Parameterization of Bootstrap Analysis for Prediction of Primary Eigenvector's Distribution

J. I. Berman[1], Y. Lu[1], R. G. Henry[1]
[1]Radiology, UC San Francisco, San Francisco, CA, United States

Introduction:

Signal noise causes uncertainty in diffusion tensor imaging (DTI) measurements. Errors in the primary eigenvector's direction can compound and result in inaccurate DTI fiber tracks. Knowledge of the probability distribution describing the primary eigenvector's direction can be incorporated in probabilistic fiber tracking algorithms. Bootstrap analysis has been used as a model independent method of characterizing the distributions of DTI measures [1]. However, the bootstrap analysis requires multiple acquisitions and intensive post-processing resources. In this study, the bootstrap analysis is performed on the primary eigenvector and the resulting distributions are parameterized with standard DTI measures. The goal is to predict features of the primary eigenvector's distribution without performing the entire bootstrap analysis.

Methods:

DTI was performed at 3T, with b=1000s/mm^2, TR/TE=12000/63ms, 17 gradient directions, 1.7 isotropic voxels, and repeated 3 times. The diffusion tensor, eigenvectors, and eigenvalues (λ_1, λ_2, λ_3) were calculated 1000 times with bootstrap samples selected from random combinations of the 3 acquisitions. A 2D histogram of the primary eigenvectors' spherical coordinates (θ, ϕ) with 50x50 bins was saved for each voxel. The 2D histogram covers one half the surface of a sphere. The histogram is centered on the primary eigenvector and rotated so that λ_2 is in the θ direction and λ_3 is in the ϕ direction. The distribution is fitted to a 2D elliptical Gaussian equation:

$$F(\theta, \phi)=A_0 + A_1 e^{-U/2} \text{ with } U= (\theta/\theta_{ax})^2 + (\phi/\phi_{ax})^2$$

The 2D elliptical Gaussian captures asymmetry of the angular distribution in the θ and ϕ directions with the θ_{ax} and ϕ_{ax} axis lengths. A chi-square goodness of fit test was performed to check the match between the Gaussian fit and the angular histogram. The three eigenvalues and residual error from the tensor fit, calculated from the 3 NEX averaged DTI set, were used as the independent variables in a multiple linear regression to each of the parameters, A_0, A_1, $\ln(\theta_{ax})$ and $\ln(\phi_{ax})$.

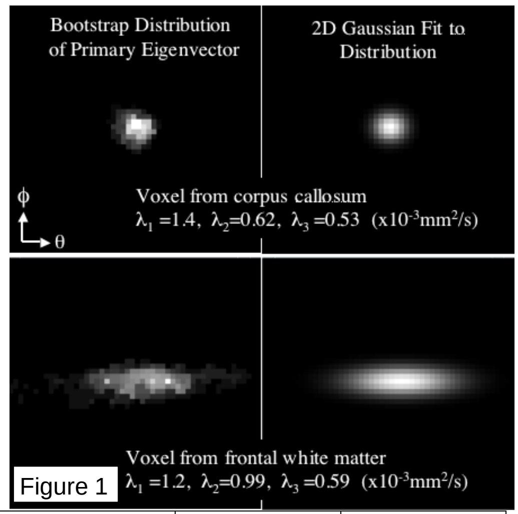

Figure 1

Results:

Figure 1 shows example angular distribution histograms and the associated 2D Gaussian fits. Results of multiple regressions are shown in the table. The mean value of A_0 was zero and was uncorrelated with the eigenvalues. The residual error of the fit to determine the tensor elements was also uncorrelated. The width of the Gaussian in the θ direction was most correlated with λ_1 and λ_2. The width of the Gaussian in the ϕ direction was most correlated with λ_1 and λ_3. Figure 2 shows an example plot of the relationship of the primary eigenvalues with the width of the Gaussian fit in the θ direction.

Parameter	Multiple Correlation Coefficient	λ_1 Correlation Coefficient	λ_2 Correlation Coefficient	λ_3 Correlation Coefficient
A_1	0.444	0.262	-0.105	-0.109
$\ln(\theta_{ax})$	0.775	-0.433	0.217	0.119
$\ln(\phi_{ax})$	0.714	-0.398	0.0403	0.245

Discussion/Conclusion: The model of the bootstrap distribution used in this study can capture the width and asymmetry in the primary eigenvalue's angular uncertainty. Voxels with high anisotropy and λ_1>>λ_2=λ_3 were observed to have tight, symmetric distributions. Voxels with λ_1=λ_2>λ_3 have distributions elongated in the θ direction. The correlation of λ_2 with θ_{ax} provides a method of predicting the asymmetry of the distribution with just the eigenvalues. Using the standard DTI eigenvalues, a probability distribution of the direction of the primary eigenvalues can be estimated and used in Monte-Carlo based probabilistic fiber tracking [2].

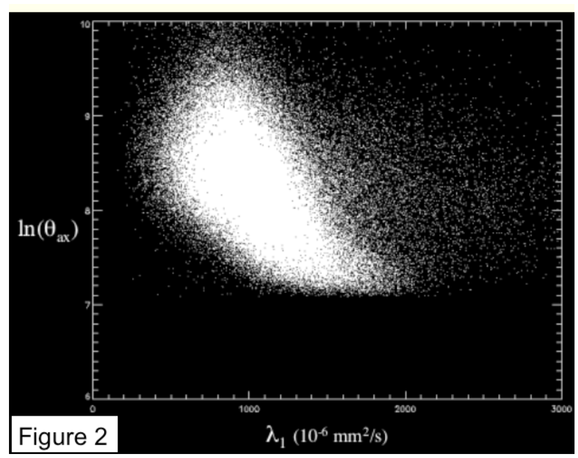

Figure 2

References:

1) Pajevic, et. al., JMR 2003:161:1-14.
2) Parker GJM. et al. IEEE Trans Med Imaging. 21:5, May 2002.