Investigation of High-Frequency Microwave Ablation using Floating-Sleeve Dipole Antennas

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Microwave ablation (MWA) is a promising low-cost, minimally invasive alternative to surgical resection for the treatment of many different types of cancerous tumors. High frequency MWA antennas are desirable because they are smaller, which makes them less invasive and able to reach tumors not accessible by lower frequency MWA antennas, but the vast majority of past MWA work has focused on the use of frequencies below 2.5 GHz. The few exceptions involve antennas operating at 9.2 GHz (Hodgson *et al.*, *Brit. J. Obstet Gynaec,* 106, 684-694, 1999), 14.5 GHz (Hancock *et al.*, *IEEE Trans. Microw. Theory Techn.*, 61, 5, 2230-2241, 2013), 18 GHz (Yoon *et al.*, *Int. J. Cancer,* 129, 1970-1978, 2011), and 24 GHz (Komarov, *Eur. Phys. J. Appl. Phys.,* 68, 2014). In the past, greater attention has been given to lower-frequency designs, in part due to concerns that the decrease in microwave penetration depth with increasing frequency would preclude the creation of sufficiently large volumes of ablated tissue.

A recent study (Luyen, *et al.*, *IEEE Trans. Biomed. Eng.,* 61, 6, 1702-1710, 2014) involving electromagnetic/thermal simulations as well as *ex vivo* bovine liver experiments demonstrated that comparable ablation zones are achieved at 1.9 GHz and 10 GHz. The results of the study suggest that at higher microwave frequencies, the higher electrical conductivity of tissue results in more compact specific absorption rate patterns with higher peak absorption, and that thermal conduction plays a significant role at higher frequencies in determining the volume of ablated tissue. These initial results at 10 GHz motivate a comprehensive study of MWA performance as a function of frequency to fully understand the viable range of operation.

We examine in detail the performance of MWA at frequencies above 2.5 GHz using computational electromagnetic and thermal simulations of floating-sleeve dipole (FSD) antennas as well as *ex vivo* ablation experiments in perfused tissue-mimicking phantoms. The dimensions of the FSD are customized for each frequency considered. We characterize the effects of operating frequency, input power, duty cycle, and ablation time on tissue heating; further, we investigate how small the antenna dimensions can be made while still achieving a clinically relevant ablation zone. While smaller-diameter probes are less invasive, their increased ohmic losses have the potential to lead to undesired heating of the surrounding healthy tissue along the feed line. Tradeoffs are thoroughly investigated as part of our study.