Overlapping Slice Coverage Using z-Interleaved Phase Encoding (ZIP) Trajectories

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INTRODUCTION

Conventional multi-slice imaging techniques for examination of a volume in clinical routine suffers under the principal problem of none ideal slice excitation profiles. Therefore the total volume under examination cannot be covered homogeneously (1-3). The slice parameters are a compromise between a loss of resolution in slice-selection direction (z-direction) for gaps between slices and saturation effects of neighboring slices because of overlapping excitation profiles. We have investigated a new method of a more homogenous volume coverage while maintaining almost the same scan time compared to conventional imaging.

THEORY

The basic idea of overlapping section coverage is to vary the slice position of the single phase encoding (PE) steps in such a manner that after the measurement there is enough data information in each section of previously defined thickness for reconstructing an image in this section (4). This can be displayed in a "k-z-diagram", in which the k-space coordinate of the PE direction is displayed as a function of the z-position of its corresponding excitation profile (Fig.1). Depending on the k-z-trajectory (KZT) it is possible to reconstruct images at additional positions than the conventional.

The signal weighting in k-space along the PE direction produced by this technique depends on the KZT, the shape of the slice profile, the slice-slice distance and the shape and position of the object in the z-direction. The resulting through-plane point spread function determines imaging properties and artifacts.

IMPLEMENTATION

We have implemented ZIP-trajectories based on T2-weighted TSE sequences. The PE scheme running from –m to m is shown in Fig.1. In conventional imaging (Fig.1 left) the full k-space (-m to m) is encoded for each slice position z_n. For the ZIP-scheme (Fig.1 right) the PE trajectory is splitted into two, partially overlapping parts of k-space running from –m to *l* and from m to –*l*. The reduced k-space part is acquired for each slice position z_n and for each intermediate slice position $z_{n+1/2}$. The PE sampling direction alternates between consecutive slices.

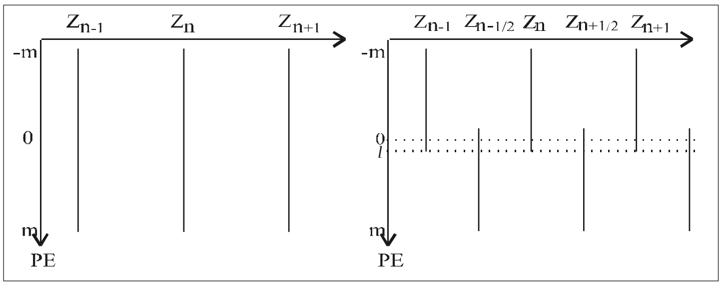

Fig.1: KZTs in conventional imaging (left) and a ZIP-trajectory (right).

Images were reconstructed for each slice position z_n and $z_{n+1/2}$. The missing part of k-space was calculated by complex averaging of corresponding PE lines of adjacent slice positions.

RESULTS

In order to evaluate the through-plane resolution and possible image artifacts we used a phantom consisting of a grid of horizontal and vertical sticks surrounded by doped water. The position of the principal slices z_n and z_{n+1} and their corresponding slice profile is depicted in Fig.2a. The two bottom rows of Fig.2b show six ZIP images reconstructed at z_n , $z_{n+1/2}$ and z_{n+1} positions. The small cylindrical stick is clearly visible for the $z_{n+1/2}$ reconstruction (Fig.2b middle panel, right stick).

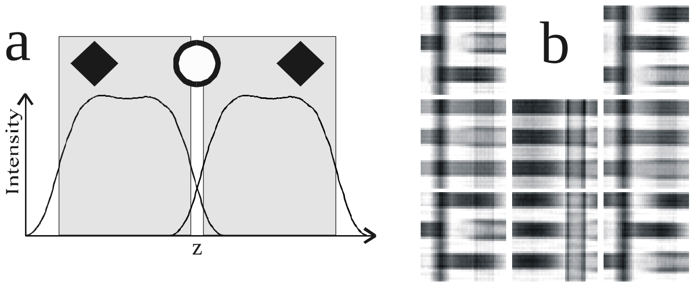

Fig.2 (a): Measured excitation slice profile at the positions z_n and z_{n+1}. (b): The top row shows slices z_n and z_{n+1} acquired with the conventional method. Rows 2 and 3 show ZIP images reconstructed at the positions z_n , $z_{n+1/2}$, and z_{n+1} with l=2 (row 2) and l= 43 (row 3) and a total of 2m=187 PE steps. The z-position of the horizontal sticks are indicated in (a) (squares: left stick, circle: right stick).

Fig.3 shows brain images acquired with the conventional multi-slice technique at positions z_n and z_{n+1} (left and right image) and the ZIP technique at the position $z_{n+1/2}$ (middle slice). Due to averaging of lines from neighboring slices SNR of ZIP images was increased by about 16% compared to the conventional technique.

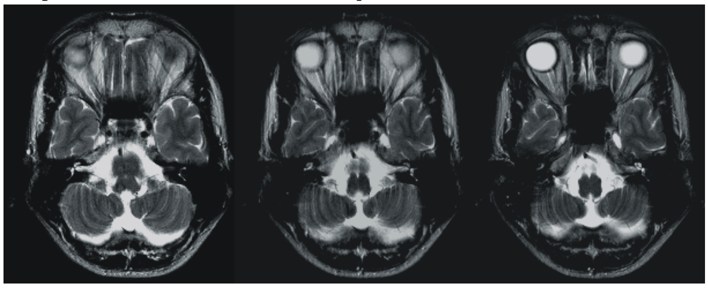

Fig.3: Brain images acquired with the conventional multi-slice technique at positions z_n and z_{n+1} (left and right image) and the ZIP technique at the position $z_{n+1/2}$ (middle slice). (TSE-sequence, ETL=17, TE=126ms, TR=4000ms, 256x255 matrix, slice thickness=5mm, gap=1mm). The measurement overlap for the ZIP-scan was 15 lines (the middle TSE k-space segment).

DISCUSSION AND CONCLUSIONS

The ZIP-scan technique for overlapping slice coverage increases the resolution in z- direction. Even for a small overlap of the low-order PE steps (-*l* to *l*) the method provides images with comparable artifact and SNR properties compared to conventional images. In this case the total measurement time is only slightly increased compared to a conventional scan.

ZIP images, however, show residual signal contributions from adjacent slice positions. This effect is reduced by smaller slice-slice distances and structures changing more slowly in z-direction than those shown in Fig.2.

For conventional multi-slice imaging with a long TR the resolution in z-direction can also be increased without saturation effects by using an interleaved excitation order and partially overlapping slice profiles. However, this is not possible for shorter TR especially in T1-weighted imaging, where the proposed ZIP-technique is expected to show increased through-slice resolution compared to the conventional technique.

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