The Influence of Trapezoidal Gradient Shape on the b-factor of Hyperecho Diffusion Weighted Sequences

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Motivation

Diffusion weighted Hyperecho (HEDW) Imaging [1-3] has maintained some interest during the last years since it has the potential to offer a probe for tissue microstructure. One meaningful parameter for such a multi spin echo diffusion sequence is the knowledge of the exact effective b-factor [4] exhibited. The present work examines the effect of the common simplification to use rectangular instead of 'real' trapezoidal gradients in the quantitation of b for HEDW imaging.

Methods

The effective b-factor of a HEDW preparation scheme of 90° - grad/2 - $[\alpha$- grad$]_4$ - 180° - [grad - $(-\alpha)]_4$ - grad/2 – Hyperecho was simulated using the extended phase graph (EPG) calculus. To investigate the impact of rectangular versus trapezoidal gradient shapes on b, the dependency of b on flip angle α and the ratio of ramp times rut and rdt to the flat top time ftt was determined for different parameter combinations. α was varied from 0° to 180°. While the ramp up time rut of 0.25 and 0.5 ms was kept constant, the flat top time ftt of the trapezoidal gradient was varied. Fixed parameters were gradient amplitude G=25 mT/m and echo spacing ESP=10 ms. The rectangular gradients were in an equal-area, equal-amplitude relation to the trapezoidal gradients and all gradients were always centered between the adjacent refocusing pulses.

To assess deviations between the resulting b-factors, absolute differences $\Delta b_{abs} = (b_{rect}-b_{trap})$ and relative changes $\Delta b_{rel} = \Delta b_{abs}/b_{rect}$ were evaluated.

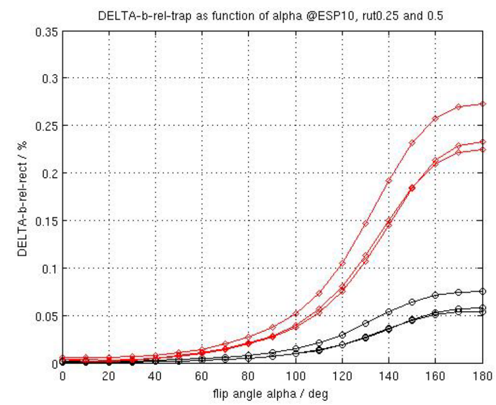

Fig. 1 Δb_{rel} as a function of α

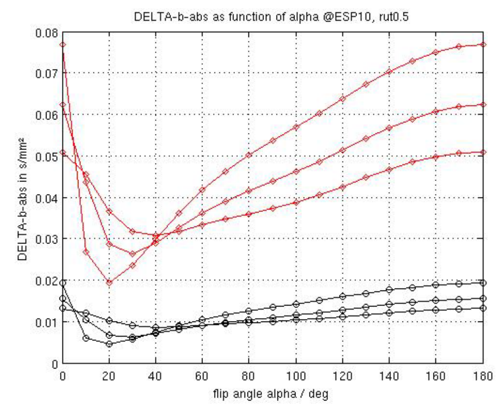

Fig. 2 Δb_{abs} as a function of α

Results

The resulting relative (Fig. 1) and absolute (Fig. 2) b-factor changes show a general dependency on alpha, ftt, and rut (rdt). The relative b-factor difference Δb_{rel} in Fig. 1 increases monotonously with applied α from 0.003% to 0.270% (rut= rdt = 0.5 ms, red curve) and from ~0% to 0.060 % (rut = rdt = 0.25 ms, black curve), respectively. Maximal ftt yields highest values of Δb_{abs} and lowest of Δb_{rel}. With ascending ratio of ftt to rut (rdt), Δb_{rel} drops, whereas Δb_{abs} increases.

The observed absolute b-factor differences Δb_{abs} are very small, they range between 0.02 to 0.08 s/mm² (rut = rdt = 0.5 ms, red curve) and from 0.005 to 0.019 s/mm² (rut = 0.25 ms, black curve), respectively.

For all simulations, the rectangular gradient showed a higher b-factor b_{rect} compared to the trapezoidal gradient b_{trap}.

Discussion

HEDW sequences display a complex signal response compared to conventional Stejskal-Tanner-sequences. This study focused exclusively on the net diffusion weighting / effective b-factor and, thus, omits additional relaxation effects that can also lead to an improved SNR for HEDW preparations, for instance, as shown in Ref. [3].

The present work investigated the influence of simplified rectangular gradient shapes for the quantitation of effective b-factors in HEDW preparations. It could be shown that this commonly used simplification is more than justified for realistic experimental settings where a high ratio of ftt to rut (rdt) occurs. The negligible differences found here may be explained by the fact that the b-factor integral demonstrates a cubic dependence on the gradient duration and, thus, the effective ratio ftt to rut (rdt) also shows a cubic behavior. However, the difference between trapezoidal and simplified rectangular gradient shapes may become noticeable for cases were either longer ramp times are desired, e.g. to avoid stronger eddy current effects, or low b-factors are needed, e.g. for the quantitation of diffusion tensors via non-vanishing b values, i.e. no measurement of images with b=0.

References

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[2] Hennig et al. MRM 46 (2001) 6
[3] Frank et al. MRM 49 (2003) 1098
[4] Il'yasov et al. AMR 29 (2005) 107