Creation of Short Microwave Ablation Zones: In Vivo Characterization of Single and Paired Modified Triaxial Antennas

Meghan G. Lubner, MD, Tim J. Ziemlewicz, MD, J. Louis Hinshaw, MD, Fred T. Lee, Jr, MD, Lisa A. Sampson, BS, CVT, and Christopher L. Brace, PhD

ABSTRACT

Purpose: To characterize modified triaxial microwave antennas configured to produce short ablation zones.

Materials and Methods: Fifty single-antenna and 27 paired-antenna hepatic ablations were performed in domestic swine (N = 11) with 17-gauge gas-cooled modified triaxial antennas powered at 65 W from a 2.45-GHz generator. Single-antenna ablations were performed at 2 (n = 16), 5 (n = 21), and 10 (n = 13) minutes. Paired-antenna ablations were performed at 1-cm and 2-cm spacing for 5 (n = 7 and n = 8, respectively) and 10 minutes (n = 7 and n = 5, respectively). Mean transverse width, length, and aspect ratio of sectioned ablation zones were measured and compared.

Results: For single antennas, mean ablation zone lengths were 2.9 cm ± 0.45, 3.5 cm ± 0.55, and 4.2 cm ± 0.40 at 2, 5, and 10 minutes, respectively. Mean widths were 1.8 cm ± 0.3, 2.0 cm ± 0.32, and 2.5 cm ± 0.25 at 2, 5, and 10 minutes, respectively. For paired antennas, mean length at 5 minutes with 1-cm and 2-cm spacing and 10 minutes with 1-cm and 2-cm spacing was 4.2 cm ± 0.9, 4.9 cm ± 1.0, 4.8 cm ± 0.5, and 4.8 cm ± 1.3, respectively. Mean width was 3.1 cm ± 1.0, 4.4 cm ± 0.7, 3.8 cm ± 0.4, and 4.5 cm ± 0.7, respectively. Paired-antenna ablations were more spherical (aspect ratios, 0.72–0.79 for 5–10 min) than single-antenna ablations (aspect ratios, 0.57–0.59). For paired-antenna ablations, 1-cm spacing appeared optimal, with improved circularity and decreased clefting compared with 2-cm spacing (circularity, 0.85 at 1 cm, 0.78 at 2 cm).

Conclusions: Modified triaxial antennas can generate relatively short, spherical ablation zones. Paired-antenna ablations were rounder and larger in transverse dimension than single antenna ablations, with 1-cm spacing optimal for confluence of the ablation zone.

Although radiofrequency ablation has been the most commonly used and researched heat-based modality to date, microwave ablation is gaining increased adoption because of a variety of advantages. These include more rapid generation of hotter temperatures, larger ablation zones when using high power, decreased susceptibility to "heat sinks," and improved energy penetration in lung, bone, and charred/desiccated tissue (1–6). Despite these advantages, a substantial limitation to the use of microwaves is the length of the ablation zone, which is often substantially greater than the transverse dimension and can be more than 6–8 cm when using a single antenna (7–10). These larger, longer, hotter ablations could have increased potential to cause damage to adjacent vulnerable structures or burns to the body wall if not carefully monitored. In addition, many tumors are somewhat spherical, and longer ablation zones may lead to increased treatment of normal background organs proximal and distal to the mass. To date, in vivo reports of microwave ablation have focused on increasing the transverse diameter of the ablation zone, often at the cost of increased length (7–10).

Ablation zone length is impacted by many factors, including antenna design and radiating segment, frequency/wavelength, ablation time, and applied power (11–14). A dual-slot antenna design has shown promise in producing a shorter, more spherical ablation zone, but is not yet commercially available (15,16). Several vendors may be working on an antenna to generate shorter ablation zones. A gas-cooled modified triaxial antenna

From the Departments of Radiology (M.G.L., T.J.Z., J.L.H., F.T.L., L.A.S., C.L.B.), Biomedical Engineering (C.L.B.), and Medical Physics (C.L.B.), University of Wisconsin School of Medicine and Public Health, E3/311 Clinical Sciences Center, 600 Highland Ave., Madison, WI 53792. Received April 9, 2014; final revision received June 29, 2014; accepted June 30, 2014. **Address correspondence to** M.G.L.; E-mail: mlubner@uwhealth.org

J.L.H. is a shareholder and medical board member of Neuwave Medical (Madison, Wisconsin). F.T.L. is a shareholder and patent holder and serves on the board of directors of Neuwave Medical and a patent holder and inventor who receives royalties from Covidien (Neuhausen am Rheinfall, Switzerland). L.A.S. is a research consultant for Neuwave Medical. C.L.B. is a shareholder and research consultant for Neuwave Medical. Neither of the other authors has identified a conflict of interest.

J Vasc Interv Radiol 2014; 25:1633–1640

http://dx.doi.org/10.1016/j.jvir.2014.06.032

has recently become commercially available which has been designed to produce shorter, tip-weighted ablation zones. The purpose of the present study was to test and characterize single and paired modified triaxial antennas in an in vivo swine model.

MATERIALS AND METHODS

Animals, Anesthesia, and Overview of Procedures

Approval for this study was obtained from the institutional research animal care and use committee, and all husbandry and experimental studies were compliant with the National Research Council (www.nap.edu/catalog.php?record_id=12910). Eleven female domestic swine (Arlington Farms, Arlington, Wisconsin) were used for this study. Preanesthetic sedation was achieved with ketamine. Sedated animals were intubated, and anesthesia was maintained with inhaled isoflurane (Halocarbon Laboratories, River Edge, New Jersey). The liver was surgically exposed at laparotomy with a bilateral subcostal incision to enable applicator placement and to verify proper positioning. Microwave ablation was then performed in each of four distinct liver lobes, and different ablation times were distributed among the animals to reduce sampling bias. After the ablation procedures (which took approximately 2–3 h), animals were euthanized with an overdose of pentobarbital sodium and phenytoin sodium (Beuthanasia-D; Schering-Plough, Kenilworth, New Jersey). Zones of ablation were immediately excised and sectioned as described later.

Microwave Ablations

All microwave ablations were performed from an open approach with the use of 17-gauge gas-cooled modified triaxial antennas with a 15-mm radiating segment (Precision PR 15; NeuWave Medical, Madison Wisconsin). Microwave power was applied continuously at 65 W from the 2.45-GHz solid-state generator. A total of 50 single-antenna ablations were performed for 2 (n = 16), 5 (n = 21), and 10 minutes (n = 13). These time periods were selected based on earlier in vivo work and clinical experience with a conventional triaxial antenna (10). At least one ablation was performed in each lobe of each porcine liver. A total of 27 paired-antenna ablations were also performed in a similar fashion, with the antennas spaced 1 or 2 cm apart and both powered at 65 W for 5 (n = 7 at 1 cm, n = 8 at 2 cm) and 10 minutes (n = 7 at 1 cm, n = 5 at 2 cm). These times and spacings were also based on earlier in vivo/ex vivo work and clinical experience (17–19).

Measurements of Ablation Zone Size and Shape

Ablation zones were excised en bloc and were sectioned parallel to the ablation applicator to optimize length measurements (coronal to the applicators for the paired antennas). Samples were optically scanned (Perfection 2450 Photograph, model G860A; Epson, Long Beach, California) and saved as electronic images. Standard ablation zone metrics including length, transverse dimension, area, and aspect ratio (width:length) were analyzed by using ImageJ software (version 1.45s; National Institutes of Health, Bethesda, Maryland) (20). Circularity was measured for the paired-antenna ablations.

Statistical Analysis

Descriptive statistics of each metric (mean length, transverse dimension, area, aspect ratio) were calculated at each time point for single and paired microwave ablations, and are reported as mean ± one standard deviation. Volumes were also calculated by using the formula for the volume of an ellipsoid ($4/3\pi abc$). The single-antenna modified triaxial data were compared across time points by using a Wilcoxon rank-sum test. The paired antenna data were compared by time within spacing and then by spacing within time by using a Wilcoxon rank-sum test. Length and area of paired antenna ablation zones were also compared versus single antenna ablations performed at the same time and power by using Kruskal–Wallis tests, with a Wilcoxon rank-sum test used for the two comparisons of each of the two-antenna ablations against the single antenna. The analysis did not account for clustering of lobes within animals because lobes were considered as independent. Exploratory and diagnostic plots were obtained to assess the validity of statistical test assumptions. A P value less than .05 was considered to indicate a significant difference. There was no adjustment of P values for multiplicity. Statistical analyses were performed in R (version 2.15.2; R Foundation for Statistical Computing, Vienna, Austria) (21).

RESULTS

The mean ablation zone lengths for single-antenna ablations at 2 min, 5 min, and 10 min (65 W) were 2.9 cm ± 0.45, 3.5 cm ± 0.55 and 4.2 cm ± 0.4, respectively (**Fig 1**). These ablation zones had corresponding transverse dimensions of 1.8 cm ± 0.27, 2.0 cm ± 0.32, and 2.5 cm ± 0.25, respectively. Aspect ratios for all single-antenna ablations were approximately 0.6 (**Fig 1, Table 1**). There was significant growth in length (P = .001) and area (P = .01) between 2 and 5 minutes, with continued significant growth from 5 to 10 minutes (length, P = .0009; area, P < .0001).

The paired-antenna ablations showed lengths of 4.2 cm ± 0.9 and 4.9 cm ± 1.0 for 5-minute ablations (65 W each antenna) at 1-cm and 2-cm spacing, respectively. Lengths of 4.8 cm ± 0.5 and 4.8 cm ± 1.3 were seen at 10 minutes with 1-cm and 2-cm spacing, respectively. Transverse dimensions were 3.1 cm ± 1.0 and 4.4 cm ±