A directional interstitial antenna for microwave tissue ablation: theoretical and experimental investigation

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Background: Interstitial microwave antennas are in clinical use for thermal ablation of tumors and benign disease. Currently available antennas have axially symmetric radiation patterns and do not provide a means for controlling heating along the angular expanse. Antennas with directional radiation patterns may provide a means for limiting thermal damage to critical structures in proximity to ablation targets. The objective of this study was to design and experimentally assess the feasibility of a directional interstitial antenna for microwave tissue ablation.

Methods: To create a directional radiation pattern, a conductive reflector was positioned behind a conventional coaxial monopole antenna, minimizing microwave propagation in that direction. 3D finite element method simulations were employed to investigate the radiation pattern of directional antenna designs at 2.45 GHz. Initial simulations indicated a suitable antenna-reflector spacing to be approximately a quarter wavelength, thus a water-cooled design was explored to minimize applicator diameter. Simulations were used to determine dimensions that optimized the antenna’s reflection coefficient and directionality. Proof-of-concept applicators were fabricated and experimentally evaluated with ablations in ex vivo porcine muscle. Fiber-optic temperature measurements and extents of visible tissue discoloration were used to characterize dimensions and directionality of experimental ablation zones.

Results: Simulations identified an optimal monopole-based design with a reflection coefficient of -23 dB at 2.45 GHz, capable of creating ablation zones measuring 19 mm (width) x 14 mm (radial depth) and 23 mm x 16 mm, when powered with 30 W and 50 W, respectively. Reflection coefficients of the fabricated water-cooled antennas (3.8 mm OD) were in good agreement with simulations (minimum -23.1 dB at 2.35 GHz). Experimental ablations at 30 W (n = 3) yielded ablation zones measuring 18.7 ± 2.1 mm x 15.3 ± 2.1 mm, restricted to ~180° of the angular expanse. The temperature elevation measured 1 cm from the applicator in the reverse direction remained under 1 °C, and visibly ablated regions were restricted to within 2 mm of the catheter, indicating directional control. At 50 W (n = 4), experimental ablation zones measured 24 ± 4.9 mm x 17.7 ± 2.8 mm. Simulations indicated the potential of high dielectric materials to reduce applicator diameter and increase ablation zone dimensions.

Conclusion: This study was undertaken to design and assess the feasibility of creating directional ablation zones with an interstitial microwave antenna. The presented applicator may provide a practical means for limiting thermal damage to critical structures in proximity to ablation targets.