Therapeutic Implications of Heat-Induced Lung Injury

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ABSTRACT

The safe and effective use of interstitial thermal therapy (ITT, radiofrequency ablation) for treatment of lung neoplasms was examined in a preclinical model. Lesions were reproducibly created in normal lung parenchyma and were affected by conductive heat loss via air and blood flow and the presence of bronchi. These observations of controlled injury to lung tissue suggest that clinical application would be appropriate and may yield advantages to selected patients with lung neoplasms (lung cancer, pulmonary metastases, etc.) or other pulmonary diseases.

Keywords: Interstitional thermal therapy, radiofrequency ablation, lung cancer, lung neoplasms, metastases, animal model

1. INTRODUCTION

Long term survival may be achieved with local control via resection for patients with primary and secondary neoplasms of the lung. Open surgical techniques, such as thoracotomy and removal of lung tissue[1;2] are well-defined and provide patients with early stage disease (Stage I or Stage II), 65 - 40 percent five year survival. In patients with pulmonary metastasis, isolated spread of an extrathoracic primary neoplasm, a 30 to 40 percent five year survival may be achieved. Surgical interventions carry a small but identifiable risk of mortality and mortality[3-5]. Improved techniques to achieve good local control with minimizing morbidity have been suggested. These techniques include laser resection, and video assisted thoracic surgery (VATS) or other minimally invasive

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Matching the Energy Source to the Clinical Need: A Critical Review, edited by Thomas P. Ryan,
Proc. of SPIE Vol. 10297 (Vol. CR75), 1029707 · © (2000) 2017 SPIE
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.375227

techniques.[6;7] Despite these options, survival for primary lung cancer and pulmonary metastases remains dependent upon tumor stage or extent of disease. Adequate tumor stage may be obtained by invasive or pathologic staging using surgical techniques such as of mediastinoscopy or mediastinotomy or by non-invasive techniques such as computed tomography of the chest or by positron emission tomography (PET scan)[8-11].

The surgeon must remove the tumor and preserve normal lung parenchyma. Thoracoscopy or minimally invasive surgical techniques may manipulate the tumor causing shedding of tumor cells within the pleural spaces, chest wall, or locally within the lung parenchyma[12]. Increased recurrences may result. ITT may minimize the associated trauma and morbidity accompanying standard open or minimally invasive proecdures.

To further study this question, accurate comparisons of treatment effects and instrument design are required. Firstly, the identification of useful treatment endpoints must be identified that can be followed over time and, secondly, observation techniques must be chosen that allow meaningful qualitative and quantitative evaluations of the treatment and its resolution. [13;14]

The basic treatment mechanism of ITT is lethal thermal injury to the targeted tissue(s) without undue harm to tissues beyond the desired treatment volume. Specifically, for ITT of cancers, the targeted tissues are the cancer itself and a band of adjacent non-tumorous parenchyma to encompass the invasive bnborders of the malignant neoplasm. Currently, the various imaging techniques including x-ray, comperized tomography (CT), magnetic resonance imaging (MRI) and ultrasound have been used to define the borders of ITT lesions during, immediately after and at various intervals after the heating treatment. In general, MRI, CT and ultrasound have been effective for reliably imaging lesions in the days following treatment but have not been useful for accurate assessment of the lesions during or in the several hours following treatment. Therefore, qualitative and quantitative pathologic techniques, albeit that they are destructive, are useful for describing, mapping and measuring the treatment lesions and their resolution over time. [13;14]

We examined the role of ITT in a preclinical model using radiofrequency energy. Direct interstitial thermal coagulation may provide local control of primary and secondary tumors of lung. Interstitial thermal coagulation has previously eradicate liver metastases successfully we evaluated interstitial thermal graduation in a precritical model of acute and chronic duration.

The following hypotheses were tested in this study of ITT in porcine lung: 1) characteristic and reproducible lethal thermal lesions can be produced with a radiofrequency probe introduced via a trochar into the inflated lung, 2) the thermal lesions will be formed of characteristic thermal damage zones, a cental thermal coagulum and a peripheral red band, whose boundaries can be measured, 3) the configuration of the acute thermal lesion will be modified by the design and size of the treatment probe and/or the bronchial and vascular anatomy of the lung, 4) lethal thermal damage manifest by tissue necrosis at three days will correspond to the outer boundary of the red thermal damage zone, 5) blood flow with be restored in the open lumens of necrotic blood vessels within three days of heating, 6) organization and healing of the thermal lesion will originate from the peripheral viable tissue and 7) the healing lesions will be the same size as the acute lesion until fibrous scar replaces the necrotic tissue.

2. MATERIALS AND METHODS

Domestic swine (female, 50 – 70 kg) were used in acute and chronic studies. Animals were housed in a temperature-controlled room and provided a 12 hour light-dark cycle. Food and water were provided *ad lib*. The experiments were approved by the Institutional Animal Care and Use Committee at The University of Texas M. D. Anderson Cancer Center. Animals received humane care in accordance with the Animal Welfare Act and the NIH "Guide for the Care and Use of Laboratory Animals". After intravenous sedation and adequate induction of general anesthesia, animals were intubated and maintained on a volume-cycled ventilator.

A LeVeen™ Needle Electrode was used (RadioTherapeutics Corporation, Mountain View, CA) at various sizes 2.0 – 3.5 cm deployed as a multi-tine array. (Figure 1) . The individual electrode arms deploy from the distal end of an insulated delivery cannula into the tissue. The Shaft working length is 12 – 15 cm with a cannula diameter of 15 gauge. The electrode was connected to a radiofrequency generator (RF2000 ™ , RadioTherapeutics Corporation, Mountain View, CA). The generator is designed to provide radiofrequency output for localized coagulation of soft tissue. The generator can supply up to 100 watts of power.

Radiofrequency energy was applied at increments from 5 - 90 watts by alternating current applied to create thermal lesions. *In vivo* lesions were created in the left lung of 10

animals (4 acute, 6 chronic). A two-phase application of the energy was used to create these lesions. The initial phase was started at a low energy level and advanced at 5 minute intervals until impedence increased to over 400 Ohms. A second phase was started at approximately 50% total energy and advanced in a a similar manner
until impedence increased to over 400 Ohms.

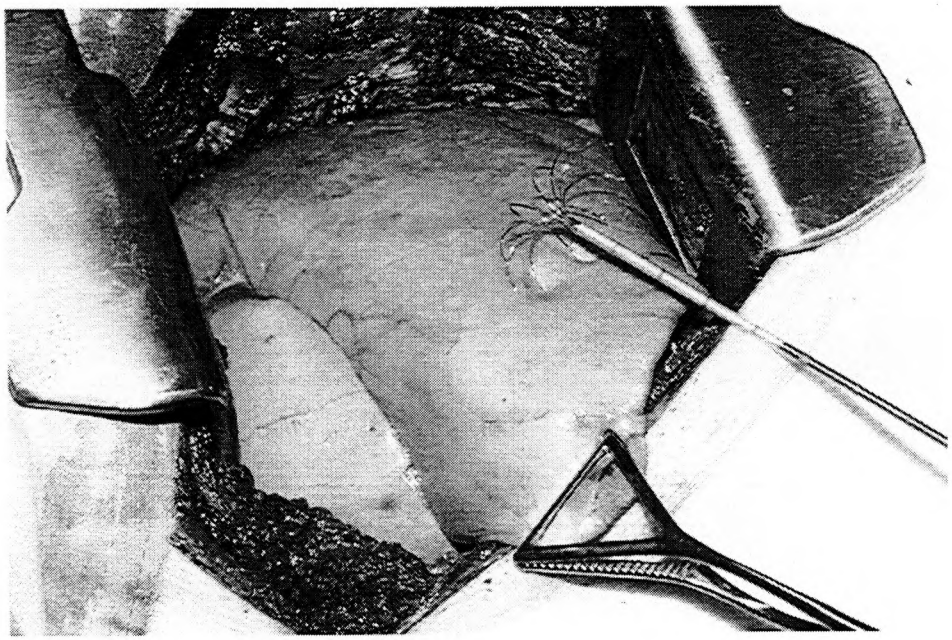
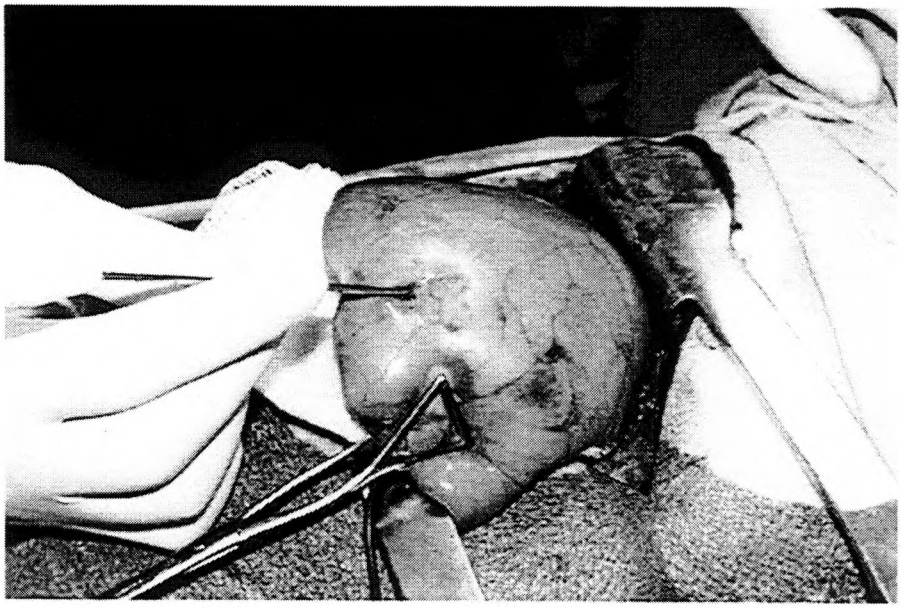


Figure 1. The LeVeen ™ Needle Electrode (RadioTherapeutics Corporation, Mountain View, CA) prior to insertion into the lung.



.Figure 2. The electrode is inserted into the lung tissue under manual guidance and supported during the ablative phase of the procedure. Active ventilation continues to keep the lung inflated and minimize the thermal trauma to surrounding lung parenchyma.

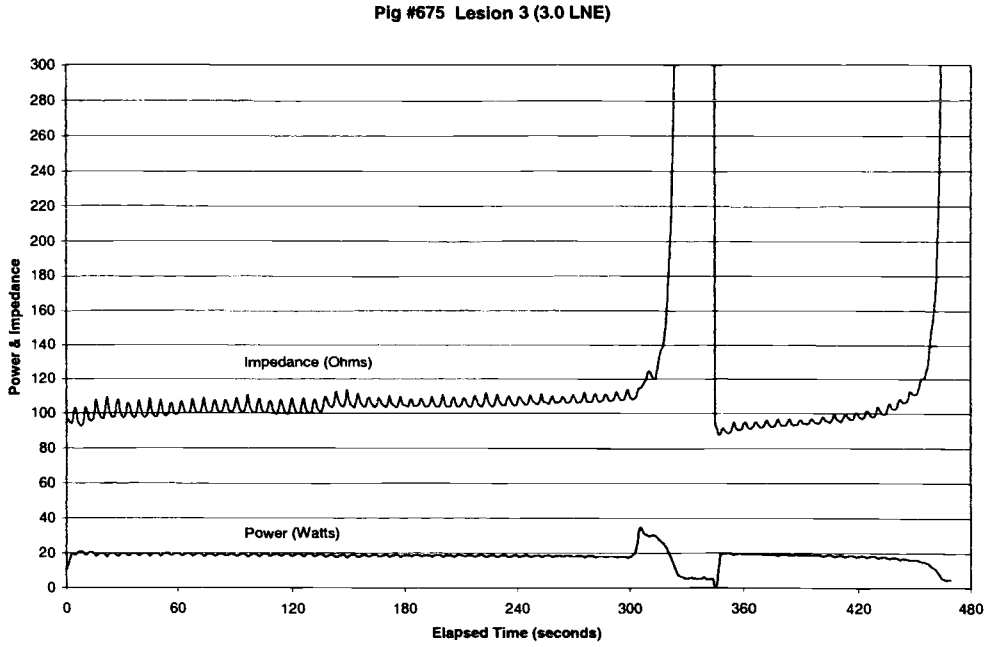


Figure 3. A two-phase application of energy is shown. The initial phase was started at a low energy level (20 watts) and continued as impedence increased to over 400 Ohms. The energy level was not required to be increased. A second phase was started at 20 watts and 400 Ohms was rapidly achieved.

Energy exposure for interstitial thermal coagulation ranged from 4 – 24 minutes per lesion. Size of lesions ranged from 1.0 to 3.0 cm. Tissue destruction was monitored by measuring lesions within the tissues one hour after injury for the acute model.

Lungs were fixed with buffered formalin via tracheal infusion. Tissue injury was evaluated grossly and valuated grossly and histologically. For chronic models, lesions were created as noted above using a 2.0 cm array

Animals were sacrificed at three days, seven days, and 28 days. Lesions were examined grossly and histologically. No animal developed any morbidity from this technique; specifically, no evidence of bleeding, infection, pneumothorax, or other intrathoracic or systemic complications were noted. Lesions range in size from 2.0 - 3.5

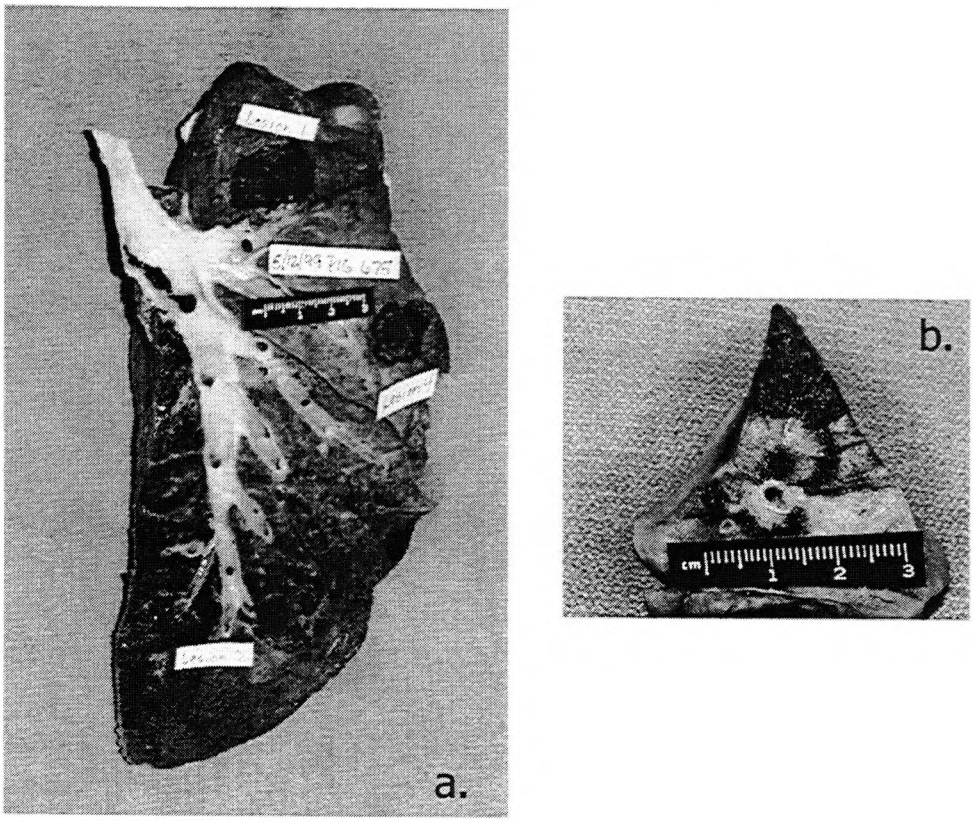


Figure 4. Fixed lung after induction of acute (a.) and chronic (b.) lesions. Multiple lesions were created (acute) to evaluate controlled destruction of lung tissue. In the chronic model, peripheral lung, distal to the treated area, occassionally became consolidated or ischemic as a result of local changes to proximal bronchus or vessels

cm in maximal dimension in the acute model. All lesions were composed of coagulated tissue without cavitation. Lesions were irregular to ovoid in shape with a peripheral zone

of red thermal injury surrounding a cental coagulum. Bronchi adhering to treated tissue remained intact.

Both lungs and the heart were removed *en bloc* from anesthetized pigs sacrificed by exsanguination. The lungs were fixed by filling the lungs with 10% buffered formalin via the trachea at 15-20 cm H2O. The lungs and hearts were then suspended in a bucket of formalin for 24-72 hours to complete fixation. The lungs were separated from the heart and sliced in orientations to best display the thermal lesions and their relationships to their parenchymal, bronchial and vascular anatomy. The lesion sizes were determined grossly by measuring the longest diameters of each fixed lesion in the x, y and z planes. The recorded measurements were of the thermal lesions only. The gross lesions were photographed, then, representative samples of every lesion were submitted for paraffin sectioning. The 4-5 μ thick sections were stained with hematoxylin and eosin stains and, in selected cases, Weigert-van Gieson's elastin stains. The sections were examined with a diffuse white light microscope and selected fields photographed.

Quantitative comparisons of lesion sizes were made with probe antennae diameter and the average largest dimensions of each lesion.

3. RESULTS

3.1 Acute studies Following ITT

The acute ITT lesions in the porcine lung were ovoid, targetoid lesions composed of a probe hole in a central tan thermal coagulum surrounded by a band-like zone of red tissue. (Figure 5 a) The walls of the lesion probe holes were hemorhagic and lined by thermally coagulated and desiccated blood and lung tissue. The boundaries between the central tan coagulum and red thermal damage zone and the red damage zone and normal lung were distinct and measurable. Microscopically, (Figure 5 b) the tan coagulum consisted of thermally coagulated lung epithelium, bronchial tissues and extracellular matrix. The bronchial epithelial cells and smooth muscle cells were spindled, shrunken and hyperchromatic (darkly staining) yet cytoplasmic and nuclear structures could be distinguished. The membranes of intravascular red blood cells were ruptured and the cells empty of hemoglobin. Frequently, the alveolar spaces were filled with proteinaceous fluid. On the other hand, the peripheral red zone, formed by an accumulation of blood, was composed .

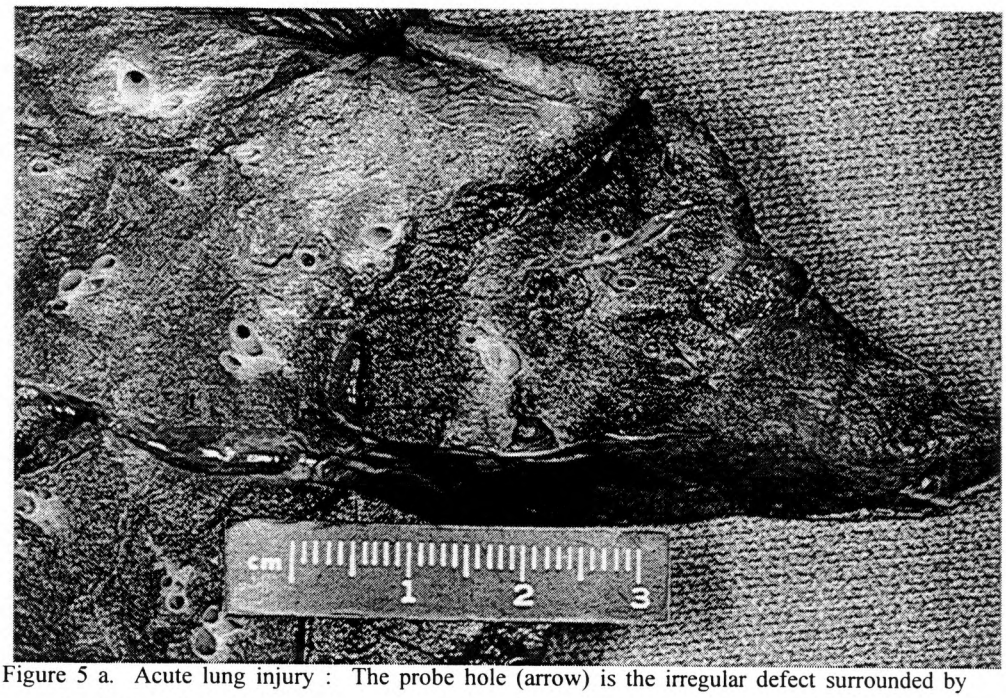


Figure 5 a. Acute lung injury : The probe hole (arrow) is the irregular defect surrounded by coagulated blood in the center of the coagulum. The outer boundary of the red thermal damage zone is distinct.

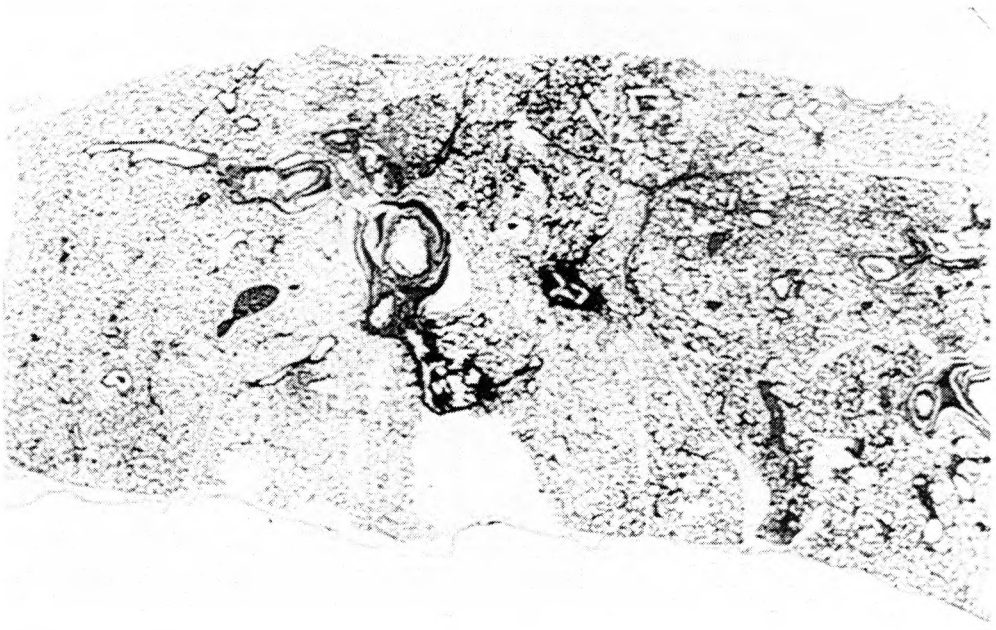


Figure 5 b. Microscopic changes following acute lung injury.

of two thermal damage subzones. The inner zone was due to hemostasis secondary to direct thermal coagulation of red blood cells in dilated, coagulated blood vessels. The outer zone formed as a result of hemostasis, focal blood clotting and hyperhemia (increased blood flow in dilated vessels) due to pathophysiologic vascular mechanisms in response to the heat. The lung tissues in the inner red zone showed less severe thermal coagulation changes than the central coagulum but the tissues of the outer red zone did not seem to be damaged at the light microscopic level.

Not infrequently, small holes formed by the deployed tines of the probe antennae were found in the microscopic sections of the coagulum and/or the peripheral red damage zone. Like the probe holes, the tine holes were variably surrounded by thermally coagulated blood and tissue and, in some cases, seemed to be associated with tissue tearing.

The walls of some large and medium sized pulmonary arteries and veins present adjacent to some probe holes were ruptured and associated with some hemorrhage into the adjacent tissues. Similarly, tears and hemorhages in pleura and pericardium were found where the probe and/or tines extended beyond the lung. In one case, placement of the probe at the lobar hilum was associated with vessel and pleural rupture and resulting pulmonary hemorrhage. Fluoroscopic images showed the probe and deployed tines to be displaced and deflected by the thick hilar bronchial walls. This displacement was not seen in fluoroscopic images of probe placement in association with segmental hilar bronchi. Blood clots were found in some segmental and subsegmental bronchi in association with ruptured large blood vessels and associated pulmonary hemorrhage.

In some thermal lesions, the large blood vessels were intact but their walls were severely damaged by transmural thermal coagulation. Occasionally, these blood vessels were occluded by fresh thrombi (intravascular blood clots). Thermal coagulation and red thermal damage extended to the bronchial walls in continuum with the adjacent lung parenchymal lesions. The large and small bronchial lumens were open and the walls were not collapsed. The nuclei of the bronchial cartilage cells showed shrinkage but otherwise the only other reliable sign of cartilaginous thermal damage was the hyalinization of the perichondial collagen. The bronchial epithelium was detached and frequently sloughed in the red thermal damage zones.

3.2 Three days following ITT

The outer boundary of the red damage zone was more defined at three days than in the acute specimens (See figure 6A gross photo, and 6B microscopic] This boundary was within 1 mm of the outer boundary of necrotic lung and bronchial parenchyma. In some places, the outer red rim boundary adjacent to bronchi was irregular with sparing of lung parenchyma surrounding the peripheral bronchus. (Figure 6A) The walls of bronchi and blood vessels in the red rim and central coagulum were distorted by transmural necrosis but their lumens were open. The bronchial cartilage showed focal cellular necrosis yet the matrix was not abnormal at the light microscopic level. Occlusive thrombi were found in many blood vessels and, in some specimens, were associated with segmental and subsegmental pulmonary hemorrhage. Occasional tears of vascular walls and pleura were associated with residual tine holes.

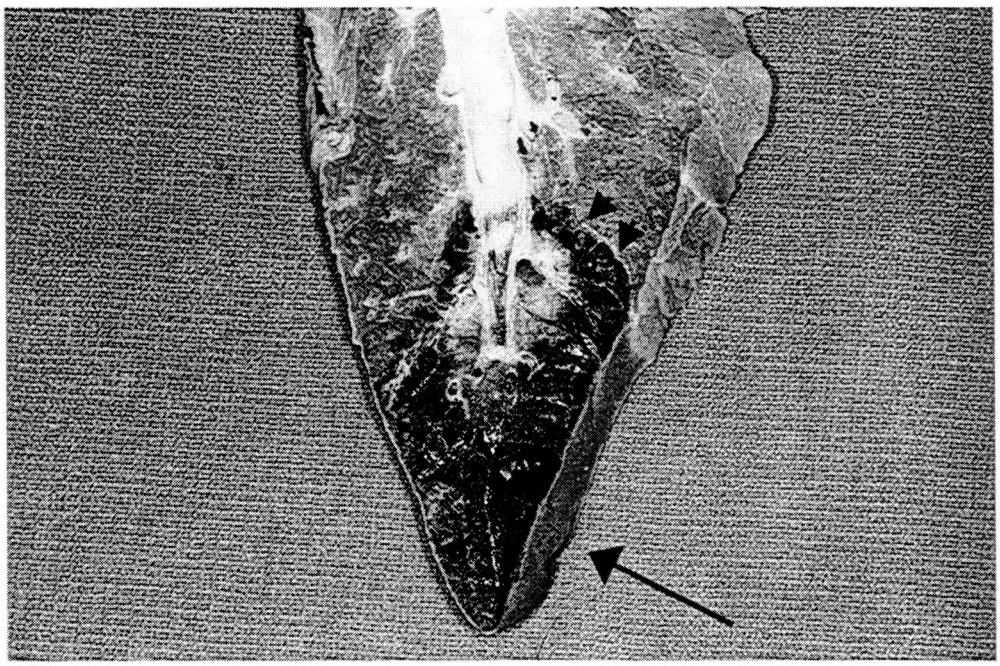


Figure 6A. Gross appearance three days following injury. Distal consolidation has occurred as a result of more proximal lung injury. Some effect upon the bronchus can be seen. Three Days Lesion. The thermal lesion is represented by the superior round targetoid lesion of the peripheral blood accumulation (arrowheads) with a light tan central coagulum. A segmental artery present at the end of a probe hole was ruptured (arrow) by the probe producing segmental pulmonary hemorrhage distal to the thermal lesion.

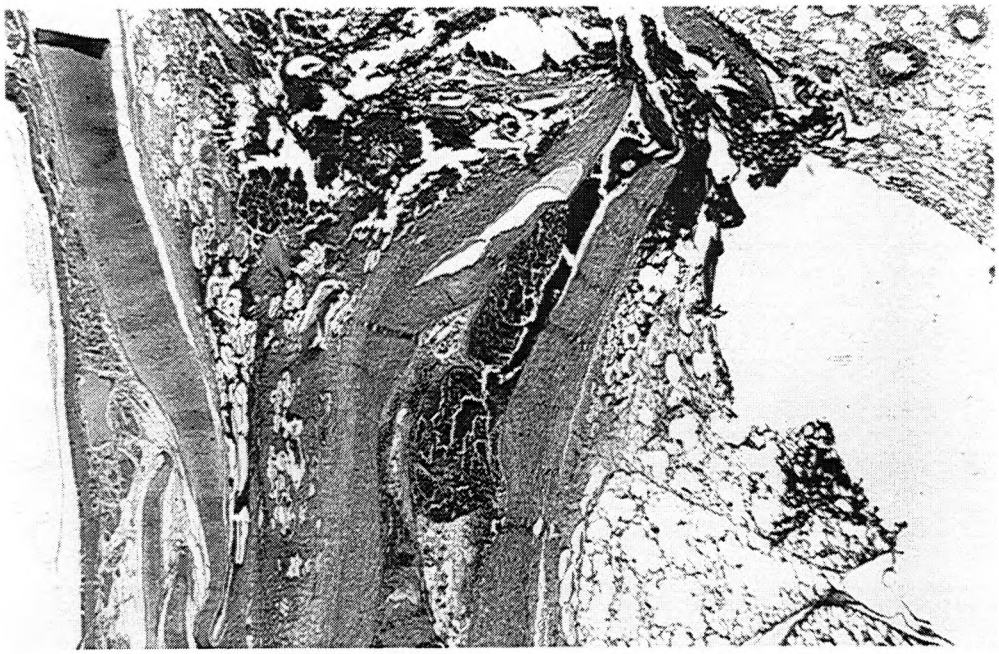


Figure 6 B. Microscopic examination of lesion after three days.

3.3 Seven days following ITT

Wound organization (inflammatory cells that clean up necrotic tissue) [15] and scar tissue formation originate from the adjacent lung and pleural tissues and encroaches and partially replaces the red thermal damage zone. [Figure 7 A gross and B microscopic] On the other hand, no blood flow or early stages of wound organization are seen in the central thermal coagulum which is composed of intact lung tissues "fixed" in situ by the thermal coagulation. Bronchial and alveolar epithelial regeneration extend from peripheral intact lung tissue for form irregular small air spaces surrounded by scar tissue. Chrondrocyte necrosis is more extensive and is associated with faded staining in the matrix suggesting the loss of acid aminoglycans.. Regenerating respiratory epithelium covers the necrotic bronchial mucosa in the larger airways with in the thermal lesion. Occlusive thrombi found in the pulmonary blood vessels in the peripheral portions of the lesion are undergoing organization and early recanalization.

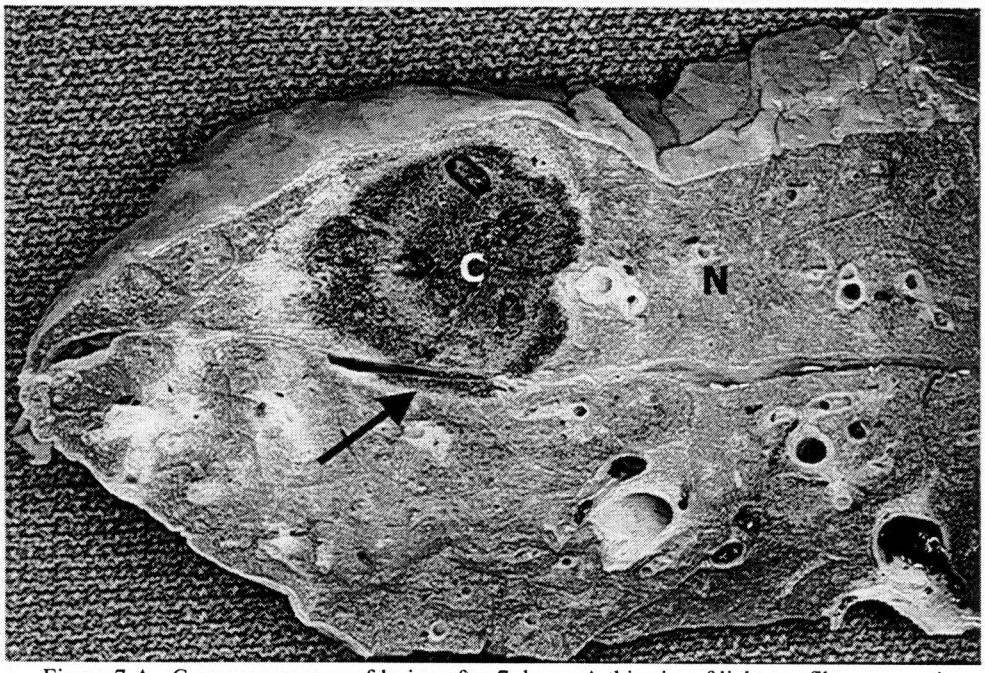


Figure 7 A. Gross appearance of lesion after 7 days. A thin rim of light tan fibrous scar tissue surrounds the ITT lesion invading into the red thermal damage zone which separates the central coagulum (C) from the normal (N) lung tissue. An invagination of the red thermal zone in the gross specimen is associated with a bronchus (arrow).

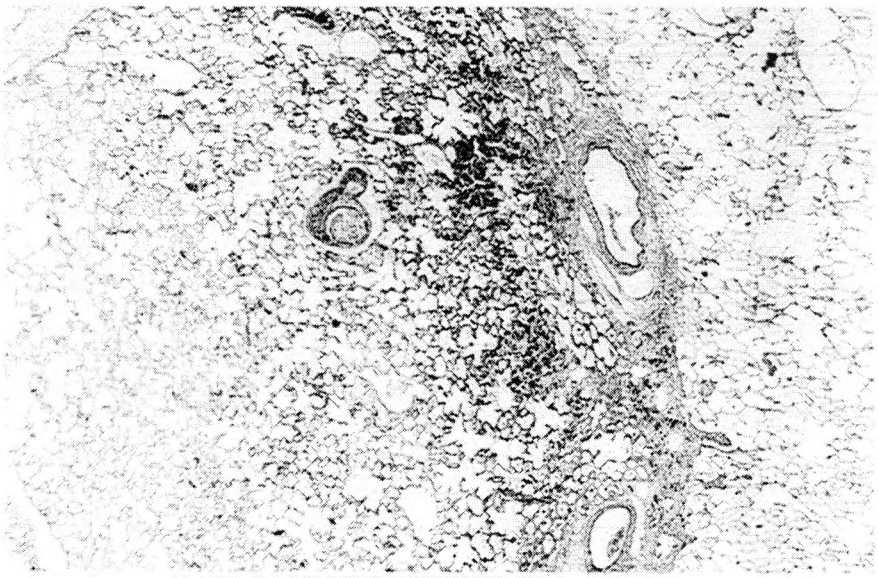


Figure 7 B. Microscopic appearance of lesion after 7 days.

3.4 28 days following ITT

The red rim of the thermal lesion has been completely replaced by light tan scar tissue that surrounds the residual central thermal coagulum. The areas of segemental pulmonary hemorrhage and infarction have resolved producing areas of pneumonitis and chronic atelectasis. [Figure 8 A gross, and 8 B Microscopic] Blood flow still has not entered into the coagulum and organization is present only at the interface of the fibrous scar tissue with the coagulum. The bronchial cartilagenous plates protrude and collapse into the lumens of some segmental and subsegmental bronchi. Fibrous scar tissue surrounds these plates and, frequently, obliterates the bronchial lumens.

Table 1 compares actual lesions developed with electrode array diameter.

Figure 8 A. Gross appearance of lesion after 28 days. The outer band of fibrous scar tissue (arrow heads) has replaced the red thermal damage zone and completely surrounds the residual central coagulum (c). The long tail of light colored tissue in the gross specimen is obstructive pneumonitis and chronic atelectasis (collapse of lung), the resolution products of pulmonary hemorrhage and bronchial obstruction by wall collapse and luminal fibrosis in the thermal lesion.

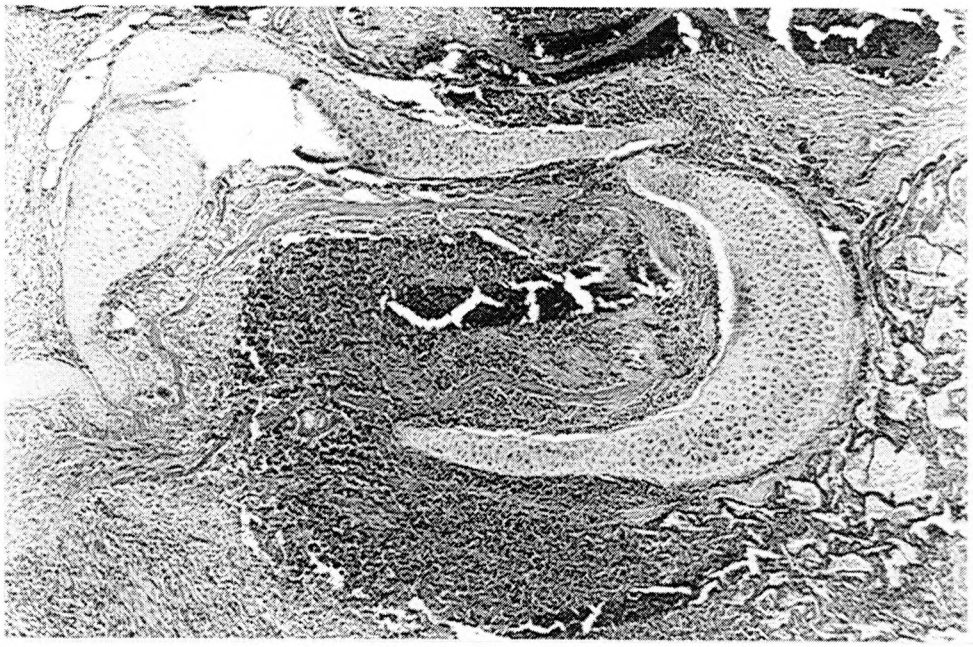


Figure 8 B. Microscopic examination of lesion after 28 days.

Table 1 The maximal diameters of fixed ovoid lesions compared to probe diameter

Probe Array Diameter	Acute (cm)	3 Day (cm)	7 Days (cm)	28 Days (cm)
2 cm	1.7x2.2x2.2 3.3x3.2x2.4 3.2x3.0x3.1 3.0x2.7x2.4 2.4x2.1x1.1 1.9x2.0x1.3	3.0x2.2x1.8 2.5x2.ox1.8	2.1x1.2x1.8 2.1x1.8x2.5	2.0x1.4x1.3 1.2x1.0x1.6
3.5 cm	3.3x2.9x2.6 2.5x2.5x1.8 3.5x4.2x2.7	2.8x2.5x4.0 5.0x3.0x3.0	3.3x3.0x3.5 4.2x2.5x3.2	2.0x2.5x2.2 2.3x2.3x2.6

4. DISCUSSION

The configuration, shape and size of the acute and early healing ITT lesions are influenced by 1) the probe size, 2) displacement of probe and deployed tine distortion by the tough bronchial walls, 3) proximity to large bronchi through which the air flows and 4) rupture of blood vessel walls and pleura by the probe and/or deployed tines with resultant pulmonary hemorrhage.

The interstitial thermal lesions can be considered to be formed by the 1) generation of the heat energy from the radiofrequency current energy and the 2) heat transfer due to diffusion and convection within the tissues. The geometry of the lesion at the points of heat generation will be governed by the electrical tissue properties and the probe size and configuration. In the lung, the heat transfer will include considerations of the thermal properties of the spongy lung parenchyma with a myriad of small, air filled spaces and the connvective loss due to blood and air flow.[16] The invagination of the outer boundary of the red thermal damage zone seen in this study suggests that the air temperature and rate of air flow in the bronchi could influence the shape of the thermal lesion. Thus, this needs to be considered in the treatment of lesions adjacent to medium sized and large bronchi.

The lesions became slightly larger at three days probably secondary to the increased blood flow and extreme edema at the periphery of the lesions. No strong correlation of lesion size with probe size was seen in this survival study that included a small number of lesions. The lesions tended to get smaller especially between 7 days and 28 days. The lesion shrinkage is probably related to the contraction of the fibrous scar tissue, a normal phenomenon seen in wound healing.

The lesions still were not completely healed at 28 days. Wound healing involves three general stages: 1) organization, 2) scar tissue formation and 3) wound contraction.[15] Organization requires the delivery of phagocytic and cytolytic inflammatory cells to the dead tissue by flowing blood. The blood cells (and tissue cells) in the central coagulum are killed directly by thermal coagulation. The extensive occlusive vascular thrombosis prevented blood access to the still open lumens of the central coagulum. Therefore, in the lung, the central coagulum persists until the vascular fibrous scar tissue with its blood flow and inflammatory cells invades into the necrotic tissue. The persistence of the coagulum can be considered to be the most important

factor for the healing delay lesion as imaged using ultrasound, computerized tomography and magnetic resonance imaging.

The distinct boundaries of thermal damage seen in the acute and survival lesions are related to different mechanisms: 1) accumulation of blood in the peripheral lesion in the acute and 3 day lesions, 2) organization and scar tissue formation and 3) persistence of the coagulum. These damage zones have different prominent components such as blood in the acute and 3 day lesion, the increase of fibrous scar tissue and the desiccated central coagulum. These components could be targeted as image markers that could be best used at different times of the treatment and healing process. [13;14]

The wedge-shaped areas of pulmonary hemorrhage seen in some 3 and 7 day specimens were related to blood vessel rupture and secondary occlusive thrombosis. Only hemorrhage, not true infarction , were seen downstream from theses damaged vessels. Since air flow was blocked by the necrosis of the bronchial walls and the occlusion of bronchial lumens in these lesions, the distal lungs could not be re-expanded. At 28 days, the histology showed obstructive pneumonia and chronic atelectasis. Therefore, a considerable amount of non-functioning lung tissue can be created by ITT particularly with the compromise of segmental blood vessels. This delayed reaction may be significant in patients with limited functional lungs, such as cancer patients with emphesema or pulmonary fibrosis due to previous radiation or chemotherapy treatments.

Early identification of the value of localized hyperthermia in treating primary lung cancer was described by Lily and colleagues.[17] They noted that significant heating could be obtained with an internal electrode array and an external electrode to apply radiofrequency current to a tumor mass. They used a dog model for preclinical studies and demonstrated that temperature profiles were reproducibly obtained over time and within the tissue. The treated a 5 cm bronchogenic carcinoma in this manner. The tumor was easily heated without significant damage of the surrounding lung and without apparent toxicity. The authors suggested that the technique may be applicable to a variety of operable but unresectable neoplasms. The authors also noted that the technique provides reproducible treatment and homogeneity of heating.[18-22]

LeVeen and colleagues[22] noted that tumor blood flow was less than blood flow to the surrounding tissue (2 percent to 15 percent). They suggested that radiofrequency energy for heating tissue locally would be easily applied to tumor. They used this

technique in 21 patients and produced tissue necrosis or substantial regression of cancer in them.

Sugaar and LeVeen[21] described the history topology of radiofrequency thermotherapy only with tumors of the lungs. Necrosis and obliteration of the tumors faster apply were found as well as generalized breakdown of the tumors.

Radiofrequency ablation or interstitial thermotherapy has been used in a number of ways to treat tumors. Marasso and colleagues [23] examined a number of treatments for local control of endobronchial tumors. They examined radiofrequency tissue ablation followed or preceded by cryotherapy. In their series of 98 patients evenly distributed between the two groups, radiofrequency tissue ablation was successful in 60 percent and partially successful in 32 percent. As well cryotherapy treatment was successful in 66 percent and partially successful in 21 percent. Local control of these endobronchial tumors was easily achieved.

Goldberg and colleagues[24] examined the efficacy of radiofrequency tissue ablation in rabbit lung. He used a 19 gauge aspiration needle and radiofrequency was applied via a coaxial electrode for six minutes at 90 degrees. Probe-tip temperature, tissue impedance, and wattage were recorded at various intervals. Marked changes in tissue impedance were noted. Homogeneous lesions were created. Maximal consolidation was recorded at three days corresponding to coagulation necrosis and the peripheral acute inflammatory reaction. By day 28, near total recovery was noted. Of note, pneumothorax occurred in 3 of the 8 subjects. In a preclinical model, the authors[25] examined whether small pulmonary malignancies could be treated with percutaneous placement of radiofrequency electrodes. They used an animal (rabbit) model of VX2 sarcoma in rabbit lung. Tumors were allowed to grow 14-21 days and they were then treated with radiofrequency ablation for six minutes at 90 degrees C. The authors examined the histologic response at various time intervals and found at least 95 percent of these nodules were necrotic at pathologic analysis.

Wang[26] noted that impedance during the radiofrequency catheter ablation was dependent upon a variety of parameters such as catheter characteristics, cabling, reference patch size, body size, and temperature.

Various Japanese authors[27-30] have used radiofrequency hyperthermia in association with radiotherapy. Patients receiving this localized themoradiotherapy tended

to have better survival than patients treated with radiotherapy alone. Hyperthermia appeared to potentiate the effects of therapy with radiation.

Kodama and colleagues[31] have examined the role of intrathoracic chemotherapy with radiofrequency thermotherapy. Patients with pleural carcinomatosis were treated with an intrathoracic injection of cisplatin followed by radiofrequency thermotherapy for 60 minutes. The temperature was successfully maintained about 40 to degrees for 40 minutes in each of two or three treatment courses and 13 patients seven patients and incomplete treatment because of side effects pleural effusion was negative in 16 of 20 patients examined following this treatment. The authors suggest that the use of localized treatments together with chemotherapy and radiofrequency thermotherapy would be helpful in improving local control in patients with pleural carcinomatosis.

Hayes and colleagues[32] created a model of the effects of a radiofrequency electrode placed adjacent to a bronchial wall tumor. They used a finite element technique and assigned variable physical properties and blood perfusion to the tumor and surrounding normal lung tissue. Using this finite element model, an effective protocol for heating a tumor of a specific geometry could be performed to evaluate thermally induced damage to the tumor and surrounding normal lung parenchyma.

Radiofrequency ablation may be used for other thoracic disorders also. Wilkinson[33] reported over 148 unilateral or bilateral side effect his for various sympathetic-related medical conditions (such as reflex sympathetic dystrophy and hyperhidrosis, etc.). He used to 18 gauge radiofrequency TIC needles to create a series of three lesions in dangling sites. Lesions were targeted by C-arm fluoroscopy and electrical stimulation. Sympathetic activity was interrupted and 96 percent of operative levels after two years and 91 percent of operative levels after three years.

SUMMARY

Radiofrequency thermal ablation of lung tissues may be accomplished in a satisfactory and safe matter. The use of radiofrequency ablation clinically requires appropriate patient selection, evaluation of the acute effects of radiofrequency thermal ablation all in primary and secondary pulmonary neoplasms prior to clerical use. In patients who are otherwise unresectable because of poor pulmonary function or location of tumor, or numbers of tumors, radiofrequency thermal ablation may provide an

appropriate local control treatment to complement systemic management with chemotherapy and other local control modalities such as radiation.

Appropriate patients for use of radiofrequency thermal ablation may include patients with lung cancer who have poor pulmonary function, patients with stage IA, or Stage IB lung cancer with a negative pet scans. Even with good pulmonary function, patients with a solitary metastasis to the lung may also undergo treatment with radiofrequency ablation to provide good local control and obviate the need for thoracotomy. As patients with pulmonary metastasis will frequently develop recurrent metastases, minimizing the number of open thoracic procedures may provide the patient with more local control options that have previously been available. Other pulmonary diseases may be treatable with thermal ablation based upon the value of this local control modality upon the lung parenchyma, or upon the disease process itself.

The application of radiofrequency ablation of lung neoplasms will be initially performed by open techniques of thoracotomy to ensure accuracy of placement, and optimize patient safety while under the physiologic control of general antsthesia. In the future this technique may not be performed solely in the operating room, and may be used by interventional radiologists as a member of the multidisciplinary team caring for the lung cancer patient.

Radiofrequency thermal ablation will provide our patients with another technique of local control for primary and secondary lung neoplasms, and potentially other pulmonary diseases. The use of radiofrequency thermal ablation must be examined within the total care of the cancer patient: including appropriate clinical and pathologic staging, and the multidisciplinary evaluation and review prior to initiation of treatment. Radiofrequency thermal ablation holds great promise for our patients with pulmonary neoplasms in the next millennium.

ACKNOWLEDGMENTS

Funding for this project was provided in part by The Charles and Beverly Adams Fund for Thoracic Surgical Research and an unrestricted educational grant from RadioTherapeutics Corporation, Mountain View, CA.

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