# Slice overlapping for reduction of EPI susceptibility artefacts

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**Introduction** Magnetic susceptibility artefacts are exacerbated at high field. Blurring worsens due to quicker T2* decay during the readout; geometrical distortion and drop-out also increase. Partially parallel imaging (PPI) methods based on array-coils [1-3] ease these problems by reducing the number of phase encoding steps collected in each readout. Conventional interleaved EPI schemes [4] simply split the collection of the full k-space data in several acquisitions though the combination of data in k-space is prone to ghosting and particularly sensitive to subject motion and flip angle inhomogeneities; when collecting the data in 2 separate shots there may be substantial loss in temporal resolution. Our method is similar to interleaved EPI in that involves the collection of 2 half length readouts. However the required data can be collected very rapidly and combined in image domain using algorithms borrowed from SENSE. Combination of our method with PPI is straightforward.

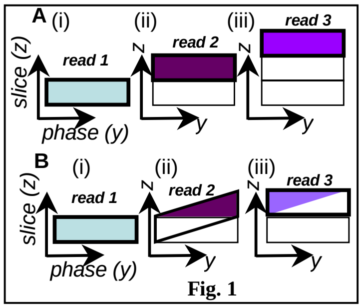

**Fig. 1**

**Theory** In a conventional acquisition scheme slices are stacked along the slice direction (e.g., z) and subsequent ones separated by (at least) the slice thickness (*slth*) (see Fig. 1A). In our method (henceforth referred as OS, for 'overlapping slices'), depicted in Fig 1B, alternate slices are tilted by an angle $\theta = atan(slth/FoV)$, and shifted along z by just *slth/2*. Given the previously excited volume is saturated, at each acquisition signal is only collected from a wedge shaped profile corresponding to half a conventional slice. Assuming little through-slice inhomogeneity (the validity of such assumption increasing with reduced *slth*), the signal intensity in each OS image across the phase encode (pe) direction (y) can be written as $I_k(y) \sim \rho(y) * S_k(y)$ *[eq. 1]* where the index k (=1,2) relates to the 2 complementary acquisitions, $\rho(y)$ is the spin density at position y and $S_k(y)$ is the equivalent of the coil sensitivity function in SENSE. For full-FoV acquisitions, the sum of two complementary OS images (e.g. from readouts 2 and 3 in Fig. 1B) corresponds to the image from a conventional rectangular slice (e.g. from readout 2 in Fig. 1A). For EPI artefact reduction, each OS dataset is acquired at half-FoV, hence halving the number of required phase encoding steps (Npe). Full-FoV images can be reconstructed as in SENSE from eq. 1 given that the 'sensitivity matrix' S is known (given perfect slice excitation profiles, $S_1(y)=y/FoV_y$, and $S_2(y)=1-S_1(y)$, though these can be measured as the ratio of an OS slice and a conventional slice acquired at full-FoV). The 'geometry factor' associated with image reconstruction has been calculated to vary from $\sqrt{2}$ at the edges of the FoV to 2 in the centre of the image.

**Methods and Results** MR imaging was performed on a 4.7T whole body scanner (MR5000, provided by Philips) with a standard birdcage head coil and head gradient set. The OS sequence was implemented as described above for both 2DFT and EPI. For improved saturation, sinc 90° pulses were used in combination with spoiler gradients following each readout and all delays were removed between subsequent excitations. Fig. 2 shows spin echo 2DFT OS image as well as a conventional image of a human brain; parameters were: *TR/TE*=1.0s/40ms, *FoV* =240mm, *slth*=3mm; Npe=96 for full-*FoV* and 48 for half-*FoV* images. Although a signal to noise loss is apparent, the OS full-*FoV* image (Fig. 2c) obtained from the half-*FoV* images in (Fig. 2a/b) matches closely the conventional image (Fig. 2c) with little sign of artefacts, though some loss in SNR is apparent. Fig. 3 shows examples of OS and conventional gradient echo (*GE*) EPI images. Parameters were *TR/TE*=3.5s/20ms, *FoV*=200mm, *slth*=4mm; Npe=64 for full-*FoV* images and 32 for half-*FoV* OS images (not shown); data matrix was 100x64 (sinusoidal read gradients) interpolated to 64x64. With respect to the conventional 1-shot EPI, reduced distortion is apparent in the 2-shot EPI image, though the total acquisition time is double in the latter. In the 1-shot image the stretch in the frontal lobe regions tends to mask the drop-out so that a positive signal is produced in the '1-shot–2-shot' image. The TWIST EPI image shows similar distortion reduction as the 2-shot EPI, with the additional advantage of recovering most of the signal in the inferior frontal lobes and having been acquired in half the time.

**Discussion & Conclusion** The OS concept has been demonstrates on human volunteers with 2DFT and EPI methods. The OS method only requires limited changes to pulse sequences and should be easily implementable on any MR scanner. Using OS-EPI, geometric distortions introduced by susceptibility variations across an imaged slice and blurring due to signal decay during the readout are reduced due to the halving of the effective readout time. In this respect, the reduction in image distortion is similar to that achievable with 2-shot interleaved EPI, though without the potential ghosting problems and time-resolution loss. Additionally, in OS-EPI, through-slice image drop-out is also substantially reduced because of the smaller local effective slice thickness in the individual wedge-shaped half-*FoV* images: these advantages may well compensate for the SNR loss of the OS images. Indeed, a pilot OS-fMRI study (single subject, conventional visual stimulus, 4.7T) indicated no significant difference in activation between conventional EPI and OS-EPI (data not shown). The OS approach may be easily combined with PPI or partial Fourier techniques for greater reduction in susceptibility artefacts or when higher spatial resolution is sought. OS-EPI promises to be particularly useful at high static magnetic fields where susceptibility artefacts are exacerbated and increased $B_1$ inhomogeneity causes larger flip angle variations.

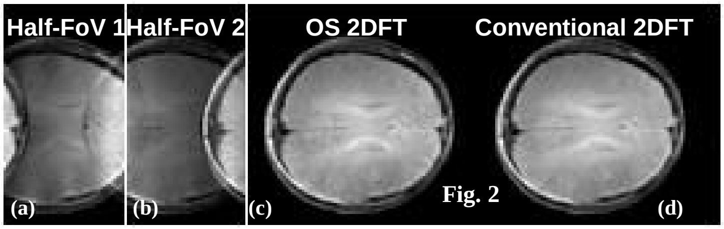

**Fig. 2**

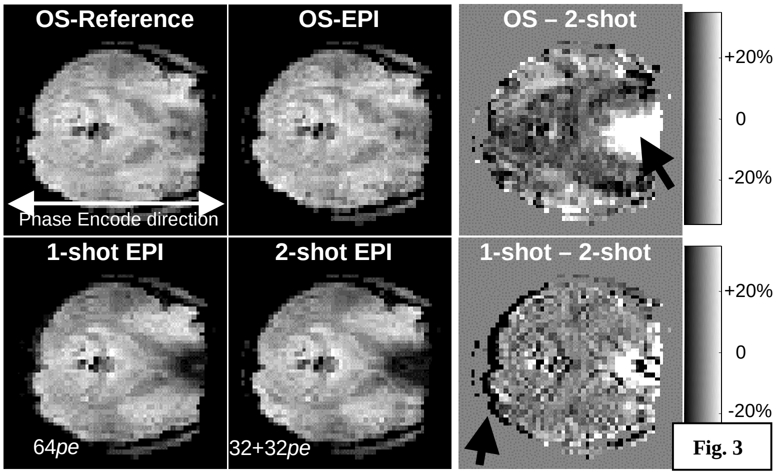

**Fig. 3**

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**References** (1) Pruessman *et al.*, MRM 42: 952-962 (1999). (2) Sodickson *et al.*, MRM 38:591-603, (1997). (3) Griswold *et al.*, MRM 2002, 47:1202-10. (4) Rdzedzian RR, SMRM 1987, 51.

**Fig. 1** Sketch of conventional (a) and OS (b) slice acquisition schemes. The filled areas indicate the profile of the volumes contributing to the acquired signal for each readout. **Fig. 2** OS (half-FoV and full-FoV reconstruction) and conventional 2DFT images of a human brain. **Fig. 3** OS and conventional GE-EPI images of a human brain. NB: the OS-Reference image was obtained adding complementary OS-EPI full-FoV images. On the right, differences images are shown to highlight improvements in distortion and drop-out (arrows). NB: 2-shot EPI requires twice the acquisition time of the 1-shot or OS half-*FoV* images.