Accelerated Mouse Spinal Cord Diffusion Measurements with SNR-Enhancing Joint Reconstruction

J. P. HALDAR[1], J. H. KIM[2], S-K. SONG[2], AND Z-P. LIANG[1]
[1]ELECTRICAL AND COMPUTER ENGINEERING, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN, URBANA, IL, UNITED STATES, [2]RADIOLOGY, WASHINGTON UNIVERSITY IN ST. LOUIS, ST. LOUIS, MO, UNITED STATES

INTRODUCTION

Parameters measured in diffusion-weighted MRI (DW-MRI) have the ability to reflect the microstructural characteristics of biological tissues, and recent work has shown that DW-MRI enables quantitative assessment of injury in mouse models of various spinal cord white-matter pathologies [1, 2]. However, despite the potential of DW-MRI for diagnosis and treatment monitoring, a major limitation of the approach is the time consuming nature of quantitative DW-MRI experiments. These experiments frequently span multiple hours for *in vivo* studies of the mouse spinal cord, with much of this time spent on signal averaging to achieve sufficient signal-to-noise ratio (SNR) for the accurate quantification of tissue diffusion characteristics. In this work, we demonstrate that the application of an SNR-enhancing reconstruction method [3] can enable at least a 4X reduction in the number of averages required for accurate diffusion quantification in mouse models of traumatic spinal cord injury and multiple sclerosis.

MATERIALS AND METHODS

Data collection: Six-direction diffusion tensor imaging (DTI) data was acquired using a conventional spin-echo imaging sequence with Stejskal-Tanner diffusion weighting gradients. Typical acquisition used respiratory gating with TE/TR 38/1200 ms, FOV 1.0 cm x 1.0 cm, slice thickness 0.75 cm, Δ=21 ms, δ=7 ms. and 128x128 acquisition matrix. Four averages were acquired and stored separately. Experiments were performed *in vivo* with 5 control mice, 5 mice with EAE (experimental autoimmune encephalomyelitis, a mouse model of multiple sclerosis) [2], 5 mice with laminectomy and acute spinal cord injury (SCI), and 5 mice with laminectomy and chronic spinal cord injury [1].

Data Processing: DW-MRI images were jointly reconstructed from a single average of the measured *k*-space data, using the penalized maximum-likelihood image reconstruction framework described in [3]. This reconstruction enforces image smoothness to enhance SNR, while explicitly modeling and preserving the high-resolution information shared between the different DW-MR images. The method provides quantitative control over the trade-off between resolution and SNR, and regularization SNR/resolution-efficient compared to averaging [3]. Regularization parameters were adjusted to enhance SNR by a factor of 2 relative to conventional Fourier reconstruction (an SNR-gain equivalent to averaging 4 times), with minimal degradation in spatial resolution. Subsequently, DTI parameters were fit to (1) conventional Fourier reconstructions from single-average data, (2) the SNR-enhancing joint reconstructions from single-average data, and (3) conventional Fourier reconstructions from 4X-averaged data.

RESULTS

Representative results are shown in Figs. 1-3. In all cases, the quantitative DTI parameters estimated from images with the SNR-enhancing joint reconstruction matched closely with the parameters estimated from the 4X-averaged conventional reconstructions. In contrast, the parameters estimated from single-average data with conventional reconstruction had larger dispersion, and for some regions of the spinal cord, were biased away from the parameters estimated with higher-SNR data. The proposed reconstruction enabled quantitative analysis of pathology with low-SNR data.

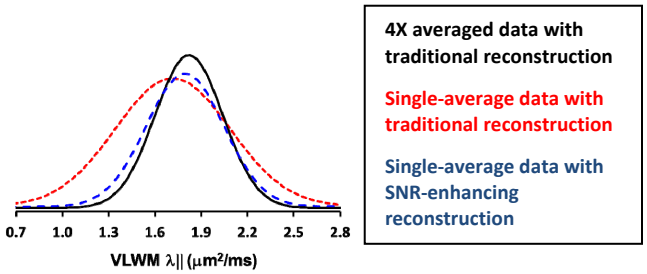


Figure 1. Histograms of the principal eigenvalue of the DTI fit in the ventrolateral white matter (VLWM) of control mice (n=5).

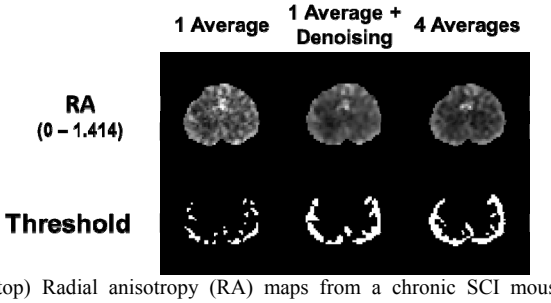
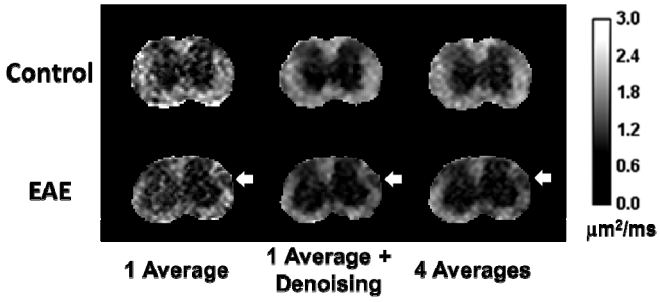


Figure 2. (top) Radial anisotropy (RA) maps from a chronic SCI mouse. (bottom) Thresholded RA map, indicating regions of spared white-matter axons.



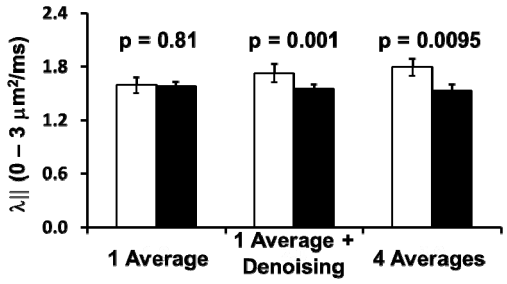


Figure 3: (left) Maps of the principal eigenvalue for a control and EAE mouse. The white arrow points to a white-matter leasion. (right) Comparison between the principal eigenvalue in VLWM between control (white) and EAE (black) mice. SNR-enhancing reconstruction greatly improves the statistical significance of the difference between the two groups.

CONCLUSIONS

Though the results of DW-MRI experiments are sensitive to noise, SNR-limitations can be overcome through signal processing methods instead of conventional signal-averaging approaches, leading to significant reductions in the data acquisition times required to obtain meaningful results and enabling relatively fast, noninvasive characterization of diffusion properties in the mouse spinal cord.

REFERENCES

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