VALIDATION OF DIFFUSION TENSOR IMAGING IN THE PRESENCE OF METAL IMPLANTS

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Introduction

Diffusion Tensor Imaging (DTI) holds viable information on white matter architecture [1] that may be used clinically, for instance in spinal cord disease. Here DTI may be particularly relevant, since success in therapy after spinal cord trauma can presently only be measured using clinical scores, but not with other imaging techniques. Unfortunately, in about 90% of the patients with traumatic spinal cord injuries DTI is impeded by metal implants that can cause substantial artefacts in the area of the lesion. DTI color maps of the spine of a patient show [2] that the images are completely distorted near the implant and the lesion, while the image quality seems significantly higher above and below the implant. More recent studies have shown that the fractional anisotropy of the diffusion tensor may be reduced not only at the point of the lesion but over the whole length of the spinal chord [3]. Thus, measurements in the regions up- or downstream from the lesion site may also serve as surrogate marker of disease progression.

The goal of the project is to estimate the distortion effects on diffusion derived quantitative parameters due to metal implants.

Methods

Two kinds of error sources caused by metal implants are conceivable in diffusion measurements: 1. the background magnetic field becomes inhomogeneous because of the susceptibility of the implant. 2. Eddy currents that are induced by the diffusion gradients distort the gradient amplitudes (G) and the diffusion weighting (b-value).

In order to investigate in detail the effects caused by an implant we used a standard titanium implant that consisted of two rods, a basket and four screws. The separate parts of this implant were cast into agarose gel and the obtained phantoms were measured with a FLASH sequence (5 mm slice thickness, TR = 9.1 ms, TE = 4.8 ms, 10 averages, bandwidth = 390 Hz/Px, matrix size 256x256, flip angle 15°, FOV = 300x300 mm²) und with a twice refocused EPI diffusion sequence (5 mm slice thickness, TR = 1500 ms, TE = 58 ms, 10 averages, bandwidth = 2380 Hz/Px, matrix size 100x100, FOV = 200x200 mm², b = 0,100,…,800s/mm² in steps of 100 s/mm²) on a 1.5 Tesla Magnetom Avanto (Siemens, Erlangen, Germany) clinical scanner.

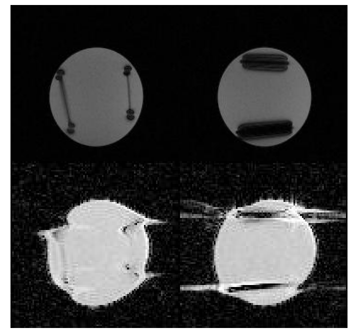

Fig. 1: Magnitude maps of an agarose phantom with two titanium rods placed parallel (top left) and orthogonal (top right) to the background field B_0 (top right). ADC maps for the same constellations (bottom).

Results

The upper panel of Fig. 1 shows the signal magnitude maps, acquired with the FLASH sequence, of a phantom with two rods, comparing parallel and orthogonal positioning of the rods with respect to the background magnetic field. Clearly, the rods oriented perpendicularly to the field cause stronger artefacts than those oriented parallel. The field gradients caused by the rods are small in the middle of the phantom. On the other hand, the Apparent Diffusion Coefficient (ADC) map of the phantom (lower panel of Fig. 1) shows some imaging artefacts but demonstrates that the measured ADC is nearly homogeneous between the rods. A quantitative analysis is given in Fig. 2 for a phantom containing the basket and a screw, where the relative error Δb/b is shown as calculated from a phase map and compared to its value obtained directly from the ADC map. Errors appear to be very well localized except for some imaging artefacts in phase direction caused by the screw, which can be seen on the ADC map.

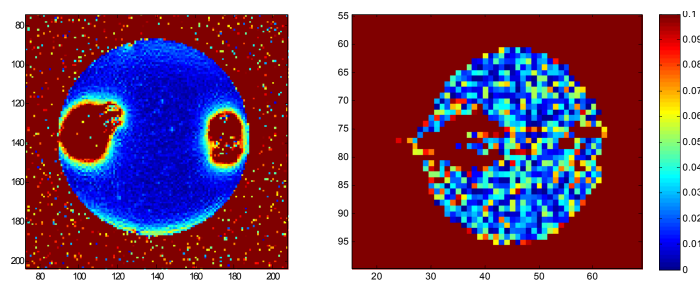

Fig. 2: Color maps of the shift Δb/b caused by the magnetization of the rods calculated from the phase map (left) and the ADC map (right) in a phantom containing a screw and the basket of the implant.

For the case of an orthogonally placed rod, expressions for the susceptibility induced field are well known. We fit the measured magnetization and obtain $\chi=156*10^{-6}$, while a direct measurement (Kirchhoff-Institut für Physik, Heidelberg) gives $\chi=188*10^{-6}$, thus, it can be assumed that the total magnetization is well described by the static expressions. These are then used to estimate the shift as a function of distance and b-value. As a model geometry we have chosen the worst case scenario of an infinitely long titanium cylinder placed orthogonal to the background field, with a radius of 1.5 mm (left) and 5 mm (right). In both cases the shift Δb/b is under 10% at distances of less than 1cm.

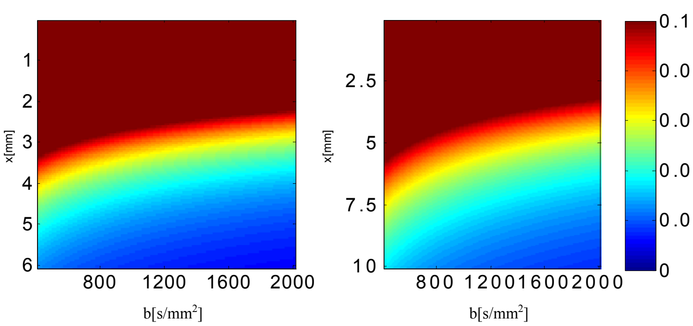

Fig. 3: Maps of the shift Δb/b as function of the distance from the object and the b value. We show magnetization in z-direction of an infinitely long cylinder placed orthogonal to the background field with radiuses of 1.5mm (left) and 5mm (right).

Discussion

These initial measurements suggest that diffusion measurements of the spinal chord in close proximity of spinal implants are feasible. In order to consolidate these results, further measurements of the complete implant, comparisons with a larger number of implants and in vivo measurements are required.

References

[1] Beaulieu, NMR Biomed 2002 [2] F. Laun, PhD Thesis [3] F. Laun et al, ZMP 2009