Influence of the Noise Floor: Paradoxical Effects on DTI

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Introduction

Since the signal in MR magnitude images is Rician distributed, the mean magnitude is biased [1]. This bias becomes apparent in images with small signal to noise ratios (SNR<5) as usually seen in diffusion tensor imaging (DTI). In diffusion MR imaging, the signal decays exponentially with the diffusion constant $D(\vec{g}_i)$ where $D(\vec{g}_i)$ characterizes the diffusion projected in the gradient direction $\vec{g}_i$. When the diffusion is anisotropic, as it is in neuronal tissue, the diffusion in one direction can be several times larger than in another direction. Thus, the diffusion weighted signal in some gradient directions can be at or even below the background noise level. In this work we present data that illustrates the effects of the magnitude bias in diffusion weighted images on DTI.

Methods

A DTI-SE-EPI sequence was used on a 1.5T clinical scanner (Avanto, Siemens Erlangen) to acquire DTI images of a cylindrical diffusion phantom [2] and of the corpus callosum (CC) of a healthy subject. DTI data of the healthy spinal cord was acquired with an inner volume DTI-SE-EPI sequence [3]. Parameters: dual gradient scheme ((1,1,0),(1,-1,0),(1,0,1),(1,0,-1),(0,1,1),(0,1,-1)); Phantom: b=1000,6000s/mm², TE=200ms, TR=3s, 32 averages, 1.25×1.25×10mm³. CC: b=1000s/mm², TE=87ms, TR=2.5s, 10 averages, Grappa×2, 2×2×2mm³, the gradient scheme was rotated in steps of 10°. Spinal Cord: b=1000, TE=80ms, TR=5s, 8 averages, gradient scheme rotated by 22° around (1,0,0); The DTI data was evaluated with NeuroQLab (MeVis, Bremen) [4]. The influence of the magnitude bias on DTI was simulated with MatLab (Mathworks). The magnitude bias was simulated by shifting the true magnitude to the expectation value of the biased magnitude. Then the tensor was derived and evaluated.

Results

Figure 1 shows the measured FA versus the angle (Phi) of gradient scheme rotation around the (0,1,0) axis. Blue dots represent the FA values as measured at the CC (SNR≈7). The measured FA varies up to 7%. The drawn line represents the expected FA with the noise bias in the magnitude images taken in account as computed with MatLab (calculation parameters: FA=0.78, ADC=0.75µm²/ms).

The arrows in figure 2a) represent the expected shift of the true eigenvector (beginning of the arrows) to the biased eigenvector (arrowhead) as computed with MatLab using similar values for FA and ADC as found in the spinal cord images. The arrows are projected on the x-y plane. Vectors that lie on a symmetry axis of the gradient scheme either act as 'attraction' or 'distraction' vectors, e.g. (0,0,1) acts as an attraction vector. The expected eigenvector shift can be observed in the in vivo spinal cord DTI images of figure 2b) where fibre tracking was performed (SNR≈3). The fibres are not properly following the spinal cord but are shifted towards the predicted attraction vector.

Figure 3 shows a colormap of the DTI phantom. The color represents the direction of the principal eigenvector as indicated by the arrows on the upper left of the figure. Figure 3a) is acquired with b=1000s/mm² and the colors match to the known circular fibre orientation. Figure 3b) is acquired with b=6000s/mm², SNR≈27. The area which used to be 'blue+red' becomes 'green', the principal eigenvector is interpreted to be perpendicular to the x-y plane. That is not due to an eigenvector shift but caused by the non-intuitive increase in the second eigenvalue as the b-value increases. When the second eigenvector exceeds the principal one, the order and therewith the fibre direction is misinterpreted.

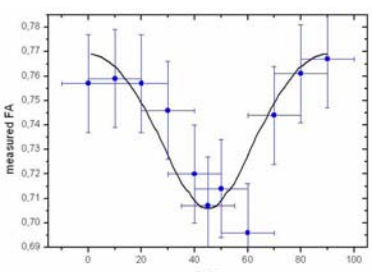


Fig. 1) Measured FA depends on the rotation of the gradient system. Blue dots for values measured at Corpus Callosum (SNR≈7). Drawn line represents the expected FA when computing the noise biased tensor.

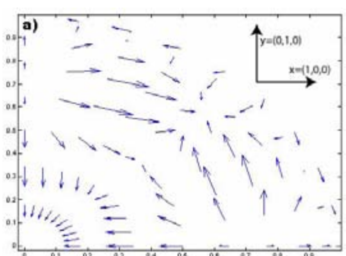
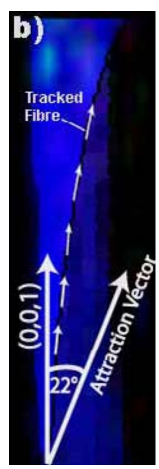


Fig. 2a) Eigenvectors are shifted from the beginning to the head of the arrow by the bias in magnitude images. **b)** Fiber-tracking of the spinal cord: fibres are shifted towards the attraction eigenvector.



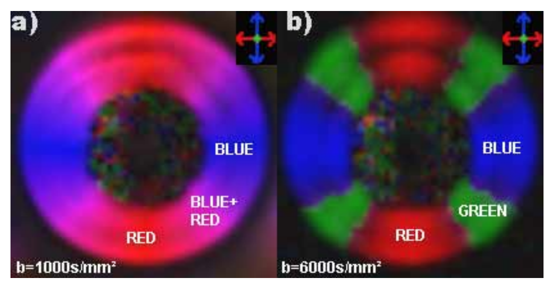


Fig. 3a) Colormap of the cylindrical DTI Phantom. The fibre orientation is represented correctly. **b)** Acquired with high b-value. Note the change in second eigenvalue in the 'green' regions.

Discussion

When evaluating anisotropic DTI data, it is important to verify that the signal in each of the diffusion weighted images is above the noise level. If not, the eigenvalues, eigenvectors and any quantitative value derived from the tensor will be biased as shown in the presented data. Furthermore, spherical symmetry is broken and the measured tensor becomes orientation-dependent. Corrections of the magnitude as proposed [1] can partly solve the bias problem for moderate b-values. But since the signal decays exponentially, DTI is not appropriate at high b-values. Moreover, averaging doesn't decrease the bias since diffusion weighted images must be averaged in magnitude images due to phase instabilities.

References

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