

Thermal Safety Evaluation of Microwave Mammography

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Breast cancer significantly impacts public health, with standard mammography facing limitations such as harmful radiation and challenges in dense breasts. This study assesses the safety of microwave imaging, a promising alternative using non-ionizing radiation, through numerical computing of temperature increases in tissues during an electromagnetic field exposure. Electromagnetic simulations were conducted using the finite difference time domain method. Hardware configuration is derived from a microwave imaging device used in clinical studies. Five digital anatomical breast models were considered, varying in presence and type of tumor, and breast density. Specific absorption rate distributions have been used to obtained temperature increases, with a peak lower than 60 μ K mostly found in fibroglandular tissue and skin depending on the frequency. No harmful effects are expected during the microwave examination.

Index Terms—breast, dosimetry, microwave imaging, safety, SAR, temperature.

I. INTRODUCTION

X-ray mammography, the current gold standard for breast cancer screening, has limitations like low sensitivity in dense breasts, the need for painful compression, and radiation risks, especially for younger women. Microwave imaging (MWI) offers a promising alternative, using non-ionizing radiation to differentiate tissues based on electrical properties, with high contrast between malignant lesions, benign lesions, and healthy tissues. The clinical use of MWI systems is foreseen, supported by ongoing trials [1], making it important to verify through robust dosimetry studies that electromagnetic fields interact safely with biological tissues in this application. In the absence of specific MWI regulations for patient exposure, our approach evaluates the thermal effects of electromagnetic fields on biological tissues in the microwave range, going beyond standard ICNIRP guidelines [2] that focus on reference metrics like Specific Absorption Rate (SAR). Since heating is the primary recognized biological effect of EM radiation in the MWI frequency range, this method assesses potential localized temperature increases.

II. MATERIALS AND METHOD

The safety assessment was conducted with the commercial software Sim4Life (version 7.2, <https://sim4life.swiss/>), implementing the finite difference time domain method. Simulations were performed at the frequencies of 2 GHz, 4 GHz, 6 GHz, and 8 GHz to cover the MWI system wide range of frequencies.

A. Hardware configuration and anatomical breast model

The system here considered was the MammoWave device [3] (UBT Srl, Perugia, Italy), which works in the frequency range of 1-9 GHz at the power of 1 mW. The transmitting Horn antenna assumes five positions, presented in Figure 1a, uniformly distributed around the breast holder. The exposure

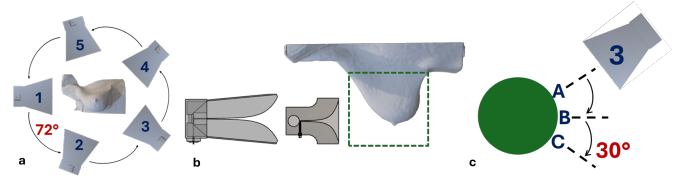


Fig. 1. a) Positions of the Horn antenna around the anatomical breast model (bottom view); b) relative positioning of Horn and Vivaldi antenna and breast model with the region of interest in the green dotted square; c) studied positions of Vivaldi antenna named by A, B and C and represented by black dotted line.

of five different anatomical breast models was simulated. They represent the case of a healthy breast (models #1, #4, and #5), the presence of a benign tumor (model #2), and of a cancerous breast (model #3). The digital models were produced starting from the data collected in a public repository of breast segmentations derived from MRI images for MWI research [4].

B. Mathematical modeling

The heat transfer in biological tissues is described by Pennes' equation [5], here expressed in terms of temperature increase [6] θ (K):

$$\rho c_p \frac{\partial \theta}{\partial t} = \nabla \cdot (k \nabla \theta) - h_b \theta + Q_{em} \quad (1)$$

where c_p is the specific heat capacity ($\text{J kg}^{-1} \text{K}^{-1}$), ρ is the mass density (kg m^{-3}), t is time (s), k is the thermal conductivity ($\text{W m}^{-1} \text{K}^{-1}$), h_b is the perfusion coefficient ($\text{W m}^{-3} \text{K}^{-1}$), and Q_{em} is representing the electromagnetic heat-source density (W m^{-3}). The latter could be expressed as:

$$Q_{em} = \frac{\sigma |E|^2}{2} = \rho \text{ SAR} \quad (2)$$

being E the peak value of the electric field generated in the considered point of tissue (V m^{-1}), σ the electric conductivity

of the tissue (S m^{-1}), and SAR the specific absorption rate of the radiation in the tissue (W kg^{-1}). Assuming negligible diffusion and perfusion terms, namely under the hypothesis of adiabatic heating, SAR and temperature increase can be related as follow

$$\theta = \frac{t_e}{c_p} \text{SAR}. \quad (3)$$

This hypothesis is feasible because of the short duration of exposure during the MWI examination, $t_e = 15$ s. The electrical properties of the healthy tissues were assigned according to the IT'IS Foundation database [7] at the studied frequencies, and assumed to be invariant with respect to temperature. Values for benign tumor and cancer are assigned according to [8]. Values of the specific heat capacity of the different breast tissues, including cancer, were set for every tissue. The tumour's mass density was assigned through a linear approximation of the relationship between the water content [9] and the mass density values of all other tissues.

III. RESULTS

For each tissue, the peak SAR value and its position were extracted from the simulation results and were used to compute the maximum temperature increase inside each breast tissue. To quantify the level of conservativeness of the adiabatic heating assumptions made in this study, a simulation for model #1 at 2 GHz with the antenna position 1 was conducted using the thermal transient solver of Sim4Life. It showed a maximum temperature increase of $2.46 \mu\text{K}$, lower than $7.42 \mu\text{K}$, which is the peak reached from the simulation in the same configuration but not taking into account diffusion and perfusion. For the worst case of temperature increase in model #1, the presence of Vivaldi antenna is simulated in different positions, as shown in Figure 1b and 1c. In the same configuration, two simulations were computed with input parameters varied of 10 % from the exact values. Table I shows the highest temperature peaks reached for every breast model.

TABLE I
MAXIMUM PEAK OF TEMPERATURE INCREASE REACHED VARYING MODEL, FREQUENCY, BREAST TISSUE, AND HORN ANTENNA POSITION.

Model	Configuration	f (GHz)	Horn	Tissue	θ peak (μK)
#1	Standard	6	3	Gland	38.2
#1	Vivaldi (B)	6	3	Gland	58.5
#1	+ 10 %	6	3	Gland	33.7
#1	- 10 %	6	3	Gland	43.7
#2	Standard	4	3	Gland	32.9
#3	Standard	8	3	Skin	27.7
#4	Standard	8	4	Skin	15.5
#5	Standard	6	4	Gland	17.5

IV. DISCUSSION AND CONCLUSION

The highest temperature increase observed in this analysis is $58.5 \mu\text{K}$. This small value is related to the low input power of 1 mW in MammoWave device. Anyway, considering the

linear relationship with the temperature increase, if increasing the power of some order of magnitude is necessary, this will not lead to temperature peaks harmful for the breast. In most cases until 6 GHz, the temperature peak occurs in fibroglandular tissue and at 8 GHz it moves to the skin. In models #2 and #3, tumors receive a rather attenuated field, being located in a more internal area of the breast. Despite the lower conductivity, it was mostly found that the benign tumor has a higher absorption than the malignant tumor, likely because the tumor in model #3 is deeper than the one in model #2. Larger temperature increases could be observed in more superficial tumors, but the order of magnitude of the obtained results reassures about the absence of thermal hazards even in such a situation. Models #4 (9.3 % of fibroglandular tissue) and #5 (25 % of fibroglandular tissue) were added to the simulation environment to assess how breast density influences the temperature increase. In case of low density, the energy of the radiation tends to be primarily dissipated at the skin level, whereas in the case of high density, a significant amount of energy reaches the most superficial areas of the glandular tissue. The worst scenario is found when the transmitter and the receiving Vivaldi antenna are at 30° from each other. In this case, an increase of the peak temperature was found in fat (+11.8 %), in fibroglandular tissue (+53.1 %), and in skin (+5.4 %) and this is due to the fact that Vivaldi can act as a scatterer and focus the EM field towards the breast. About the variation of 10 % from exact values in the electrical and thermal properties of breast tissues, the maximum variation in the results is 15 %.

The small temperature increases found in breast tissues during the MI examination with the considered configurations suggests that MI can be performed without harmful effects.

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