ExLoc: Excitation and Encoding of Curved Slices

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Introduction In conventional 2D MR imaging experiments, parallel sets of planes are excited by the slice selection procedure. For certain applications, however, adaptation of the slice shape to the specific region of interest would result in improved relevant volume coverage for fewer excited slices, and therefore increased efficiency. In particular for fMRI experiments, this would not only allow an increased sampling rate of the BOLD signal, but also separate loci of activation could be simultaneously excited for synchronized data acquisition. As a possible example, Fig. 1 shows slices with the shape adapted to the back of a head, where the entire primary visual cortex is covered with few slices.

In this work, we present a method (ExLoc) for excitation of curved slices, where the curvature, orientation and position are each adjusted to the object under investigation. More importantly, we complement curved-slice excitation by spatial encoding along the curved surface. Compared to linear spatial encoding, this reduces partial volume effects by maintaining a local rectangular voxel shape. In addition, through-slice dephasing, due to encoding-gradient components orthogonal to the slice, is avoided. In the following, the ExLoc method is explained and demonstrated on phantom experiments.

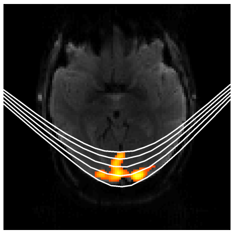

Fig. 1: An example of curved slices for acquisition of an fMRI activation map.

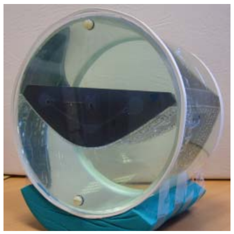

Fig. 2: Phantom containing a structured curved plate and doped water.

Methods Imaging experiments were performed on a 3T Tim Trio system (Siemens, Erlangen, Germany), equipped with a PatLoc gradient insert [1]. A cylindrical container containing a structured, curved plate with the container axis pointing along the z dimension served as phantom (Fig. 2). Reconstruction was performed using Matlab (The MathWorks, Natick, USA).

The ExLoc method uses switchable nonlinear fields combined with linear gradients to design a field producing the desired curved slice. As shown in Fig. 3 a), one quadrupolar PatLoc field is sufficient to define a curved slice. For a given excitation frequency, the curvature is set via the gradient amplitude. Adding the second, orthogonal PatLoc field allows rotation of the slice within the xy-plane and customization of the slice orientation. The final positioning of the slice is achieved by adding linear x and y gradient fields (Fig. 3 b). As for standard slice selection, slice thickness can be either adjusted via the rf-pulse bandwidth or the amplitude of the effective slice-selection gradient field. For spatial localization, linear frequency encoding is applied along the z-dimension using the corresponding linear gradient. Although a linear gradient may be used for encoding along the curved dimension (l), it is no longer globally aligned to the excited slice. This is to say that the 3D voxel shapes become distorted, thereby reducing effective resolution. We therefore apply the field combination orthogonal to the slice-selection field for phase encoding. Hence the encoding-field gradient is globally aligned to the slice surface.

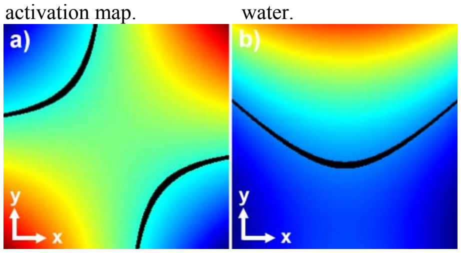

Fig. 3: Quadrupolar PatLoc field prior (a) and after rotation and subsequent movement with additional linear gradients (b). Black color marks the frequencies within the excitation bandwidth.

Fourier reconstruction of the curved-slice data yields an image in distorted coordinates, referred to as cz-space, with varying intensity, as the phase-encoding field is of nonlinear nature. Determination of the individual voxel's width along l to transform the image into the undistorted space (lz-space) requires knowledge of the encoding-field's slope along the curved dimension. The latter is calculated from the individual field components, either analytically or from a reference measurement [2]. Besides the variable voxel width, also the varying slice thickness is taken into account for intensity correction.

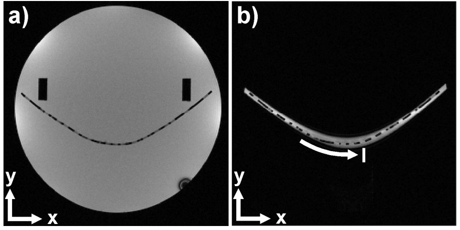

Fig. 4: Cross-section of the phantom (a) and of the excited curved slice (b).

Results and Discussion Fig. 4 shows localizer images representing a cross section of the curved plane (a) and of the excited curved slice (b) whose shape was adjusted to match the phantom. Fourier reconstruction of the curved-slice data (spin echo (SE) sequence adapted for both gradient sets; matrix: 512x512; FOV: 210×~210 mm; TR/TE: 100/18 ms; BW: 390 Hz/pix; 10 averages) results in a distorted image in cz-space with the distortion along c as squeezing of the letters clearly shows (Fig. 5 a). After distortion and intensity correction (Fig. 5 b), the uniform structures exhibit similar lengths as indicated by the red bars.

As the presented data demonstrates, a combination of linear and PatLoc gradient fields allows excitation of curved planes with flexible curvature, orientation and position. No time consuming spatial selective rf-pulses are necessary. The resulting slices generate an organic shape that may be more suitable for anatomical imaging than conventional parallel planes. This allows an improved coverage, which may be beneficial for many applications. Combination of the ExLoc method with higher order gradient systems [3] would further extend the variety of possible slice shapes.

During encoding, the applied combination of gradients provides a field with gradients globally aligned to the slice. The non-linear nature of the field results in varying voxel size and intensity variation, but is compensated by transformation into lz-space. As the magnitude of the encoding gradient varies along the curved l direction, the encoding parameters need to be chosen to achieve desired resolution based on the weakest local gradient. It is advisable to use a strongly curved gradient as readout direction, where this requirement is easier to accomplish. The benefit of the curved encoding field is that the local rectangular shape of the individual voxels is maintained as schematically shown in Fig. 6. This would not be the case for pure linear spatial encoding, resulting in increased partial volume effects and a loss of local resolution. For the field geometry used in this study with a maximum slice curvature of 90°, the effect is on the order of 25%. However, it becomes severe for stronger curved slices. In addition, the applied orthogonal gradients allow 3D encoding by maintaining the curved geometry for each partition.

The presented ExLoc method represents a step towards an object-customized MRI system and may be advantageous for various applications such as fMRI. In the future we plan to implement these techniques in vivo.

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References [1] Gallichan et al., MRM (in press); [2] Schultz et al., MRM 2010 (online); [3] Juchem et al., JMR 2010, 204:281-289;

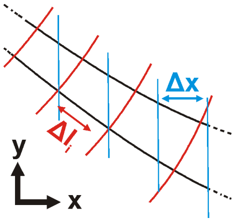

Fig. 6: Curved-slice cross-section showing voxel shapes for the orthogonal nonlinear (red) and the linear encoding gradient (blue).

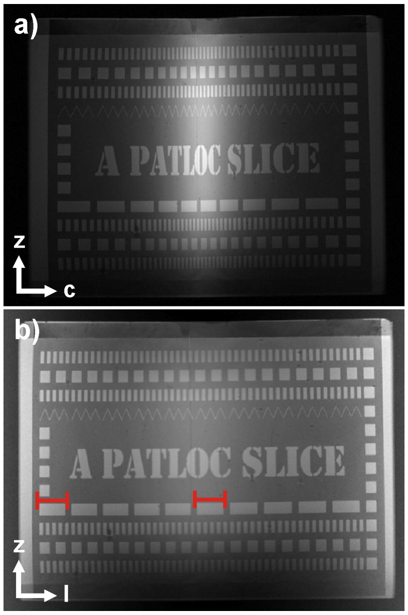

Fig. 5: Curved-slice data after FT reconstruction (a) and with distortion and intensity correction (b). (Images cropped)