Impact of Motion on Parallel Transmission

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INTRODUCTION – Great strides have been made to leverage complementary encoding information from spatially inhomogeneous RF transmit fields of individual coil elements (on top of regular gradient encoding) to accelerate traversal through excitation-k-space and, hence, to shorten the duration of complex multi-dimensional RF pulses, as well as to simply mitigate B_1^+ inhomogeneities at ultrahigh field [1,2, 3,4].

Due to the sequential nature of MRI, patient motion is still one of the unsolved problems in MRI and it should also affect parallel Tx (pTx). Similar to image formation on the receive side, a fundamental requirement for RF transmission is encoding consistency. That is, when RF and gradient pulses are played out, the encoded object should not change. This has been described for the receive side [5] and is currently also under investigation for the transmit side at our lab. However, an even more obvious challenge occurs when pose changes happen between the measurement of coil sensitivities & design of the corresponding RF waveforms and the point in time when RF pulses are actually played out on the system (as the patient might be exposed to an entirely different B_1^+ field). While adaptive techniques can be used to adjust gradient waveforms to patient motion to keep the placement and orientation of a multi-dimensional RF pulse in check, those methods generally are not able to make corresponding changes to the B_1^+ fields. Ultimately, failure of this will affect one's pTx approach to fully handle unwanted aliasing in the excited region, as well as impair the outcome of pTx-based B_1^+ mitigation and B_1+-shimming approaches.

The purpose of this simulation study was to demonstrate pTx's sensitivity to motion and how desired excitation patterns can potentially be degraded by patient motion.

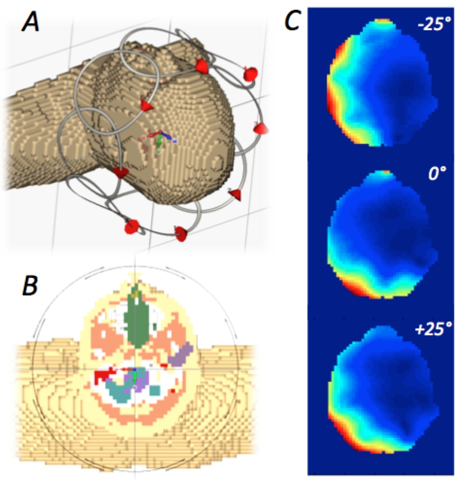

Fig. 1 – A) distribution of 8 current loops ; B) Cross-section of human head model and tissue parcellation; C) Simulated B_1^+ (magnitude) maps for coil #2 for +/-25deg head (+reference position) at 7T.

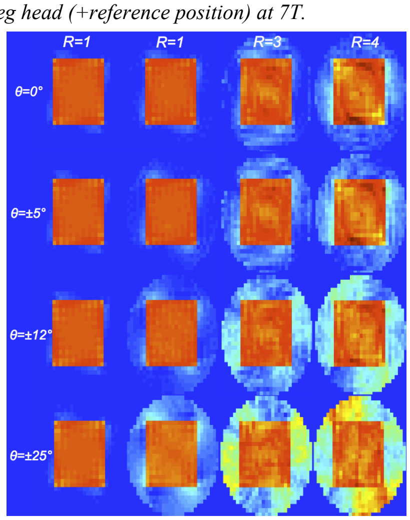

Fig. 2 – Bloch simulations of tranverse magnetization (magnitude) for 8-ch pTx experiement in which brain model was rotated by between RF pulse design and RF transmission. Left-to-right: Excitation-k-space reduction factor R=1,2,3, and 4. Top-to-bottom: 0 (reference), ±5, ±12, and ±25 degrees head rotation. For comparison all images are scaled identically.

METHODS – • _FDTD Simulations_: B_1^+ maps were simulated by Finite Difference Time Domain modeling (Microwave Studio, CST, Darmstadt, Germany). Specifically, eight circular coils were distributed equally along the circumference of a 28cm diameter cylinder with 25% overlap. Each coil was driven with current ports when a head model was at the center of the cylinder (Fig. 1A). The voxels of the human head model were assigned frequency-dependent permittivity and conductivity corresponding to the various tissue types (Fig. 1B). In the simulation, the cylinder was rotated in steps of 5 degrees to cover the range of +/-25 degrees (Fig. 1C).

• _pTx RF Pulse design_: Using the simulated B_1^+ fields from each of the 8 pTx coils, corresponding 2D RF pulse waveforms were designed to excite a 11x11cm rectangle over a target FOV of 22cm employing a constant density spiral gradient waveform, matrix=32x32. To shorten overall RF pulse length, pulses were also designed with subsampled excitation-k-spaces ranging from R=1…4.

• _Bloch Simulation_: Ignoring relaxation and off-resonance effects, the magnetization generated by the pTx RF pulses was simulated by using those B_1^+ maps that reflected patient rotations of θ=±5˚, ±12˚, and ±25˚. This allowed us to investigate the impact of the patient's different B_1^+ exposure between RF pulse design and when pulses are actually played out. The simulation performed without any net head rotation between RF pulse design and transmission was used for reference purposes.

RESULTS & DISCUSSION – Fig. 1C shows the results from FDTD simulations performed for 7T. Clearly, the B_1^+ field depends strongly on the object within the coil. In contrast to lower fields, the orientation of an anisotropic object, such as the human head, relative to the coil location needs to be considered at high field. That is, at 7T coil and object needs to be looked at as a whole. Fig. 2 shows the results from Bloch simulations where the RF waveforms –previously designed for pTx with θ=0° – are played out when the object is exposed to a slightly different B_1^+ field (due to motion). For R=1 (i.e. no acceleration) motion artifacts on the excitation pattern were only appreciated for the ±25° experiment. Also for 2x acceleration, motion up to ±12° was acceptable. As expected, we observed the most notable deviations from the desired square excitation pattern for the largest degree of motion and the highest acceleration factors (Fig.2 bottom right).

Aside from considerable excitation outside the targeted area, motion in pTx can potentially bear even safety hazards. It has been pointed out already that RF pulse design for pTx warrants extra care to avoid excessive SAR [6], and researchers spent a great deal of work to add extra constraints to the RF design models [3,6]. As can be seen from Fig. 2, those SAR considerations might become jeopardized in case of severe motion when dominated by B_1^+ fluctuations not accounted for. The effect of motion on SAR is subject of a forthcoming study.

Although current systems have only a limited set of transmit coils – with typically relatively smoothly varying B_1^+ fields – similar to the receive case, motion sensitivity becomes increasingly challenging with a larger number of coils/smaller size array elements (relative to FOV). This should be also considered in future developments.

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