MRI planning for SAR management in pTx systems

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Target audience: MR physicists and physicians working with Ultra-high field MR scanners.

Purpose: Current approaches to acquire clinical 7-T MR data within acceptable SAR limits require imaging with reduced flip angle and/or number of slices, which reduces SNR/Contrast/Detectability, thereby undermining the potential benefits of high-resolution imaging. For instance, FLAIR has been either omitted at 7-T [1], or has been implemented with a compromise in slice coverage [2] due to its relatively high-power inversion pulse. Another approach is to increase the acquisition time as shown in [1] for the T2-TSE sequence. Parallel transmission RF pulse design has recently shown to be able to manage global [3] and local SAR [4-7] in 7-T systems if a correct patient head and torso model is known. Nevertheless, it is unclear if patient-specific SAR reduction methods could be implemented in a feasible way in the clinical practice in the near future. In this work, we propose an effective protocol for enabling patient-specific SAR modeling and reduction to utilize the full capability and clinical promise of 7-T MR imaging.

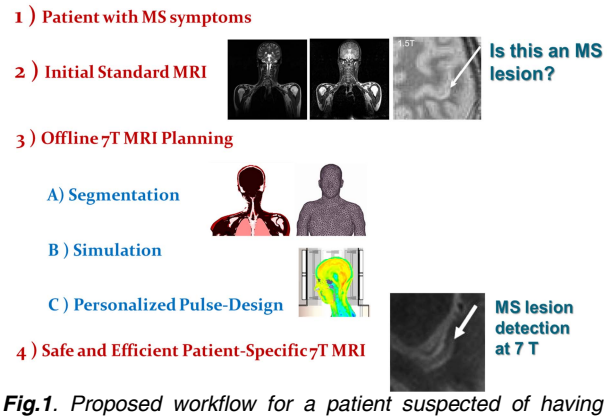

***Fig.1**. Proposed workflow for a patient suspected of having Multiple-Sclerosis [ref].*

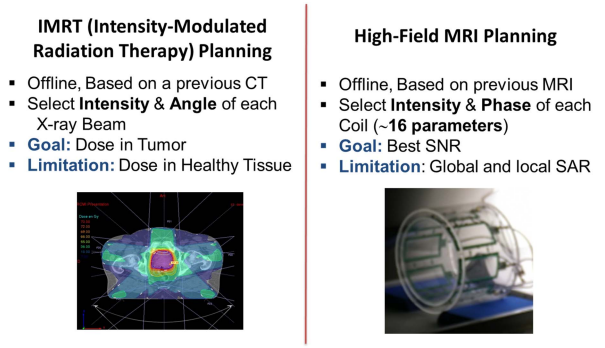

Fig.2. The proposed workflow is similar to the one currently used in clinical IMRT.

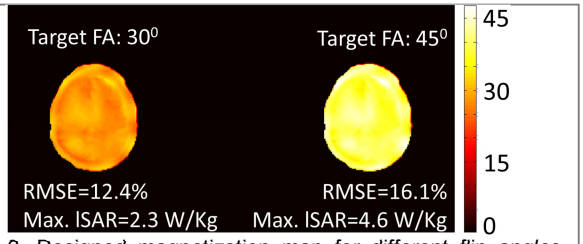

Fig. 3. Designed magnetization map for different flip angles (FA) subject to local SAR 10g (lSAR) constraints created for this specific subject.

Methods: Proposed Workflow: Patient-specific electro-magnetic (EM) models may be used for the SAR estimation and reduction, but they require excessively long computational times (~hours) for segmenting and solving the EM fields within the patient model. To solve this computational problem, we propose to use the anatomical information in the patient's prior MR images to optimize pulse design for 7 T MRI (Fig1). Overall, this approach is similar to current clinical practice in inverse modulated radiotherapy planning (IMRT) [8] (Fig 2). Our main assumption is that patients referred to a 7-T scan would have previous 1.5-T or 3-T MR images. The proposed workflow consists of automatic tissue-segmentation in the MR images [9,10], simulation of each coil's electromagnetic field propagation in the tissue [11], and utilization of an optimized pulse-design that reduces the electrical field deposition [12,13] (SAR reduction) while keeping a good uniform magnetization map (Fig.1). Finally, immediately prior to the 7-T MR acquisition, fast scout images will be obtained to ensure proper patient location.

Verification of the proposed workflow: We investigated the proposed approach with 8 healthy volunteers. Images of the head and torso were acquired on a General Electric Signa HDxt 3.0T MR scanner using the body coil for excitation and an 8-channel quadrature brain coil (head imaging) and the body coil (torso imaging) for reception. Subjects were positioned supine with the head aligned with the back, and a tape holding their chest to minimize respiration motion artifacts. Imaging was performed using a 3D T1-weighted IR sequence. Image preprocessing was carried out using 3D Slicer built-in modules [14]. The preprocessing steps included: MRI bias correction (N4 ITK MRI bias correction), registration (general registration BRAINS) for movement correction, and automatic segmentation [9,10]. A script takes the segmented voxelized images, converts them into SAT files and imports them into SEMCAD [ref] as models. We tested our approach using simulated data for 7T head array with 8 Tx channels. SAR matrices for each coil were computed using the EM fields simulated by SEMCAD [11] and were compressed in a reduced set of VOPs [15]. Pulse design optimization was performed fby following the approach described in [12,13]

Results: Fig. 3 shows one case where a good uniform magnetization field was obtained (Root-mean-square-error (RMSE)=12.4% for flip angle (FA) of 30º, and RMSE= 16.1% for FA of 45º), while keeping the local SAR 10g under the safety limits (2.3 W/Kg and 4.6 W/Kg respectively) (Fig. 3). Based on this approach, we have been able to generate personalized MR acquisitions with SAR management without compromising the image quality. The total computational time was < 8h hours (2 h segmentation, 5.5 h EM simulation, and ~1 min pulse design).

Discussion and Conclusion: This work demonstrates the feasibility of performing an off-line patient-specific 7T MR acquisition planning based on previous MR images. Although an online MRI planning is desirable, and it will be probably possible in the future with faster techniques and computers, the proposed option could benefit current existing 7T MR scanners. Future work includes the verification of these results and the protocol with real acquisitions.

References: [1] Kollia K (2009) AJNR 30(4): 699-702 [2] Zwanenburg JJ (2010) Eur Radiol, 20(4): 915-22. [3] Zhu Y (2004). MRM **51**(4): 775-784. [4] Guerin B (2013). MRM DOI: 10.1002/mrm.24800. [5] Brunner D (2010). MRM **63**(5): 1280-1291. [6] Lee J (2012). MRM, **67**(6): 1566-1578. [7] Sbrizzi, A. (2012). MRM **67**(3): 824-834. [8] Sanghani M (2006) Tech. Cancer Res Treat. 5(5):447-50. [9] Torrado-Carvajal A (2014) Proc. ISMRM 22:1177. [10] Torrado-Carvajal A (2014) Proc. ISMRM 22:4906. [11] SEMCAD X (SPEAG, Zurich,. Switzerland) [12] Martin A (2013) Proc. ESMRMB 69-70. [13] Martin, A. (2014). Proc. ISMRM **2014**: 69-70. [14] Pieper, S (2004) Proc. ISBI 2004, 632–635. [15] Eichfelder, G. (2011). MRM **66**(5): 1468-1476. [16] Polimeridis, A.G.(2014) Journal of Computational Physics,269: 280-296.