Three Dimensional Imaging with Independent Slab Excitation and Encoding

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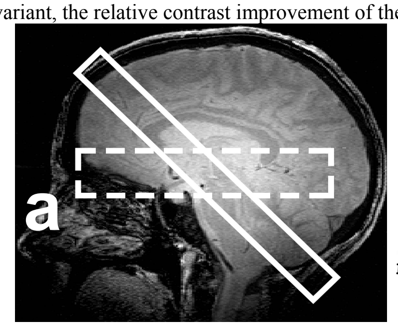
INTRODUCTION A new class of 3D Cartesian MRI is introduced for Independent Slab Excitation and Encoding (ISEE), whereby the voxel encoding orientation is independent of the acquisition slab orientation. The excitation region is chosen for the optimal region of interest, while the encoding direction is arbitrarily oriented for ideal voxel alignment. The method is particularly useful with anisotropic voxels, enabling voxel alignment to produce minimal blurring of oriented fine structures, while maintaining ideal volume placement. For phase susceptibility or susceptibility-weighted imaging (SWI), ISEE enables oblique excitation volumes with voxel orientation maintained along the main field direction, thus enabling ideal anatomic orientation of the imaging volume, without the constraint of volume alignment with the main magnetic field (1,2). The new method is described and then applied to phase imaging and SWI in healthy volunteers.

METHODS The 3D ISEE method involves the application of slab excitation and slab spatial encoding at independent arbitrary angles, unlike the traditional orthogonal angle typically used. This concept is illustrated in Fig. 1, where the slab RF excitation is applied obliquely and the acquisition volume is applied axially. Signal excited from outside the prescribed slab phase encoding volume will be mapped to different locations within the acquisition volume due to aliasing. For 3D ISEE, aliasing is a natural part of the data collection process, with reconstruction involving a simple re-mapping process. In the schematic of Fig 1, the excited image segments are mapped into the acquisition volume with most of the signal coming from outside of the imaging acquisition volume, resulting in substantial aliasing of image portions. This results in a set of axial images where each slice contains multiple axial slices from different locations of the original obliquely excited volume.

The ISEE method was tested on phantoms and five healthy volunteers (mean age 25.8 ± 3.7 yrs) at 4.7 T. Results for phase and SWI are presented using a 3D gradient echo sequence that enabled standard 3D imaging or 3D ISEE by altering the orientation of the RF slab excitation gradient, independently from the slab encoding gradients. The image volume was centered to include deep gray matter structures known for high iron content and distinct visibility in phase and SWI images. Three scanning protocols were applied: a standard axial SWI; a standard single oblique angled at 45º to the main field ; and the ISEE method with identical single oblique slab selection but with an axial encoding volume. Most parameters were kept fixed between imaging methods: TE/TR 15/35.7 ms, flip angle 11º, bandwidth 35 kHz, excitation slab thickness 4 cm, in plane FOV 22.2 x 16.1 cm with 512 x 256 matrix. For the first two scans the slab phase encoding matrix was 22 slices each 2mm thick, for ISEE 32 slices were used also with 2 mm slice thickness. Additional slices are required for ISEE to enable complete unwrapping of the aliased portion without overlap. The number of additional slices depends on the angle chosen, (1/cos[angle] multiplier). The resulting image sets were processed to produce standard SWI and phase images. Images from the ISEE method were then reformatted to retrieve image slices similar to those produced in the standard oblique method. ROI measurements were made on the SWI images and on the standard magnitude images. Contrast measurements were made bilaterally in iron-rich structures in comparison to local background signal. The ROIs encompassed the extent of each structure within one slice. To assess the SWI contrast performance of each imaging variant, the relative contrast improvement of the SWI image over the standard magnitude image was reported.



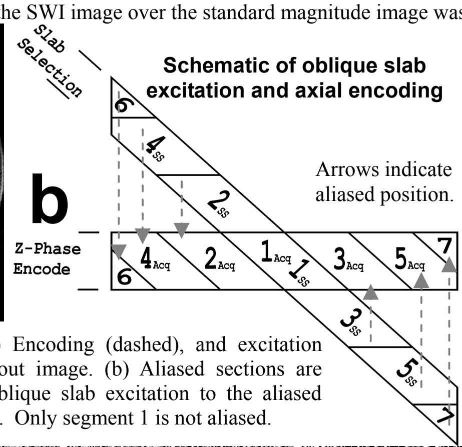


Fig. 1 (above) 3D ISEE example. (a) Encoding (dashed), and excitation volumes (solid) shown on a sagittal scout image. (b) Aliased sections are detailed, from the position within the oblique slab excitation to the aliased position in the acquired transverse volume. Only segment 1 is not aliased.

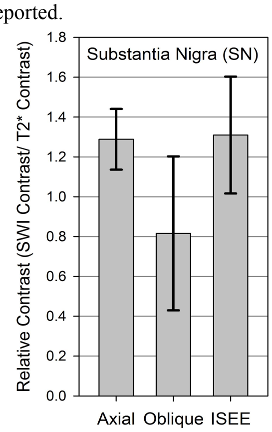


Fig. 3 (left) Relative contrast enhancement between SWI and its corresponding magnitude from 5 volunteers in iron rich substantia nigra (10 measurements). Standard oblique SWI yields significantly reduced contrast compared to standard axial. With ISEE, oblique SWI fully recovers the contrast available in standard axial SWI.

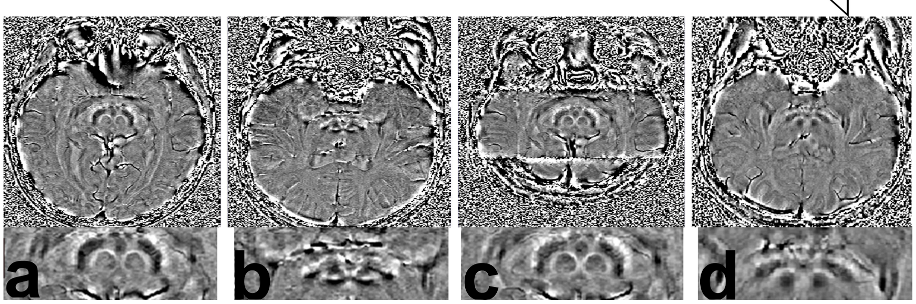


Fig. 2 (left) Phase images with iron-rich region (substantia nigra, red nucleus) enlarged below.
(a) standard axial, (b) standard oblique showing overwhelming distortion from oblique voxel alignment, (c) oblique ISEE as acquired with axial acquisition showing anterior and posterior aliased portions, (d) same ISEE data set as (c) after reformatting into oblique plane. In (c) oblique ISEE provides same result to (a) except for aliasing, by preserving axial voxel alignment along the main field, while using an oblique excitation volume. In (d), unaliased ISEE recovers contrast that was distorted in the standard oblique (b).

RESULTS Figure 2 shows phase images that are highly dependent on the main magnetic field direction. The oblique slice in Fig 2b produces a phase that is distorted, because the voxel direction is not aligned with the main magnetic field. Particularly in the central iron-rich region it differs significantly from the axial slice in 2a. The ISEE method shown in 2c uses the identical oblique RF slab excitation as 2b, but shows a result typical of a standard axial scan with preserved contrast. In 2d, the ISEE image is reformatted into an oblique view without the distortion in 2b. Figure 3 gives SWI results from all volunteers. Typically one expects a substantial improvement in the SWI image contrast over the magnitude image in areas with iron-related susceptibility differences. For the standard axial orientation, SWI has 1.3 times the contrast of the magnitude, but for standard oblique imaging, SWI has significantly worse image contrast than its magnitude raw image. Applying the ISEE method fully restores the expected gain from oblique SWI to the same as axial SWI. In conclusion, a new 3D MRI method based on arbitrary voxel alignment within an ideal slab excitation has been introduced. Application to oblique phase imaging or SWI has been shown, where the ISEE method removes the necessity for main field alignment of the excitation volume, enabling optimal anatomic positioning at any oblique angle while maintaining voxel alignment with the main magnetic field.

REFERENCES 1. Xu Y, Haacke EM. Magn Reson Imag. 2006; 24:155-160. 2. Deistung, A, et al. Magn. Reson. Med. 2008; 60:1155–1168.
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