# Effects of slab boundary artifacts on diffusion measures in 3D multi-slab diffusion imaging

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**Purpose**:

Multi-slab 3D imaging has potential for achieving robust, high-resolution diffusion data. Its compelling features include compatibility with the optimal TR in terms of SNR efficiency (1–2 s), ability to achieve thin slices and robust 2D navigator correction[1-4]. However, multi-slab acquisitions suffer from artifacts at slab boundaries, with higher signal at the slab center than at the slab boundary. If these effects were purely multiplicative, they would not propagate into diffusion measures after normalization by a b=0 reference image; however, several studies have demonstrated slab boundary artifacts in diffusion tensor metrics (Fig. 1). In this study, we aim to investigate how saturation, partial volume and static field inhomogeneity affect slab boundary artifacts and may alter diffusion tensor measures (ADC and FA).

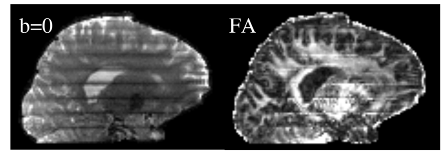


Fig. 1. Slab boundary artifacts in b=0 image and FA map

**Methods**:

Bloch simulations considered a multi-slab acquisition covering 8 slabs, 10 slices per slab, 20% overlap and interleaved excitation. Unless otherwise specified, simulations used twice-refocused SE, TR/TE=2500/71ms, SLR pulses for 90°/180° with TBW=20/8 and duration 7.16/11.52ms. ***Saturation effects.*** To generate detailed slab profile simulations, we assumed T1/T2 values at 3T: WM 840/70ms, GM 1320/110ms, CSF 3000/2000ms. ***Partial volume model.*** A primary aim of this work is to examine partial volume contributions to residual slab boundary artifacts in diffusion metrics. We therefore simulated signal using a partial-volume model that in general included CSF, WM and GM compartments. ADC calculations included all three compartments while FA calculations considered only pairs of tissue types. Diffusion coefficients for each tissue type were as follows: $D_{CSF}$=3.0 um$^2$/ms, $D_{GM}$=0.7 um$^2$/ms, $D_{WM}$ =1.4/0.35 um$^2$/ms (parallel/perpendicular). For FA calculations, a standard set of 6 directions was assumed. ***B0 inhomogeneity.*** The slab profile is sensitive to B0 inhomogeneity, especially when the bandwidth of excitation pulse ($BW_{90}$) and refocusing pulse ($BW_{180}$) are not matched, so we simulated slab profiles at different off resonance frequencies with $BW_{90} = BW_{180}$ and $BW_{90} = 4\times BW_{180}$.

**Results:**

***Saturation effects.*** Fig. 2 (a) and (b) show the simulated slab profile without/with saturation effects from slab crosstalk. The signal amplitude is much lower at slab boundary due to the saturation effects. Fig. 2 (c) shows the difference between (a) and (b). With an interleaved acquisition, the repetition time of excitation at two ends of the slab is not identical, resulting in an asymmetric slab profile. Fig. 2 (d) shows combined slab profiles across the 3D volume (concatenated after discarding upper- and lower-most slice for each slab[3]), demonstrating tissue- and slab-specific saturation effects (the latter due to the interleaved excitation scheme).

***Partial volume results*** Fig. 3 shows the relative error in ADC and FA between slab centre and slab boundary from the partial volume model. Both the ADC and FA vary with slice location (not shown), with relative error that depends on the partial volume ratio of the tissues. Relative errors in ADC are on the order of a few percent when the fraction for either CSF or WM is very low (regardless of GM fraction), but increase to ~10% when WM and CSF are roughly evenly mixed, in which case maximal error reaches ~14%. The relative error of FA value is higher than for ADC (up to 20-30%), especially when the WM fraction in one voxel is low.

***B0 inhomogeneity.*** Fig. 4 shows the slab profile as a function of off-resonance frequency. When $BW_{90} = BW_{180}$, the slab profile is only shifted with the shape unchanged. However, when $BW_{90} \neq BW_{180}$, the slab profile is shifted and distorted by B0 inhomogeneities, introducing more signal loss at slab boundaries.

**Discussion and conclusions:**

In multi-slab imaging, slab boundary artifacts are modulated by many factors, including saturation, partial volume and B0 inhomogeneity, as shown here. The result is that these artifacts may not be effectively normalized by b=0 images and errors can propagate into diffusion quantification. In an accompanying abstract, we present a method for removing these artifacts in image reconstruction through joint estimation of the slab profile and underlying image.

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**Reference:** 1. M Engström et al., MRM, 2013. doi: 10.1002/mrm.24594. 2. Frost R et al., MRM, 2013. doi: 10.1002/mrm.25062. 3. M Engström et al., MRM, 2014. doi: 10.1002/mrm.25182. 4. Van AT et al., MRM, 2014. doi: 10.1002/mrm.25169.

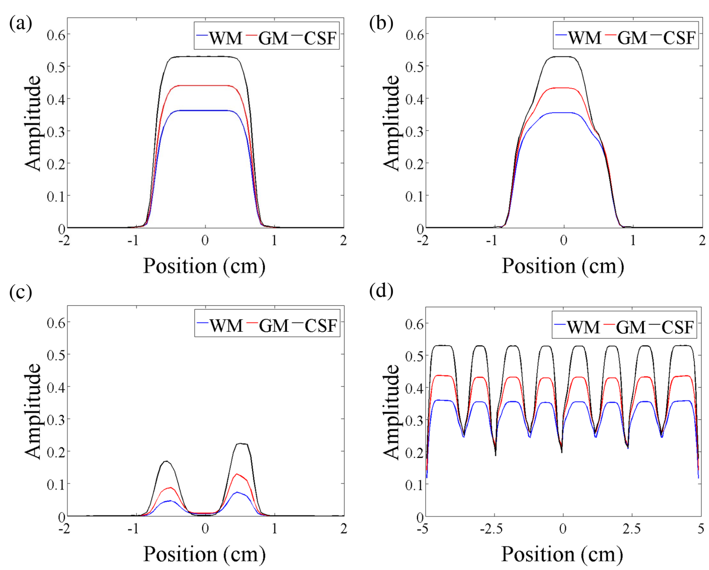


Fig. 2 Simulated slab profile. a) Profile of one slab without slab crosstalk. b) Profile of one slab with slab crosstalk. c) Difference between a) and b). d) Multi-slab profile after combination.

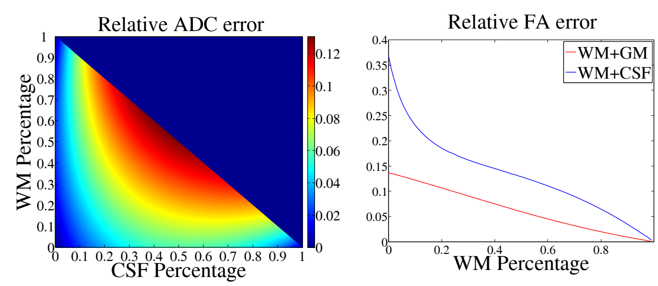


Fig. 3 Left: relative ADC error as a function of WM and CSF percentage. Right: relative FA error as a function of WM percentage

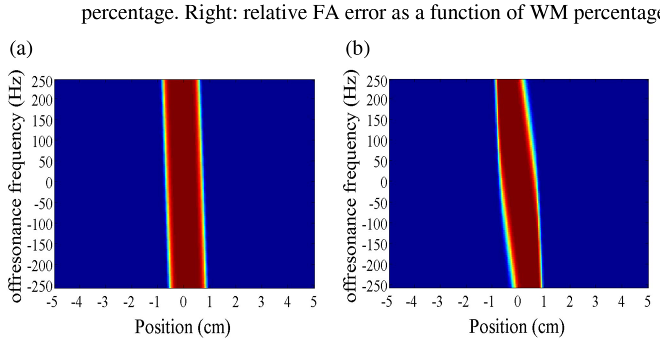


Fig. 4 Slab profile at difference off-resonance frequencies. a) $BW_{90} = BW_{180}$. b) $BW_{90} = 4\times BW_{180}$.