda 3$)/2) of each voxel in edema. Linear regression coefficients of $\lambda_{/\!/}$ to $\lambda_{\perp}$(RC$_{\lambda_{/\!/}-\lambda_{\perp}}$) were recorded. We also compared the metrics of the pure vasogenic edema group(metastasis and meningiomas) and tumor-infiltrated edema group(malignant gliomas) with t-test for independent samples. Receiver operating characteristic(ROC) curve analysis was conducted to demonstrate the differential accuracy of these parameters. P-values less than 0.05 are considered statistically significant.

Results
The increase of $\lambda_{\perp}$ along with $\lambda_{/\!/}$ in tumor-infiltrated edema was faster than pure vasogenic edema(Figure 1). Regression coefficients in tumor-infiltrated edema(0.724±0.125) were significantly higher than that of pure vasogenic edema(0.571±0.111), P value=0.001. Other metrics except for FA and $\lambda_{\perp}$ showed no significantly different between two groups. ROC curve analysis showed the curve using RC$_{\lambda_{/\!/}-\lambda_{\perp}}$ had the maximum area under curve(0.828)(Figure 2).

Discussion
Due to the damage of axons and myelin, tumor-infiltrating edema has greater radial diffusivities than pure vasogenic edema. But the direct comparisons of $\lambda_{\perp}$ will be influenced by the degree of edema and can not reveal the diffusion characteristics induced by damaged axons and myelin. FA is a nonspecific metrics and affected by edema, too. RC$_{\lambda_{/\!/}-\lambda_{\perp}}$ showed more effective than other metrics in discriminating tumor-infiltrated edema from pure vasogenic edema. This may be because the relative changes of the two diffusivities was less influenced by edema. The faster changes of $\lambda_{\perp}$ to $\lambda_{/\!/}$ in tumor-infiltrating edema may reflect the destruction of neurofiber structures.

Conclusion
Relationship analysis of $\lambda_{/\!/}$ and $\lambda_{\perp}$ may be helpful in discriminating tumor-infiltrating edema from pure vasogenic edema.

Fig. 2: ROC curves showed areas under the curve were 0.244 for FA, 0.680 for $\lambda_{\perp}$, 0.828 for RC$_{\lambda_{/\!/}-\lambda_{\perp}}$.

References
1 Mukherjee P, Miller JH, Shimony JS, et al. AJNR Am J Neuroradiol. 2002 Oct;23(9):1445-56.