Treating Brain Cancer With Heat Therapy Using A Novel Noninvasive Microwave Applicator

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Abstract

Heat cancer therapy (HT) involves increasing tumor temperatures to 40-44°C and is a potent radiosensitizer for the treatment of solid tumors, including brain cancer. Current strategies to heat deep-seated targets in the brain are primarily invasive, and existing HT applicators do not have the appropriate frequency, geometry, and number of sources to focus at depth. This study presents a numerical and experimental investigation of a novel 915 MHz annular phased-array applicator with 72 antennas designed to target brain tumors using focused microwave heating.

The proposed applicator consists of 3 rings of 24 dipole antennas (30 × 6 mm^2) enclosed in a cylindrical frame with 26 cm diameter and 13 cm length. The applicator includes a water compartment (bolus) placed between the head and the antennas for microwave energy coupling and cooling of superficial tissues. The antenna array configuration was optimized in COMSOL Multiphysics® using realistic head anatomical models that include skin, fat, skull, cerebrospinal fluid (CSF), and brain tissues. The RF Module was used to simulate the specific absorption rate (SAR, W/kg), which was then used as a heat source in the Bioheat Transfer (BT) interface. The water in the bolus circulates at a controlled temperature (23°C), so we computed the fluid flow using the Laminar Flow (LF) interface. The physics coupling is given by RF→BT↔LF. The Optimization Module was also used to optimize the applicator input power so that the temperature in a 2-cm diameter target was within 40-44°C, while keeping healthy tissues below 42°C. Tissue properties were based on the IT'IS Database V3.4 with added temperature-dependent blood perfusion that increase 1.5 (2.5)-fold at 45°C in the tumor (healthy brain) tissues. For the experimental investigation, we used cylindrical head phantoms with brain dielectric-mimicking properties. A cross-shaped array of catheters was inserted in the phantoms to facilitate temperature and electric field measurements, which were compared with MR thermometry scans. The antenna focus was characterized by the 50% SAR isovolume (SAR50).

Using the center of the phantom as the target, simulations predicted a SAR50 focus of 3.4×1.4×1.5 cm^3 with an ellipsoid shape. For the same antenna settings, MR images confirmed the size and position of the central focus (4.0×1.5×1.5 cm^3). Simulations prove that the focal volume can be centered anywhere within the skull and shifted laterally to cover larger tumor volumes. Similarly, the head phantoms also confirmed reliable and predictable focus steering. Heating of realistic tumor models to a minimum of 40°C is demonstrated via simulations, while sparing healthy tissue due to its high blood perfusion. Enhanced power deposition was observed near larger CSF pockets, but natural convection diffused the extra heating.

The feasibility of heating small targets in a head phantom using a novel microwave brain applicator is demonstrated with experiments and numerical simulations. By providing a dedicated noninvasive HT brain applicator, adjuvant HT will likely significantly increase clinical outcomes of radiation (RT) treatments, as it has in many other HT+RT clinical trials.

Figures used in the abstract

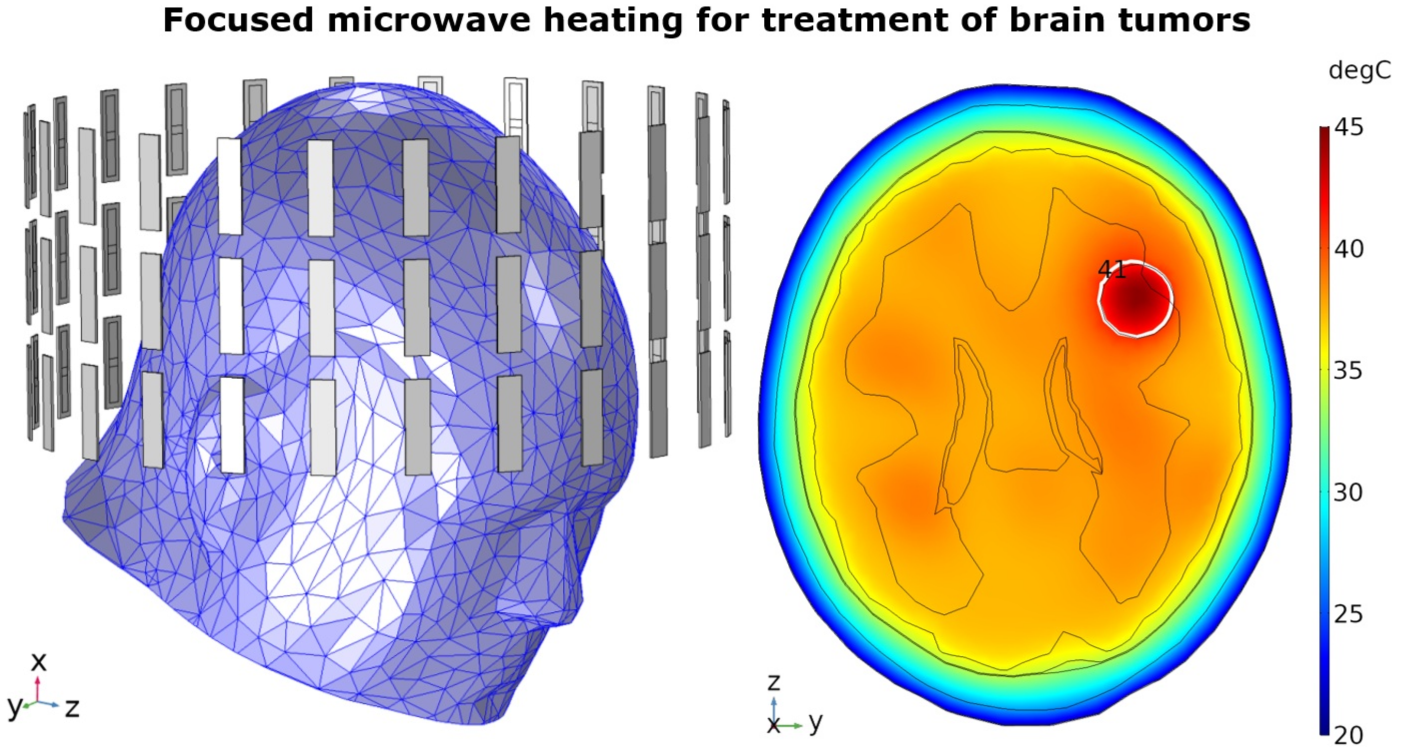

Figure 1 : Noninvasive microwave applicator layout and temperature map (°C) in a cross-section of the human head showing a heat focus centered in a tumor model.