Defining New Metrics in Microwave Ablation of Pulmonary Tumors: Ablation Work and Ablation Resistance Score

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ABSTRACT

Purpose: To investigate pulmonary microwave ablation metrics including ablation work, ablation resistance score, and involution.

Materials and Methods: Retrospective review was performed of 98 pulmonary tumor ablations using the NeuWave Certus Microwave Ablation System (NeuWave Medical, Madison, Wisconsin) in 71 patients (32 men and 39 women; mean age, 64.7 y ± 11.5). Ablation work was defined as sum of (power) * (time) * (number of antennas) for all phases during an ablation procedure. Ablation zone was measured on CT at 3 time points: after procedure, 1–3 months (mean 47 d), and 3–12 months (mean 292 d). Ablation zones were scored based on location for pulmonary lobe (upper = 1, middle/lingula = 2, lower = 3) and region (peripheral = 1, parenchymal = 2, central = 3), and the 2 were summed for ablation resistance score.

Results: Ablation zone on CT at 1–3 months was significantly smaller in regions with higher ablation resistance score ($P < .05$). There was a significant correlation between ablation work and ablation zone measured on CT performed after procedure ($P < .001$), at 1–3 months ($P < .001$), and at 3–12 months ($P < .05$). Ablation zone significantly decreased from after procedure to 1–3 months ($P < .001$) and from 1–3 months to 3–12 months ($P < .001$), with change from after procedure to 1–3 months significantly greater ($P < .01$).

Conclusions: Pulmonary microwave ablation zone is significantly smaller in regions with higher ablation resistance score. Ablation work correlates to ablation zone with a nonlinear involution pattern in the first year and may be useful for planning before the procedure.

ABBREVIATIONS

LN = Lung (antenna), PR = Precision (antenna)

Thermal ablative techniques applied to the lung include radiofrequency (RF) ablation, microwave ablation, and cryoablation. Compared with RF ablation, microwave ablation in the lungs has been shown to produce a larger ablation zone (1). Wolf et al (2) reported the clinical success of microwave ablation for treatment of pulmonary malignancies in patients deemed medically inoperable with cancer-specific mortality yielding a 1-year survival of 83%. Perfusion-mediated tissue cooling (heat sink) describes the perfusion-related loss of energy deposition associated with thermal ablation, which may be a cause of local recurrence secondary to sublethal temperatures of the target lesion (3–5). Prior studies demonstrated the heat-sink effect in the lung with RF ablations adjacent to vessels > 3 mm, with an increased rate of recurrence after ablation of tumors in direct contact with such vessels (6,7). Studies have also suggested that microwave ablation is less susceptible to the heat-sink effect compared with RF ablation (8–10). In addition to perfusion, impedance caused by ventilation is

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F.G.A. is a paid consultant for HealthTronics, Inc (Austin, Texas) and participated in a clinical trial for Galil Medical, Inc (Arden Hills, Minnesota). R.D.S. is a paid consultant for NeuWave Medical, Inc (Madison, Wisconsin) and HealthTronics, Inc, receives grants from HealthTronics, Inc, and performed research for Galil Medical, Inc. None of the other authors have identified a conflict of interest.

J Vasc Interv Radiol 2016; 27:1380–1386

http://dx.doi.org/10.1016/j.jvir.2016.05.026

a unique confounding factor associated with thermal ablation in the lungs. Decreased ventilation via bronchial occlusion with single-lung ventilation has been shown in animal studies to increase microwave and RF ablation zone size in the lungs (11,12). Both ventilation and perfusion have a meaningful impact on pulmonary microwave ablation, and each has been shown to have regional variances throughout the lung (13,14). Studies have demonstrated higher perfusion of the lower/central lung and greater ventilation in the lower lung (13,15–17). The in vivo effects of these regional perfusion and ventilation variations on microwave ablation have not been well studied to date.

Multiple previous studies reviewed imaging after procedures to demonstrate characteristics predicting treatment success, including an ablation zone size 4 times greater than the tumor size before ablation (18–23). Although it is believed that ablation energy delivered is important for ablation zone size, previous studies mostly focused on ablation power (24,25). Ablation work (power * time) is a measure of the total energy delivered and, in contrast to power alone, can simultaneously account for power, ablation time, number of antennas, and differences in these parameters between ablation phases. Clinical outcomes with thermal ablation in the lungs are an important area of continued investigation. However, the purpose of this study is to investigate technical factors of in vivo microwave pulmonary ablation, including ablation work, temporal involution, and regional ablation resistance.

MATERIALS AND METHODS

After institutional review board approval, a retrospective chart review of 98 noncavitary pulmonary tumor ablations using a NeuWave Certus Microwave Ablation System (NeuWave Medical, Inc, Madison, Wisconsin) was performed. All cases were performed percutaneously under computed tomography (CT) guidance by 1 of 3 operators (R.D.S., F.G.A., S.J.G.) between June 2011 and July 2015. Exclusion criteria included use of an ablation antenna other than the Precision (PR) or Lung (LN) antenna. Ablation parameters were at the discretion of the operator and with the following treatment endpoints: tissue temperature > 60°C, concentric ground-glass margin > 5 mm, and operator security with obtained technical success. Ablation power and time were obtained from the ablation system recordings for each ablation phase (defined as continuous ablation at a single power); 45 of 98 (45.9%) pulmonary tumors were treated with > 1 ablation phase. Ablation work was calculated as the sum of work (power * time) for each individual phase according to the equation $W_A = \sum_{i=1}^{n} P_i * t_i * N$ (W_A = ablation work [J], n = number of ablation phases, P = power [W], t = ablation time [s], N = number of ablation antennas).

CT scans performed immediately after the procedure, 1–3 months after the procedure (earliest thoracic CT scan in 1–3 month period, n = 80), and 3–12 months after the procedure (latest thoracic CT scan in 3–12 month period, n = 66) were reviewed by a single senior radiology resident (R.A.A.) blinded to procedural ablation factors. Ablation zone refers to the area of ablation on CT and was defined as the outer edge of the peripheral margin of dense ground-glass opacity (5,23). Maximal length and maximal perpendicular measurements were obtained for each ablation zone on the image with the largest apparent ablation zone. Ablation zone was then calculated according to the equation for an ellipse ($A = \pi ab$). Involution of the ablation zone refers to the decrease in ablation zone over time as a result of elimination of induced coagulation and accompanying cicatrization (5).

The shortest distance from the ablation zone isocenter to the closest costal pleura was measured for each ablation zone and categorized into the peripheral (≤ 2 cm), parenchymal (2–4 cm), or central (≥ 4 cm) pulmonary region. Each ablation was assigned a score for pulmonary lobe of ablation (upper lobe = 1, middle lobe/lingula = 2, lower lobe = 3) and pulmonary region of ablation (peripheral = 1, parenchymal = 2, central = 3). The 2 scores were summed for an ablation resistance score ranging from 2 to 6. Ablation resistance scores were categorized into low (score of 2–3), medium (score of 4), and high (score of 5–6) ablation resistance score groups (**Fig 1**).

Statistical analysis was performed using IBM SPSS Statistics for Windows software (IBM Corporation, Armonk, New York). Variables with a significantly skewed distribution (tumor size before ablation, ablation zone after procedure, ablation zone at 1–3 months, ablation zone at 3–12 months, ablation work, and maximum/perpendicular ablation dimensions) were compared using Kruskal-Wallis test. Otherwise, variables with an assumed normal distribution and homogeneous variance based on Levene test were comparatively analyzed using analysis of variance. Statistical significance was assessed with an α value of .05. Ordinal and nominal variables were compared using Fisher exact test. All correlations were performed with Pearson correlation method (2-tailed) with calculation of the Pearson correlation coefficient (r). Mean values are reported with ± SD.

Patients included 32 men and 39 women. Mean patient age was 64.7 years ± 11.5. Oncologic histology included 34 primary pulmonary tumors (28 adenocarcinoma, 4 squamous cell carcinoma, 2 neuroendocrine) and 64 metastatic pulmonary tumors (21 colorectal, 19 renal, 7 uterine, 7 adenoid cystic carcinoma, 2 pancreatic, 2 hepatic, 2 ependymoma, 1 endometrial adenocarcinoma, 1 myxoid fibrosarcoma, 1 melanoma, 1 cardiac sarcoma). Mean maximal tumor diameter was 1.5 cm ± 0.7 (range, 0.4–3.6 cm); 4 tumors were > 3 cm