Signal Considerations in Slicewise Dynamic B0 shimming.

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INTRODUCTION

Dynamic Shimming (DS) improves B_o field homogeneity compared with global volume shimming (GS) by updating shim coil currents in real time [1, 2]. The most frequent approach for estimating slice-wise shim values in DS involves removing the redundancy of functionally degenerate shim terms from an in-plane field regression and assuming a linear through plane inhomogeneity profile [3]. This approach yields excellent in-plane inhomogeneity compensation but compromises intravoxel signal recovery in areas of nonlinear through plane inhomogeneities. Here, we present a slice-wise shim calculation method based on maximizing the voxel signal. We present signal simulations and *in vivo* T_2^* measurements comparing this method with conventional slice-wise and static GS methods.

METHODS

All studies were performed on a 7 Tesla whole body human MRI system (Philips Healthcare Inc, Cleveland, OH, USA). Slice wise storage and dynamic update of 2^{nd} order shims was performed using a separate shim control hardware module. ('*Load & Go Real Time Shims'*, Resonance Research Inc, Billerica, MA, USA).

Shim Simulations Fieldmaps were acquired using a multislice echo gradient recalled echo (GRE) scan for the whole brain (n=3, 25 axial slices, 64 x 64 matrix, slice thickness/gap = 3/1 mm, TR/ first TE/ΔTE = 196/4/1 ms) with all shims set to zero. Post-shim fieldmaps were simulated with 2^{nd} order DS with two different optimization routines and GS.

Conventional degeneracy approach (DS_DG) A non-degenerate shim subset was obtained by eliminating the in-plane functional redundancies of the 0^{th} through 2^{nd} order shim terms for any given slice. This set was used to calculate the in-plane corrections by multiple linear least squares fitting of the field offset values. Linear through plane corrections were estimated by fitting 3 slice in-plane shim residual fieldmaps centered on the target slice. The final residual fieldmaps were used to estimate the voxel-wise signal using the expression

$$|S| = \prod_{j}^{3} \Delta r_j \,\mathrm{sinc}\left(\pi TE\, \Delta r_j \frac{\partial f}{\partial r_j}\right) \quad (1)$$

where, $\partial f / \partial r_j$ gave the field gradients along *x, y* and *z* calculated using the nearest neighbor voxels, Δr_j gave the voxel sizes [2]. A maximum signal assuming the intravoxel gradients and TE to be zero was calculated as S_0.

Signal optimized approach (DS_SO) 2^{nd} order slice-wise shim values were calculated by minimizing the number of pixels in the slice of interest having $|S|/S_0$ as given in Eq. 1, less than 0.95. The optimization allowed non linear through plane correction thereby minimizing the intravoxel field gradients (and maximising the signal) rather than the absolute field offsets.

Global Shimming (GS). The 25 slice fieldmap volumes were fit to a full 2^{nd} order shim set in the least squares sense. Residual fieldmap volumes were calculated and Eq 1 was employed to yield slicewise $|S|/S_0$ maps.

***In vivo* T_2^* measurements** *In vivo* T_2^* measurements were performed with each of the above shimming methods to provide estimates of signal losses. A multiecho GRE sequence with the same image geometry as above was used for sampling the signal decay (64 x 64 matrix, TR/first TE/ΔTE = 723.0/1.4/3.0 ms, 8 echoes, voxel size 3.9 x 3.9 x 3 mm). Voxel-wise T_2^* maps were calculated by the scanner's built-in algorithm [4]. Post-shim fieldmaps were also collected to compare in-plane field improvements.

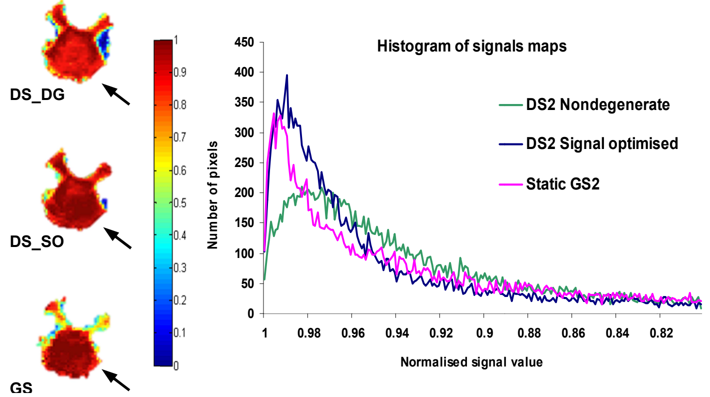

Fig.1 (a) Simulated $|S|/S_0$ map for one slice. DS_SO is predicted to considerably improve signal over DS_DG and GS. (b) Histogram of whole volume signal maps, showing greater number of voxels with higher signal with DS_SO.

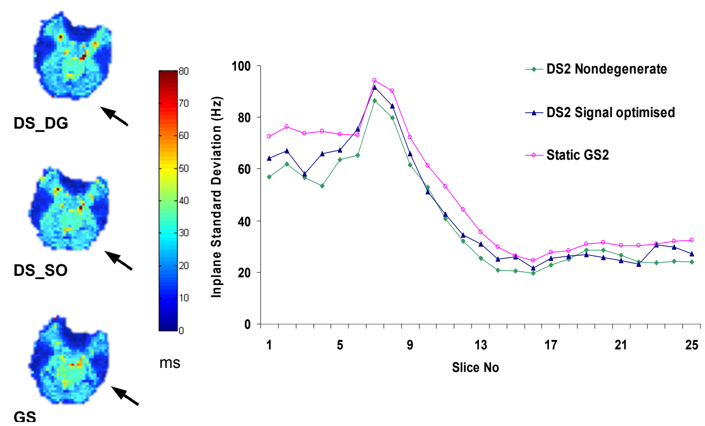

Fig.2 (a) T_2 maps for the slice in Fig 1. DS_SO shimming lends to higher signal recovery than DS_DG and GS. (b) Slice-wise in-plane field inhomogeneity (and hence distortion) is slightly elevated in DS_SO over DS_DG but still less than GS.*

RESULTS

Figure 1a shows simulated $|S|/S_0$ maps for a single slice for the three shimming techniques. The DS_SO technique with non-linear slice specific shimming predicts higher signal recovery compared to both the conventional slice-wise shimming and GS methods. This is quantified for the entire volume in the histogram of the signal maps shown in Figure 1b. T_2* maps shown in Figure 2a confirm the predictions of signal recovery. There is only a very slight cost in terms of increased in-plane inhomogeneity of the DS_SO over the DS_DG approach and DS_SO in-plane homogeneity is superior to that delivered by static GS (Figure 2b).

DISCUSSION

Estimating the slice specific shims in a manner that optimizes the intravoxel signal clearly improves signal recovery performance of DS. The largest benefits of adopting this approach will be seen in the inferior and frontal regions of the brain that have highly nonlinear inhomogeneity profiles. The penalty in slightly higher in-plane field offsets is acceptable in the context of ever increasing parallel imaging factors and improved distortion correction techniques. Global shim optimization by maximizing signal recovery has been presented earlier in the context of BOLD sensitivity [5]. Furthermore, in the setting of multi-slice MRSI, where through-plane inhomogeneity can become significant, the benefits of DS_SO may be even greater.

REFERENCES

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