Radiofrequency Antenna Helmet Array for Thermal Magnetic Resonance of Brain Tumours at 297 MHz

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Abstract

Thermal magnetic resonance (Thermal MR) uses an RF-applicator to add a thermal intervention dimension to a diagnostic imaging device. Optimizing the performance of RF applicator configurations can eventually improve the performance of Themal MR. Recognizing this opportunity this work examines the feasibility of multi-channel RF applicators using broadband Self-Grounded Bow-Tie (SGBT) antenna building blocks. The focus is on enhancing focal RF power deposition in a target volume by using a multi-channel helmet RF array configuration versus conventional annular RF arrays. A 10-channel helmet RF applicator was designed for Thermal MR, evaluated in EMF simulations and benchmarked against an annular RF array using the same number of RF-elements. Our phantom studies demonstrate that the helmet RF applicator affords an ~10%- 30% improvement in maximum SAR_{10g} in the TV over the conventional annular RF array. Our preliminary findings obtained for the human head voxel model Duke show improved target coverage of high SAR_{10g} for the helmet RF applicator.

1. Introduction

Magnetic resonance imaging (MRI) is a mainstay of diagnostic imaging. Adding a thermal intervention dimension to an MRI instrument is conceptually appealing for local thermal therapy treatment (hyperthermia) as an adjuvant to cancer chemo- and radiotherapy.[1] ThermalMR[2] exploits localized radiofrequency (RF) power deposition in a target volume (TV) by adjusting electric field components of multiple independent RF sources. This is done by setting the individual E-fields to constructively superimpose in the TV while canceling each other outside of the TV to preserve healthy tissue. Ultrahigh field (UHF) MRI is ideally suited for an integrated thermal intervention within a Thermal MR setup as it operates at shorter wavelengths compared to conventional MRI scanners. An integrated RF applicator provides the opportunity for enhancing localized temperature manipulation along with high resolution diagnostic imaging and MR thermometry. Optimizing the performance of RF applicator configurations improves the applicability of Themal MR.[1] Recognizing this opportunity this work examines the feasibility of multi-channel RF applicators using broadband Self-Grounded Bow-Tie (SGBT) antenna building blocks.[2] The report focuses on two RF applicator configurations: (i) 10-channel annular RF array (AA, Figure 1) with the RF elements equally positioned around the head and a (ii) 10-channel helmet RF array (HA, Figure 1) with 8 RF elements being equally arranged around the head plus two elements covering the top of the head. [4,5,6,7]

2. Methods

Electromagnetic field (EMF) simulations of both 10-channel RF applicators were performed in CST Microwave Studio (CST Studio Suite 2020, Dassault Systèmes, Vélizy-Villacoublay Cedex, France) at 297.2 MHz for a brain tissue (ε=60.12, σ=4S/m) mimicking phantom and for the head of the human voxel model (HVM) Duke.[8] SAR calculations were averaged over 10g of tissue or phantom material (SAR_{10g}) according to IEEE/IEC standard 62704-1.[9] For focusing SAR on the target volume (TV), a SAR focusing method[10] was applied to compare the two antenna arrangements. Average SAR_{10g} was evaluated for a TV (size=3cm, depicted by the green square borderline in Figure 1, SARavg>40W/kg), and for a safe margin (SARmax<40 W/kg, size=5cm, depicted by the red borderline). Target coverage (TC) was defined as the percentage of covered TV by SARmax>40 W/kg. Mean target SAR_{10g} (MTS) was evaluated to compare results.

3. Results

Equal excitation of each RF element yielded 2.93 W/kg maximum SAR_{10g} for the HA RF applicator and 1.86 W/kg for the AA RF applicator in the center of the phantom (Figure 1, 2nd row, left panel). The SAR focusing method yielded MTS=55.9 W/kg (100% TC) for the HA applicator and MTS=63.7 W/kg (100% TC) for the AA applicator for TVs placed in the main lobe plane of the phantom (Figure 1). For TVs placed at off-center planes MTS=58.4 W/kg (100% TC) was achieved for HA (Figure 1). The AA provided MTS=39.4 W/kg (39% TC). RF focusing on a TV placed in a superior plane of Duke's brain yielded MTS=45.9 W/kg (97% TC) for the HA and MTS=34.8 W/kg (2% TC) for the AA (Figure 1). Moving the TV into the main lobe plane of Duke's brain resulted in MTS=62 W/kg (100% TC) for HA and MTS=54.1 W/kg (79% TC) for AA, targeting a TV placed in an inferior plane of Duke's brain provided MTS=55.3 W/kg (92% TC) for HA and MTS=49.9 W/kg (55% TC) for AA.

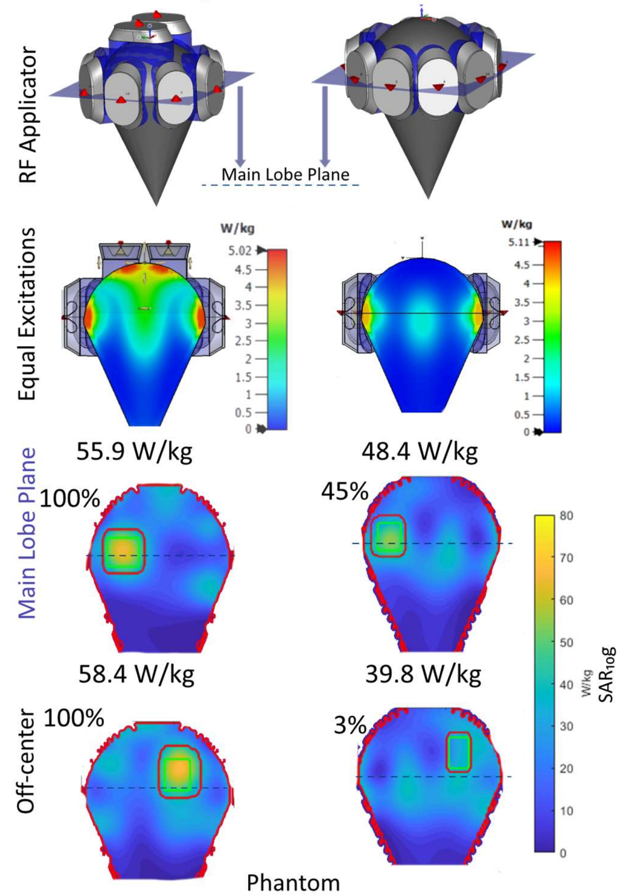

Figure 1. Design of the helmet RF applicator and of the 10-element annular RF applicator and their SAR_{10g} distributions inside the phantom. Mean target SAR_{10g} values and target coverage percentages are annotated in the figure.

4. Discussion and Conclusion

Enhancing targeted localized RF power deposition requires high-density RF antenna arrays. This constitutes a challenge for Thermal MR of the head due to the small surface area. To address this challenge the helmet RF applicator takes advantage of two SGBT antenna placed in a direction that provides limited contribution to MRI but which allows for ample contribution to RF-induced heating. Previous Thermal MR applicators have considered only annular configurations, since antennas whose magnetic field is almost parallel to the main magnetic field B_0 provide limited contributions in imaging. However, since MRI is just one dimension of Thermal MR there is no reason to exclude the use of alternative configurations that can enhance the RF-induced heating aspects, as demonstrated here.

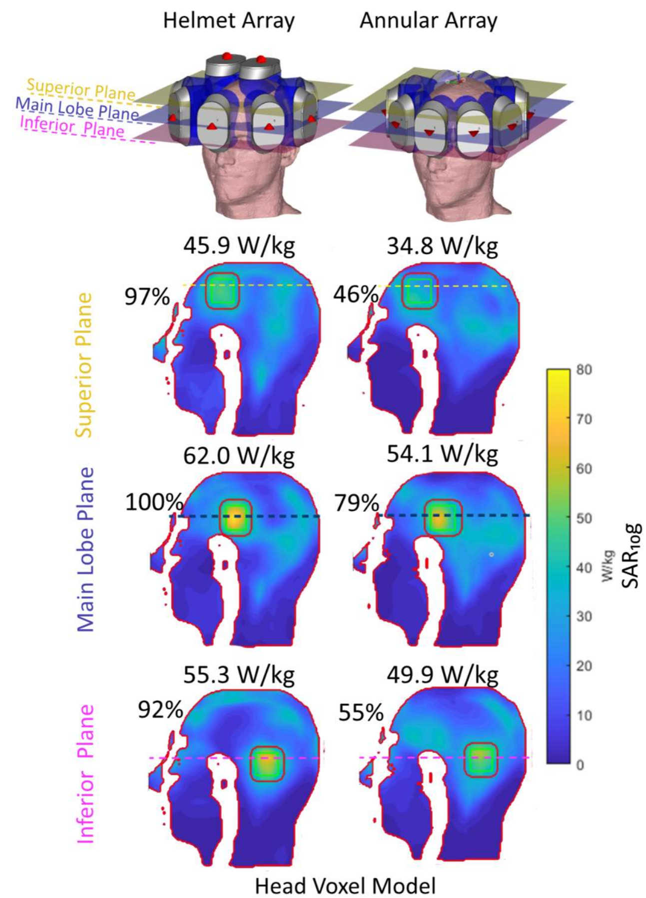

Figure 2. Design of the helmet RF applicator and of the 10-element annular RF applicator and their SAR_{10g} distributions inside the Duke voxel model. Mean target SAR_{10g} values and target coverage percentages are annotated in the figure.

Our phantom studies demonstrate that the helmet RF applicator affords a ~10%- 30% improvement of maximum SAR_{10g} in the TV over the conventional annular RF array. Our findings obtained for the human head voxel model Duke show higher maximum MTS and improved target coverage of high SAR_{10g} for the helmet RF applicator. To conclude, the 10-channel helmet RF applicator is better suited for Thermal MR than the 10-channel annular RF applicator.

6. Acknowledgements

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