Simulations of SNR Efficiency of DTI Using Parallel Imaging and rFOV Acquisition at 3 T and 7 T

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Introduction

Diffusion tensor imaging (DTI) is a powerful, non-invasive technique to study white matter structure in the human brain in vivo. Compared to other MR imaging techniques DTI suffers from an intrinsically low SNR. Consequently, great potential arises from ultra-high field scanners through the associated SNR gain. Yet, DTI at 7 T is hampered by increased B_0 inhomogeneity and faster T_2 decay.

Typically, image acquisition relies on single-shot EPI which achieves relatively high SNR and is fairly robust against physiological motion. Critical shortcomings of EPI image quality are susceptibility related artifacts which scale linearly with the magnetic field strength. To minimize these artifacts, several acquisition methods have been proposed which aim for a reduction of the echo train length. Among these are partial Fourier and reduced FOV (rFOV) acquisition [1, 2] as well as parallel imaging (PI) methods [3, 4].

In the present work, simulations were performed in order to investigate under which conditions the SNR gain at ultra-high field strengths can be tapped, provided that higher reduction factors have to be applied to account for the increase of susceptibility related distortions. For this purpose, SNR efficiency at 3 T and 7 T was calculated and compared for different rFOV sizes and reduction factors.

Methods

SNR efficiency was calculated according to (adapted from [5]):

$$SNR \propto B_0 \cdot e^{-TE/T_2} \cdot \sqrt{T_{Train}} \cdot \sqrt{f_{corr}} \,/\, g$$

The first term accounts for a *linear* increase of the SNR with the main magnetic field strength, the second for signal reduction due to spin relaxation. T_2 relaxation times in white matter were set to 69 ms [6] for 3 T and 53 ms for 7 T, respectively. T_2 at 7 T was derived from spin-echo experiments with varying echo times. The echo times (TE) and the echo train lengths (T_{Train}) were computed as a function of the rFOV size and the reduction factor, thereby accounting for the SNR loss per shot caused by the shortening of the readout train when rFOV acquisition or PI were applied. In terms of SNR efficiency the actual SNR loss, however, is smaller since the acquisition time is likewise reduced, so that more signal averages can be acquired in the same timeframe. This was incorporated through the correction factor f_{corr}. The same gradient performance was assumed on both systems. The last term finally incorporates the g-factor penalty in the case of PI acquisition [7]. Mean and maximum g-factor maps at 3 T and 7 T were derived experimentally in a volunteer for various FOV sizes and reduction factors. The 3 T system was equipped with an 8-channel, the 7 T system with a 16-channel receive-only head coil array. Reduction was performed along the AP direction. The relative SNR efficiency at 7 T compared to 3 T was analyzed for a scan with the following parameters: FOV = 200 mm, acquisition matrix = 200, b-factor = 1000 s/mm^2, partial Fourier encoding of 60 %.

An image acquired at 7 T with the same rFOV size and reduction factor as at 3 T features considerably stronger image warping and signal pileup due to the linear increase of B0 inhomogeneity with the magnetic field strength. Thus, to ensure comparable image quality in terms of susceptibility related artefacts, 7/3-times higher reduction factors were used at 7 T. Therefore, to every SNR value at 3 T the corresponding value at 7 T with the same FOV size but a 7/3-times higher PI reduction factor was assigned. The 7 T SNR map is effectively compressed in this step.

Results

Figure 1 shows the dependence of the mean g-factors on the rFOV size and the reduction factor. As predicted in recent theoretical work, a greater range of PI acceleration factors is feasible at 7 T [8]. The introduction of large coil arrays will increase this range further in favor of higher field strengths. Figure 2 shows the relative SNR map of 7 T compared to 3 T. Despite stronger T2 decay SNR at 7 T is always higher than at 3 T. As explained above, two images acquired with the same combination of rFOV size and reduction factor will feature significantly different image quality though. Fig. 3 shows the relative SNR taking increased susceptibility into account. There are two regions where SNR at 7 T is higher than at 3 T. Images acquired in region 1 will feature strong susceptibility artifacts which abate with increasing reduction factor and decreasing rFOV size, however, SNR gain will drop simultaneously. The transition to region 2 occurs for rFOV sizes of 40 mm at a reduction factor of 4.5 and for rFOV sizes of 180 mm at a reduction factor of 9. The corresponding mean g-factors at 7 T are 3.3 and 4.2, respectively. At these g-factors image quality will be deteriorated due to spatially inhomogeneous noise amplification.

Discussion and Conclusion

The simulations show that due to the linear increase of susceptibility distortions with field strength and the resulting need of higher reduction factors at 7 T it is in practice difficult to achieve the potentially available SNR gain. However, higher reduction factors than in the present study without pronounced noise amplification can be reached, sufficiently large coil arrays provided [8]. Moreover, more than a linear increase of SNR with field strength has been reported [9].

Some effects have not yet been taken into account in the present work. Firstly, increased B1 inhomogeneity at higher field strengths causes a spatially varying SNR. Moreover, due to an increased SAR level at 7 T, pulse duration is usually prolonged, leading to an increased TE (on our system presently 2.4 ms). This increase strongly depends on the nature of the applied pulse pair and cannot generally be quantified. Finally, enhanced through-plane B0 dephasing has not been incorporated.

References

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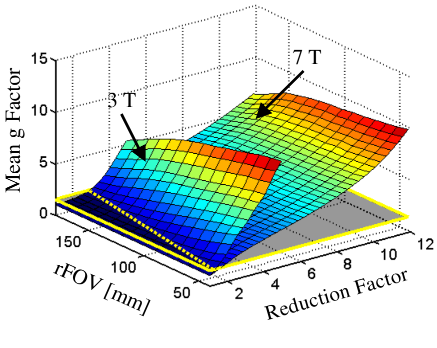

Fig. 1: Maps of mean g-factors at 3 T and 7 T. The gray plane was set arbitrarily to a g-factor of 1.5.

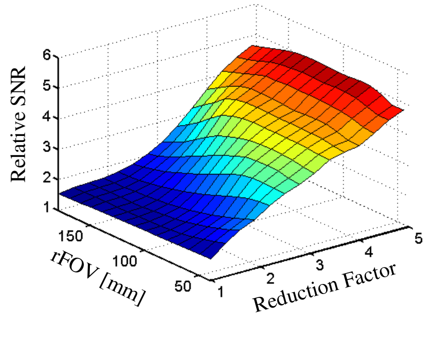

Fig. 2: Relative SNR (SNR_{7T}/SNR_{3T}): Without correcting for linearly increased susceptibility SNR at 7 T always exceeds SNR at 3 T.

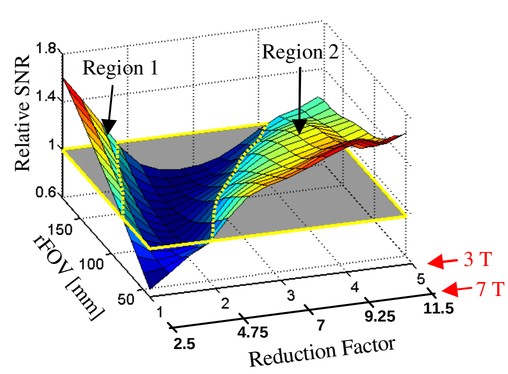

Fig. 3: Relative SNR (SNR_{7T}/SNR_{3T}) corrected for increased susceptibility: For all points that lie above the yellow-bordered plane SNR at 7 T increases SNR at 3 T.