In-Vivo Curved Multi-Slice Imaging

Hans Weber[1], Daniel Gallichan[1], Anna M. Welz[1], Chris A. Cocosco[1], Sebastian Littin[1], Jürgen Hennig[1], and Maxim Zaitsev[1]
[1]*Department of Radiology, Medical Physics, University Medical Center Freiburg, Freiburg, Germany*

Introduction

Based on a superposition of spatially linear and nonlinear magnetic field components, ExLoc [1] allows selection of slices with flexible curvature, orientation and position. As the encoding fields generated are oriented orthogonal to each other, spatial encoding along the curved dimension is achieved, thus maintaining a local rectangular shape of the individual voxels (Fig. 1). No complex and time consuming multidimensional RF-pulses are necessary.

In this work we explore ExLoc's potential for multi-slice imaging. Selection and encoding of stacks of slices by maintaining the curved geometry for each slice results in improved relevant volume coverage for fewer excited slices and thus increased efficiency for particular applications (Fig. 2). We present the results of experiments performed on a phantom, as well as a demonstration in vivo.

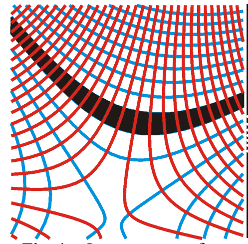

Fig. 1: Isocontours of an ExLoc slice selection field (blue), the corresponding orthogonal encoding field (red) and a cross-section of the selected slice (black)

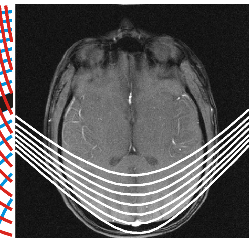

Fig. 2: Example for a stack of curved slices. Slice shape is adjusted to the occipital lobe for a more efficient coverage of the visual cortex.

Methods

Within ExLoc imaging, conventional multi-slice selection with constant RF-pulse bandwidth BW_0 and constant frequency-offset increment would result in slices with centre thickness (CT = max. thickness of a curved ExLoc slice) and inter-slice spacing varying from slice to slice due to the non-linear nature of the encoding field applied during slice selection. Figure 3a qualitatively sketches the variation in CT for a second order field. One possible solution for selection of multiple slices with constant CT and equidistant spacing might be a respective shift of the nonlinear encoding field for every selection, resulting in shifted copies of the original slice. However, as slice thickness also varies along the curved slice-dimension, adjacent slices would no longer fit together without overlap, thus preventing an efficient coverage. As an alternative, individual adaptation of the RF-pulse bandwidth and frequency increment for every single slice would allow a defined center thickness and slice position in combination with complementary slice shapes. Figure 3b demonstrates the principle. The individual RF-pulse bandwidths BW_i and frequency offsets for a given center thickness CT_0 and inter-slice spacing can either be calculated from an analytical field description or from a reference field map.

For demonstration purposes, the multi-slice ExLoc concept was implemented on a 3T MAGNETOM Trio Tim system (Siemens, Erlangen, Germany) equipped with a PatLoc gradient insert which generates fields of the form x^2-y^2 and 2xy in addition to the standard linear gradients [2]. The available field components of first and second order allow adaptation of slice curvature, orientation and position along one slice dimension. Data acquisition was performed with an adapted spin echo sequence. Individual bandwidths and frequency offsets were automatically calculated by the sequence for every single slice based on an analytical description of the field components. To visualize the shape of the selected slices, cross-sections were imaged with linear encoding perpendicular to the excited slices. Prior to in-vivo imaging, the sequence was evaluated for peripheral nerve stimulation and acoustic noise to meet IRB guidelines [3].

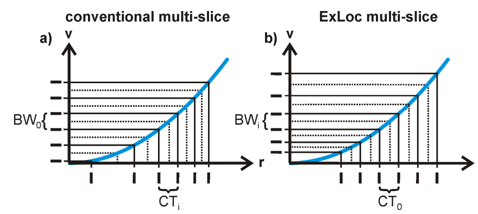

Fig. 3: Relation between RF-pulse bandwidth (BW) and curved slice center thickness (CT) for a second order encoding field. Conventional, fixed BW_0 results in varying CT_i (a), whereas for ExLoc bandwidth adaption (BW_i) a constant CT_0 is achieved (b). The dotted lines mark the applied frequency offsets.

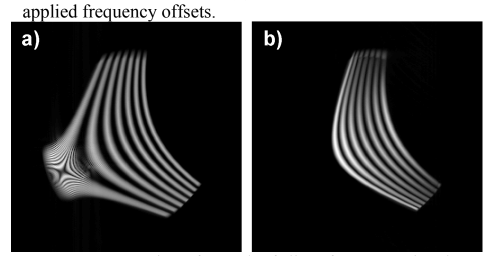

Fig. 4: Cross-section of a stack of slices for conventional multi-slice selection (a) and with individual bandwidth and frequency offset adaptation (b).

Results and Discussion

Fig. 4 presents cross sections of stacks of slices within a homogenous phantom for conventional multi-slice selection (a) and with bandwidth and frequency offset adaptation for every RF pulse (b). With the latter, slices exhibit constant CT and inter-slice distance. A stack of 7 curved slices (TR/TE: 600/25 ms; matrix: 256 × 256; FOV: 29.8 - 23.7 × 21.0 cm; CT: 8.8 mm) is presented in Fig. 5. The stack is orientated along the occipital lobe (a), resulting in a stepwise penetration into the brain (b - h). Compared to conventional planar multi-slice imaging, spatially separated brain regions with similar distance from the skull can now be imaged in the same slice. This may allow, for example, a more direct comparison of the hemispheres in neuroimaging. In multi-slice mode the individual slices are encoded with different combinations of the nonlinear fields. This causes a variation in resolution between the slices, combined with different FOV sizes along the curved dimension.

As demonstrated in phantom and in vivo, ExLoc enables multi-slice imaging with constant center thickness and inter-slice spacing. This allows efficient coverage also for extended volumes, which can not be described with a single curved slice. In future work, we will also apply the multi-slice ExLoc concept to echo planar imaging for functional imaging.

Acknowledgement This work is a part of the INUMAC project supported by the German Federal Ministry of Education and Research, grant #13N9208.

References [1] H. Weber et al., Proc. ISMRM 2011, #2806; [2] A. Welz et al., Proc. ESMRMB 2009, #316; [3] C. Cocosco, Proc. ISMRM 2011, #714;

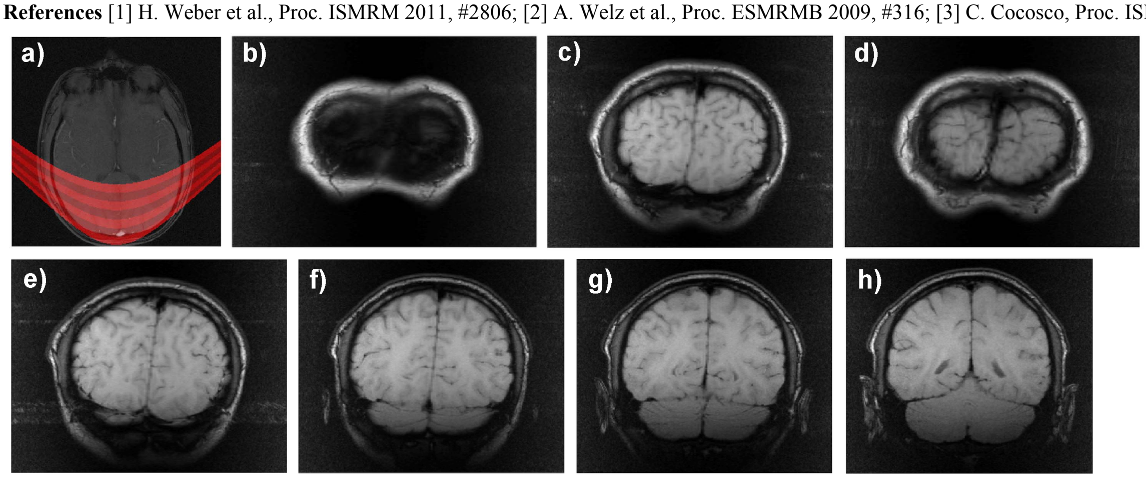

Fig. 5: Stack of 7 curved spin echo slices acquired in a multi-slice acquisition. The curvature, orientation and position of the slices are adapted to the occipital lobe as shown on the localizer image (a). The slices (b-h) represent a stepwise progression through the brain from posterior to anterior in curved coordinates. The slight increase in spatial resolution towards the FOV periphery is due to the nonlinear nature of the phase encoding field (Applied along the horizontal image dimension).