Improved EPI at 7T with Dynamic Multi-coil Technique (DYNAMITE) Shimming

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INTRODUCTION: Echo-planar imaging (EPI) and its variants form the core of many functional and structural imaging studies. Image quality of these scans deteriorates drastically with increasing B_0 inhomogeneities. Although post-processing can correct aspects related to image distortion, the only way to prevent signal dropout is by improved shimming. Commonly, higher-order static spherical harmonic (SH) shims are used to address this issue. Further gains have been reported with dynamic SH shimming, wherein the shim settings are optimized on a per-slice basis and updated during imaging in a slice-specific fashion.[1] Recently, even better results were reported when dynamic shim fields were generated by an array of small individual coils placed around the subjects' head.[2, 3] In this study, we demonstrate that this dynamic multi-coil technique (DYNAMITE) leads to less distortion and reduced signal dropout in EPI of the human brain at 7 Tesla, in comparison with those acquired with SH shims.

METHODS: Five healthy volunteers aged 25-45 yrs (4 males) were scanned at 7 Tesla using EPI, multi-gradient-echo T_2^* mapping and B_0 mapping scans to assess the benefits of DYNAMITE, compared with 3rd order SH shimming. Correction fields for SH and DYNAMITE shimming were derived from a B_0 field map that was based on a whole-brain 2d multi-slice gradient-echo acquisition.[2] Under both shim conditions, the EPI images and T_2^* maps were acquired at 3 isotropic resolutions (3 mm, 2 mm, 1.56 mm) and at identical slice positions, with full brain coverage (13 axial slices, 20x20 cm^2 FOV and 9 mm slice spacing). The EPI images were obtained with TE= 30 ms, TR= 4.175 s, using single shot (3 mm isotropic, 16 averages), 2 shot (2 mm, 8 averages) and 4 shot (1.56 mm, 4 averages) sequences. The T_2^* data were acquired with 6 echo-times between 4 and 46 ms. The residual B_0 maps were also acquired using the same scan (5 echoes, inter-echo spacing of 2.5 ms) at 1.56 mm isotropic resolution and at the same slice positions as EPI and T_2^* maps. To compare EPI distortions under SH and DYNAMITE shims, an outline of the brain was derived from an anatomical reference image and overlaid on the EPI images. Average B_0 inhomogeneity and T_2^* were calculated globally and per slice.

RESULTS: Figure 1 shows the residual B_0 inhomogeneities and the corresponding single shot and four shot EPI images of two example slices from one of the subjects (with overlaid brain boundaries). We find substantial residual B_0 variations with SH shimming (mean/SD of 33/49 Hz and 17/24 Hz for the top and bottom slices, respectively) in comparison with DYNAMITE (11/17 Hz and 8/13 Hz, respectively). We observe significant distortion and signal voids in EPI images with SH shimming (more in 1-shot than 4-shot) in the Posterior-Anterior direction (see arrows; different colours denote opposite directions of the distortion), in comparison with DYNAMITE. Similar improvements were observed in all the datasets and across brain regions. These results are corroborated by our B_0 mapping results and histogram analysis of T_2^* maps (results not shown).

DISCUSSION: We observe that B_0 homogeneity can be substantially improved by using DYNAMITE instead of SH shims. This leads to significant improvement in EPI image quality (reduced distortion and signal drop-out) without the need for distortion correction. This is desirable for functional MRI and structural EPI scans at high fields.

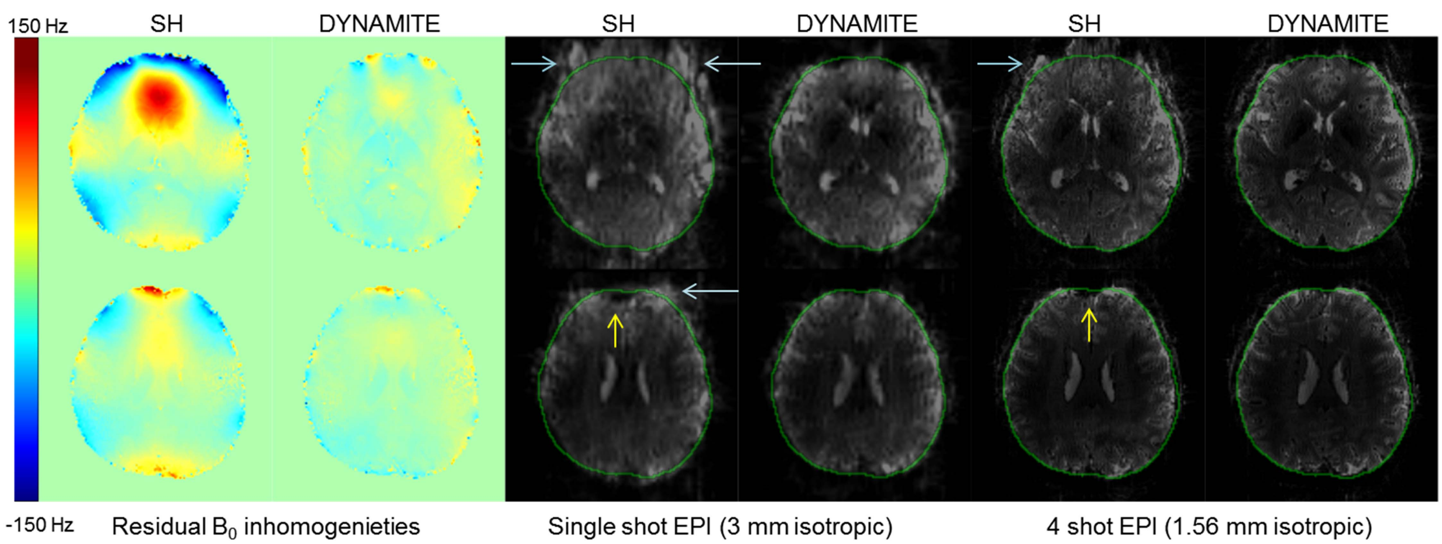

Fig. 1: Residual B_0 inhomogeneities and EPI images from a volunteer scanned at 7 Tesla using SH (3rd order static spherical harmonic shimming) and DYNAMITE (dynamic multi-coil technique-based shimming) approaches. White arrows point to EPI distortions in the Posterior-Anterior direction and yellow arrows indicate the Anterior-Posterior pixel shifts.

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[1] Concepts Magn Reson. 37B:116-128 (2010); [2] J Magn Reson. 212:280-288 (2011); [3] J Magn Reson. 236:95-104 (2013).