Diffusion Tensor MRI: Combination of Signals from Phased Array Coils

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Introduction

An area of magnetic resonance imaging where any increase in image quality would be particularly welcomed is with diffusion tensor imaging (DTI). It has been shown before that the usual Sum of Squares (SoS) method of combination of signals from phased array coils is less than optimal when SNR is low as in DTI. In this abstract, we present an alternative technique for the combination of signals from phased array coils and we compare the impact of this method to the standard SoS technique in the evaluation of the major DTI parameters.

Method

Our alternative method (Sens Complex) is a modification of an algorithm proposed by Bydder et al. [1] in 2002. The reconstructed signal P_{opt} can be written in a matrix form as:

$$P_{opt} = \frac{S^T R^{-1} b^*}{\sqrt{b^T R^{-1} b^*}}$$

where S is the vector of signals from all elements, R is the noise correlation matrix and b is the vector of estimations of the coils sensitivity profiles. These complex sensitivity profiles are created by heavily low-pass filtering real and imaginary images obtained from the magnitude information of non-weighted images (NWIs) and the phase information from each diffusion weighted image (DWI). NWIs, automatically generated by most DTI sequences, have a much better signal-to-noise ratio (SNR) than weighted images and their signal magnitude is then better for computing the sensitivity profiles. The heavy filtering creates profiles that keep approximately the same phase as the DWIs in high signal regions while the averaging changes the phase in very noisy regions. After the multiplication of the profiles with their corresponding DWI, the noise level regions in resulting images still have a random phase, as opposed to the SoS where the phase in these areas becomes null, leading to the Rician noise bias. Furthermore, this method can be combined with the averaging of the data from multiple repetitions in the complex space, thus allowing us to take further advantage of the normally distributed noise in complex MR data, so a minimal noise bias is introduced.

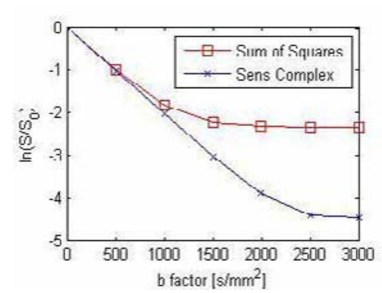

Fig.1 Semi-logarithmic plot of the mean diffusion in a phantom as a function of the b factor. 30 repetitions average and 12 elements phased array head coil.

From twelve DWIs using non-collinear diffusion gradients, we calculated diffusion tensors for each voxel and each combination method using the technique proposed by Basser et al. [2] and a multivariate linear regression. From these tensors, we calculated fractional anisotropy (FA) values and principal diffusion directions.

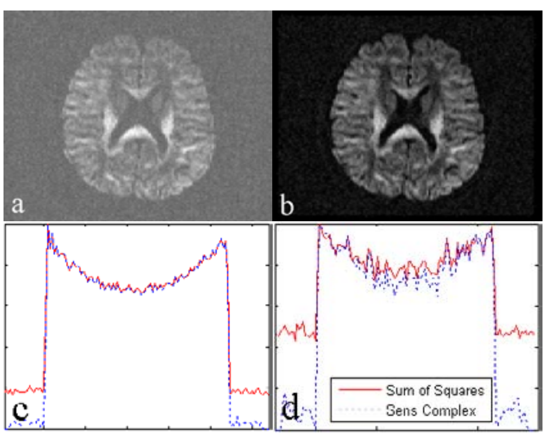

Fig.2 DWIs for 12 repetitions average and 12 elements phased array head coil in a brain a) SoS and b=2000s/mm^2 b) Sens Complex and b=2000s/mm^2 and the profile of a uniform phantom at c) b=500s/mm^2 d) b=1000s/mm^2

Combination method	Parameter	Value ± c.i. 95 %
Sum of Squares	Fractional anisotropy (FA)	0.57 ± 0.06
	Direction	± 7.8 °
Sens Complex	Fractional anisotropy (FA)	0.78 ± 0.03
	Direction	± 4.5 °

Tab. 1 Uncertainties on estimates of FA and principal direction in white matter (splenium of corpus callosum). Average of 12 repetitions with a b factor of 2000s/mm^2 and n=100 samples.

Results

As the value of b is increased, SNR gets lower and the signal intensity decreases toward the noise floor. In theory, a semi-logarithmic plot of the mean signal of a DWI divided by the mean signal of the NWI will be linear, but the noise will make it nonlinear at high b values. Using a water phantom, we show on Fig.1 that the Sens Complex combination method follows this linear relation up to twice the value of b as compared to the classical SoS. Similar results were also observed in the brain. We can see on Fig.2 that the noise floor on DWIs is much lower with Sens Complex combination than with SoS, but the signal intensity does not significantly change.

Results of the estimation of FA and diffusion direction calculated from diffusion tensors for a region of interest in white matter are presented in Tab.1. The errors have been derived using a bootstrap-like algorithm. We observe that FA values obtained from Sens Complex are significantly higher. This increase in anisotropy is believed to arise from the much lower noise floor present in Sens Complex images. This underestimation of the real anisotropy at low SNR has been predicted by Jones and Basser [3] using Monte-Carlo simulations. The Sens Complex method shows a lower underestimation effect and is believed to give a better estimate of the real anisotropy. Moreover, we also notice that Sens Complex gives more precise estimates of both FA and principal direction than the SoS combination method. As anisotropy and diffusion direction are the main parameters used to achieve white matter tractography, we believe that the Sens Complex combination method would give more accurate results in recreating white matter fibers pathways.

Conclusion

We have found that the Sens Complex combination method produces better and more precise estimations of FA and principal direction in DTI compared to the classical SoS. To follow up on these results, we are looking forward to compare white fibers pathways recreated from diffusion tensors calculated from Sens Complex and SoS combination techniques.

References

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2. Basser, Peter J. et al. *Journal of Magnetic Resonance B* 103, 247-254 (1994).
3. Jones, Derek K. and Peter J. Basser, *MRM* 52, 979-993 (2004).