Estimation of the Uncertainty of Diffusion MRI Fiber Tracking Parameters with Residual Bootstrap

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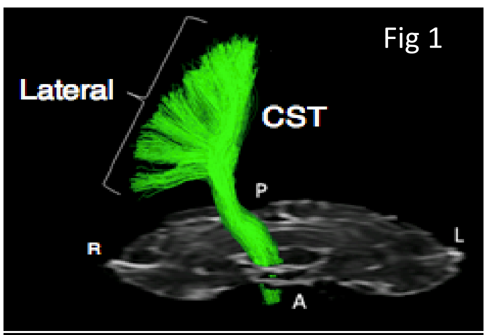
BACKGROUND AND MOTIVATION: A recent comparison of bootstrap approaches in the estimation of uncertainty of voxelwise DTI parameters such as FA and ADC demonstrated that the application of residual bootstrap (RB) provided an unbiased empirical non-parametric approach to characterizing the parameter uncertainty [1]. Fiber tracking (FT) based on diffusion MR has important applications for structural connectivity analyses of brain diseases [2] and pre-operative FT of the brain [3]. The RB analysis on voxelwise DTI parameters is not appropriate to characterize the uncertainty in the large 3D regions defined by FT. Therefore, we will illustrate the appropriate implementation of RB to obtain the uncertainty of fiber tracking parameters (FTPs) such as the number of streamlines, the length of a track, and the volume of a track in a fiber bundle.

METHODS: To validate our method, we performed a Monte Carlo (MC) simulation in which we defined a well-known noiseless 55 direction ground truth raw diffusion weighted (DW) data set and from that ground truth created 1000 separate DW data sets by adding Rician noise [1] (Fig.1). Fiber tracking was performed on each of these DW data sets using deterministic DTI, probabilistic DTI, deterministic q-ball, and probabilistic q-ball FT algorithms [4]. FTPs were extracted from each of the fiber tracked data sets creating a MC distribution of FTPs. The standard error (SE) was calculated for the distribution. One of the 1000 DW data sets from the MC simulation was chosen for RB analysis in which 1000 resampled DW data sets were created to be tracked by the four FT algorithms. Again, FTPs were extracted and a distribution of FTPs was created in which the SE was also caluclated. This was done at low and high SNR levels. The FTP chosen for analysis was number of streamlines. For the high SNR data set using QBALL deterministic FT, we used RB to resample the chosen DW data from the MC simulation 5000 times to compare the effect of using more than 1000 bootstrap iterations.



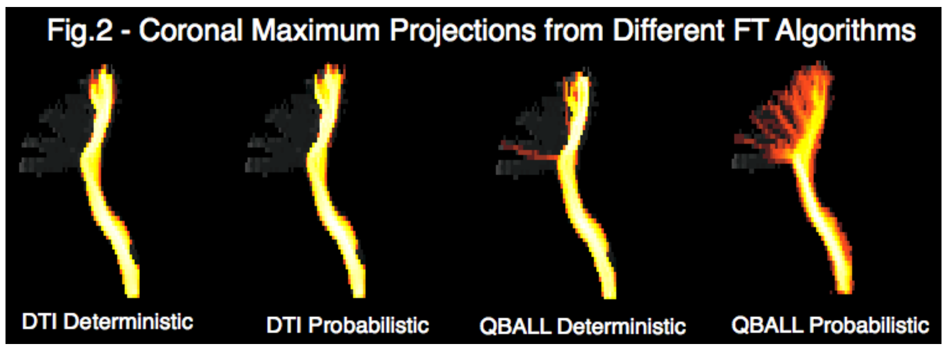


Table 1: Summary of the calculated SE of each of the four FT algorithms at low and high SNR

SNR	DTI Deterministic			DTI Probabilistic			QBALL Deterministic			QBALL Probabilistic		
	FTP*	SE	CV**	FTP*	SE	CV**	FTP*	SE	CV**	FTP*	SE	CV**
5 MC	3495	440	0.13	3342	383	0.11	3192	430	0.13	2554	283	0.11
5 RB	3481	482	0.14	3340	415	0.12	3182	446	0.14	2522	299	0.12
20 MC	4069	103	0.03	4036	132	0.03	4088	211	0.05	4051	199	0.05
20 RB	4071	111	0.03	4064	148	0.04	4098	224	0.05	4068	188	0.05

FTP = Mean of Number of streamlines, CV** = coefficient of variance = SE/FTP**

RESULTS: The SE (red) from the MC distribution and the SE from the RB distribution are similar for all four fiber tracking algorithms and at the two SNR levels (Table 1). Q-ball probabilistic fiber tracking was able to better characterize the lateral pathways of the CST while maintaining a relatively low SE (Fig.2). Resampling 5 times more improved the accuracy of the SE of the QBALL deterministic at high SNR from 224 to 215 pushing it much closer to the MC SE of 211.

CONCLUSION: The MC simulation revealed that RB is able to characterize the uncertainty of FTPs at low and high SNR and for four different FT algorithms. Larger number of resampled DW data yielded more accurate estimation of the SE. Probabilistic QBALL fiber tracking was shown to be the best in yielding low SE of FTPs while maintaining its sensitivity in finding lateral pathways.

[1] Chung SW, et al. 2006. [2] Wahl M, et al. 2009 [3] Berman JI,et al. 2007. [4] Berman JI, et al. 2008.