The Diffusion Sensitivity of Turbo Spin Echo Sequences Significantly Depends on the Relaxation Times and Diffusion Coefficient

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INTRODUCTION

Recent work showed that 'modern' types of fast / turbo spin echo sequences (FSE/TSE) using low and varying refocusing flip angles and strong gradients (high resolution) such as SPACE, VISTA, and CUBE have an inherent diffusion sensitivity b_{eff} [1], which can generate participating diffusion contrast in the image [2]. The current work demonstrates that these b_{eff} are not sequence-specific constants, on the contrary, they notably depend on the relaxation times and T_2 in particular, as well as on the diffusion coefficient. Thus, TSE inherent diffusion sensitivity significantly depends on the tissue, which is also valid for TSE based preparation schemes such as the superstimulated echo mechanism [3,4], as is also shown below.

METHODS

Inherent diffusion sensitivities b_{eff} of TSE sequences cannot be solved analytically, thus, a published extended phase graph approach via signal intensities was employed [5]. It defines b_{eff} via the net signal damping experienced by diffusion effects [5]: $I(D)=I_0*\exp(-b_{eff} D)$ with $I_0=I(D=0)$. In this strict form, which may seem obvious at first glance as being the net diffusion damping, infinite relaxation times are presumed without saying. Thus, the second more accurate signal expression accounts for relaxation in the way that $I=I(T_1,T_2,D)$ and $I_0=I(T_1,T_2,D=0)$. – The corresponding TSE signal intensities I are calculated for each echo N to give $b_{eff}(N)$ with and without relaxation.

For the simulation of SPACE imaging, an isotropic $(0.6mm)^3$ protocol was presumed: FOV=220x220mm^2, 384 slices, BW=620Hz/px, TE=422ms, ESP=4.22ms, duration RF_{refoc}=0.7ms, duration RF_{exc}=0.4ms.

For diffusion encoded superstimulated echo preparations a TRAPS based approach according to [3,4] was used. Three and four preparation pulses were used that merely serve as the examples #1 to #4.

RESULTS

Figure 1 depicts the effective diffusion sensitivity b_{eff} of a SPACE sequence in dependence of the echo number N, using a typical refocusing flip angle schedule (*top left*). As was already noted [1], noticeable diffusion sensitivity b_{eff} accumulates along the echo train (*top right*). However, b_{eff} considerably depends on the diffusion coefficient and therefore tissue, as can be seen by comparing CSF with WM/GM, the latter both demonstrating the same isotropic diffusion coefficient. Furthermore, including relaxation effects shows that the resulting 'real' b_{eff} vastly drop for tissues with low T_2 such as WM and GM (*bottom right*). The data also differs between WM and GM to a minor degree then. CSF remains almost unchanged. The importance of considering relaxation effects is underlined by calculating the relative error RD-NR if relaxation is neglected (*bottom left*).

The observations of Fig. 1 are of a more general nature inherent to TSE based sequences and preparations: The same is true for 2D TSE sequences with low flip angles (not shown) and for superstimulated echo preparations as demonstrated in Fig. 2. The calculation of effective b-factors for four such preparations reveals pronounced differences for WM whether relaxation is ignored or not (*left*), whereas relaxation effects for CSF are completely negligible again. However, the different results for WM and CSF omitting relaxation also demonstrate a dependency on the diffusion coefficient.

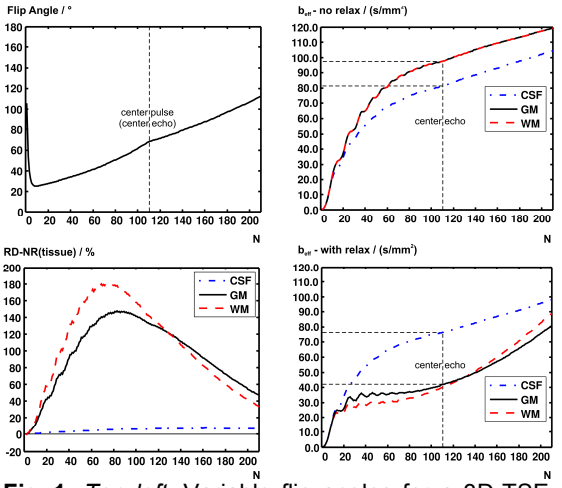

Fig. 1: *Top left*: Variable flip angles for a 3D-TSE sequence with extended echo trains (SPACE, VISTA, CUBE …). *Top right*: Resulting inherent diffusion sensitivity b_{eff} accumulating along the echo train dependent on echo number N, omitting relaxation. *Bottom right*: Determination of b_{eff} including tissue relaxation times. The results are vastly different, particularly due to different and low T_2. *Bottom left*: Resulting b_{eff} deviation if neglecting relaxation (RD-NR) for each echo, which underlines the findings.

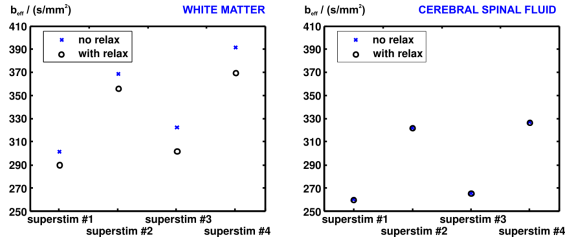

Fig. 2: Diffusion sensitivities b_{eff} exhibited by four different examples of TSE based superstimulated echo preparation schemes. *Left*: Results for WM display the same strong dependency on the relaxation times, whereas the effect is tiny for CSF (*right*). The different no relax values depict the additional dependence on the diffusion coefficient.

DISCUSSION AND CONCLUSION

Modern TSE sequences with low and varying flip angles may have an inherent diffusion sensitivity b_{eff} that cannot be neglected anymore [1]. Here, it was shown that these b_{eff} are not a sequence-specific constant anymore, they depend markedly on the T_1 and T_2 relaxation times as well as on the diffusion coefficient D (Fig. 1). Hence, TSE sequences demonstrate a tissue-specific diffusion contrast, which becomes non-negligible for sequences such as SPACE. This finding is more of a general nature such that TSE based preparation schemes like superstimulated echoes [3,4] display the same behavior (Fig. 2). Thus, b-factors for TSE based sequences and preparations are only well defined if the corresponding tissue is specified.

REFERENCES

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