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Gaël Saïb[1], Raphael Tomi-Tricot[1], Vincent Gras[1], Franck Mauconduit[2], Nicolas Boulant[1], Alexandre Vignaud[1], Michel Luong[3], Eric Giacomini[1], Edouard Chazel[1], Denis Le Bihan[1], Laurent Le Brusquet[4] and Alexis Amadon[1]

[1]CEA/ISFJ/Neurospin/UNIRS, Gif-sur-Yvette, France, [2]Siemens Healthineers France, Saint-Denis, France, [3]CEA/DRF/IRFU/SACM, Gif-sur-Yvette, France, [4]Laboratoire des Signaux et Systèmes, Université Paris-Saclay/CentraleSupélec/CNRS, Gif-sur-Yvette, France

SYNOPSIS

In Time-Of-Flight sequences, ramp pulses such as TONE's are frequently used to compensate for thru-slab blood flow saturation in cerebral MRA. At Ultra High Field, fast-kz spokes in parallel transmission allow to mitigate B_1^+ heterogeneities in the slab selection process. Here we extend their use for TONE pulses and show improvement of the flip angle ramp fidelity with a homemade z-segmented head array in comparison to a purely azimuthally-distributed commercial coil.

INTRODUCTION

Time-Of-Flight (TOF) sequences suffer from blood flow saturation (BFS) effects avoiding the full visualization of the arterial vasculature in the human brain [1]. Several studies demonstrated that crescent flip angle (FA) profile excitations compensate this effect in the slab direction [2, 3]. Despite the 7T MRI benefits in terms of SNR and contrast for TOF sequences [4], at this field strength, B_1^+ heterogeneities hamper reaching the targeted ramp profiles everywhere in the brain. So far fast-kz spokes have proven useful to homogenize slice or slab profiles, especially in conjunction with parallel transmission (pTX) [5]. In this context, spokes are here associated with TONE pulses to provide a linear FA ramp profile. The impact of a pTx coil array segmentation along the slab direction (z) is sought by comparing the performances of the implied RF weight optimizations with two pTx head arrays: a purely azimuthally-distributed commercial coil and a homemade z-segmented coil.

MATERIALS & METHODS

3D B_0- and B_1-mapping of a human head was performed with 5-mm resolution on a 7T scanner (MAGNETOM, Siemens AG, Healthineers, Erlangen, Germany) with an 8-Tx/Rx RAPID head array (RAPID Biomedical GmbH, Rimpar, Germany) and our homemade 12Tx/22Rx "ASTRE" coil [6]. The ASTRE coil includes 1 Tx/Rx circularly polarized patch close to the top of the head and 11 Tx/Rx azimuthally-distributed dipoles segmented in two rows along the z-direction to provide degrees of freedom for controlling the FA profile in this direction. Either coil was connected to an 8-channel amplifying Tx-array system, eight of the dipoles in the ASTRE configuration being pairwise coupled. Different spoke excitations were optimized to select a variable flip angle pattern from 10° to 40° in a 50-mm slab located in the upper part of the brain, which is highly impacted by BFS effects. The spoke excitations were composed of three identical but weighted sub-pulse waveforms played at optimized (k_x, k_y)-locations. The k-space encoding matrix in the Small Tip Angle approximation was built using the 3-D B_0 and B_1 maps measured on the same volunteer in both coils. Joint optimization of (k_x, k_y)-locations and complex RF weights for each channel and spoke was performed under SAR and power constraints [7,8]. The maximum peak amplitude per channel was set to 160V for both coils. Although the ASTRE coil withstands a higher average power per channel than RAPID, power constraints were fully relaxed by increasing the TR to 1000 ms and the sub-pulse duration to 3 ms to proceed to a fair comparison. In this context, two optimization criteria were formulated in a Magnitude Least Squares problem. The first one (c_1) consisted in minimizing the root-mean-squared error from the desired FA ramp pattern, simply based on virtual square pulses played at the spokes (k_x, k_y)-locations.

$$c_1 = \frac{\left\| |FA_{computed}| - |FA_{desired}| \right\|_2}{\sqrt{N_{vox}} \cdot |FA_{center}|}$$

where the RMS is computed over all voxels in the slab. Then a conventional sub-pulse SINC waveform with TBW=10 was applied to each weighted spoke to insure slab selection.

The second criterion (c_2) aimed at minimizing the RMS error from a constant FA, the target at the center of the slab (25°), while a predesigned ramp waveform applied to the weighted spokes took care of the desired linear slice profile.

$$c_2 = \frac{\left\| |FA_{computed}| - |FA_{center}| \right\|_2}{\sqrt{N_{vox}} \cdot |FA_{center}|}$$

In that case, the TONE waveform was obtained by multiplying the frequency response of the above SINC pulse by the wanted ramp, and by inverse Fourier transforming the resulting product.

All FA profiles and ramp RMS errors (normalized to 25°) were computed with a full Bloch simulation under Matlab. Prior to this study, FA measurements were performed with an AFI sequence [9] on a phantom to validate the FA patterns returned by the Bloch simulation (Figure 1).

RESULTS & DISCUSSION

Figure 2 compares the sum of B_1 magnitudes available for transmission for both RF coils. Thanks to its 3 transmit segments along z, ASTRE offers a better potential for controlling the FA profile in that direction. Indeed, considering c_1, ASTRE almost succeeded in generating the desired profile without using a ramp excitation waveform. This was impossible to perform using RAPID. However as expected, addressing c_2 while using an adapted sub-pulse shape eased the fidelity to the ramp profile. Then the NRMSE and slab profile were slightly better for ASTRE and significantly improved for RAPID (Figure 3, Table 1).

CONCLUSION

Z-segmented transmit coils facilitate the TONE desired ramp profile useful to compensate the BFS effects in off-centered locations for TOF at 7T. Yet non segmented coils can still perform ramp profiles provided adequate RF waveforms. Then kz-spokes were proved useful to improve in-plane homogeneity with such ramp pulses.

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FIGURES

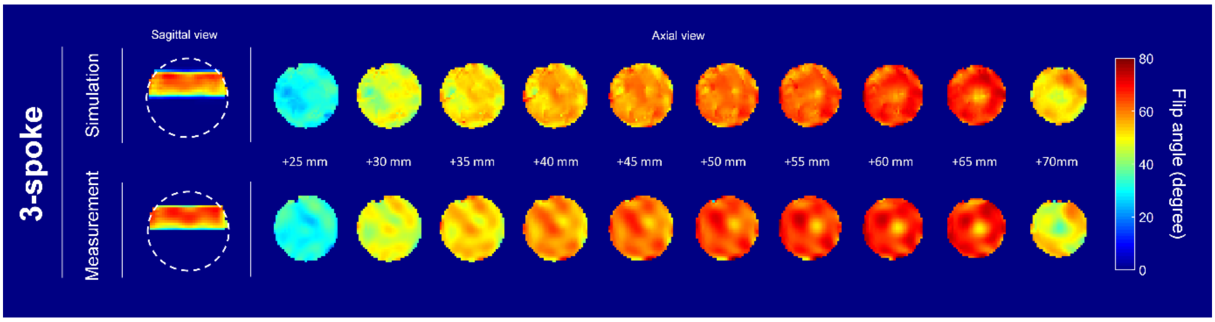

Figure 1: Agreement between FA simulation and measurements with 3-spoke excitations targeting FA=45° to 75° in a 50-mm slab of a spherical water phantom using the ASTRE coil: this validates the simulations performed in this study.

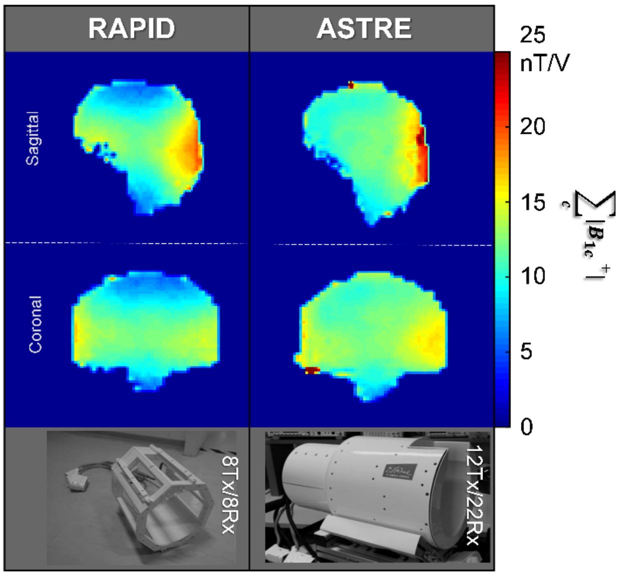

Figure 2: Sum of Tx-channel B1+ magnitudes for the RAPID and ASTRE coils. The individual B1 maps were acquired with the XFL sequence [10] on the same volunteer for each coil. The maps were masked using the Brain Extraction Tool [11] to focus the pulse design on the brain only.

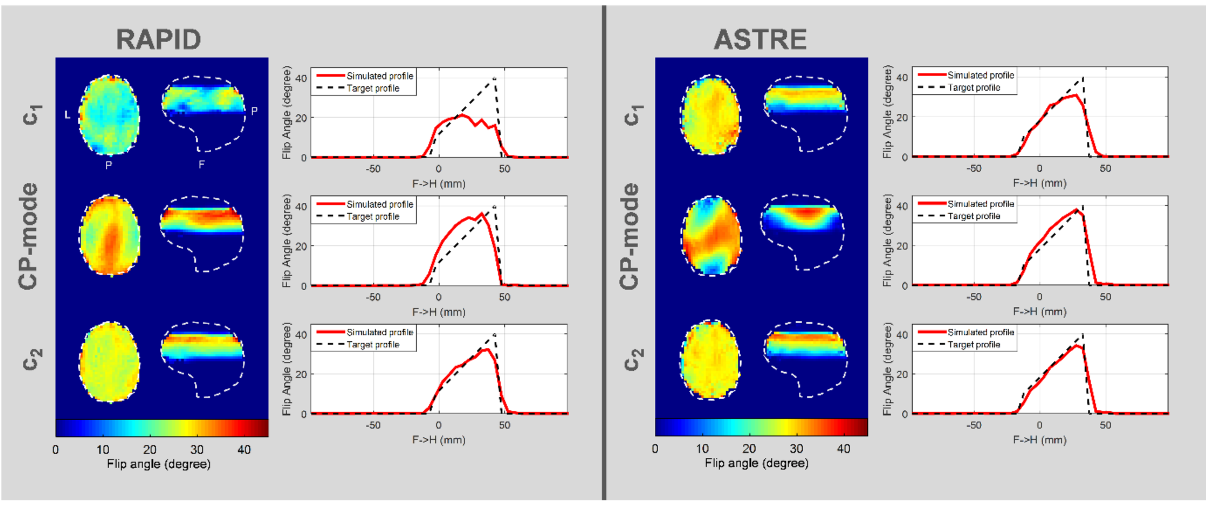

Figure 3: Flip angle Bloch simulations for 3-spoke excitations following c1 and c2 designs, and for the standard circularly polarized (CP) mode (TBW=10). As for c_2, the CP-mode was performed using a ramp excitation waveform. Axial and sagittal flip angle maps and associated slab profiles are shown at the center of the slab of interest.

NRMSE (%)	RAPID	ASTRE
3-spoke (c_1 design)	38.5	20.6
CP-mode	27.7	26.8
3-spoke (c_2 design)	18.1	15.0

Table 1: Final FA-NRMSE according to c_1, obtained from FA-map Bloch simulations after each pulse design presented in Methods and Fig. 3.