Looking for the optimal DTI acquisition scheme given a maximum scan time: Are more b-values a waste of time?

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Introduction

Reliable inference of the diffusion tensor (**D**) values in cerebral white matter requires sufficient sampling of non-collinear directions and appropriate choice of the b-values. Several studies have looked at the minimum number of directions required for robust estimations of fractional anisotropy (FA), apparent diffusion coefficient (ADC) and fibre orientation (e.g [1-3]), and a few others have analyzed acquisition schemes using more than one b-value (e.g. [4-6]). However, even though there are many studies in the literature regarding DTI acquisition schemes, one fundamental question has not yet been fully addressed: are multiple b-values a waste of time, or a valuable way of increasing the accuracy and reproducibility of DTI results?

Methods

Simulations were performed for $6 \leq N_d \leq 60$ and $1 \leq N_b \leq 5$ (where N_d is the number of directions and N_b the number of b-values). The highest b-value used was b_{max}=1570 s/mm^2, and the other b-values were chosen in order to give an equal spacing within the interval $0 \leq$ b-value $\leq b_{max}$. For each acquisition scheme, the noise-free diffusion weighted signals were calculated according to the diffusion tensor model [7]. Rician noise was then added to this data, and scaled to different values of signal to noise ratio (SNR). The values of FA, ADC and α (the angle between the simulated and the estimated direction) were then estimated from this data. To evaluate the performance of each scheme in the presence of noise, the procedure of noise generation and determination of ADC, FA and α, was repeated 2^{13} times. Variable fibre orientation was also realized by spatially rotating the fibres at 400 discrete orientations. Finally, these simulations were repeated for different values of simulated FA and ADC.

Results and Discussion

By applying a methodology similar to the one described by Papadakis *et al* [1], the minimum number of unique sampling directions required for robust estimation was individually determined for ADC, FA and α: N_{ADC}>21, N_{FA}>22, N_{α}>28. These results agreed with previous studies of Papadakis[1] and Jones[3]. If we use more than 1 b-value, however, the number of minimum directions required for ADC estimation decreases with N_b, while the N_{FA} and N_{α} remain constant despite of the number of b-values used.

The results obtained for ADC show a systematic bias relatively to the simulated value. This effect has been documented and is due to the Rician noise distribution. However, Fig. 1 shows that as we increase N_b, the estimated ADC gets closer to the simulated value, which suggests that this bias effect can be minimized by increasing N_b, and not by increasing N_d. Even though FA is not as affected by this bias, the same conclusion can be drawn for this parameter.

For a maximum number of total acquisitions of 20 (a number smaller than the minimum required for robust estimation of any of the 3 parameters), the optimal acquisition scheme for estimating FA and α is the one employing 20 directions and 1 b-value. For ADC, however, while a scheme employing 10 directions and 2 b-values produces results that are closer to the simulated ones, a scheme using 20 directions and 1 b-value produces results that are less variable in the presence of noise. In this case, a choice must be made in the light of the purpose of the study: if we want to compare our results to the ones obtained for other populations done on different machines, then a value closer to the "real" one would be preferable; if we are using only our own data values as controls or looking at trends in the subjects over time, then it would be preferable for the results to be as stable as possible.

If our maximum scan time allows us to acquire up to 60 volumes (the maximum number typically used in clinical studies), the plots presented in Fig. 1 show that a scheme employing 12 directions and 5 b-values takes us as close to the simulated ADC value as we can get for this maximum number of total acquisitions. Also, this acquisition scheme corresponds to the smallest variations due to noise and fibre rotation. For FA, the scheme using 30 directions and 2 b-values produces results more stable and accurate than the ones obtained with 60 directions and 1 b-value. Using 20 directions and 3 b-values does not produce a significant improvement in the estimated mean values of FA, and the results become more dependent on fibre orientation. For estimating fibre direction, the acquisition scheme using as many directions as possible is still the one producing the best results in terms of accuracy and stability.

Finally, the use of more than 1 b-value accounts better for the great diversity of diffusivities we find in the brain.

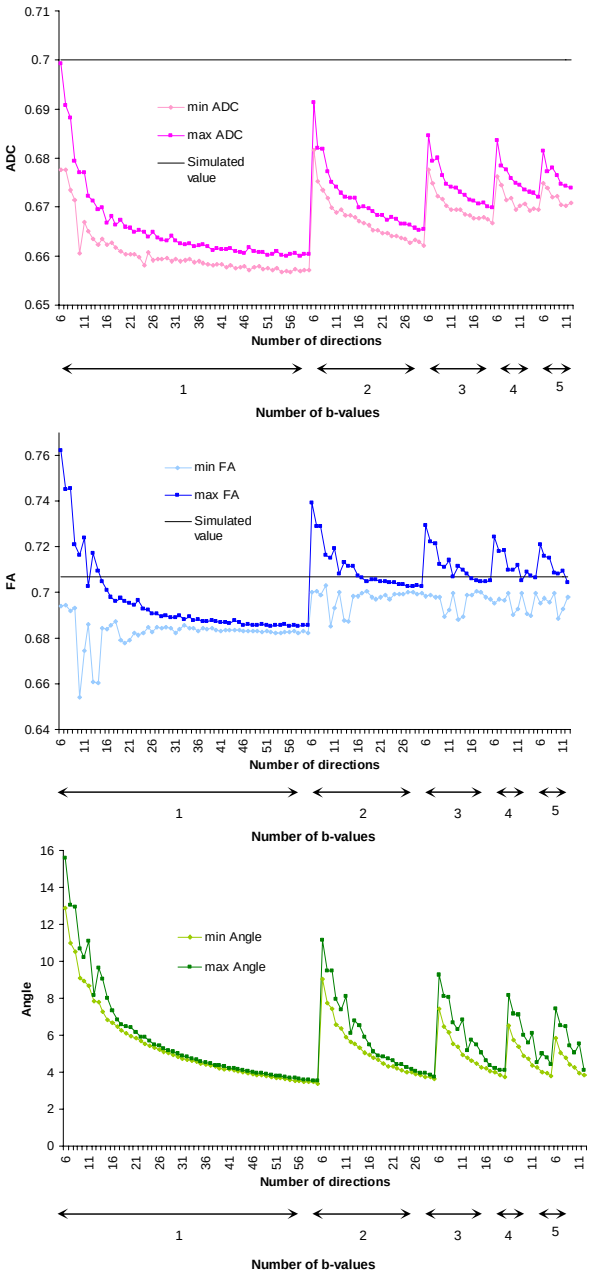

Fig. 1 – Results obtained for ADC, FA and α for all acquisitions schemes with a maximum of 60 total acquisitions (simulated SNR=10).

Conclusion

This study has shown that the use of more than 1 b-value is useful for estimation of ADC and FA. While for tractography studies we should use as many sampling directions as allowed by scan time limitations, for follow-up, intersubject or multicenter studies, the use of more than 1 b-value will improve the accuracy of the scalar diffusion parameters, as long as the minimum number of directions required for robust estimation of each parameter is still used.

References

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