Outcomes of an Algorithmic Approach to Management of Pneumothorax Complicating Thermal Ablation of Pulmonary Neoplasms

Nour-Eldin Nour-Eldin, MD, MSc, EDiR, Nagy N.N. Naguib, MSc, Ahmed M. Tawfik, MSc, Karen Koitka, MBBCh, Ahmed S. Saeed, MD, and Thomas J. Vogl, MD

ABSTRACT

Purpose: To investigate the outcomes of an algorithm for treatment of pneumothorax in association with radiofrequency (RF) and microwave (MW) ablation of pulmonary neoplasms.

Materials and Methods: This retrospective study included data from 248 ablation sessions for lung tumors in 164 patients (92 men; mean age, 59.7 y ± 9.8): 200 RF ablations (80.6%) and 48 MW ablations (19.4%). Pneumothorax was classified as mild, moderate, or severe. Twelve patients developed mild pneumothorax and were observed for further complications, and 33 developed moderate or severe pneumothorax and were managed with percutaneous aspiration of the pneumothorax. The decision to abort or continue ablation was determined based on clinical response to percutaneous aspiration, clinical distress, and feasibility of applying the applicator within the lesion.

Results: Incidence of pneumothorax was 18.1% (45 of 248 sessions), with four (8.9%) occurrences during MW ablation and 41 (91.1%) during RF ablation. Pneumothoraces were mild in 12 sessions (26.7%), moderate in 27 (60%), and severe in six (13.3%). Complete evacuation of the pneumothorax was achieved in 25 of 33 sessions (75.8%). Intercostal tube drainage was indicated in eight sessions (24.2%), including six severe and two moderate pneumothoraces. Pneumothorax evolved immediately after thoracic puncture in 10 patients. Ablation therapy was aborted in two sessions in which severe pneumothorax occurred, and an intercostal chest tube was inserted.

Conclusions: Mild pneumothorax can be managed by close observation without interruption of ablation therapy. Manual evacuation was an effective strategy for management of moderate pneumothorax and allowed for adequate positioning of the electrode, but did not suffice for severe and progressive pneumothorax, which required placement of an intercostal chest tube.

ABBREVIATIONS

MW = microwave, RF = radiofrequency

Thermal ablation may be used to treat a variety of thoracic malignancies, including primary lung cancer, recurrent primary lung cancer, metastatic disease, chest wall masses, and painful, bony thoracic metastases (1–14). As the use of this modality becomes more widespread, it is vital that associated complications be considered and evidence-based management protocols established for situations in which they arise. Pneumothorax is the most frequent serious complication of thoracic thermal ablation, with a reported mean incidence of 28% (1–12). There is a need for evidence-based knowledge regarding the factors associated with pneumothorax development and appropriate management protocols.

Most scientific research has focused on therapy efficacy and complications of thermal ablation, but there are currently no protocols to guide the management of these associated complications. The purpose of the present study was to investigate the outcomes of an algorithm for the treatment of pneumothorax occurring in association with thermal ablation of lung neoplasms.

From the Diagnostic and Interventional Radiology Institute (N.E.N.E., N.N.N.N., A.M.T., T.J.V.), Johann Wolfgang Goethe University Hospital, Theodor-Stern-Kai 7, Frankfurt, Hessen 60590, Germany; Department of Internal Medicine (K.K.), Toowoomba Base Hospital, Toowoomba, Australia; and Diagnostic and Interventional Radiology Department (N.E.N.E, A.S.S.), Cairo University Hospital, Cairo, Egypt. Received January 19, 2009; final revision received May 24, 2011; accepted May 31, 2011. Address correspondence to N.E.N.E.; E-mail: nour410@hotmail.com

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MATERIALS AND METHODS

Approval to carry out the study was obtained from the institutional review board. Informed consent was obtained from all patients (including approval for ablation therapy, management of emergent complications, including pneumothorax, and the anonymous use of data for research work). A retrospective analysis of a prospectively collected database of lung ablations with a predetermined pneumothorax management protocol was performed. The study involved 248 ablation sessions for lung tumors carried out in the time period between March 2004 and August 2008. Of the 248 sessions, 20 were for primary lesions and 228 for metastatic lesions in 164 patients (92 men, 72 women; mean age, 59.7 y ± 9.8 [SD]). A total of 200 cases were ablated by radiofrequency (RF) energy and 48 were ablated by microwave (MW) energy. In all cases, the malignancies were deemed medically inoperable or the patient had refused surgical intervention. Tumors were pathologically proven and were classified as primary lung neoplasms (non–small-lung cancer) in 20 patients and as metastatic lung neoplasms in 228 patients with no evidence of extrapulmonary metastases. Patients were excluded from ablation therapy if there were more than five lesions, if any lesion had a diameter greater than 5 cm, or if there was uncorrectable coagulopathy indicated by an International Normalized Ratio greater than 1.8 or platelet count lower than 75,000. The ablation protocol at the authors' institution was designed to ablate one lesion per session.

Rationale and Study Protocol

Radiologic evaluation of preprocedural, intraprocedural, and postprocedural images was consensually carried out by two senior radiologists. The study analysis focused on the circumstances of pneumothorax management rather than on the risk factors involved in pneumothorax development. Emphasis was placed on the onset of pneumothorax before or after insertion of the applicator (ie, electrode for RF ablation or antenna for MW ablation) within the lesion, pneumothorax severity (mild, moderate, or severe), management pathway selection, and monitoring of response to treatment.

Preablation Assessment

The thermal ablation treatment plan for an individual was devised by the treating interventional radiologist in consultation with the patient and the referring physician. Self-referred patients were assessed by a multidisciplinary team that included representatives from thoracic surgery, medical oncology, and pulmonary disease departments. A comprehensive clinical history and physical examination was documented, in addition to a review of recent imaging studies and a discussion of the indications, risk, and benefits of the procedure. Preprocedural laboratory investigations, including complete blood count and coagulation profile, were completed.

Prophylactic antibiotics were not routinely administered. The ablation parameters (including applicator type, length, and number), in addition to the position of the patient and site of puncture, were planned according to tumor size and anatomic location.

Ablation Technique

All lung ablations were performed with the use of computed tomographic (CT) fluoroscopic guidance with 5-mm collimation (SOMATOM 4; Siemens, Erlangen, Germany) under aseptic conditions by two interventional radiologists with more than 8 and 15 years of experience in interventional radiology, respectively. Ablation was performed under conscious sedation with fentanyl citrate (1 μg/kg of body weight) and midazolam hydrochloride (0.010–0.035 mg/kg). Continuous electrocardiography, pulse oximetry, and blood pressure monitoring was carried out for the duration of the procedure. Oxygen was administered to patients via a nasal cannula at a rate of 3–5 nL/min during the ablation. The patient was positioned depending on the location of the lesion to ensure the shortest ablation path in the position most tolerable for the patient. RF ablation was carried out with the use of (i) a CelonProSurge bipolar internally cooled applicator (20–40-mm electrode length, 15-gauge shaft [1.8 mm], and 100–250-mm shaft length; Celon, Teltow, Germany) in 148 ablation sessions or (ii) a RITA Starburst XL device (14-gauge/6.4-F, nine arrays plus active trocar tip, five thermocouples, shaft length of 10, 15, and 25 cm; RITA, Manchester, Georgia) in 52 sessions. Each lesion was ablated with the use of one applicator, with the exception of four cases in which two applicators (Celon bipolar electrodes) were applied simultaneously to ablate the lesion. Microwave ablation was performed with Covidien antennas (shaft length of 12, 17, or 22 cm, radiating section of 3.7 cm) and Covidien MW generators (Covidien, Boulder, Colorado) in 48 sessions. Applicators were applied through a single pleural puncture without guiding needles. The target location was monitored by CT during ablation, and the applicator was manipulated to ensure optimal positioning within the lesion. Periodic CT fluoroscopic scanning was performed to assess the applicator position and the progress of associated complications. To prevent seeding of malignant cells in the needle tract during applicator removal and to induce local hemostasis of the tract, needle tract coagulation was routinely performed at the end of the procedure.

CT Classification of Pneumothorax Severity

Pneumothorax was classified based on axial CT images according to the largest distance of retraction of the pulmonary surface estimated after scanning of the entire chest. Pneumothorax was classified as mild if it was associated with lung surface retraction of less than 2 cm from the pleural surface, moderate if it was associated with retraction of 2–4 cm, and severe if it was associated with retraction of more than 4 cm, increased progressively on two con-

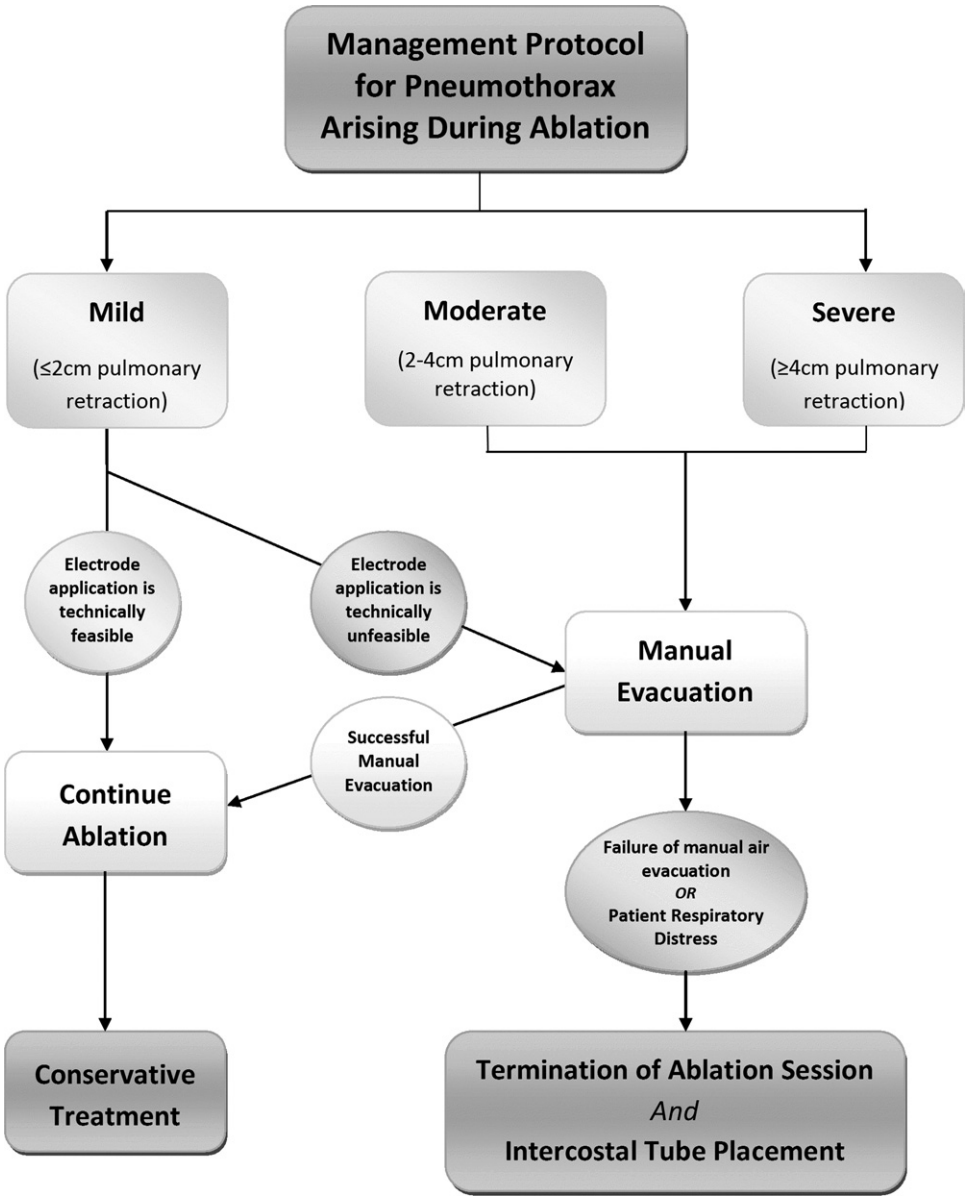


Figure 1. Protocol algorithm for the management of pneumothorax arising during the ablation procedure.

secutive radiologic control images within the first 2 hours after the procedure, was associated with mediastinal shift, or was accompanied by respiratory or circulatory distress (**Fig 1**) (15).

Pneumothorax Management Protocol

The proposed protocol for pneumothorax management was devised according to available evidence. Various studies have described the management of pneumothorax complicating a variety of thoracic interventions, particularly lung biopsy and thoracic ablation therapy (1,3–10,15,16). This knowledge was combined with our institutional technical experience in the field of thoracic intervention to formulate the algorithm for the management of pneumothorax complicating pulmonary ablation therapy (**Figs 1, 2**).

Pneumothorax detected during ablation session. Patients in whom pneumothorax developed after thoracic puncture with the applicator but before completion of the ablation procedure constituted one group. The protocol of management was as follows.

In the case of mild pneumothorax not interfering with proper positioning of the applicator within the lesion, ablation therapy was continued under close observation (particularly of the vital signs) and pneumothorax progression was monitored by limited fluoroscopic CT scanning. If adequate positioning was not possible because of slippage of the retracting lung, manual evacuation of the air from the pleural sac was carried out, followed by reapplication of the electrode on complete expansion of the retracted lung.

In the case of pneumothorax causing lung surface retraction of more than 2 cm from the pleural surface and

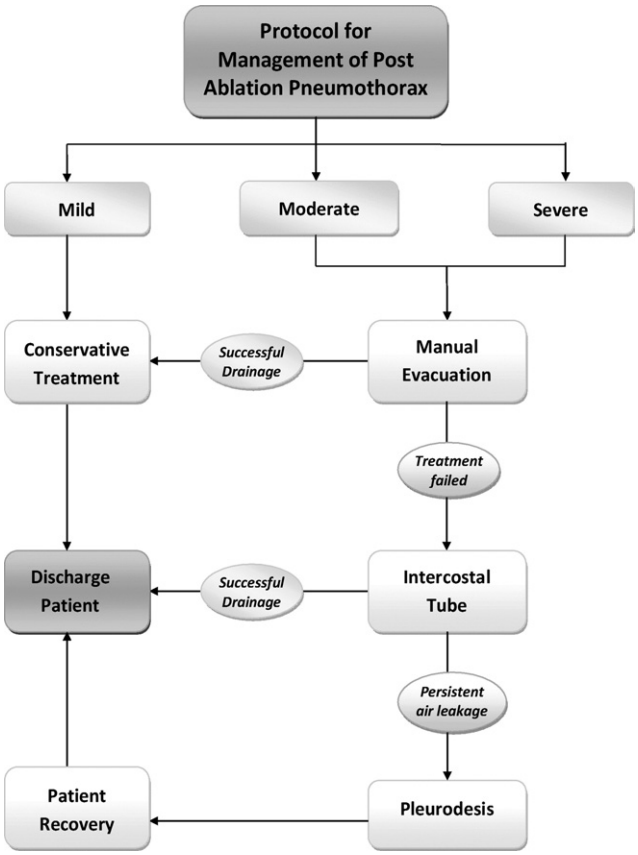


Figure 2. Protocol algorithm for the management of pneumothorax developing after the ablation procedure.

progressively increasing with time during the ablation procedure, pneumothorax was manually evacuated with an intercostal catheter (5- or 10-F). If the air progressively decreased without reaccumulation, ablation therapy was continued. If the pneumothorax was refractory to manual evacuation or the patient developed respiratory distress, the procedure was immediately terminated and an intercostal chest tube was inserted.

Pneumothorax accumulating after ablation therapy. Mild pneumothorax that accumulated after ablation therapy was managed by observation of clinical status and vital signs. Chest CT examinations were carried out at 1 hour and 8 hours after the procedure. Patients were deemed safe for discharge if they remained asymptomatic and there was no increase in pneumothorax size. A 24-hour postprocedure follow-up CT scan was mandatory to exclude delayed development of pneumothorax (**Fig 2**).

Moderate and severe pneumothorax were primarily treated by immediate manual evacuation with use of an intercostal catheter (5- or 10-F). On complete successful evacuation of the air, management was continued as for a mild, stable pneumothorax.

Failure of manual air evacuation or a progressive increase in patient respiratory distress necessitated insertion of a large-bore (16–22-F) intercostal chest tube for drainage. The patient was then followed up regularly to ensure resolution of the pneumothorax and improvement of patient symptoms. Persistent pneumothorax despite intercostal chest tube placement was managed with pleurodesis.

Catheter Application and Manual Air Drainage of Pneumothorax

In the cases that required manual evacuation of air, an intercostal catheter (5- or 10-F) was inserted. The anatomic sites for thoracic puncture drainage were the second or third intercostal space in the midclavicular line or the fifth or sixth intercostal space in the anterior axillary line. To facilitate optimal air drainage, the chosen site was closest to the area of maximal pulmonary retraction. Infrequently, a posterolateral approach was required for patients who were in prone position during ablation and developed a pneumothorax. This allowed for continuation of ablation in cases of successful pneumothorax evacuation. The draining catheter was inserted in a cephalad direction under CT guidance to ensure adequate positioning over the lung surface (ie, not trapped between lung fissures) and allow free drainage of air. When adequate position had been achieved, the external end was connected to a three-way stopcock and a 50-mL syringe. The valve of the stopcock was alternately opened (to allow suction of air by the syringe) and then closed (to allow air to be expelled outside sequentially).

Endpoint of Manual Evacuation

Manual evacuation was continued, and limited CT scans were taken every 2–3 minutes to assess the course of pneumothorax. Successful drainage was indicated by a progressive reduction of accumulated air in the pleural sac as visualized on CT images, an increase in resistance during suction of air, and the absence of air reaccumulation on cessation of suction. The evacuation was terminated when there had been complete evacuation of air from the pleural sac. Manual evacuation of pneumothorax was defined to be successful when there was complete evacuation of air from inside the pleural sac and an absence of reaccumulation of air. Failure of manual evacuation was considered when there was (i) progressive increase of pneumothorax size despite manual evacuation, (ii) an absence of air reduction after 10–15 minutes of continuous manual suction, or (iii) persistent clinical distress. These events suggest a persistent air leak, and indicated placement of an intercostal chest tube for adequate drainage. The volume of aspirated air was estimated by measuring the number of syringes aspirated.

Postprocedural Positioning

After the ablation procedure, the patient was positioned to ensure that the aspiration/ablation puncture sites were dependent in an attempt to reduce reaccumulation of air (15,16). This position favors development of dependent atelectasis and close apposition of the visceral and parietal pleural surfaces, providing a physical barrier to the further leakage of air (15,16).

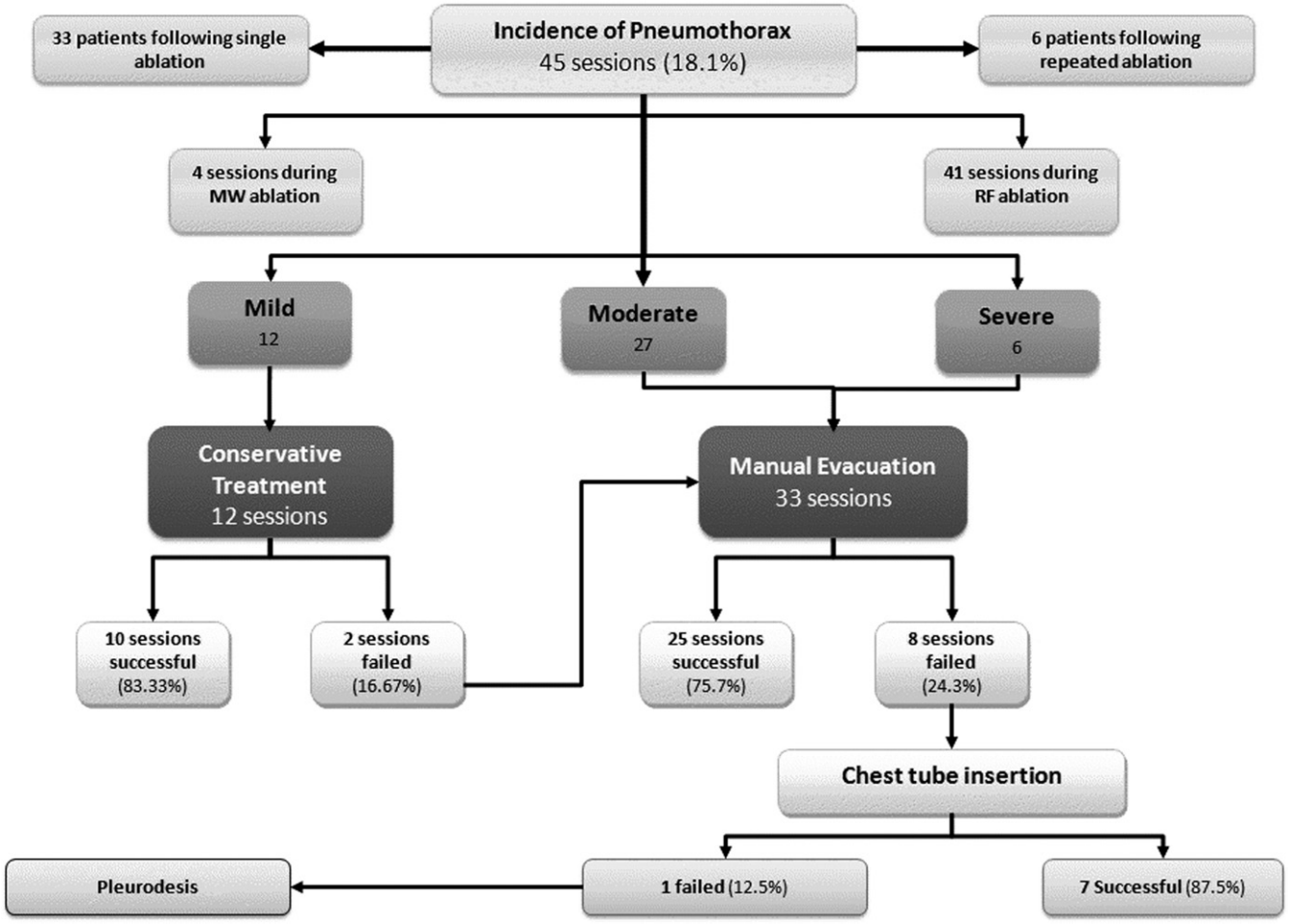


Figure 3. Algorithm of the sequence of management of cases involved in the study.

Statistical Analysis

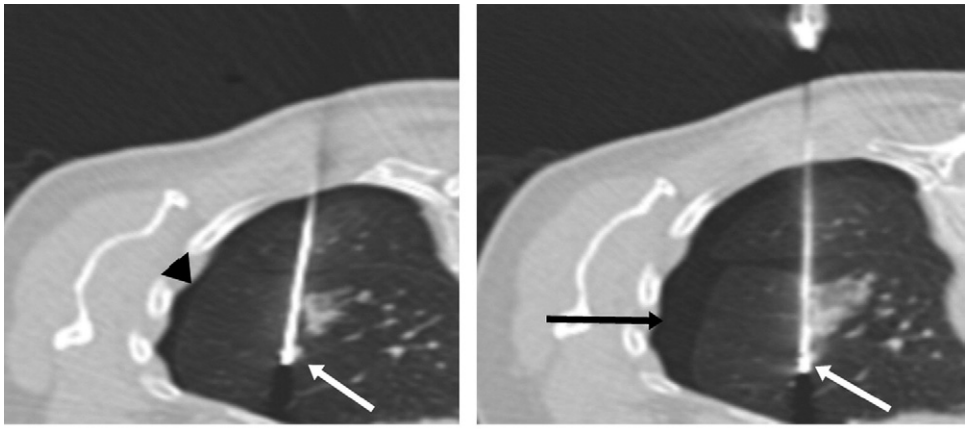
Data are expressed as means ± SD, ranges, incidences, and success/failure rates of different management tools. Statistical significance was assessed by Fisher exact test with Bias software (version 8.6 for Windows; Epsilon-Verlag, Frankfurt, Germany). *P* values lower than .05 were considered to indicate statistical significance.

RESULTS

The incidence of pneumothorax was 18.1% (45 of 248 sessions) in 39 patients (33 patients had a single occurrence of pneumothorax and six developed repeated pneumothorax on repeat ablation). According to CT image classification, mild pneumothorax occurred in 12 sessions, moderate in 27 sessions, and severe in six sessions. Classified according to histopathology of the ablated lesions, pneumothorax developed during ablation of non–small-cell lung cancer in three sessions (15%; three of 20) and during ablation of metastatic lesions in 42 sessions (18.4%; 42 of 228).

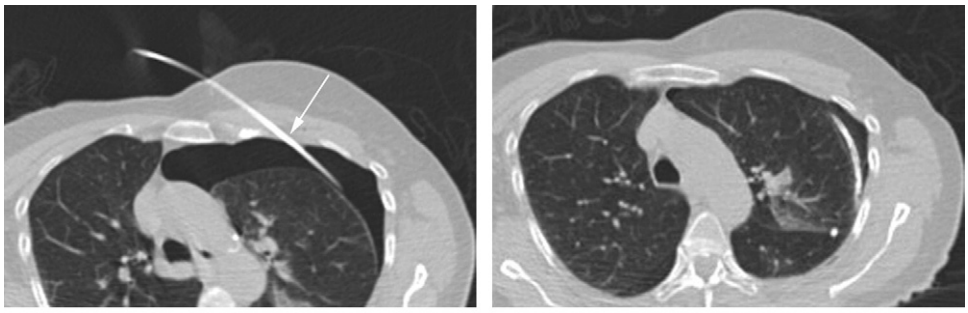
Pneumothorax developed in four of 48 sessions of MW ablation, an incidence rate of 8.3% (coefficient index, 2.3%–20%), including two mild and two moderate pneumothoraces. During RF ablation, 41 of 200 sessions were complicated by pneumothorax, an incidence rate of 20.5% (95% CI, 15.1%–26.8%). This included 10 mild, 25 moderate, and six severe cases of pneumothorax. This difference in the incidence of pneumothorax between RF and MW ablation was not significant ($P = .59$; **Fig 3**). Emphysema was diagnosed in 61 of 164 study patients (37.2%), and represented a significant risk factor for the development of pneumothorax ($P = .012$): 21of 39 patients (53.8%) who developed pneumothorax also had emphysema.

The 12 sessions in which mild pneumothorax occurred were initially observed only (**Fig 4**). Observation was sufficient management for 10 of 12 sessions (83.3%), but in the other two, there was a progressive increase in size of the pneumothorax during the first 24 hours, which required manual evacuation. Manual evacuation of pneumothorax was carried out in 33 sessions (23 through the midclavicular line, nine through anterior axillary line, and one through posterolateral thoracic wall; **Fig 5**). Successful evacuation was achieved in 25 of 33 sessions (75.8%), but the other eight (24.2%) required chest tube insertion after failure of manual evacuation (**Fig 6**). In one session that required chest tube insertion, a persistent air leakage developed,



a. b.

Figure 4. Images of pulmonary metastases from breast carcinoma in a 52-year-old woman. **(a)** During RF ablation (in prone position), mild pneumothorax developed (black arrowhead) but did not interfere with electrode positioning (white arrow) or produce clinical distress during ablation. Pneumothorax was managed by observation without cessation or premature termination of the session. **(b)** Note the RF electrode within the lesion (white arrow) and the mild increase of pneumothorax during the procedure (black arrow). Ablation continued without interruption of the ablation session, and pneumothorax was managed by close observation.



a. b.

Figure 5. Images of lung metastasis from colorectal carcinoma in a 46-year-old man. **(a)** RF ablation was complicated by moderate pneumothorax, which was evacuated manually by a 10-F intercostal catheter (white arrow). **(b)** Axial CT image after manual evacuation shows near-complete expansion of the lung.

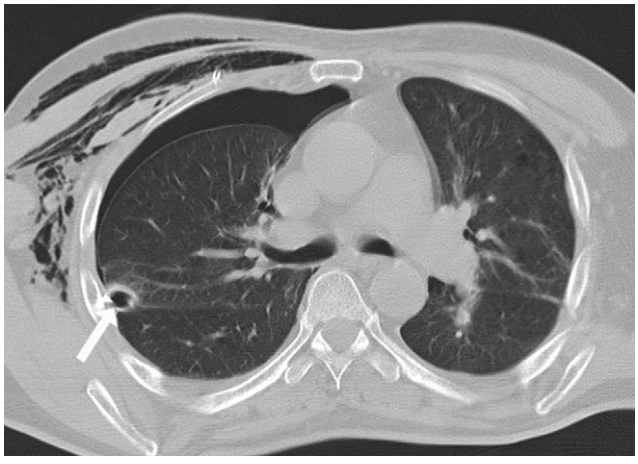


Figure 6. Image of severe right-sided pneumothorax and surgical emphysema complicating RF ablation of a right basal pulmonary metastasis from hepatocellular carcinoma in a 51-year-old man. After failure of manual evacuation, an intercostal chest tube was placed (arrow).

which necessitated pleurodesis. Of the eight sessions in which manual evacuation failed, six were cases of severe pneumothorax and two were cases of moderate pneumothorax. The mean volume of air evacuated manually in successful sessions was 480 mL ± 50.8 (range, 250–950 mL). Durations of hospital stay were 24 h for cases managed by close observation, 24–48 h for cases managed by manual evacuation of pneumothorax, and as long as 7 days for patients who underwent chest tube insertion. Persistent air leakage after 7 days despite chest tube drainage was an indication for pleurodesis (17). Chronologically, pneumothorax evolved immediately after thoracic puncture in 10 sessions. Development of pneumothorax did not interfere with adequate applicator (ie, electrode or antenna) insertion in six sessions, and in two sessions (with moderate pneumothorax), manual evacuation was sufficient to allow positioning of the applicator. Severe pneumothorax developed in another two sessions, which required cessation of ablation therapy and intercostal chest tube insertion. In contrast, in the remaining 35 sessions, pneumothorax developed after insertion of the applicator within the lesion or after the completion of the ablation procedure.

Completion of ablation without cessation of current flow or withdrawal of the applicator was achieved in 37 sessions, including all cases of MW ablation (**Fig 4**). Cessation and premature termination of the ablation session represented the management for all cases of failed manual evacuation (eight sessions in total, including two before adequate applicator positioning and six before completion of the proposed ablation). A repeat ablation session was indicated for all cases of aborted or prematurely terminated sessions.

DISCUSSION

Pneumothorax is a frequent complication of transthoracic RF ablation of lung neoplasms. In most large studies, the mean incidence of pneumothorax is approximately 28%, with a range of 15%–52% (1–13). Emphysema has been reported to be a significant risk factor associated with the development of pneumothorax during pulmonary ablation therapy (12). A pneumothorax of marked size not only leads to postablation morbidity, but also impacts the end result of therapy, as ablation may be terminated because of clinical compromise necessitating drainage of the pneumothorax or because of a technical inability to adequately position the applicator (18).

Our classification of pneumothorax according to axial CT images into mild, moderate, and severe categories provides quantitative criteria for identifying how and when to intervene. The mechanism allowing for reexpansion of the lung affected by pneumothorax after manual evacuation is the reapproximation of the visceral and parietal pleural surfaces, creating a physical barrier to further leakage of air. In the study by Jones (19), 45 of 69 patients with a pneumothorax (> 20% of the hemithorax) had sufficient reexpansion after aspiration to remain ambulatory. In the series by de Baère et al (20) looking at the management of pneumothorax complicating RF ablation of lung tumors, 23% of pneumothorax cases were aspirated by using a 5-F catheter under CT guidance.

The temporary nature of air leakage causing mild retraction of the lung is illustrated by the fact that the majority of mild pneumothorax cases required observation only. Despite this knowledge, close follow-up is essential to ensure that there is not a delayed progression of the pneumothorax. In contrast, progressive moderate and severe pneumothoraces represent variable rates of continuous air leakage. Failure of evacuation occurs when the rate of air leakage exceeds the rate of manual evacuation, thus explaining the need for intercostal chest tube placement in all cases of severe pneumothorax (**Fig 6**). When the rate of air leakage is significantly less than the rate of manual evacuation, approximation of pleural surfaces can occur, and sealing of the leaking area can begin. The approximation of pleural surfaces thereby allows for continued placement of the applicator within the lesion, alleviates any clinical distress, and allows the possibility of completion of the ablation session (**Fig 5**). Persistent air leakage despite chest tube application for a period of more than 7 days necessitates sealing of the leaking surface by means of pleurodesis. This is important to prevent epithelialization of the leaking tract and hence prevent the formation of bronchopleural fistula.

The present study was limited by the heterogeneity of lung tumors seen between primary and metastatic lesions and the inclusion of pneumothorax complicating MW and RF ablation rather than a solitary method of ablation. Another limitation of the study was the impact of needle tract ablation, as pleural coagulation may affect the response of the pneumothorax to treatment. However, this technical point should be considered for further assessment. The effectiveness of the proposed management protocol for pneumothorax complicating ablation therapy needs results obtained by other centers for a universal protocol to be developed. It would also be worthwhile to consider alternative options for pneumothorax management, such as a one-way valve or conventional chambers attached to suction.

In conclusion, a mild pneumothorax developing during ablation therapy of lung neoplasms can be managed under close observation, without interruption of the ablation session. Manual evacuation can be effectively used to manage moderate pneumothorax and to overcome the effect of the pneumothorax on the positioning of the applicator within the lesion. Manual evacuation is ineffective in treating severe and progressive pneumothorax, and intercostal chest tube insertion is mandatory in these cases and is considered to be the procedure of choice.

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