Local Thickness Adaptation for Curved Slice Selection

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Introduction

Conventional MRI is restricted to perform imaging along planar slices. However, for certain applications, adaptation of the slice shape to the specific anatomy would allow to directly follow its structure. In the case of extended structures, an improved coverage with fewer slices can be achieved and thus data acquisition with increased efficiency. Compared to curved slice selection using complex multi-dimensional RF-pulses [1], application of spatially adapted encoding fields allows selection of curved slices in combination with conventional short RF-pulses. Importantly, combination with geometrically matched spatial encoding fields, as proposed by the ExLoc concept [2], enables spatial encoding within the slice's curved coordinate system under preservation of a locally rectangular voxel shape (Fig. 1). However, due to the nonlinear slice-selection field, this technique results in slices with varying thickness (Fig. 2), with the rate of variation being dependent on the local slice curvature. A spatially varying slice thickness is undesirable for many applications, especially in regions where the slice becomes too thick to observe the structure of interest.

In this study we investigate the combination of nonlinear encoding fields with multi-dimensional RF-pulses in order to adapt the thickness variation of curved ExLoc slices, using both simulations and preliminary phantom experiments. Compared to conventional multi-dimensional excitation with linear encoding fields to excite a curved slice, using this approach allows for considerably shorter RF-pulses to be used.

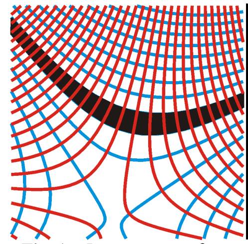

Fig. 1: Isocontours of an ExLoc slice selection field (blue), the corresponding encoding field (red) and a cross-section of the selected slice (black).

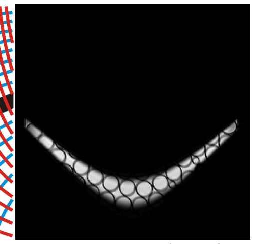

Fig. 2: Cross-section of a curved ExLoc slice, selected with a 1D RF-pulse. The thickness varies along the curved dimension.

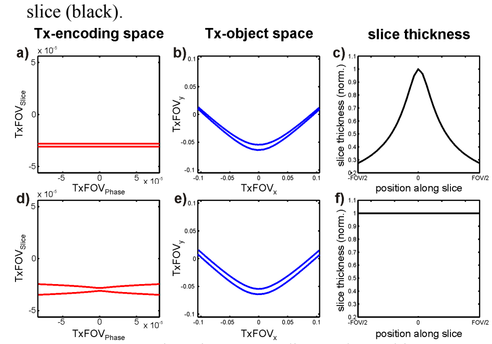

Fig. 3: Cross-sections in Tx-encoding and Tx-object space as well as the corresponding thickness variation for an ExLoc slice without (a-c) and with (d-f) thickness adaptation.

Methods

For the sake of clarity, the method is presented along one curved slice dimension. Fig. 3b shows the simulated cross-section of an ExLoc slice excited by a conventional 1D RF-pulse in object coordinates (= Tx-object space). Its normalized thickness-variation along the curved dimension is given in Fig. 3c. In encoding coordinates [3] (= Tx-encoding space), the curved slice with varying thickness corresponds to a planar slice with constant thickness. Its cross-section is shown in Fig. 3a - and also represents the RF-design target which serves as basis for the RF-pulse calculation. Consequently, in order to achieve a constant slice thickness in Tx-object space (Fig. 3e & f), an increasing slice-thickness towards the edges in Tx-encoding space (Fig. 3d) is required. Correct scaling of the slice thickness is given by the reciprocal of the normalized slice-thickness of the original ExLoc slice (Fig. 3c). Further analysis of the adapted RF-design target shows that along the dimension perpendicular to the slice surface, highly resolved edges are required in order to achieve a sharp pulse profile. The corresponding high frequency information requires extended transmit k-space coverage along this dimension. However, changes along the second target-dimension are smooth and can thus be described with low frequencies only. Aligning the EPI-like trajectory along the highly resolved dimension, only a few spokes are necessary.

In the case of conventional linear encoding fields, the RF-design target is given by the Tx-object space representation shown in Fig. 3e. Sufficient description of the cross-section requires high spatial frequencies along both transmit k-space dimensions. In turn, this requires extended transmit k-space coverage along each dimension and consequently a longer and more complex RF-pulse.

For demonstration purposes, slice-thickness scaling in the Tx-encoding space was calculated for an ExLoc slice with geometry shown in Fig. 2. Resolution of the RF-design target (Fig. 4a) perpendicular to the slice was chosen accordingly to describe the thinnest section of the slice with 3 voxels, resulting in total of 80 voxels. Along the slice surface, the FOV was divided into 16 voxels. Within the resulting transmit k-space, only 5 equidistant spokes were placed manually prior to calculation of the monopolar trajectory and the RF-pulse (Fig. 4c, RF-pulse duration: 11.2 ms). Figure 4b shows the corresponding RF-design target using linear encoding fields only. In order to achieve an almost comparable resolution, 36 × 36 voxels were chosen. All 36 spokes were required for sufficient transmit space coverage, resulting in a 34.1 ms long RF-pulse (Fig. 4d).

Data acquisition was performed on a 3T MAGNETOM Trio Tim system (Siemens, Erlangen, Germany) equipped with a PatLoc gradient insert [4], resulting in a total of 5 magnetic field components (linear x,y,z and quadratic x^2-y^2 and 2xy). During excitation each logical transmit gradient was mapped to the corresponding superposition of linear and nonlinear magnetic field components. As shown in Fig. 2, the curved slice dimension was oriented in the xy-plane, with the second slice-dimension pointing along the z-axis. Transmission was not accelerated, as no parallel transmit coil was available for the PatLoc system. Spatial encoding in the xy-plane was performed with a 2D gradient echo sequence in order to map the slice cross-section.

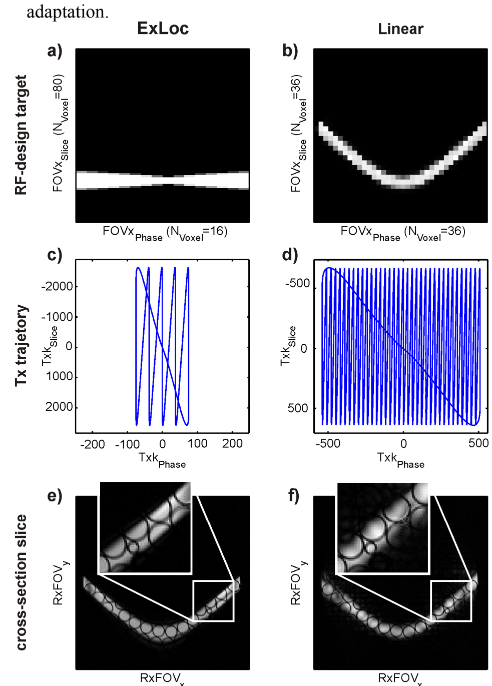

Fig. 4: Comparison of RF-design target, corresponding transmit k-space trajectory and resulting slice cross-section for ExLoc (a, c, e) and Linear encoding fields (b, d, e).

Results and Discussion

The mapped cross-section of the ExLoc slice with adapted slice thickness is shown in Fig. 4e. The curved slice exhibits a more constant thickness without loosing its high edge resolution (see blow-up) and homogenous excitation. The cross-section of the slice selected with linear encoding fields only (Fig. 4f) reveals much lower edge resolution despite the RF-pulse being 3x longer. Furthermore, the long pulse duration amplifies off-resonance sensitivity, resulting in inhomogeneous excitation.

With the primary slice shape provided by the ExLoc encoding fields, adaption of the slice thickness of curved ExLoc slices with multi-dimensional excitation is possible with comparably short RF-pulses. As the custom-built PatLoc gradient insert is currently not calibrated with respect to timing errors and preemphasis to the same accuracy as industrial gradient systems, we were forced to use a longer monopolar transmit k-space trajectory for the ExLoc slice, rather than a typical bipolar trajectory. We expect that methods such as magnetic field monitoring [5] would provide a method to perform this calibration and allow even shorter pulses. In future work, the technique will also be extended to allow further local changes of the slice shape in order to further increase the ability to adapt to the anatomy.

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References [1] P. Boernert, MAGMA 2003, 16:86-92; [2] H. Weber et al., Proc. ISMRM 2011, #2806; [3] G. Schultz et al., MRM 2010, 64:1390-1404; [4] A. Welz et al., Proc. ESMRMB 2009, #316; [5] B. Wilm et al., MRM 2011, 65:1690-1701;