

Microwave-induced thermoacoustic monitoring of pulsed microwave ablation: Sensitivity analysis of temperature-dependent signal characteristics

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Microwave ablation (MWA) is an effective cancer treatment that involves using a minimally invasive antenna inserted into a tumor to heat cancerous tissue to temperatures greater than 60°C, causing coagulation and necrosis, i.e. instant cell death. The goal of MWA is to heat a sufficient margin of tissue around the tumor, assuring all cancerous cells are killed and recurrence is prevented. This requires image guidance and monitoring during MWA. The limitations of current clinical imaging techniques motivate the development of more accurate and cost-effective MWA monitoring techniques that are capable of reliably determining the extent of the ablation zone during the MWA procedure.

Pulsed MWA is a recently developed technique that utilizes microwave pulses instead of continuous-wave energy for heating tissue and therefore is capable of simultaneously generating thermoacoustic (TA) waves (A. L. Evans, J. F. Sawicki, H. Luyen, Y. Mohtashami, N. Behdad, and S. C. Hagness, “Feasibility Study of Microsecond Pulsed Microwave Ablation Using a Minimally Invasive Antenna,” *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 4, pp. 627–631, Apr. 2021). The thermoacoustic effect occurs when tissue absorbs a microwave pulse and undergoes a micro-temperature rise. The resulting tissue expansion induces the generation of an acoustic pulse. During pulsed MWA, the increasing macro-scale temperature over many microwave pulses causes changes in the characteristics of the TA wave due to the change in temperature-dependent tissue properties, giving rise to the potential for leveraging the dynamic characteristics of the received TA waves to monitor the progression of MWA in real-time. The temperature-dependent tissue properties of liver change measurably over the temperature range of interest for MWA. Previous studies have shown that the amplitude and time of arrival (TOA) of the TA signal change with temperature during the MWA procedure (A. L. Evans, C. Ma, and S. C. Hagness, “Microwave-induced thermoacoustic signal characteristics in a dynamic temperature environment,” *Biomed. Phys. Eng. Express*, vol. 8, no. 3, p. 035020, Apr. 2022).

We designed and conducted a sensitivity analysis to investigate how the changes in tissue properties due to microwave heating affect the key characteristics of the TA signals generated during pulsed MWA. In this study, we considered the temperature-dependent thermal and acoustic properties of liver tissue. We performed simulations of MWA in liver tissue using COMSOL Multiphysics to quantify the impact of temperature on the peak-to-peak amplitude and TOA of the microwave-induced TA signal. We varied the heat capacity, thermal conductivity, density, speed of sound, and the coefficient of thermal expansion individually over their expected range of values based on their known temperature dependence. Pressure-acoustics and thermoviscous acoustics simulations were used to model TA signals generated from the time-varying microwave power absorption density that was calculated in the electromagnetics simulation. The findings from this sensitivity analysis further elucidate how the TA signal characteristics relate to the heating of liver tissue during MWA, setting the foundation for future development of MWA monitoring techniques based on microwave-induced TA waves.