Comparing the Practical Effects of VOP Compressions for SAR Monitoring at 7 T

Sydney N. Williams[1], Paul McElhinney[1], David A. Porter[1], Shajan Gunamony[1,2]
[1]*Imaging Centre of Excellence, University of Glasgow*, [2]*MR Coiltech*

Purpose: With the increasing popularity of ultra-high field imaging systems, there are also a growing number of groups interested in parallel transmission (pTx) to help combat B_1^+ inhomogeneity associated with a reduced RF wavelength. However, because of increased power absorption within the body at higher fields, pTx must be used with careful monitoring of specific absorption rate (SAR). In practice, this is made computationally tractable with the method of virtual observation points (VOPs) which are generated for a set worst-case SAR overestimation tolerance [1] and are used for configuring pTx coil files for SAR look-ahead during scanning, as well as pTx pulse design [2]. The percentage SAR overestimation used in VOP compression introduces a trade-off between fewer VOPs (computationally "cheaper") and larger overestimations (stricter, more conservative scanning). Previous works have studied the safety implications of different human body electromagnetic models and positions in VOP compressions [3] or even evaluated SAR for patient-specific body models to reduce the safety margin on an individual basis [4-6]. In this study we explore the practical effects of VOP compression for use with a custom 8 Tx/32 Rx coil [7] and investigate how distinct VOPs affect pTx scanning and pulse design at 7 T.

Methods: A 3D electromagnetic model was generated using a transient time domain solver (CST Microwave Studios, Darmstadt, Germany) of our 8 Tx/32 Rx 7 T coil. We then simulated the B_1^+ field of three body models: Duke, Ella (Virtual Family cohort [8]), and Gustav (CST), which had a 1 mm isotropic resolution. For each body model, the B_1^+ field was generated for a head centered at isocenter and also positioned slightly out of the coil centered at z=-10 mm and z=-20 mm. These models were combined in various configurations for VOP compression with varying amounts of percentage overestimation.

The practical effects of scanning with different VOP files were compared by substituting in various configurations on a MAGNETOM Terra 7T scanner with software version VE12U (Siemens Healthineers, Erlangen, Germany) and scanning a head-and-shoulders sucrose gel phantom with conductivity 0.38 S/m. RF power deposition and % SAR real-time estimate were reported in normal operating mode for a basic in-house single-slice turbo spin echo (TSE) sequence (FOV = 300 x 300 mm^2, matrix size 128 x 128) with low SAR load (echo train length =1, TE/TR=11 ms/500 ms) and high SAR load (echo train length =9, TE/TR=55 ms/750 ms), all at a fixed reference voltage of 240 V.

These same sets of VOPs were incorporated into pTx pulse design to observe the trade-off between excitation accuracy and design computation time. In this instance, 8-channel B_1^+ maps were used to design a single-slice magnitude least-squares B_1^+ shim [9] for a nominal 90° flip angle with constraints on local and global SAR generated from the VOPs [10] as well as peak RF voltage per channel. The different pTx shim designs were evaluated in simulation for their flip angle normalized root mean squared error (NRMSE) as well as their total computation time on an Intel i7-7700 32GB RAM workstation.

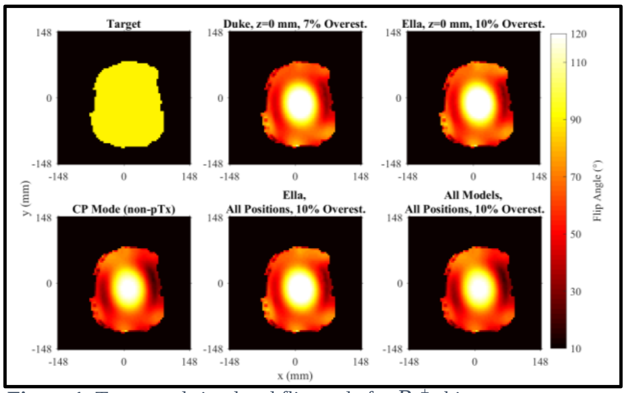

Figure 1: Target and simulated flip angle for B_1^+ shim configurations 2, 4, 9, and 11 as well as the general CP excitation.

Results: Table 1 reports the various VOP configurations investigated in this study along with their power deposition behavior, experimentally with the TSE sequence and in simulation for a pTx shim design. The real-time SAR estimates for all configurations were 18% with the low-SAR TSE and 76-77% for the high-SAR TSE. Note that initially 5% and 7% overestimation were used for VOPs generated with the Duke model at isocenter (configurations 1 and 2), but in the case of Ella and Gustav this compression generated more VOPs than tolerated by the 7 T Terra scanner. Therefore, only 10% was considered for future comparisons. The final configuration 9 included all body models at all positions (except for Gustav which only included z=0 and 20 mm).

In terms of experimental effects, we found very little variation in power deposition amongst different VOP configurations. In practice this is useful, because it could allow the pTx user to choose their VOP configuration for pTx pulse design purposes, knowing that the effective variation while scanning is low. Importantly, we also identified the upper limit for VOP file size on our scanner which is the true practical limitation of our VOP compression.

Figure 1 shows the simulated flip angle B_1^+ shims for a few of the VOP configurations outlined in Table 1. In the case of pTx designs, we found that VOP configurations had a significant effect on the optimization. In some cases, the non-linear optimization could not satisfy all VOP constraints (configurations 6, 8, and 9). Using the VOP generated with the Ella model positioned at isocenter with 7% overestimation yielded the best NRMSE (0.34) with fastest design time for this B_1^+ shim design. By comparison, a circularly-polarized (CP) mode excitation achieved a slightly higher NRMSE (0.38). As expected, NRMSE generally improved at the expense of computation time, but there is an additional factor of the chosen VOP configuration to include in this trade-off.

Table 1: VOP configurations tested experimentally and used for simulated pTx shim design for our custom 8 Tx/32 Rx head coil. Configurations with an asterisk did not meet all SAR constraints enforced by the VOPs so would be unrealizable for scanning.

#	Models Used	Z Position [mm]	Overest. [%]	# VOPs (local)	Av. Power Low SAR load /High SAR load [W]	Flip Angle NRMSE	Design Time [sec]
1	Duke	0	5	327	1.56/6.63	0.34	2.0
2	Duke	0	7	157	1.57/6.63	0.35	1.2
3	Duke	0	10	73	1.57/6.68	0.36	0.7
4	**Ella**	**0**	**10**	**214**	**1.57/6.69**	**0.34**	**1.5**
5	Gustav	0	10	244	1.58/6.70	0.35	1.6
6	Duke*	[0; -10; -20]	10	84	1.58/6.72	0.39	0.2
7	Ella	[0; -10; -20]	10	224	1.58/6.73	0.35	1.6
8	Duke, Ella, Gustav*	0	10	110	1.58/6.71	0.39	0.2
9	Duke, Ella, Gustav*	[0; -10; -20]	10	126	1.58/6.70	0.39	0.2

Discussion/Conclusions: This study served as a preliminary investigation for core pTx development, where there is a need to know how VOP models affect pTx performance. For the models and sequences tested, we found: 1) distinct VOP configurations cause little variation in SAR deposition for scanning, 2) VOP configurations significantly alter pTx optimization behavior, and 3) there is an upper limit to number of VOPs permitted for scanning. Future analysis will be conducted on this topic for full dynamic pTx pulse design.

References: [1] G. Eichfelder and M. Gebhardt, *MRM* 2011. [2] J. Lee et al., *MRM* 2012. [3] S. Wolf et al., *MRM* 2013. [4] Jin et al., *Phys. Med. Biol.* 2012. [5] H. Jeong et al., *ISMRM* 2019. [6] E. Milshteyn et al., *ISMRM* 2019. [7] G. Shajan et al., *ISMRM* 2019. [8] A. Christ et al., *Phys. Med. Biol.*, 2010. [9] K. Setsompop et al., *MRM*, 2008. [10] Hoyos-Idrobo et al., *IEEE TMI*, 2013