Parallel 2D excitation of thin limited slice profiles

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Introduction

The use of 2D pulses is advantageous for multi-slice EPI applications such as DWI with a FOV reduced along the PE direction [1-4]. In these methods, multiple thin slice profiles are excited, which are limited along two encoding directions of the 2D excitation trajectory and extend across the imaged object along the non-encoded dimension. A disadvantage of 2D pulses is that they have long durations due to a high resolution of the profiles required. In parallel excitation (PEX) [5, 6], B_1 variations between multiple elements of a transmit array are used for suppression of excitation artifacts caused by undersampling of the trajectories. In this manner, 2D pulses are shortened significantly using parallel RF transmission. In this work, accelerated 2D PEX is examined experimentally for selection of restricted profiles encoded by Cartesian trajectories.

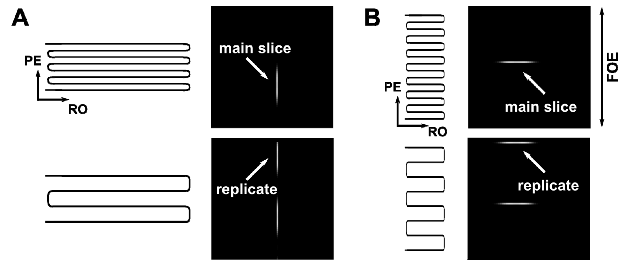

Fig. 1. Illustration for encoding the thickness of a limited slice profile along the RO (A) or PE (B) directions of an EPI excitation trajectory. The excitation replicates due to undersampling are either in (A) or outside (B) the plane of the main profile. The slices extend in the third non-encoded spatial direction across the object.

Theory

For Cartesian excitation trajectories (Fig. 1), the thickness of a slice limited in 2D space can be encoded along either the RO (Fig. 1A) or PE (Fig. 1B) directions [3, 4]. Undersampling of the trajectories leads to an effective reduction of the field of excitation (FOE) defined during pulse design and, as a result, the periodic excitation lobes of the main profile become closer, as illustrated in Fig. 1. As can be seen, the difference between these two encoding schemes is that the undersampling replicate is excited in the plane of the main profile for the case in Fig. 1A and outside this plane for the situation in Fig. 1B. In PEX, sensitivities of the multiple elements of a transmit array are taken into account during calculation of 2D pulses [5, 6] and if they exhibit a sufficient B_1 variation within the FOE along the encoding dimensions, the replicates can be eliminated during excitation.

Materials and Methods

The experiments were carried out on a 3T MR scanner (Siemens Magnetom Trio) with an 8-channel TxArray extension and transceive array (Rapid Biomedical GmbH, Rimpar, Germany). For the acquisition of profiles in a doped water phantom, a 3D FLASH sequence was used with TR values of 175 ms and 875 ms for flip angles of 30° and 90°, respectively.

Two slice profiles were designed as excitation targets, for which 2D pulses were calculated. For the first pattern, the encoding scheme from Fig. 1A was used and a fully-sampled Cartesian trajectory was defined over a FOE of 38.4 (x) × 24 (y) cm^2 and grid size of 192 (x) × 16 (y) with a maximum gradient of 25 mT/m. The thickness of the profile was 4 mm and pulse duration was 16.186 ms. For another target, the scheme in Fig. 1B was employed and a non-accelerated trajectory was calculated over a FOE of 38.4 (x) × 9.6 (y) cm^2 and grid size of 32 × 32 for a maximum gradient of 5 mT/m. The latter value was taken for minimizing the RF power required for the RF shape. The profile thickness was 6 mm and pulse duration was 17.832 ms. Afterwards, both trajectories were undersampled by skipping every second PE line. The durations of the accelerated trajectories were 8.16 ms and 10.293 ms for the schemes from Fig. 1A and B, respectively. The 2D pulses were calculated with an iterative optimization method using conjugate gradients for the small-tip-angle approximation. Relative axial single-slice B_1-sensitivities of the coil elements [7] were taken into account during the calculations.

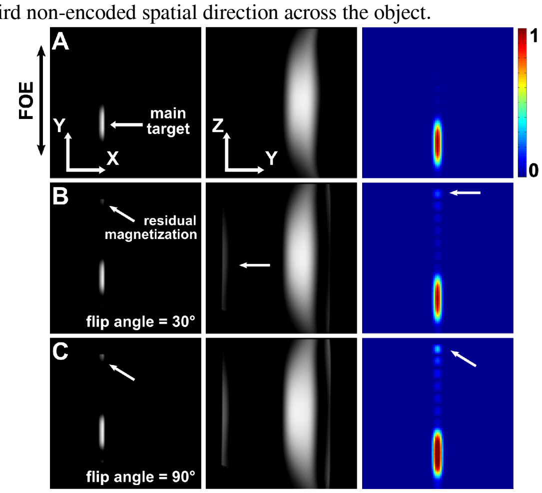

Fig. 2. FLASH images (in black and white) and simulations (in color) of slice profiles excited by non-accelerated (A) and accelerated (B, C) 2D pulses computed using central axial B_1-sensitivities. The pattern encoding scheme is from Fig. 1A and [3].

Results

Experimental profiles scanned are demonstrated in Fig. 2 for the case, when the slice thickness was encoded along the RO dimension of 2D excitation (Fig. 1A and [3]). As can be seen, the replicate of the main profile could be reduced to a negligible level within the defined FOE by using the B_1 data during calculation of the accelerated pulses. However, as indicated by the arrows, a thin stripe of residual magnetization was excited at the edge of the imaged object, which is in accordance with the simulations. The residual fraction reaches up to 40% at this location for a flip angle as high as 90°, indicating that suppression of the replicate was unachievable for this accelerated pulse. Fig. 3 shows profiles excited by 2D pulses for the encoding scheme along the PE direction (Fig. 1B and [4]). The defined FOE is denoted by a dashed square and was smaller than the phantom size. The use of the B_1 data during calculation of the accelerated pulses helps suppress the replicate to a negligible level. At some locations, this fraction reaches a level below 30% for a flip angle of 90°, as indicated by arrows in Fig. 3.

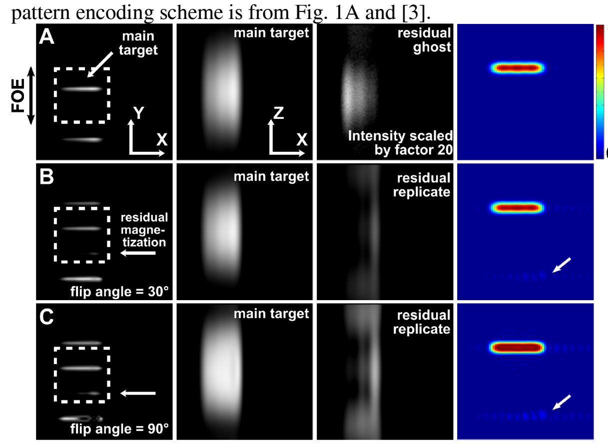

Fig. 3. Experimental excitation of profiles by non-accelerated (A) and accelerated (B, C) 2D pulses calculated using B_1 data. The target encoding scheme is from Fig. 1B and [4]. Simulations are in color.

Discussion and Summary

The data obtained suggests that application of PEX to selection of a limited slice is not perfect. For accelerated 2D pulses based on Cartesian trajectories with the PE direction along the profile thickness, the residual magnetization is outside of the plane of the main target (Fig. 3) and is suppressed effectively by refocusing in such inner volume DWI as in [4]. Furthermore, this fraction corresponds to a small tip angle and therefore would not lead to a strong signal destruction in multi-slice acquisition due to relaxation and long TR values in EPI and DWI. Nonetheless, the FOE is rather small, when the thickness of the profile is encoded along the PE direction of the trajectory. As a consequence, B_1 variations between the individual transmit elements are reduced within the FOE on the B_1 data along the encoding dimensions compared to the scheme from Fig. 1A and [3]. Thus, corresponding accelerated 2D pulses calculated using B_1-maps require high RF power. This should not be seen as a big disadvantage, since numerous design methods such as VERSE [8] have been proposed for a minimization of the RF power. Recently, rotated Cartesian trajectories have been demonstrated for encoding limited slice profiles in [9]. The use of PEX for tilted excitation planes has not been investigated in this work and will be undertaken in future studies.

References

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