Diffusion Tensor Shape and Tertiary Eigenvector Encoded Colormaps Reveal Features in Human Brain Tumor

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INTRODUCTION

In Diffusion Tensor Imaging (DTI), the Diffusion Tensor (DT) summarizes diffusivities measured along 6 or more directions as three eigenvalue-eigenvector pairs, and a widely used visualization method is the fractional anisotropy (FA) weighted principal eigenvector direction encoded colormap ($\mathbf{v}_1$FA). DTI has mainly been used to assess brain white matter fibers, but the potential to assess micro-structures at the tumor cell level is unexplored. Zhang et al. [1] recently demonstrated that organized directional diffusion of water molecules within rat tumor models using $\mathbf{v}_1$FA colormaps. However, similar results in human DTI studies, using $\mathbf{v}_1$FA maps have not been reported. In this preliminary work, we examine DTI data of *in vivo* human brain tumors using additional visualization methods to supplement $\mathbf{v}_1$FA colormaps.

METHODS

Pulse Sequence: A patient (F 58yrs) with meningioma provided signed statement of informed consent, and underwent diffusion-weighted imaging (TR/TE 3609/60ms; FOV 117mm × 230mm × 230 mm, matrix 256 × 256, resolution 3mm × 0.9mm 0.9mm; SENSE factor 2.7; b values 0 and 800s/mm^2, 15 non-collinear directions) on a Philips Intera 3T MRI system. *Image Processing:* DWI images were processed by DTI Studio (version 2.4) to derive eigenvalues and eigenvectors. These were further processed by in-house software, where shape indices $cl=\lambda_1/(\lambda_1+\lambda_2+\lambda_3)$, $cp=2(\lambda_1-\lambda_2)/(\lambda_1+\lambda_2+\lambda_3)$ and $cs=3\lambda_3/(\lambda_1+\lambda_2+\lambda_3)$, and tensor invariants [2], tensor norm ($TN=\sqrt{(\lambda_1^2+\lambda_2^2+\lambda_3^2)}$), FA, and tensor mode ($TM=\sqrt{2}\,\mu_2^{(-3/2)}\mu_3$), where μ_n is the nth central moment of the eigenvalues, were derived. *Visualization: (1)* DT shape indices color encoded and principal eigenvalue (λ_1) weighted (clcpcsλ_1) colormaps [3] where the red-green-blue (RGB) values are $cl\cdot\lambda_1/RGB_{ub}$, $cp\cdot\lambda_1/RGB_{ub}$ and $cs\cdot\lambda_1/RGB_{ub}$ respectively, and the arbitrary upperbound RGB_{ub} = 0.001 mm^2/s. *(2)* DT invariants Hue-saturation-value (HSV) coded (TNFATM) colormaps [3], where hue (H) ranges from red to green to blue corresponds to TM from -1 (planar, $\lambda_1=\lambda_2>>\lambda_3$), to 0 (orthotropic, $\lambda_1-\lambda_2=\lambda_2-\lambda_3$), to 1 (linear, $\lambda_1>>\lambda_2=\lambda_3$), saturation (S) reflects $FA/FA_{max}(TM)$, and value (V) (or brightness) reflects $V_{min}+(1-V_{min})(TN/TN_{ub})$, where $FA_{max}(TM)$ is the maximum possible FA for value TM, minimum brightness V_{min}=0.5, and the arbitrary upper bound for TN, TN_{ub}=upper quartile of TN. *(3)* Planar shape index weighted tertiary eigenvector direction encoded colormap ($\mathbf{v}_3$cp) [4].

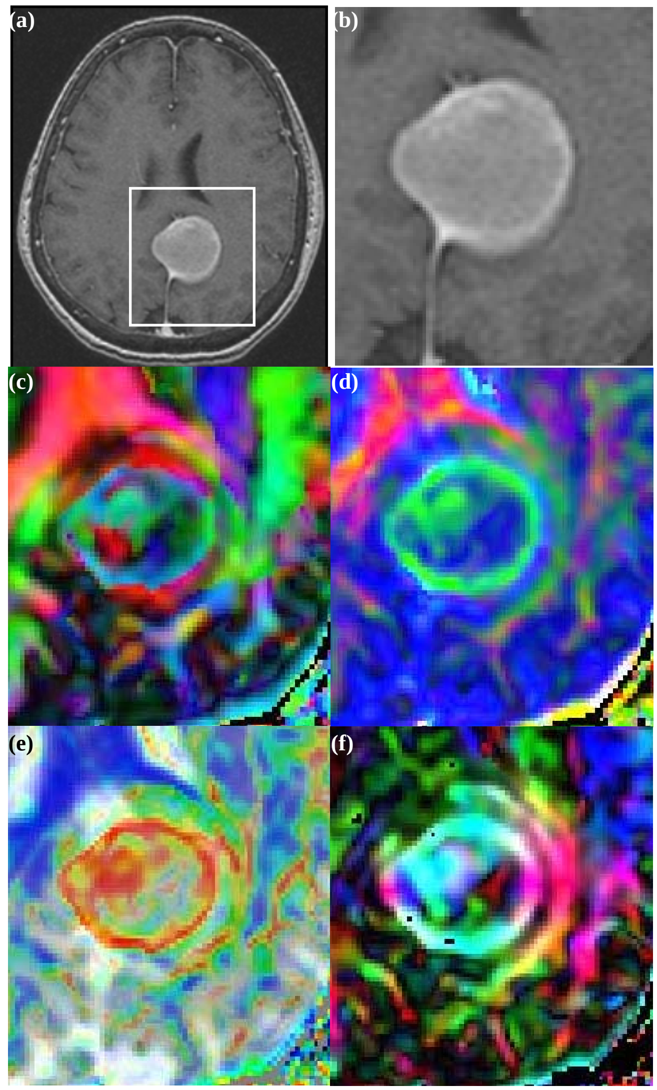

Fig. 1 (a,b) T1 image, (c) $\mathbf{v}_1$FA, (d) clcpcsλ_1, (e) TNFATM, and (f) $\mathbf{v}_3$cp colormaps.

RESULTS

Fig. 1 shows images of the meningioma at a level below the largest diameter of the tumor. The region specified by white rectangles in Fig. 1(a) is shown in Fig. 1(b-f). The clcpcsλ_1 and TNFATM colormaps demonstrate high diffusivity regions as strong blue and white, and linear DT regions as strong red and blue, respectively. Direction encoding in the $\mathbf{v}_3$cp colormap is the same as $\mathbf{v}_1$FA but it shows the direction normal to planar tensors (high cp). A rim feature is not obvious by looking at the $\mathbf{v}_1$FA colormap Fig 1 (c), while clcpcsλ_1 Fig 1 (d), and TNFATM Fig 1 (e), colormaps reveal a rim of planar tensors at the boundary of the tumor. In the $\mathbf{v}_3$cp Fig 1 (f), colormap, *cyan* (a combination of blue and green) colored anterior and posterior parts of the rim suggests planar tensors with normals pointing upward and towards either anterior or posterior directions. In the same image, *magenta* (a combination of blue and red) colored left and right parts of the rim suggests planar tensors with normals pointing upward and towards either left or right directions.

DICUSSION AND CONCLUSIONS

DTI contains much information beyond FA and $\mathbf{v}_1$FA colormap that has not been well exploited to study tumor microstructure. Zhang et al [1], using $\mathbf{v}_1$FA colormap detected patterns of diffusion directionality in tumors. We found the clcpcsλ_1 and TNFATM colormaps can potentially allow the identification of planar tensors that are not differentiable from linear tensors in $\mathbf{v}_1$FA colormap. In planar tensors, it may be appropriate to extract information contained within the tertiary eigenvector (Zhang et al. [4]). Here, the $\mathbf{v}_3$cp colormap at a level below the largest diameter of the tumor suggests the tertiary vector is pointing towards the center of the tumor although there are two possible directions represented by each of the colors cyan and magenta. Further experiments would be needed to assess the unexplored potential of information contained within the DTI, beyond $\mathbf{v}_1$FA colormaps.

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