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A new bronchoscopic catheter for the transbronchial ablation of pulmonary nodules

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ABSTRACT

Objectives: With the objective of simultaneous bronchoscopic biopsy and ablation of malignant solitary pulmonary nodules, we have developed a flexible monopolar radiofrequency (RF) catheter that can be deployed through the working channel of most bronchoscopes.

Materials and Methods: Fresh tumor specimens were heated in a water bath to 37 °C, and the RF catheter was inserted into the tumors within the specimen. Temperature sensors were positioned 3 mm, 5 mm and 7 mm from the electrode to measure the temperature of the surrounding tissue every 1 s. The ablation was conducted by applying RF energy for 8 min. The ablated specimens were evaluated by cutting the tissue samples along the top of the device and measuring the ablation zones.

Results: Five ablations were performed in 3 specimens. All of the ablation zones had a major axis length (along the electrode axis) between 18.9 mm and 22.8 mm and a minor axis length (perpendicular to the major axis) between 13.3 mm and 18.0 mm. The temperature data showed that all of the temperature sensors detected 60 °C or higher. These results demonstrate that the RF catheter was capable of generating ablation zones that were locally contained in ex vivo human cancerous lung specimens and that incorporated the tumor tissues.

Conclusion: We present the results of a benchtop study demonstrating the local control of ablation achieved using the RF device. This study suggests that the ex vivo ablation of lung malignancy with a new bronchoscopic RF catheter is feasible and that in vivo tumor ablation with this method in humans merits further study.

1. Introduction

Lung cancer is the leading cause of cancer-related death worldwide [1]. According to current guidelines, radical lobectomy remains the standard of care for patients with early-stage non-small cell lung cancer (NSCLC). However, up to 25% of patients with early-stage NSCLC cannot tolerate such surgery secondary to their comorbid conditions. For patients with peripherally located stage I NSCLC who present with comorbidities or other reasons for inoperability or for any patient refusing surgery, stereotactic ablative radiotherapy (SABR) is the preferred treatment, with 5-year local control rates of approximately 90% [2–4]. Radiofrequency ablation (RFA) is a reasonable less-invasive option for patients who are unfit for surgery. Conventional tumor RFA involves computed tomography (CT)-guided insertion of an ablation catheter through the chest cavity in a percutaneous manner to ablate the tumor with thermal energy. As this method breaches the pleura, the rate of iatrogenic pneumothorax following transthoracic RFA [5] is markedly higher than that following transbronchial approaches [6]. Recently, peripheral bronchoscopy made it possible to assess pulmonary nodules for diagnostic purposes [7]. However, a bronchoscopic device used to treat pulmonary nodules during the same procedure, thereby avoiding a second administration of anesthesia, is not yet available. Thus, we designed and developed a flexible monopolar radiofrequency catheter that can be deployed through the working channel of most bronchoscopes. A bronchoscopic method to access peripheral lung nodules in combination with the simultaneous bronchoscopic ablation could provide the least invasive treatment option in high-risk patients with early-stage lung cancer. This study was

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conducted to demonstrate first results of such bronchoscopic RF catheter for ablating tumors in explanted human lung tissue by 1) generating evidence of a measurable ablation zone, 2) confirming a sufficient ablation zone for the treatment of early-stage lung tumors, and 3) determining the force required to insert and remove the RF catheter into lung tumors.

2. Materials and methods

2.1. Specimen preparation

Patients with NSCLC who underwent curative intent surgery at the Department of General Thoracic Surgery, Thoraxklinik, of Heidelberg University Hospital in Heidelberg, Germany were included in this study.

Lung tissue specimens were resected from the patients and then used for the pathology analysis. The remaining portion of each specimen was immediately sealed in a container and frozen until 2 days prior to testing, at which time it was placed in a refrigerator to thaw. Each tissue specimen was placed in a sealable plastic bag and submerged in a 37 ± 3 °C water bath. Upon removal, the internal temperature of each specimen was verified to be 37 ± 3 °C, and the overall specimen size was documented.

2.2. RF catheter

The RF catheter is a flexible, monopolar, bronchoscopic RF catheter capable of use in a working channel of 2.0 mm or larger. The flexibility of this catheter allows it to treat upper lobe tumors. An 18-mm-long, noncooled, active electrode is present at the distal end of the device (Fig. 1).

This electrode is placed in direct contact with the target tissue to deliver monopolar RF energy from a typical electrosurgical generator. Since the shaft of this device is electrically insulated, there is very minimal risk of inadvertently heating the tissue along the catheter.

2.3. Pre-RF energy delivery procedure

The specimen was placed on a piece of aluminum foil, which was connected to the dispersive electrode using a standard cable with alligator clips on each end. The specimen was palpated to determine the tumor location and insertion path for the RF catheter. A FleXNeedle® (Broncus Medical, Inc., San Jose, CA, USA) 18-gauge needle tip was inserted into the specimen to create the path to the tumor. The maximum force required to insert the FleXNeedle® tip into the tumor was recorded. After the FleXNeedle® was withdrawn from the specimen, the RF catheter was inserted into the specimen through the same path. The force required to insert the RF catheter along the axis of the electrode was recorded. Three T1 fiber optic temperature sensors (Neoptix, Quebec City, QC, Canada) were radially located 3 mm, 5 mm, and 7 mm from the central axis of the RF catheter electrode. The 3 mm location was selected to obtain temperature data from tissue close to the electrode (and avoid the risk of damaging the temperature sensor), and the other locations were selected due to tissue size. These sensors were then connected to the Neoptix reflex signal conditioner (Neoptix) to record real-time temperature data. Due to the amount of time involved in setting up each test and the small size of each specimen, the temperature of the specimens dropped to room temperature (approximately 20 °C). The test setup did not allow for controlling the temperature of the specimen during the setup, and reheating the samples was not an option because the test setup would need to be repeated, which would result in the specimens cooling as they had before. Since the specimens were approximately 17 °C cooler than 37 °C, the resultant ablation zones would be smaller because more RF energy would be utilized to heat the cooler tissue specimen.

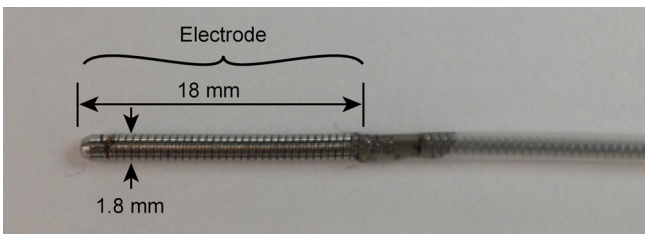

Fig. 1. The monopolar RF catheter is capable of use in a working channel of 2.0 mm or larger. An 18-mm-long, noncooled, active electrode is present at the distal end of the device.

2.4. RF energy delivery procedure

The ERBE VIO 300 D electrosurgical generator (ERBE USA, Marietta, Georgia, USA) was used to generate the RF energy for this study. To measure the voltage during the test, a Fluke 8920 A true RMS voltmeter (Fluke Corporation, Everett, WA, USA) and a Tektronix TDS 210 two-channel digital real-time oscilloscope (Tektronix, Inc., Beaverton, OR, USA) were connected from the catheter to the generator connection and Thermoguard dual dispersive electrode (Conmed, Utica, NY, USA). The voltmeter was used to display real-time voltage measurements, which were recorded at 30-second increments. The oscilloscope was used to monitor the voltage waveform during the test. The ERBE VIO 300 D generator was set at Soft Coag, 7 W, and Effect = 1. For each test, the RF energy was delivered for 8 min. These settings and time were chosen as they were found to produce sufficient ablation zone sizes in ex vivo beef liver at 37 °C. The Neoptix reflex signal conditioner was set to record the temperature at the same time as when the RF energy delivery began. Once 8 min had been reached, the RF delivery from the ERBE generator was stopped. The reflex system still recorded temperature data for an arbitrary amount of time after the 8-minute ablation. Afterwards, a razor blade was used to cut along the top of the RF catheter axis to remove the top of the specimen. The size of the ablation zone was determined by both the change in tissue color and by palpation to detect an increase of firmness. The ablation zone size and specimen dimensions were measured using calipers (Mitutoyo, Aurora, Illinois, USA) and documented.

This study was approved by the local ethics committee of the University of Heidelberg.

3. Results

A total of 5 tumor ablations in 3 specimens were completed. In some instances, the same specimen was used for more than one ablation test. Each specimen was received after portions of it were removed for the pathological examination. Therefore, not all of the tumors were present or complete. The overall size of the tissues was small, thus limiting the possible size of the resultant ablation zone.

3.1. Ablation results

The ablation zone sizes demonstrated in this study confirmed that the RF catheter device generated a measurable ablation zone up to the following sizes: the major axis length (along the length of the electrode), which ranged from 18.9 mm to 22.8 mm, and the minor axis length (perpendicular to the major axis), which ranged from 13.3 mm to 18.0 mm. A summary of the ablation results is shown in Figs. 2 and 3. Unless otherwise noted in the figures, the tumor became firm and turned a brighter white color after the ablation. Similarly, the parenchyma also became firm after the ablation, but it changed from its original red color to brown. There was a sharp transition in firmness from the ablated tissue to the unablated tissue, and the edge of the ablated tissue was easy to identify by palpation (with a gloved hand) and visual color change. Each ablation had at least one portion that