LABORATORY INVESTIGATION

Comparison of Conventional and Cone-Beam CT for Monitoring and Assessing Pulmonary Microwave Ablation in a Porcine Model

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ABSTRACT

Purpose: To compare cone-beam computed tomography (CBCT) with conventional CT for assessing the growth and postprocedural appearance of pulmonary microwave ablation zones.

Materials and Methods: A total of 17 microwave ablations were performed in porcine lung in vivo by applying 65 W for 5 minutes through a single 17-gauge antenna. Either CT (n = 8) or CBCT (n = 9) was used for guidance and ablation zone monitoring at 1-minute intervals. Postprocedural noncontrast images were acquired with both modalities. Three independent readers measured the length, width, cross-sectional area, and circularity of the ablation zones on gross tissue samples and CT and cone-beam CT images. The measurements were compared via linear mixed-effects models for postprocedural appearance and with a polynomial mixed effects model for ablation zone growth curves.

Results: On postprocedural images, the differences between cone-beam CT and CT in mean length (3.84 vs 3.86 cm; $\Delta = -0.02$; $P = .70$), width (2.61 vs 2.56 cm; $\Delta = 0.06$; $P = .46$), area (7.84 vs 7.65 cm^2; $\Delta = 0.19$; $P = .35$), and circularity (0.85 vs 0.85; $\Delta = 0.01$; $P = .62$) were not statistically significant after accounting for intersubject and interrater variability. Also, there was no significant difference between CT and cone-beam CT growth curves of the ablation zones during monitoring in terms of length ($p_{Int.} = 1.00$; $p_{Lin.Slope} = 0.52$; $p_{Quad.Slope} = 0.69$); width ($p_{Int.} = 0.83$; $p_{Lin.Slope} = 0.98$; $p_{Quad.Slope} = 0.79$), area ($p_{Int.} = 0.47$; $p_{Lin.Slope} = 0.27$; $p_{Quad.Slope} = 0.57$), or circularity ($p_{Int.} = 0.54$; $p_{Lin.Slope} = 0.74$; $p_{Quad.Slope} = 0.80$). Both CT and cone-beam CT overestimated gross pathologic observations of ablation length, width, and area ($P < .001$ for all).

Conclusions: Cone-beam CT was similar to conventional CT when assessing the growth, final size, and shape of pulmonary microwave ablation zones and may be useful for monitoring and evaluating microwave ablations in lung.

Thermal ablation is a safe and effective treatment option for primary and metastatic tumors of the lung (1–4). Technical success and local control with thermal ablation depend on proper targeting of the tumor, intraprocedure monitoring, and postprocedure assessment of ablation zones with adequate margins (5,6). The criterion standard imaging modality for guiding pulmonary thermal ablation has been conventional computerized tomography (CT) owing to its high spatial resolution and the inherent contrast between tumors, treatment effects, and background lung parenchyma (7,8). However, CT-guided interventional procedures lack real-time monitoring abilities, and the physical and spatial limitations of CT for maneuvering may result in impractical conditions and longer procedure times (9).

Cone-beam computerized tomography (CT) is an emerging modality well suited to interventional procedures that uses a C-arm to provide either real-time fluoroscopic or tomographic images with high spatial resolution and 3-dimensional image reconstruction (10,11). Cone-beam CT offers less soft tissue contrast than conventional CT and is more prone to motion degradation because data acquisition lasts longer (5–8 seconds) than conventional CT. Despite these shortcomings, cone-beam CT is widely accessible and used in angiography suites for navigational purposes during interventional procedures (12).

In lung, an organ with inherent soft tissue contrast, cone-beam CT has been used for guiding certain transthoracic, transbronchial, and endobronchial procedures, such as

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EDITORS' RESEARCH HIGHLIGHTS

- This study compared cone-beam CT and conventional multidetector CT for monitoring percutaneous microwave ablation of normal swine lung. Multiple-imaging ablation and 1-hour histologic specimen measurements were analyzed.
- There were no significant differences in the mean differences in lesion measurements between histologic specimens and both cross-sectional imaging platforms, suggesting that cone-beam CT may be used for monitoring and postprocedural assessment of lung ablations.

video-assisted thoracoscopic surgery, biopsy, and thermal ablation (13–21). In addition to being used to guide thermal ablations, cone-beam CT was also investigated for its diagnostic accuracy in delineating ablation zones in liver (22,23). Although studies have discussed using cone-beam CT for guidance in the lung (13–21), the diagnostic accuracy of cone-beam CT for monitoring and assessing thermal ablation zones in the lung has not been formally evaluated. The purpose of the present study was to compare cone-beam CT with conventional CT for assessing microwave ablation zones in an in vivo porcine lung model.

MATERIALS AND METHODS

The study was approved by the Institutional Animal Care and Use Committee and was performed in accordance with the Guide for Care and Use of Laboratory Animals (24). The porcine model allowed in vivo creation of ablation zones similar in size to those in human patients. This model has been used in previous studies on microwave ablation in lung (25).

Ablation Procedure

Four female domestic swine with a mean weight of 55 kg were used in the study. Subjects were sedated with an intramuscular administration of 7 mg/kg of tiletamine hydrochloride and zolazepam hydrochloride (Xyla-Ject; Phoenix Pharmaceutical, St Joseph, Missouri), intubated endotracheally facilitated with 0.05 mg/kg atropine (Phoenix Pharmaceutical), and then underwent anesthesia induction and maintenance with 2% inhaled isoflurane (Halocarbon Laboratories, River Edge, New Jersey). After being anesthetized, subjects were placed prone on the bed of either a conventional 64-slice CT scanner (Lightspeed HD 750; General Electric, Boston, Massachusetts) or a cone-beam CT scanner (Artis Zee; Siemens Medical Solutions, Forchheim, Germany).

A total of 17 pulmonary microwave ablations were performed in the 4 subjects. A total of 4 or 5 ablations per subject were performed sequentially (maximum 1 per lobe). Single microwave antennas (PR-15; Neuwave Medical) were placed percutaneously into the lung parenchyma with the use of either CT or fluoroscopic guidance. Heart, large airways, and blood vessels were avoided during antenna placement to minimize the effects of heat sink and motion. Ablations were performed sequentially with only 1 antenna placed at a time. Antenna placement order and location were varied to balance the study groups. All ablations were created by applying 65 W for 5 minutes (Certus140; NeuWave Medical).

Image Acquisition

The subjects were divided equally into 2 groups to undergo ablation under either conventional CT or cone-beam CT guidance. Either conventional CT ($n = 8$) or cone-beam CT ($n = 9$) data was collected at 1-minute intervals during each ablation monitoring. After all ablations were performed in each subject, postprocedural noncontrast images were acquired with both CT and cone-beam CT for that subject. For example, if the ablations were performed under cone-beam CT, then after acquiring a postprocedural noncontrast cone-beam CT scan, the subject was transferred to the CT for a postprocedure conventional CT scan. This transfer process resulted in an approximately 10- minute delay between the postprocedural scans with the 2 modalities. After all image acquisitions were completed, animals were killed by with the use of intravenous 0.2 mL/kg 390 mg/mL pentobarbital sodium and 50 mg/mL phenytoin sodium (Beuthanasia-D; Schering-Plough, Kenilworth, New Jersey), and the lungs were excised en bloc.

Ablation Zone Assessment

For gross pathologic assessment, the ablation zones were sectioned through the antenna insertion track. NADH vital staining was applied to differentiate normal and ablated tissue. NADH staining relies on the reduction of nitroblue tetrazolium chloride by viable cells and provides a more accurate representation of cell death immediately after ablation (26). Length, width, cross-sectional area, and circularity were measured from the stained tissue sections with the use of ImageJ (27). Cross-sectional area refers to a single reference CT slice at the center of the ablation zone with the largest diameter. This is the slice that corresponded with pathologic measurements. Isoperimetric ratio was used as a measure of circularity and calculated as $4\pi \times$ area/perimeter^2 (25) A ratio equal to 1 is a perfect circle and values closer to zero represent shapes that are less circular. The same metrics were also measured and calculated with the use of intra- and postprocedural conventional CT and cone-beam CT images based on the ground-glass appearance of the ablated zones (28–30). Intraprocedural imaging also allowed assessment of ablation zone dimensions with minimal inflammatory reaction. As a primary end point, postprocedural imaging measurements were performed by 3 independent readers with 1–13 years of experience, whereas ablation zone growth and postprocedural histology measurements were assessed by 1 reader. Two ablation zones in 1 subject were excluded because a large pneumothorax and associated atelectasis obscured the underlying ablation zones. This resulted in 15 ablation zones included in the analysis.