Mean Apparent Propagator (MAP) MRI: a novel diffusion imaging method for mapping tissue microstructure

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INTRODUCTION: Diffusion-weighted magnetic resonance (MR) signals reflect information about underlying tissue microstructure and cytoarchitecture. We propose a quantitative, efficient, and robust mathematical and physical framework for representing diffusion-weighted MRI data obtained in "*q*-space," and the corresponding "mean apparent propagator (MAP)" describing molecular displacements in "*r*-space." We also define and map novel quantitative descriptors of diffusion that can be computed robustly using this MAP-MRI framework.

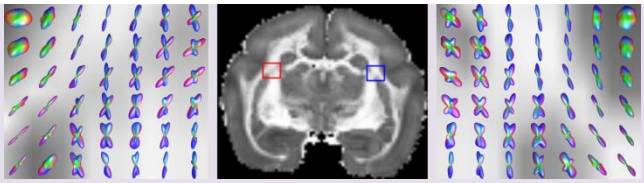

Fig. 1: Coronal grayscale propagator anisotropy (PA) map of the excised marmoset brain (center) is shown with companion MAP-MRI-derived orientation profiles. The internal capsule extends superiorly from the bottom left corner through the orthogonal fibers of the external capsule to become the corona radiata.

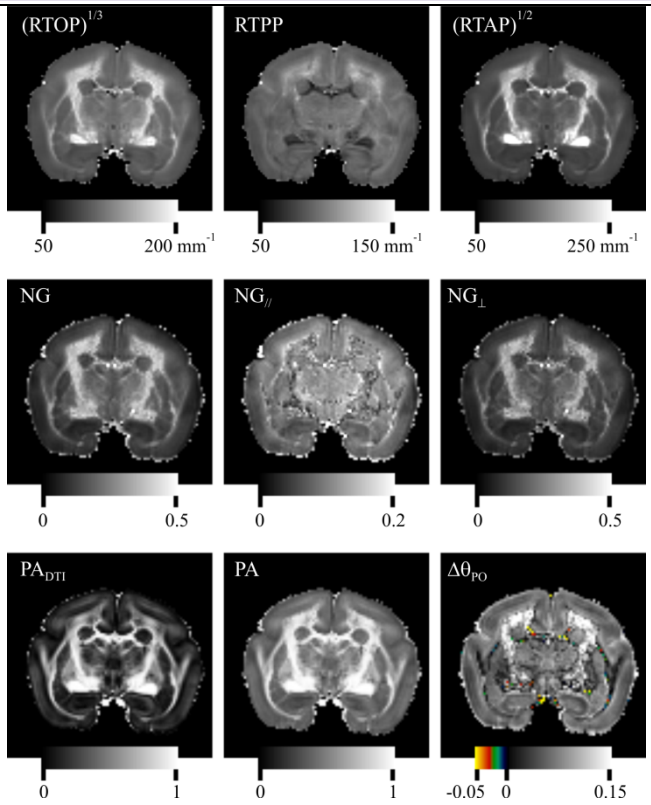

Fig. 2: Coronal MAP-MRI-derived scalar maps. **First row:** The cube-root of the return-to-the-origin probability (RTOP), and the square root of the return-to-the-axis probability (RTAP) are provided so that these quantities have the same dimension with the return-to-the-plane probability (RTPP). **Second row:** Three non-Gaussianity indices (from left to right: three-dimensional, parallel with and perpendicular to the principal eigenvector of the diffusion tensor) are illustrated. **Third row:** DTI- and MAP-MRI-derived PA maps are shown. The final image represents the change in anisotropy due to the non-Gaussian terms of MAP-MRI.

MAP-MRI: We describe efficient analytical representation of the three-dimensional *q*-space MR signal in a series expansion of Hermite functions[1] that accurately describes diffusion in many complex geometries. The lowest order term in this expansion contains a diffusion tensor that characterizes the Gaussian displacement distribution, equivalent to diffusion tensor MRI (DTI). Inclusion of higher order terms enables the reconstruction of the true apparent propagator whose projection onto the unit "displacement" sphere provides an orientation distribution function (ODF) that contains only the orientational dependence of the diffusion process.

The MAP-MRI framework represents the propagator as a vector in an abstract space. Therefore, it is meaningful to measure the (dis)similarity of two propagators via an angular metric. Such a measure was used to introduce several scalar indices. The dissimilarity between the MAP and its isotropic counterpart is used to define the propagator anisotropy (PA) index. Since MAP-MRI subsumes DTI, the PA index can be computed from DTI as well, which enables measurement of the contribution of the non-Gaussian terms to overall anisotropy. The dissimilarity of the full MAP and the Gaussian propagator leads to measures of non-Gaussianity (NG). Due to the separability of the basis, NG can be quantified along directions parallel and perpendicular to the principal eigenvector of the diffusion tensor.

Other important measures this representation provides include the return-to-the-origin probability (RTOP), and its variants for diffusion in one- and two-dimensions—the return-to-the-plane probability (RTPP), and the return-to-the-axis probability (RTAP), respectively. These zero net displacement probabilities measure the mean compartment (pore) volume and cross-sectional area in distributions of isolated pores irrespective of the pore shape.

EXPERIMENTS & RESULTS: MR images of an excised, formalin-fixed marmoset brain washed in buffered saline were acquired on a 7T Bruker Avance III scanner. A total of 489 acquisitions were performed by sampling *q*-space on 7 different shells defined by *b*-values: 200, 800, 1800, 3200, 5000, 7200, and 9800 s/mm^2. Figure 1 illustrates the ODF maps computed using the MAP-MRI framework in a region with orientational complexity. The above-mentioned scalar indices are shown in Figure 2.

DISCUSSION & CONCLUSION: MAP-MRI is a new comprehensive framework to model the three-dimensional *q*-space signal and transform it into apparent propagators. The salient features of the approach include the reconstruction of the MAPs in an anatomically consistent reference frame, and the anisotropic scale parameter. The anisotropically-scaled basis not only improves the ability of MAP-MRI to adapt to very different signal profiles, but can reduce the technique to the widely-employed DTI method if only the first of the basis functions is employed. Consequently, the MAP-MRI technique subsumes DTI while also providing several novel, quantifiable parameters that capture previously obscured intrinsic features of nervous tissue microstructure. The employed basis makes the MAP-MRI framework very robust and it also may be adapted to the technical limitations of *in vivo* imaging of clinical patients. Hence, MAP-MRI should prove helpful for investigating a spectrum of important scientific problems regarding the functional organization of normal and pathologic nervous tissue.

REFERENCE: 1. Ozarslan et al., Proc Intl Soc Mag Reson Med, 16, p. 35, 2008.