Intravoxal V1-IP: An Improved White Matter Index Compared to Diffusion Anisotropy

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Introduction Diffusion Tensor Imaging (DTI) measures water diffusion dynamics while precisely unveil the underlying cellular structures and neurological pathologies (1). Among the indices derived from DTI, the value of diffusion anisotropy has commonly been used to define the regions of white matter. However, there are some drawbacks of using diffusion anisotropy as a white matter index. 1) Diffusion anisotropy is sensitive to noise (2). Noise leads to over-estimated diffusion anisotropy in gray matter, which reduces the specificity of diffusion anisotropy in characterizing white matter. 2) Disease can usually lead to a decrease of diffusion anisotropy, which reduces the sensitivity of diffusion anisotropy to differentiate white matter from gray matter. 3) There is no definitive mathematical definition of "diffusion anisotropy". There have been more than six equations proposed to quantify diffusion anisotropy in the past decade (3 – 5).

White matter also exhibits a strong diffusion orientation, major eigenvector of diffusion tensor, V1, as compared to gray matter and ventricles. V1 has been widely used to reconstruct neuronal tractography in 3-dimensional space (1, 6). However, V1 is not an objective index. V1 is a vector, which changes with scanning coordinates. In this study, we proposed to use V1 to derive an objective scalar index, the intra-voxel V1 inner product (intra-voxel V1-IP, Eq. [1]), to serve as an imaging marker for white matter. Since the inner product calculation tends to cancel the randomly V1 directions from noise, we expect intra-voxel V1-IP to present better noise tolerance than diffusion anisotropy. V1 is also not sensitive to axonal and/or myelin damage, so we expect that intra-voxel V1-IP can preserve its sensitivity in differentiating white matter from gray matter with disease process. We compared the performance of intra-voxel V1-IP and relative anisotropy (RA) and their ratios between white matter and gray matter at various noise levels. We also evaluated if white matter damage (optic nerve degeneration resulting from retinal ischemia) changes sensitivity of intra-voxel V1-IP and RA in identifying white matter tracts.

Theory Two DTI data sets were repeatedly acquired with identical imaging parameters from the same imaging slices. V1 of each DTI, marked as *v1*(x,y) and *v1'*(x,y) respectively, was derived, where (x,y) represents the voxel coordinate. The intra-voxel V1-IP was calculated as Eq. 1.

$$\text{intra-voxel V1-IP}\ (x,y) = v1(x,y) \cdot v1'(x,y) \qquad \text{[Eq. 1]}$$

Materials and Methods

Five 8-week-old female C57BL/6 mice were used. Transient retinal ischemia was induced in the right eye to cause axonal damage in the right optic nerve. At three days after ischemia, mice were perfused with formalin. DTI was acquired on a Bruker 11.7T with TR 2.5 s, TE 29 ms, Δ 20 ms, δ 3 ms, NEX 1, 2, 4, and 8, slice thickness 0.6 mm, FOV 2 cm, data matrix 128×128 (zero filled to 256×256), 6-encoding directions with b-values of 0 and 1 ms/μm^2. Axial diffusivity, radial diffusivity, major eigenvector (V1), and relative anisotropy (RA) were quantified. Intra-voxel V1-IP and RA were measured from gray matter (cortex), normal white matter (left optic nerve), and injured white matter (right optic nerve).

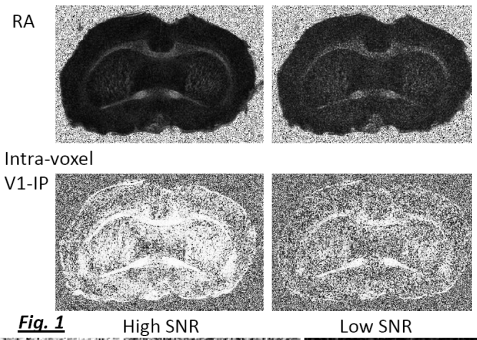

Fig. 1

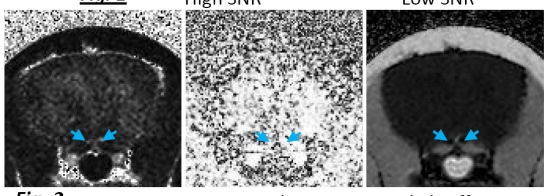

Fig. 2

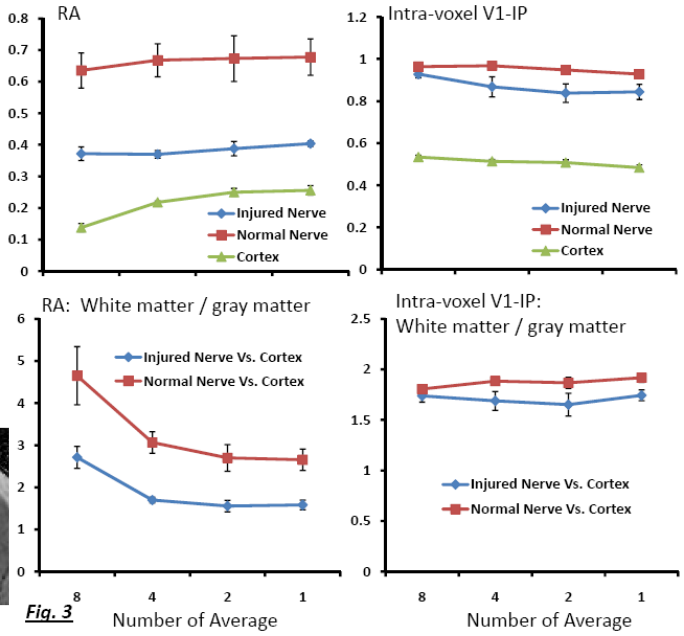

Fig. 3

Results Both RA and intra-voxel V1-IP showed clear images to identify white matter tracts (Fig. 1). When signal-to-noise ratio (SNR) decreased, noise led to increased RA in gray matter, which significantly reduced the ratio of RA between white matter and gray matter (Fig. 1 and 3). In contrast, the ratio of intra-voxel V1-IP between white and gray matter remained unchanged along with various SNRs. Comparing normal optic nerves and injured nerves after retinal ischemia (arrows in Fig. 2), RA was significantly reduced 50% in injured nerves (Fig. 3), while intra-voxel V1-IP was equivalent between injured and normal nerves. Intra-voxel V1-IP can tolerate noise and disease progress better than RA for differentiating white matter tracts from gray matter.

Discussions and Conclusions In this study, we converted V1 to an objective DTI index, the intra-voxel V1-IP, to serve as an objective DTI index to differentiate white matter from gray matter. It has been reported that RA changes with background noise and neurological diseases (1, 2). In contrast, we demonstrated that the proposed intra-voxel V1-IP preserves the ratio between gray and white matter with different noise levels as well as under pathological conditions. Thus, intra-voxel V1-IP is better than RA to for its insensitive to noise and neural diseases in differentiating white matter from gray matter and ventricles.

References (1) Mori et al, Neuron 2006: 51(5): 527-539 (2) Sun et al., Magn Reson Med 2001: 46: 1088-1096
(3) Basser et al., JMR B 1996: 111(3): 209-219 (4) Basser et al., NMR Biomed. 1995 Nov-Dec;8(7-8):333-44.
(5) Pierpaoli et al., MRM 1996 Dec;36(6):893-906 (6) Jones et al., IEEE Trans Med Imaging 2008 Sep;27(9):1268-74

Acknowledgement: *NMSS: RG 3864.*