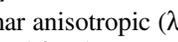# Application of Novel Directionally Encoded Colormaps for Isolating Linear Anisotropic Structures in Human Brain Diffusion Tensor Magnetic Resonance Imaging

D. B. Ennis[1], G. Kindlmann[2], M. Mogensen[1], T. Vertinksy[1], S. W. Atlas[1], R. Bammer[1]

[1]Department of Radiology, Stanford University, Palo Alto, CA, United States, [2]Laboratory of Mathematics in Imaging, Harvard University School of Medicine, Boston, MA, United States

INTRODUCTION. Diffusion tensor magnetic resonance imaging (DTMRI) is increasingly used to assess the white matter integrity of patients with a variety of pathologies. T_2 images are often combined with trace and fractional anisotropy (FA) maps in the complete assessment of brain pathology. While trace and FA maps indicate the mean bulk diffusivity (magnitude of isotropy) and the level of structural organization (magnitude of anisotropy) neither map indicates the kind of underlying anisotropy. A recent report outlined an orthogonal decomposition of tensor information (tensor invariants) into the magnitude of isotropy, magnitude of anisotropy, and the mode of anisotropy [1,2]. The mode of anisotropy characterizes the kind of anisotropy as it ranges from linear anisotropic ($\lambda_1 >> \lambda_2 \cong \lambda_3$) to orthotropic to planar anisotropic ($\lambda_1 \cong \lambda_2 >> \lambda_3$) as shown here: -1 ●●●●●●◖◗⧸⧸⧸⧸ +1. Tensor mode (TM), however, has not been used for the assessment of white matter integrity in pathological conditions. TM can be incorporated into novel directionally encoded colormaps (DEC) that highlight the orientation of linearly anisotropic structures. Without the use of TM, standard DECs highlight structures that include planar anisotropy, in which the primary eigenvector direction is only known within a plane of rotation. A comparative evaluation of DECs that incorporate TM is demonstrated.

METHODS. *Pulse Sequence*: DTMRI images were acquired on a GE 1.5T scanner as part of a routine clinical exam. All patients provided signed statements of informed consent. Data were acquired in 2 patients undergoing clinical examination subsequent to presenting with glioblastoma multiforme (GBM). A diffusion weighted, slice-interleaved, spin echo-planar imaging sequence was used to acquire images. The scan parameters were: field of view 24cm, TE/TR=74/5300ms, 128x128 encoding matrix, slice thickness of 3mm, *b*-value=1000s/mm^2, 23 encoding directions + 1 reference (*b*=0). *Image Processing*: DWI images were first corrected for image distortions introduced from eddy currents using in a mutual-information based registration technique [3]. Tensor data (**D**) were generated from linear regression of the logarithm of the DWI. The following tensor invariant maps were calculated from the tensor data: $\text{tr}(\mathbf{D})$, $\text{FA}(\mathbf{D})$, $\text{mode}(\mathbf{D}) = 3\sqrt{6}\det(\tilde{\mathbf{D}}/\text{norm}(\tilde{\mathbf{D}}))$, where $\tilde{\mathbf{D}}$ is the deviatoric component of the tensor, $\tilde{\mathbf{D}} = \mathbf{D} - (1/3)\text{tr}(\mathbf{D})$. TM is defined on the interval [-1,+1] where -1 indicates planar anisotropy and +1 indicates linear anisotropy. DECs that incorporate mode (DECM) are generated by encoding the components of the primary eigenvector into the red, green, and blue channels of a color image, then devaluating the color intensity by the product of FA and mode. The effect is to lower the brightness of planar anisotropic structures and to highlight features that are highly linear anisotropic. All colormaps are equally window-leveled.

RESULTS. Figures 1 and 2 demonstrates a T_2 image, a DEC, and a DECM. The patient in Fig. 1 presented with neoplastic infiltration and edema in the area of a previously resected GBM. Figure 1B indicates that the posterior part of the external capsule is a continuous fiber track, but Figure 1C indicates that this path is likely disrupted (white arrow). The patient in Fig. 2 presented with GBM and surrounding vasogenic edema. The tissue surrounding the external capsule in Figure 2B appears as a large fibrous mass, but the DECM (Fig. 2C) clearly delineates a smaller band of linear anisotropic structure. We believe that such a map may provide important insight to surgeons during tumor resection treatment.
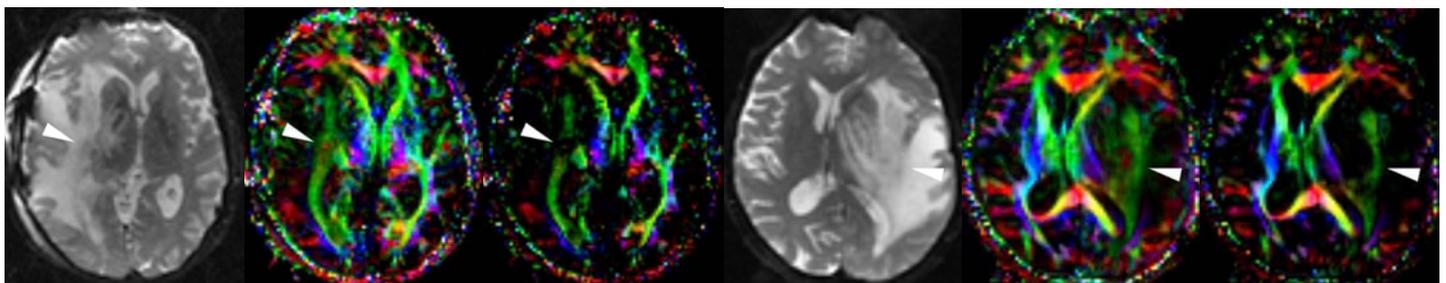

Fig. 1A. T_2 image   **1B.** DEC image   **1C.** DECM image   **Fig. 2A.** T_2 image   **2B.** DEC image   **2C.** DECM image

CONCLUSIONS. Directionally encoded colormaps that incorporate TM highlight regions of high linear anisotropy. This technique's utility lies in reducing the intensity of confounding areas of planar anisotropy. In many brain abnormalities one frequently observes a reduction of FA that accompanies tissue disruption and the associated increase in the unrestricted diffusion of protons. However, in situations when WM alterations maintain high diffusion anisotropy, such as seen in GBM, the DECMs provide additional value (with comparison to the FA-modulated DECs). Specifically, the use of DECMs for investigating the effect of the tumor by distinguishing between tracts which retain high linear anisotropy within the tumor, versus those that were reduced to predominantly planar anisotropy, appears to be of great advantage. Fiber tracking in the normal human brain is challenging, but may be improved through the incorporation of TM as a confidence measure of the primary eigenvector direction. The challenge of identifying fibrous tracks and their interruption is improved through the incorporation of tensor mode. DECMs in patients with GBMs demonstrate the ability to more clearly visualize existing fiber tracks and disrupted fiber tracks within tumors.

REFERENCES.
[1] Ennis & Kindlmann, *ISMRM Conf.* 2005. [2] Ennis & Kindlmann, *MRM*, 2005 {In Press}. [3] Bammer, *ISMRM Conf.* 2001.