Validation of a very fast B1-mapping sequence for parallel transmission on a human brain at 7T

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Introduction: At Ultra High Field, B1 inhomogeneities plague MR images with losses of signal and contrast. To mitigate such a problem, parallel transmission (pTx) requires a set of $B1^+$-maps associated with each transmit channel. A number of relatively accurate B1-mapping sequences exist in the literature, where a tradeoff usually has to be found between accuracy and speed so that a minimal amount of time is spent on calibration for subject-specific RF-shim or tailored pulse design. Here we examine the potential of a very fast 2D B1-mapping sequence originally introduced in [1], which we modified for multi-slice acquisitions [2] in the framework of the interferometric technique [3]. This was applied to human brain B1 calibration at 7T with an 8-channel Tx-array. In addition to the flip angle (FA) maps obtained from the proposed sequence and a standard reference B1-mapping technique, we compare the performance of tailored pulses found based on both calibration methods.

Methods: ***B1-mapping methods:*** The sequence in [1], hereafter referred as XFL, plays a saturation pulse on a single channel which produces a spatially-dependent FA= $\alpha(r)$ to be measured. This preparation pulse is immediately followed by a gradient spoiler and a slice-selective imaging readout train played on all channels in a Circularly-Polarized (CP) combination (Fig. 1). With no magnetization preparation, a reference image is obtained which is divided from the partially-saturated image to obtain a map of $cos[\alpha(r)]$ for that particular channel. While only one reference image is needed, the saturation scheme is repeated for all 8 Tx-channels with a repetition time long enough for full T1 relaxation of all tissues in the brain. We extended the method to multislice imaging by using a very selective VERSE'd saturation pulse already presented in [2]. However, this time, to avoid the typical EPI artifacts especially present at high field, a FLASH readout is adopted. Nevertheless, contrary to the EPI readout, the FLASH train, acquired in centric phase-ordering fashion, introduces a T1-bias in the obtained FA-map as it tends to converge towards a T1-dependent steady state which does not keep track of the initial longitudinal magnetization we are interested in measuring. We therefore know the resulting FA-maps will be slightly less accurate, but much faster to obtain compared to one of the gold standard methods currently employed by many pTx users. This standard [4-6] is the combination of 8 FLASH acquisitions for relative B1-mapping and one or two AFI [7-8] sequences for absolute scaling. This method is hereafter referred as FLAFI for "FLash + AFI". Moreover, to avoid large dynamic ranges of FA that jeopardize the accuracy of the individual-channel FA-maps, in both approaches, whether XFL or FLAFI, we use the interferometric concept introduced by ref. [3], which also allows for less SAR-demanding FA-encoding pulses. To apply this concept to the XFL method, we acquired 8 extra scans with shorter TR and no preparation pulse to recover the relative phase-maps corresponding to the FA-encoding pulses. The 8 combined-Tx phase maps associated with the amplitude maps collected from the first 9 scans (reference + combined-Tx saturated scans) allows the complex FA-maps of the individual channels to be retrieved [3].

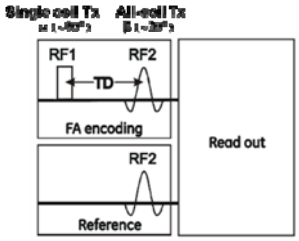

Fig. 1 : B1-mapping sequence of ref.[1]

***Experimental setup*:** Experiments were performed on a Siemens 7T Magnetom scanner (Erlangen, Germany), equipped with an 8-channel Tx-array and a AC84 head gradient set (max. strength: 80 mT/m; slew rate: 333 T/m/s). A home-made transceiver-array head coil was used, which consists of 8 stripline dipoles distributed every 42.5° on a cylindrical surface of 27.6-cm diameter, leaving an open space in front of the subject's eyes. Both the 10-sec- and 6-min-averaged RF powers were monitored in real time for each transmit-channel to ensure patient safety and compliance with the SAR guidelines [9]. The two B1-mapping techniques were compared on short- (~ 300 ms) and long- (~4 s) T1 phantoms before validation on an informed and consenting human subject, following the rules of our institutional review board. In all cases, the targeted resolution for both techniques was 5 mm isotropic, with a coverage of the entire 16-cm spherical phantoms or of the whole human brain.

Sequence parameters and calibrating RF pulses: **1. XFL**: 32 axial adjacent slices, 48x48 matrix, TR = 20 s for first 9 scans, 8 s for last 8 scans; saturation VERSE'd pulse duration = 4 ms with max. voltage = 110 V on each channel; targeted saturation FA in combined-Tx ~ 90°; saturation slice thickness = 5 mm; imaging FA ~ 15°, imaging slice thickness = 3mm; TE = 2.5 ms, FLASH TR = 5 ms; total acquisition time for 8 Tx-channels ~ 4 min. **2. FLAFI** : 3D FLASH: sagittal orientation, 48x48x36 matrix, TR = 50 ms, square 0.1-ms RF pulse targeting combined FA ~ 5° with 30 V on each channel; 3D AFI: same acquisition matrix, TR = TR1+TR2 = 240 ms; TR2/TR1 = 5; square 0.9-ms RF pulse targeting combined FA ~ 90° with 60 V on each channel; 2 complementary AFI acquisitions for better accuracy. Total FLAFI acquisition time for 8 Tx-channels ~ 25 min.

***Tailored pulse design*:** The sets of individual-channel B1-maps obtained from both methods were used to design Transmit-SENSE pulses targeted to reach a FA=4° uniform excitation in the whole human brain. For this purpose, a 5 k_T-point trajectory was adopted as reported in [10], taking the ΔB0-map into account in addition to the B1-maps. Eventually, the tailored pTx pulses obtained from both sets of B1-maps were evaluated in a 1.5 min FLASH sequence similar to that of the FLAFI method, so their performance could be compared from their resulting FA-maps (assuming the FLAFI method constitutes the most accurate measurement).

Results: Comparing the FAs obtained from the 2 methods on a voxel-by-voxel basis inside the spherical phantoms, correlation factors of ~ 0.99 are obtained for all Tx-channels. When fitting slopes through the associated scatter plots, we get XFL/AFI = 1.04 +/- 0.02 for the short-T1 phantom, and 0.98 +/- 0.02 for the long-T1 phantom, which tends to show the XFL systematic FA-errors are less than +/- 5%. When applied to the human brain, the XFL/FLAFI scatter plots are depicted for each Tx-channel in Fig. 2. It shows good agreement between the two methods, except for the higher-FA points close to coil elements 4 and 5, where XFL seems to underestimate slightly the strength of $B1^+$. Nevertheless, when evaluating the performance of the tailored k_T-point pulses issued from both B1-mapping methods, we obtain very similar FA-maps, as shown in Fig. 3. The normalized *rms* spread of FA values within the brain with respect to their mean is 7.9 % for the FLAFI-based k_T-point pulses, and 9.7 % for the equivalent XFL-based pulses. However, it should be pointed that the two measurements took place more than 30 minutes apart, so subject motion could explain part of the observed difference (the FLAFI-based pulses were evaluated right after the FLAFI B1-mapping). More data are needed to confirm such results.

Conclusion: XFL could yield B1-maps 6 times faster than the standard FLAFI method. Although it may not have the same precision as other B1-mapping techniques, it can be used for rapid Tx-array calibration prior to RF shim or tailored pulse design. Such rapid calibration is important for applications in true clinical sessions, or indeed for any research in the actual application of pTX techniques. When applied to k_T-point pulses, XFL seems to yield acceptable errors on a human brain at 7T, causing only an approximately 20% increase in the standard deviation expected from the optimal B1-mapping technique.

References: [1] H-P. Fautz et al., ISMRM 2008, p.1247. [2] A. Amadon et al, ISMRM 2010, p. 2828. [3] D.O. Brunner et al., ISMRM 2008, p. 354. [4] P.-F. Van de Moortele et al., ISMRM 2007, p. 1676. [5] K. Setsompop et al, MRM 60:1422 (2008). [6] M.A. Cloos, et al., ISMRM 2011, p. 3838. [7] V.L. Yarnykh, MRM 57:192 (2007). [8] K. Nehrke, MRM 61:84 (2009). [9] Boulant, et al., ISMRM 2011, p. 3850. [10] M.A. Cloos, et al., DOI.10.1002/mrm.22978.

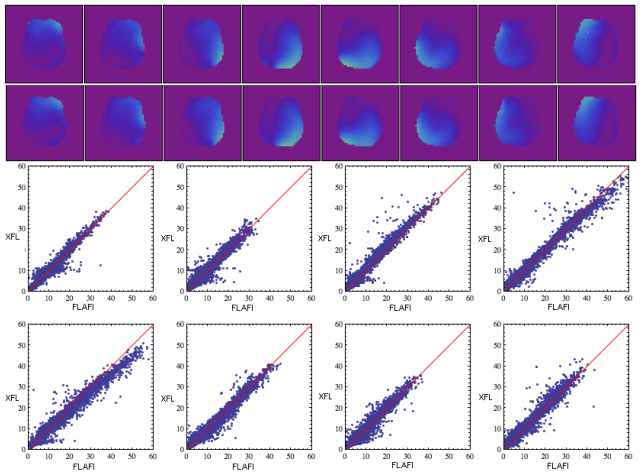

Fig. 2: Upper inset: comparison of FA-maps from the FLAFI (upper row) and XFL (lower) methods (central axial slice shown for each of the 8 Tx-channels). Scatter plots are voxel FA-values reported from both methods (in °) for each of the 8 Tx-channels.

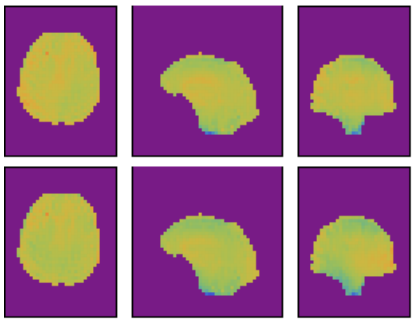
Fig 3: Human brain FA-maps obtained from the application of k_T-point pulses based on FLAFI B1-calibration (upper row) versus XFL's (lower row): the distributions are almost identical, except for a slightly larger standard deviation for XFL: mean and normalized *std* on the entire brain are 3.9° ± 7.9 % (FLAFI) versus 3.7° ± 9.7 % (XFL).