RF pulse designs for MPRAGE at 9.4T

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Target Audience: MR physicists, engineers and clinicians who are interested in acquiring human brain T1-weighted images at UHF.

Purpose: 3D high resolution T1-weighted (T1w) brain images obtained by MPRAGE [1] are used routinely as anatomical reference in functional studies and in tissue classification, because they provide great anatomical details as well as high tissue contrast. At ultra high field (>3T), both the inversion pulse and the excitation pulse in MPRAGE are affected by RF inhomogeneities which increase with field strength [2]. Furthermore, the effectiveness of the inversion pulse is often limited by the increased SAR at high field as well as the intrinsic RF hardware limits. These result in both intensity variation and contrast loss across the T1w images, which are then often difficult for clinicians to interpret and also lead to erroneous results in automated tissue segmentations. In this study, we demonstrated that the intensity and contrast variation due to transmit inhomogeneities typically observed in T1w images at 9.4T can be mitigated by replacing the inversion pulse and the excitation pulse in a standard vendor-supplied MPRAGE with TR-FOCI [3] and kt-points pulses [4], respectively.

Methods: All experiments were performed with a 9.4T human MR scanner (Magnetom 9.4T, Siemens Medical Solutions, Erlangen, Germany) with a 8-channel dual-row transmit and 31-channel receive array coil [5] operated in parallel transmission (pTx) mode. In vivo images were acquired from a 33-year-old male volunteer who gave written, informed consent and the study was approved by the local ethics committee. In the modified MPRAGE sequence, the hyperbolic secant (HS) adiabatic inversion pulse was replaced by a TR-FOCI pulse with a duration of 13ms and a peak amplitude of 10 μT [3]; the rectangular excitation pulse was replaced by a full pTx kt-points composite pulse consisted of 8 sub-pulses of 200 μs duration interleaved by 80 μs gradient blips, i.e. an overall pulse duration of 2.24ms. The amplitudes and the phases of the sub-pulses for each transmit channel were calculated using the spatial domain method [6] with magnitude least square optimisation [7]. Localised B1+ drop out in the optimised solution was avoided by using a region growing algorithm [8]. For the pulse design, B1+ maps from each of the transmit channels were acquired with a T2* compensated version of DREAM [9] (TE_{ste} = 2.22ms, TE_{fid} = 4.44ms, TR = 7.5s, 4mm x 4mm voxel size, 4 mm slice thickness) using a transmit channel phase encoding scheme [10], and B0 maps were recorded separately using two 3D GRE with different echo times (TE1 = 1ms, TE2 = 3.21ms, TR = 30ms, FA = 8^o, 5 mm isotropic voxel size). T1w images from both the original and the modified versions of MPRAGE (TE = 3.64 ms, TR = 3s, FA = 5^o, TI = 1.5s, 0.5 mm isotropic voxel, 384 x 384 x 256 matrix, BW = 180 Hz/Px, GRAPPA factor 2) were acquired for comparison. The transmit coil's default CP mode RF phase setting was used for the inversion pulses in both cases and also for the excitation pulse in the original version of the sequence.

Results and Discussion:

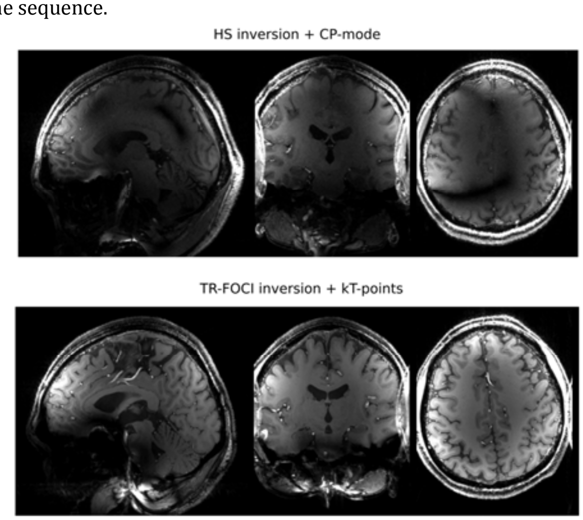

Figure 1: T1w images acquired with MPRAGE using hyperbolic secant inversion pulse and rectangular excitation pulse in CP mode (top row); using TR-FOCI inversion pulse and kt-points excitation pulse (bottom row).

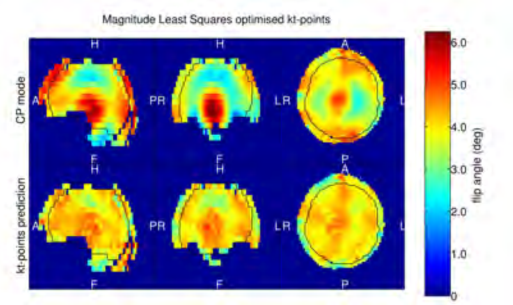

Figure 2: Predicted flip angle spatial distribution of the rectangular pulse in CP mode (top row) and the kt-points excitation (bottom row). The black contour shows the outline of the brain mask used in the optimisation.

Figure 1 shows the T1w images from the two versions of MPRAGE. It can be seen that the combination of TR-FOCI inversion and kt-points excitation has led to reductions in both intensity variations and contrast loss across the image. Figure 2 shows that the kt-points excitation resulted in a more homogeneous distribution of flip angle than the rectangular pulse in CP mode. The improved homogeneity of the excitation equated to improvements in the uniformities in intensity and reduction of contrast variations across the image. The TR-FOCI inversion pulse was designed to achieve full inversion even at low B1+ compared to the HS inversion pulse [3]. The improved inversion efficiency by using TR-FOCI resulted in a more uniform inversion across the whole brain, which in turns reduced contrast variations.

Conclusion: By using TR-FOCI for inversion and kt-points for excitation, intensity variation due to transmit and contrast loss due to insufficient B1+ for inversion in T1-weighted images obtained by MPRAGE at 9.4T were mitigated. Together with the high SNR available at 9.4T this enables ultra-high resolution MPRAGE images with 0.5mm isotropic resolution unaffected by transmit artefacts.

References: [1] Mugler JP, Brookeman, JR. MRM 15 (1990) 152. [2] Van de Moortele P, et al. MRM 54 (2005) 1503. [3] Hurley AC, et al. MRM 63 (2010) 51. [4] Cloos MA, et al. MRM 67 (2012) 72. [5] Shajan G, et al. MRM 71 (2014) 870. [6] Grissom W, et al. MRM 56 (2006) 620. [7] Setsompop K, et al. MRM 59 (2008) 908. [8] Poole MS, et al. ISMRM 22 (2014) 944. [9] Nehrke K, et al. MRM 71 (2014) 246. [10] Tse DHY, et al. JMR 245 (2014) 125.