Local Shape Adaptation for Curved Slice Selection

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Purpose The application of a set of nonlinear, but locally orthogonal, spatial encoding magnetic fields in combination with a conventional 1D RF-pulse allows both excitation and geometrically matched local encoding of curved slices (ExLoc [1]). Adaptation of the field shape, and thus curvature, orientation and position of the slice, to the shape of the anatomy under investigation is achieved by composing the encoding fields of linear and nonlinear field components. As demonstrated previously [2], combination of the ExLoc concept with multidimensional excitation (ExLoc MDE), allows compensating for the varying slice thickness originating from the nonlinearity of the slice encoding field and thus also excitation of a curved slice with constant thickness. Within this study, we exploit the ExLoc MDE technique for additional local adaptation of the slice shape. Its potential is explored based on simulations and both phantom and in-vivo experiments.

Methods Figure 1a) shows the cross-sections of a set of simulated slices with equal center position but different curvature in object coordinates [3] (= Tx-object space). Slice I corresponds to a slice with constant thickness and a curvature similar to an ExLoc slice generated by a combination of first (x, y) and second order (2xy, x^2-y^2) field components and a conventional 1D RF-pulse (= base slice). Slices II and III represent slices with increasingly deviating curvature, which can no longer be generated by the given field components alone. Figure 1b) shows the same slices after transformation into Tx-encoding space. With the latter being the space which is connected to the transmit k-space by the Fourier transformation, it is the slice shape in Tx-encoding space, which defines the RF-design target used for the RF-pulse calculation. (Note that for purely linear encodings fields, the representation in Tx-encoding space would be similar to the one in Tx-object space.) In Tx-encoding space, Slice I is similar to a conventional planar slice, except its increasing thickness. This means that along the Tx-phase dimension, it solely consists of low frequency components. Therefore its excitation requires only a low coverage along the corresponding transmit k-space dimension and can be realized by a trajectory with a few spokes. This would not be the case for purely linear encoding fields, where the RF design target would be similar to the representation shown in Tx-object space (Fig. 1a). Also with the more complex shapes of the slices II & III, a more extended coverage in transmit k-space is necessary. The number of spokes theoretically required for description of the slice at a certain position along the Tx-phase dimension, is shown in Fig. 1d. The underlying model determines the number of spokes from the resolution along the Tx-phase dimension necessary to describe the local slice normal, under consideration of the local slice thickness and the given resolution along the Tx-slice dimension (= number of points per spoke). For comparison, Fig. 1c shows the corresponding numbers assuming purely linear encoding fields.

For verification of the ExLoc MDE technique, cross-sections of the different slices were acquired in a cylindrical phantom filled with tubes and doped water (Fig. 2a-c). Data acquisition was performed on a 3T MAGNETOM Trio TIM system (Siemens, Erlangen, Germany) equipped with a PatLoc gradient insert [4], offering the two additional second order fields described above. The number of spokes was varied within the range of the values determined by the model in order to find the minimum number necessary. With increasing deviation from the base slice shape, the excited slice is no longer orientated orthogonal to the in-plane encoding fields. To analyze the altered encoding behavior, the resulting voxel shape was determined for all selected slice shapes (Fig. 2d-f). As a quantitative measure for the voxel distortion, the ratio of the voxel diagonals was determined and displayed in color-coding. ExLoc MDE was also applied to a healthy volunteer after ethics approval. In a first step, an ExLoc base slice was adjusted to the lateral rim of the brain by choosing the appropriate combination of encoding field components. In a second step, the shape of the base slice was further adjusted to the brain (Fig 3a). Finally, the cross-section of the selected slice was mapped.

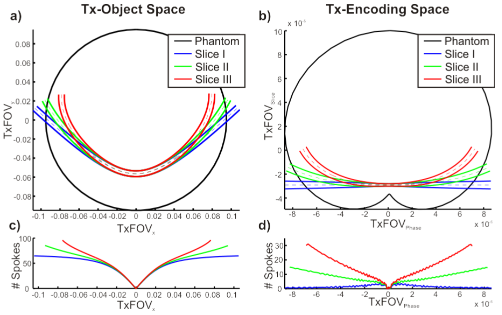

Fig. 1: Cross-sections of the target slices in Tx-object (**a**) and Tx-encoding space (**b**). The local number of spokes (**c** & **d**) was determined for 96 points per spoke.

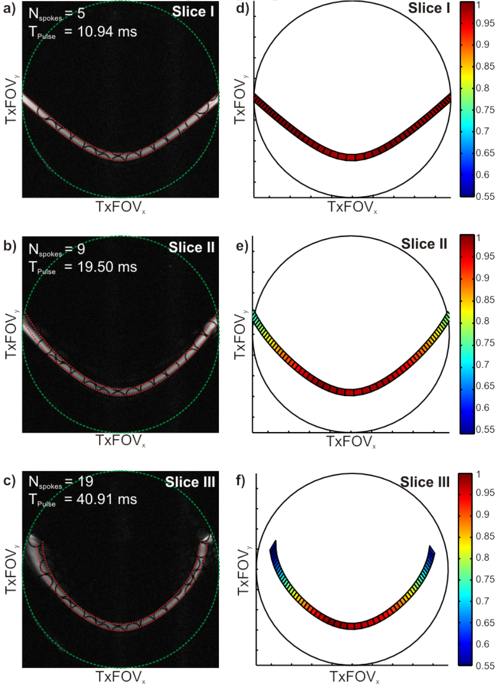

Fig. 2: Acquired cross-sections of slices I – III (**a-c**) within the phantom. The dotted lines along the slices marks the borders of the corresponding target slice, the dotted circle the area covered by the phantom. The resulting voxel shapes (**d-f**) were simulated for 60 encoding steps along the slice. The color-coding shows the ratio of the voxel diagonals as a measure for the voxel skewness. A value of one corresponds to a rectangular voxel.

Results and Discussion The acquired cross-sections for both the phantom and in-vivo experiments are shown in Fig. 2a-c and Fig. 3b respectively. For the phantom experiments, the maps acquired with the lowest number of spokes possible that still allowed exciting the desired slice shape (= N_{Spokes}) are displayed. As the good agreement with the plotted target slice borders demonstrates, the combination of ExLoc with multidimensional excitation in general allows a local adaptation of the slice shape. The already curved ExLoc slice, defined by the slice selection field, serves as a base slice with a shape already close to the desired one. Therefore, compared to conventional, purely linear encoding, much lower deviations from a plane slice in the relevant Tx-encoding space are seen, which require a lower k-space extent to be covered. Furthermore, as the comparison of the actually applied number of spokes with the ones predicted by the model revealed, coverage of the local spokes values within the inner 50% of the $TxFOV_{Phase}$ range appeared to be sufficient. Note that the length of the applied RF-pulses (= T_{Pulse}) in this study is comparably long, as the missing calibration of the gradient insert for phase alterations due to eddy currents and concomitant fields did not allow the usage of a bipolar trajectory or RF transmission on the ramps. An undesired phase evolution is also considered to cause the deviations at the edges of the slices in the case of the longer RF-pulses (see e. g. Fig 2b, c). Future work will therefore include the measurement of the total phase evolution in order to allow the application of shorter RF-pulses.

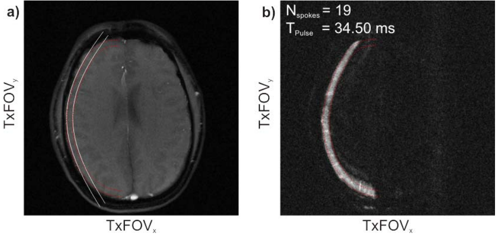

Fig. 3: Localizer image (**a**) with the borders of the base ExLoc slice (solid lines) and after local adjustment to the lateral rim of the brain (dotted lines). The acquired cross-section of the slice (**b**) shows good agreement with the target slice within the center and small deviations toward the edges.

The main advantage of the ExLoc concept is the geometrically matched encoding of the curved slice. Thus the actual limitation of the ExLoc MDE technique is given by the increasing voxel distortion with increasing deviation from the base slice. However, for typical slice shape modifications like those shown in this study, the voxel shapes are still within acceptable limits. Combination of ExLoc with multidimensional excitation might therefore further improve imaging with slice shapes individually adapted to the anatomy under investigation.

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References [1] H. Weber et al., MRM 2012, doi: 10.1002/mrm.24364; [2] H. Weber et al., Proc. ISMRM 2012, #2206; [3] G. Schultz et al., MRM 2010, 64:1390-1404; [4] A. Welz et al., Proc. ESMRMB 2009, #316;