Using wild bootstrap to evaluate the effect of spatial resolution on MR diffusion parameters

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Introduction: Bootstrap analysis has been suggested to be advantageous for estimation and characterization uncertainties of DTI derived parameter like FA, ADC or principal eigenvector (PEV). Three kinds of bootstrap methods were investigated in the past: repetition, residual and wild bootstrap. The latter methods are so called model-based resampling techniques which outperform repetition-based resampling even if multiple-acquisitions were used [1]. Wild bootstrap was used to quantify cardiac pulsation artifact [2], to optimized clinical protocols in terms of number of directions vs. number of repetitions [3] and to evaluate the accuracy and precision of DTI parameters between MR systems [4]. However, up to now, the bootstrap method was not used to investigate the effect of spatial resolution on DTI measures.

Material and Methods: We acquired whole data sets of healthy volunteers using a standard DTI EPI sequence and a 3T whole body MR system (Tim Trio, Siemens Medical, Erlangen, Germany). The spatial resolution was systematically adjusted by increasing the read-out resolution, number of phase steps and slice thickness in order to obtain data sets with isotropic spatial resolution of 2.5 down to 1.5 mm in steps of 0.1 mm. Echo time and repetition time were always set to be as short as possible and the bandwidth was set to obtain the smallest possible echo spacing. In a second experiment we set an isotropic spatial resolution of 1.7 mm and evaluated the effect of increasing the number of excitations (NEX) from 1 to 5 on FA, std(FA) and confidence interval of principal eigenvector orientation know as Cone of uncertainty (CU) [5]. Both protocols use 5 b0 images and 30 diffusion weighted images (Jones30 [6]). The wild bootstrap analysis was implemented using initial weighted linear regression and wild bootstrapping was engaged using the Rademacher function. The number of bootstrap samples was set to 1000 in all cases.

Results: Fig. 1 shows the results for the evaluation of increased spatial resolution. It can be clearly seen from the transversal images, that the noise in FA maps increase with increased spatial resolution. This is also clearly demonstrated in the std(FA) maps (second row), the same holds true for the cone of uncertainty of the principal eigenvector (PEV) – third row. Details of this effect can be revealed from 1d profiles draw along the LR and AP orientation (second and third column). For example the 1d profile in AP direction (third column) shows that the FA profile of the genu of the Corpus Callosum remains sharp until the resolution goes below 1.8 mm. The same effect can be observed in the CU measure, which increases clearly from 1.8 to 1.7 mm isotropic resolution. Fig. 2 shows the results for the evaluation of the effect of number of excitations (NEX). Although regions of high anisotropy (e.g. CST) benefit from increasing NEX in terms of decreasing std(FA); CU and mean FA do not change with increasing NEX in this region. The improvement through increasing NEX can also be revealed by the observed sharpening of the 1d profiles.

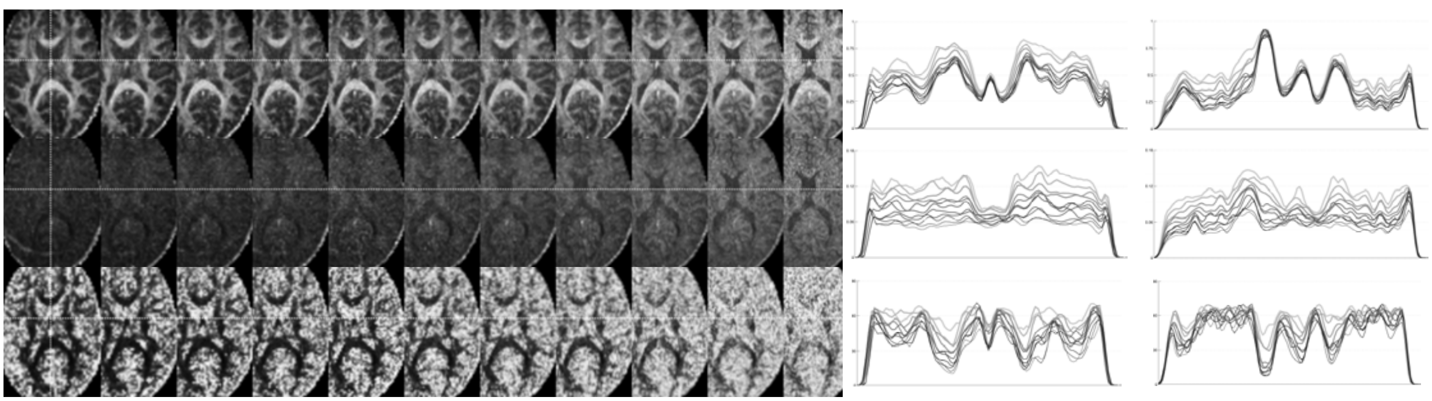
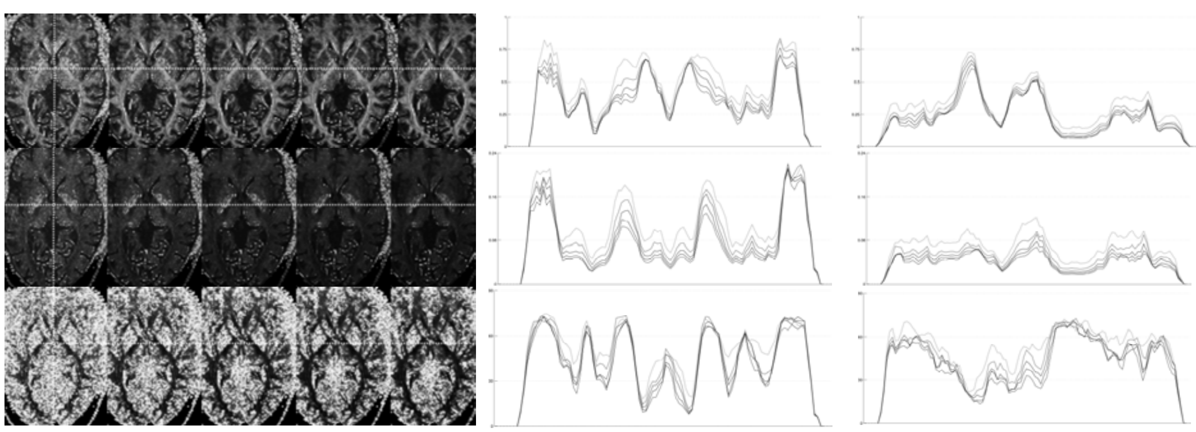


Fig.1 Top-down: mean FA, std(FA) and CU. The dotted lines show the location of 1d profiles along the L-R axis (second row) and the A-P axis (third row). 1d profiles graphs are encoded by line thickness and gray values: the thinner and darker the line the lower the spatial resolution and vice versa.

Fig. 2 Evaluation of the effect of NEX (1 to 5). The arrangement of quantitative measures is equal to Fig. 1. std(FA) and CU typically decreases with NEX and structures revealed by FA maps become sharper with increased NEX. 1d profiles graphs are encoded by line thickness and gray values: the thinner and darker the line the higher the NEX.



Discussion: Our experiments clearly demonstrated the usefulness of the bootstrap approach for evaluation of the effect of spatial resolution on DTI derived parameters. Although we are currently unable to confer the results directly to other DTI acquisition protocols, we think, that the proposed approach might help others to make clear decisions based on quantitative measurements (e.g. by means of CU or std(FA)) regarding protocol optimization.

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