Slab Profile Encoding for Minimizing Venetian Blind Artifact in 3D Diffusion-Weighted Multislab Acquisition

Anh T Van[1], Murat Aksoy[1], Samantha J Holdsworth[1], Daniel Kopeinigg[1], Sjoerd B Vos[2], and Roland Bammer[1]

[1]*Radiology, Stanford University, Palo Alto, CA, United States,* [2]*Image Sciences Institute, University Medical Center Utrecht, Utrecht, Utrecht, Netherlands*

TARGET AUDIENCE – Researchers interested in diffusion imaging, multislab acquisition, and venetian blind artifacts.

INTRODUCTION – Multislab 3D acquisition has recently been proposed as an efficient method for achieving high isotropic resolution diffusion-weighted imaging (1,2). However, imperfect RF pulse profiles give rise to signal dropout and aliasing in the slice direction (Fig. 1), which results in 'venetian blind' artifacts when reformatting the image in the slice direction. The current remedy to the 'venetian blind' artifacts is oversampling in the slice direction, overlapping adjacent slabs, and combining (averaging or cropping) overlapped slices in the reconstruction (1,2). Oversampling lengthens scan time, and overlapping worsens the spin history effects due to slab crosstalk. In this work, we introduce a novel reconstruction approach to mitigate 'venetian blind' artifacts by reconstructing all the slabs collectively using a SENSE-like method with the slab excitation profiles as the sensitivity maps. This approach requires minimal slab overlapping and no slice-direction oversampling. We call the method profile encoding (PEN).

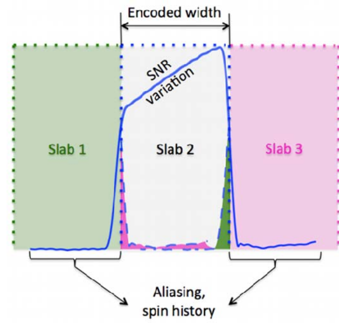

Fig. 1 *– Venetian blind artifacts.*

METHOD – *Reconstruction algorithm:* In a multislab acquisition with N_{slab} number of slabs, each with an excitation profile $S^{(l)}(r)$, individual slab image can be expressed as

$$I_k(z) = \sum_{l=1}^{N_{slab}} S^{(l)}\big(r(z)\big)\rho\big(r(z)\big) \qquad k = \overline{1,\ N_{slab}}, \qquad (1)$$

where $\rho(r(z))$ is the imaged object, z is the location in the slice direction within each slab ($0 < z < \Delta z$, Δz is the encoded slab thickness), and $r(z)$ is the location in the slice direction within the imaged object that aliased to location z in the considered slab ($0 < r(z) <$ FOVz, FOVz is the full field of view of the object in the slice direction). Eq. [1] is essentially the equation for an algebraic reconstruction similar to Cartesian SENSE in image space where $I_k(z)$ is the individual undersampled coil image, $S^{(l)}(r)$ is the coil sensitivity and $\rho(r)$ is the unaliased full field of view (FOV) image. Writing Eq. [1] in vector form for all slabs gives

$$\begin{bmatrix} I_1(z) \\ \vdots \\ I_{N_{slab}}(z) \end{bmatrix} = \begin{bmatrix} S^{(1)}\big(r_1(z)\big) & \cdots & S^{(1)}\big(r_{N_{slab}}(z)\big) \\ \vdots & \ddots & \vdots \\ S^{(N_{slab})}\big(r_1(z)\big) & \cdots & S^{(N_{slab})}\big(r_{N_{slab}}(z)\big) \end{bmatrix} \begin{bmatrix} \rho\big(r_1(z)\big) \\ \vdots \\ \rho\big(r_{N_{slab}}(z)\big) \end{bmatrix}. \quad (2)$$

In short, $\mathbf{I}(z) = \mathbf{S}\rho(\mathbf{r}(z))$. Therefore, the reconstructed unaliased pixels in the final image corresponds to location z in the individual slab images can be estimated by

$$\hat{\rho}\big(\mathbf{r}(z)\big) = \big(\mathbf{S}^H\mathbf{S}\big)^{-1}\mathbf{S}^H\mathbf{I}(z). \quad (3)$$

Slab profile estimation: There are several ways to estimate the slab profile map: (i) Bloch simulation of the employed RF pulse and accompanied gradient waveforms; (ii) low resolution multislab scan with minimal oversampling in the slice direction (enough to cover the transition band and main ripples of the excitation profile) and conventional sensitivity map estimation for parallel imaging (divide individual slab images by the sum of squares of all slab images). The first method does not require an additional calibration scan but might compromise the reconstruction quality in the presence of B_1 or B_0 inhomogeneity and slab crosstalk. The second method requires a separate calibration scan but the estimated slab profiles reflect the B1 and B0 inhomogeneity and are therefore more accurate. For diffusion-weighted imaging which usually requires the acquisition of multiple diffusion directions, the added time for the calibration scan is minimal as compared to the time otherwise spend on oversampling and extending TR for reducing slab crosstalk (2).

Data acquisition: Phantom data were acquired to test the performance of the proposed algorithm. A 3D multislab spin echo EPI sequence was implemented on the GE MR750 system. Acquisition parameters were: 1.9x1.9x1mm^3, 24 slabs of 10 mm thick, 2 mm overlapping between adjacent slabs, no oversampling in the slice direction, TE/TR = 26/4000 ms. A low resolution calibration scan was used to estimate the slab profiles.

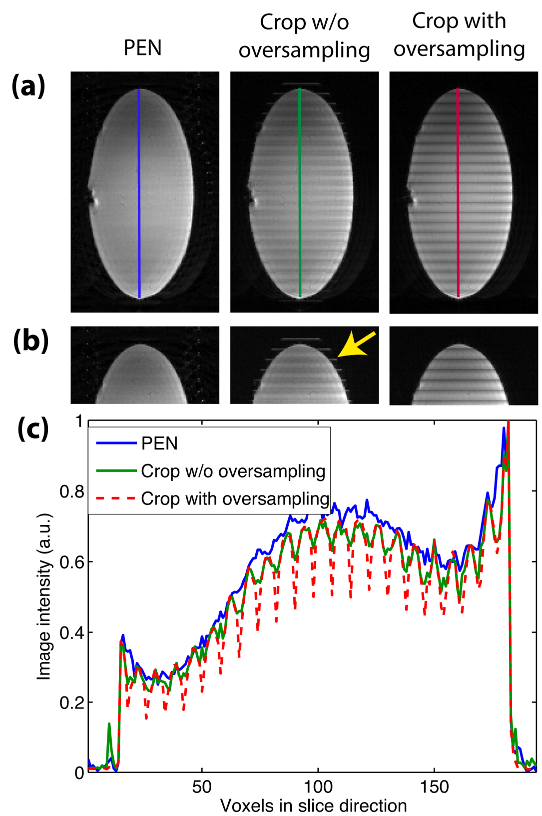

Fig. 2 *– (a) Slice direction reformat; (b) Zoom-in for aliasing artifacts; (c) Cuts (indicated by lines in (a)) through the slice direction.*

RESULTS & **DISCUSSION** – Fig 2(a) shows the slice direction reformatted images reconstructed with the proposed algorithm (left), conventional cropping of overlapped slices on data without (middle) and with (right) oversampling in slice direction (middle and right, respectively). The crop w/o oversampling image shows signal dropouts and slab aliasing (Fig 2(b), pointed by the arrow) at the slab boundaries. Oversampling in the slice direction removes the aliasing artifact but signal dropouts at the slab boundaries due to slab crosstalk and edge roll-off slab profile still remains. Due to aliasing and the homogeneity of the phantom, the crop w/o oversampling shows a more benign signal dropouts than the crop with oversampling. The PEN algorithm mitigates both the aliasing and signal dropout artifacts, giving a flat image. Figure 2(c) shows cuts through the slice direction of the reconstructed images. Cropping with and w/o oversampling result in ripples in the image profile with maximum ripple magnitudes of 20% and 5% of maximum signal, respectively. PEN gives a smoother image profile (as expected on a homogeneous phantom) than the other two methods.

CONCLUSION – By reconstructing all the slabs collectively using the proposed PEN method, venetian blind artifacts in multislab acquisition can be mitigated with minimum slab overlap and without the need of oversampling in the slice direction. A long TR has been used traditionally to mitigate slab crosstalk in spin-echo based 3D multislab acquisition. Since effect of signal dropouts due to slab crosstalk is embedded in the estimated slab profile, it is accounted for in the reconstruction. Therefore, for a spin-echo-based acquisition with PEN, it is no longer necessary to extend TR to mitigate the slab crosstalk, and a much shorter TR (~4000 ms) can be used, resulting in a highly SNR efficient acquisition.

References: [1] Van et al, ISMRM 2010 p. 1391; [2] Engstrom et al., ISMRM 2012 p. 117.

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