Tradeoffs Between Tensor Orientation and Anisotropy in DTI: Impact of Diffusion Weighting Scheme

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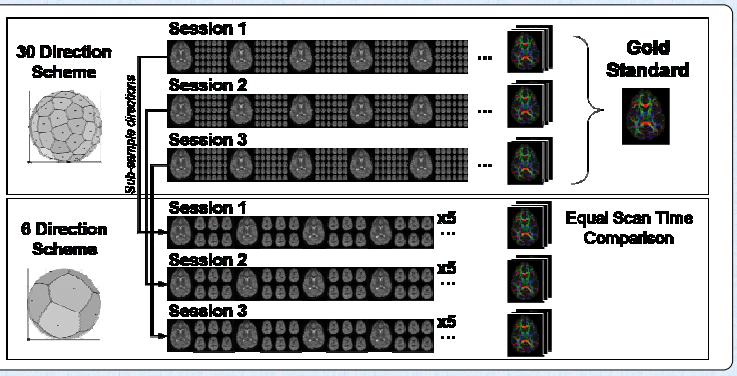
INTRODUCTION

- Diffusion tensors can be estimated from 1 non-diffusion-weighted (DW) and at least 6 DW images [1], but more images are commonly acquired to boost the signal-to-noise ratio.
- Substantial theoretical and experimental work has gone into developing optimized DW schemes with varying numbers of DW directions each designed to address different imaging objectives [2-3].
- The effects of DW schemes on the accuracy and precision of tensor estimation and derived contrasts have been investigated by simulation and *in vivo* to improve reliability.
- Strong evidence supports that increasing the number of unique directions (directional resolution) is preferable to increased repetitions given an equal amount of scan time [3-4].
- However, the specific types of gains and losses (if any) in estimation errors that occur when choosing between high and low directional resolution schemes have not been systematically evaluated.
- This study details potential differences between DTI findings using differing protocols, tantamount to proper comparison across studies and to interpretation of subtle findings which may be close the experimental precision.

To characterize how the directional resolution of a diffusion weighting scheme impacts fractional anisotropy (FA), mean diffusivity (MD), and principal eigenvector (PEV) measurements relative to the orientation of diffusion tensors.

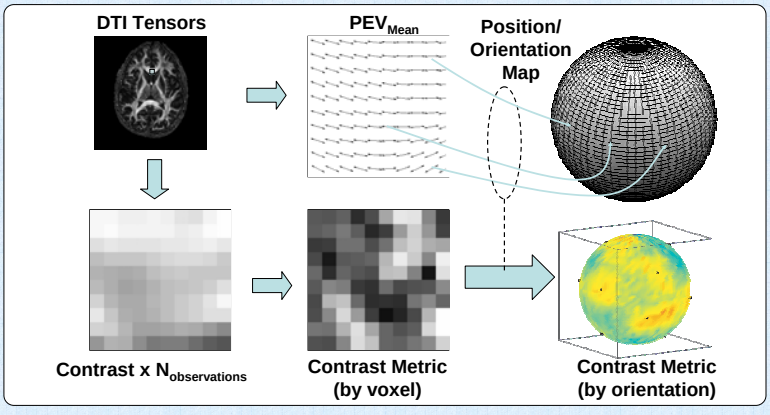


Methods

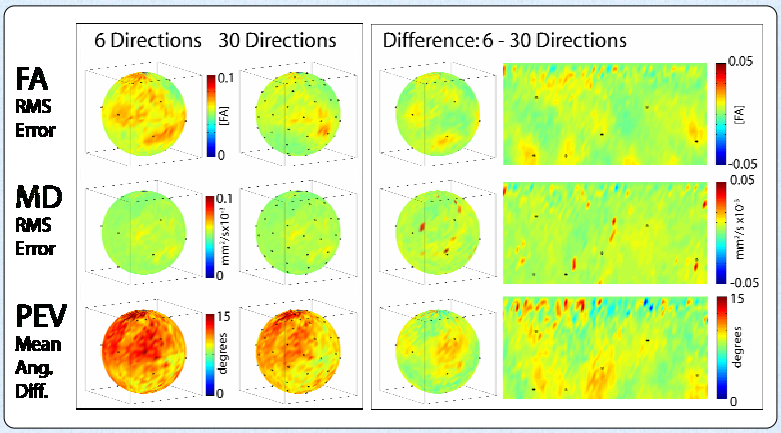
- A healthy 24 year old male was studied in 3 scanning sessions, each consisting of 15 DTI scans on a 1.5T system (Intera, Philips Medical Systems, The Netherlands) after written informed consent. A multi-slice, spin echo, single-shot EPI sequence (SENSE = 2.0) was used to acquire 25 slices (parallel to AC-PC) with 2.5 mm isotropic voxels (no slice gap). Diffusion weighting was applied along 30 PE optimized directions (b = 1000 s/mm^2, G = 19.5 mT/m, TR/TE = 3652/100 ms). Five minimally weighted images (b0) were also acquired and averaged. Data were co-registered with FSL FLIRT (FMRIB, Oxford, UK). To provide an equal scan time comparison, subsets of 5 repetitions of 6 DW directions were selected without replacement from the full 30 set using minimum PE criteria. Gold standard results were obtained by averaging the high SNR DTI contrasts, each using all 15 DTI scans in a session.

ANALYSIS BY TENSOR ORIENTATION

- To assess tensor estimation as a function of the underlying fiber orientation, all voxels with a gold standard FA>0.25 were binned by their gold standard PEV orientation. Error metrics were averaged over the bins. Mean square errors (MSEs) relative to the gold standard contrast were reported for FA and MD, while orientation effects were assessed by reporting the mean angular differences (MADs) between the observed PEV and the gold standard PEV.



RESULTS

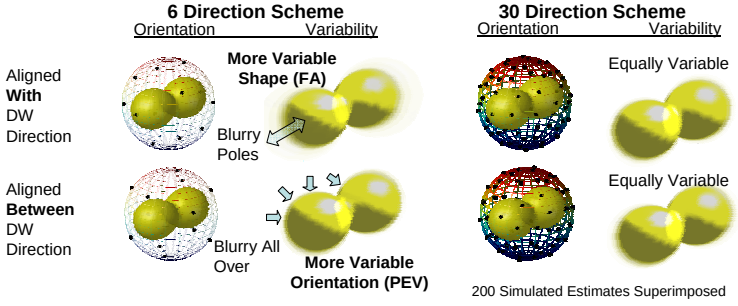


- The 6 direction scheme has a large impact on RMS errors of DTI derived metrics and this effect depends on the alignment of the underlying tensor (left column).
- For tensors aligned with a sampling direction (versus between), PEV is more accurately determined while FA is less accurately estimated.
- The 30 direction scheme minimizes the variability of RMS measures for a tensor of unknown orientation (center column).
- The orientation differences between the 6 and 30 direction schemes highlights the differences in reliability that occur with differing DW schemes (right columns)
- The choice between sampling at independent directions versus repeated directions produces a tradeoff between determining the anisotropy/shape (e.g., FA and MD) and orientation (e.g., PEV) of the tensor.
- The measurement accuracy and precision of DTI-derived contrasts may not be optimal for tensors aligned with the DW directions. This can be appreciated by considering the "diffusion peanut" for a prolate tensor [10]. For a prolate tensor, the diffusivity changes less rapidly at the poles and equator. A DW scheme that oversamples slowly changing regions (low orientation variance) on the diffusion peanut, determines the eigenvalues well (hence, FA). Over-sampling the rapidly changing regions of the diffusion peanut well determines the orientation well (hence, PEV).

CONCLUSION

- **DW schemes can introduce systematic differences in the accuracy and prevision of orientation and anisotropy.**
- **These differences are small and should have minimal impact on interpretation of typical clinical studies.**
- **For large population or high SNR studies, the effect of the DW scheme should be taken into account to avoid potentially biased results.**

Preview: MONTE CARLO DTI SIMULATIONS



ACKNOWLEGEMENTS This work was supported by NCRR P41RR15241 (van Zijl), RO1AG20012 (Mori), U24 RR021382-021 (mBIRN), R01 NS056307-01 (Prince), and the Office of Naval Research NDSEGF (Landman) .

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