Overcoming the SAR limitation of magnetization transfer pulses at 7 Tesla using parallel transmission

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Target audience: RF engineers, MR physicists, ultra-high field practitioners.

Purpose: Magnetization transfer (MT) pulses can be used for saturation (1-5) and as a contrast mechanism sensitive to macromolecular metabolites (6-8). MT pulses have high SAR however, which severely hinders their deployment at high field. In this work, we design parallel transmission (pTx) MT pulses with reduced local SAR for improved MT saturation at 7 T.

Methods: *Pulse design*: We design pTx MT pulses exciting several frequencies simultaneously, much like Simultaneous Multi-Slice excitations (but without gradients) (9). We use Fermi sub-pulses for maximum SAR vs. B1+ efficiency. We optimize the channel- and frequency-dependent pTx amplitudes by maximization of the total square flip-angle: $\sum_f \|\mathbf{FA}_f\|_2^2$, where $\mathbf{FA}_f$ is the flip-angle map at frequency *f* (easily computed from the B1+ maps, pTx amplitudes and the sub-pulse time-integral). This objective function is a measure of the total energy deposited in the bound protons pool (BPP). Local SAR and global SAR are constrained to their FDA-approved limits using constraints of the form $\mathbf{x}_{TOT}^H \mathbf{Q} \mathbf{x}_{TOT} \le L$, where $\mathbf{x}_{TOT}$ is the total MT pulse (sum of all frequencies) and **Q** is a generic SAR matrix. We also constrain total peak voltage. *Simulations*: We evaluated this strategy in electromagnetic simulations of a 8-channel pTx coil at 7 T loaded with a realistic head/shoulder body model (10). SAR matrices were compressed to a smaller number of virtual observation points to reduce computation time (11). *Experiments*: We evaluated our approach on a 7 T 8-channel pTx system ("Step 2" pTx Magnetom 7 T, Siemens, Erlangen) loaded with a realistic 3D-printed, 3-compartment (brain, bone and "everything else") 3% agar head phantom. SAR constraints were not enforced in these experiments (the peak voltage constraint was enforced).

Results/Discussion: Although a few studies have reported on pTx MT pulse design (5,12), to our knowledge this work represents the first attempt at overcoming the SAR limitation of MT pulses using pTx. Fig. 1 shows MT pTx pulses designed using four methods: (i) birdcage (BC) mode; (ii) 1 frequency played on every transmit channel; (iii) full pTx at a single frequency and (iv) full pTx at 8 frequencies. Although all designs were local SAR-limited, they created different amount of global SAR and FA^2 in the BPP. As with our previous work with Simultaneous Multi-Slice (10), the strategy (iv) was able to deposit more energy in the BPP than strategy (iii) under the FDA local SAR limit of 8 W/kg. This is because of "SAR hopping" of the local SAR hotspot between frequencies: Since the total SAR map is the sum of the SAR maps at the different frequencies, the total local SAR can be reduced by moving the local SAR hotspot at the different frequencies. Fig. 2 shows preliminary experimental results obtained at 7 T (BC mode vs. full pTx @ 1 frequency). At constant maximum peak voltage, the full pTx approach was able to deposit twice as much energy in the BPP than the BC mode strategy, which resulted in an average increase of the saturation efficiency of on-resonance spins by (0.77-0.72)/(1-0.77)=22%. **Acknowledgement**: Siemens MR, R01EB006847, R01EB017337, P41EB015896. **References**: **[1]** Henkelman MRM 1993;29(6):759-766. **[2]** Wang MRM 1997;37(6):957-962. **[3]** Lin MRM 2003;50(1):114-121. **[4]** Schmitter MRM 2012;68(1):188-197. **[5]** Schmitter MRM 2014;71(3):966-977. **[6]** Gass Annals of Neurology 1994;36(1):62-67. **[7]** Ropele MRM 2005;53(1):134-140. **[8]** van Zijl MRM 2011;65(4):927-948. **[9]** Guérin MRM DOI: 10.1002/mrm.25325. **[10]** Guérin MRM 2014 DOI: 10.1002/mrm.25243. **[11]** Eichfelder MRM 2011;66(5):1468-1476. **[12]** Keupp ISMRM 2011;19:710.

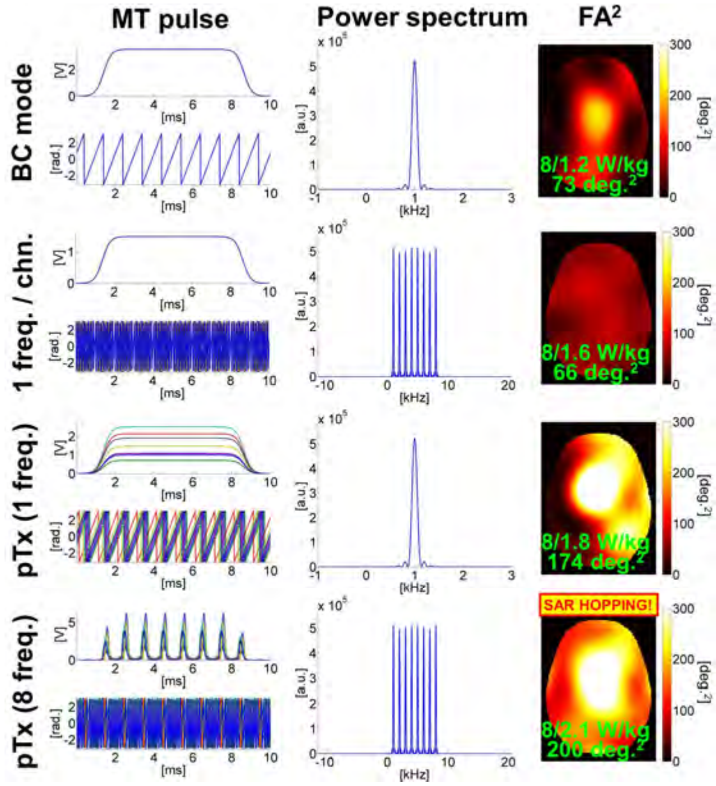

Fig 1. MT pulse, power spectrum and square flip-angle maps (simulations) of four MT pTx strategies (FA^2 is a measure of the energy dumped into the bound protons pool). The green numbers below each FA^2 map indicate the local/global SAR in W/kg and the mean of the FA^2 map in degrees^2. The increased performance of pTx (8 freq.) compared to pTx (1 freq.) is due to local SAR hopping between frequencies.

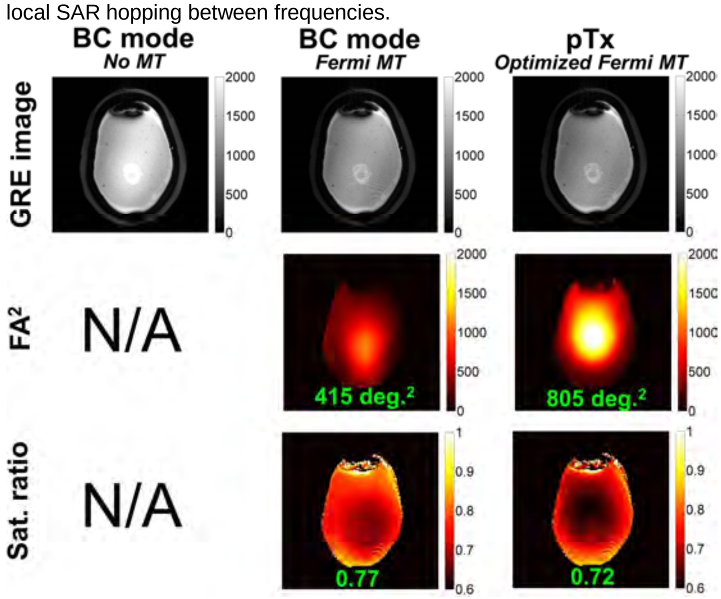

Fig. 2. GRE images, square flip-angle maps and saturation ratios (relative to the case without MT) obtained with the BC mode and full pTx (1 freq.) MT strategies in a realistic 3D-printed 3% agar head phantom. The green numbers below the FA^2 and saturation ratio maps indicate their mean value within the mask.