Interventional Radiology

5

Claudio Pusceddu, Francesco Allegra, and Luca Saba

Abstract

Computed tomography (CT) and ultrasound (US) are currently considered as the the main imaging modalities in the field of interventional radiology. Because of the different characteristics of these modalities their use is different. In particular CT is widely used to obtain accurate needle-tip localization and excellent delineation of interposed vital structures but the most important draback is the lack of real-time imaging. On the other hand US is readily available, relatively inexpensive, and allows for real time imaging. Moreover, Color flow Doppler imaging can help identify the vascular nature of the mass and the adjacent vascular structures. In this chapter we will show the different Interventional Radiology Procedures by showing advantages and limits of these techniques.

Keywords

Computed tomography · Ultrasound · Interventional radiology

C. Pusceddu (✉)
Department of Radiology, AOB, Cagliari, Italy

F. Allegra · L. Saba
Department of Radiology, University of Cagliari, Cagliari, Italy

5.1 Interventional Radiology Procedures

5.1.1 Guidance Techniques

Computed tomography (CT) and ultrasound (US) are the main imaging modalities aimed at the field of interventional radiology, both diagnostic and therapeutic.

- **CT** provides high spatial and high contrast resolution that allows accurate needle-tip localization, excellent delineation of interposed vital structures, and target viable portion of a mass; it also allows for early detection of complications (i.e., pneumothorax) [1]. On the other hand different density between normal tissues and lesions on noncontrast CT images may not be sufficiently large; another disadvantage is the lack of real-time imaging and last, but not least, use of ionizing radiation [2].
- **US** is readily available, relatively inexpensive, and portable, and does not use ionizing radiation. It is optimal for superficial lesions and provides real-time visualization and monitoring of the needle tip. Color flow Doppler imaging can help identify the vascular nature of the mass and the adjacent vascular structures. Ultrasound-guided biopsy may not be possible when lesions are too deep or behind a

M. Anzidei, M. Anile (eds.), *Diagnostic Imaging for Thoracic Surgery*,
https://doi.org/10.1007/978-3-319-89893-3_5

reflective surface such as bone or gas-filled bowel, limited for obese patients [3].

5.2 Lung and Mediastinal Biopsy

Lung cancer remains the most common cancer diagnosed worldwide and represents the leading oncologic cause of death. Not all lung masses are primary, with greater than 70% of multiple lung nodules representing metastatic deposits. Also mediastinum represents a region of interest due to frequent localization of lymph nodes or masses.

5.2.1 General Principles

Relative contraindications to percutaneous lung biopsy include uncooperative patients, positive-pressure ventilation, severe respiratory compromise, pulmonary artery hypertension, severe interstitial lung disease, small lesions close to the diaphragm, and central lesions adjacent to large vessels or bronchi.

The platelet count, prothrombin time, international normalized ratio (INR), and activated partial thromboplastin time should be routinely checked prior to the procedure. Although local standards apply, according to recent consensus guidelines, INR should be corrected if >1.5, and transfusion should be performed for platelet counts <50,000/μL.

Clopidogrel (Plavix®) should be held for 5 days prior to the procedure. Aspirin does not need to be held, but the last dose of low-molecular-weight heparin should be held prior to the procedure [4].

5.2.2 Indication

The most common indication for *lung* biopsy is an indeterminate solitary pulmonary nodule, both in cases where the nodule in question is almost certainly malignant but unsuitable for resection and where it is of equivocal or likely benign nature, but also biopsy is frequently performed for solitary or multiple pulmonary nodules, masses, or consolidations when tissue is required to diagnose and further characterize potentially malignant lesions.

Another common indication is suspected lung abscess in which bronchoscopy or sputum cytology and culture have not yielded a diagnosis; additional indications include enlarging ground-glass opacities, and evaluating for local recurrence following therapy [5].

The vast majority of *pleural* biopsies are performed to evaluate for malignant diseases of the pleura, including malignant mesothelioma, metastatic disease, and lymphoma. However, many benign conditions may also involve the pleura (i.e., pleural tuberculosis) [6].

About *mediastinal* lesions: Masses and lymph node are the most common indications for biopsy.

5.2.3 Patient Preparation

Patient positioning should be chosen based on the location of the lesion, size of the lesion, and patient's ability to tolerate positioning. The prone position is preferred because the posterior ribs move less than the anterior ribs, posterior intercostal spaces are wider than the anterior intercostal spaces, and prone positioning prevents the patient from visualizing the needle during the procedure, which may decrease anxiety. The oblique and decubitus positions are less desirable because they are not as stable, but they can be utilized if necessary for lateral subpleural lesions.

For CT-guided procedures, preliminary 3- or 5-mm-thick contiguous axial slices are obtained to confirm the location of the target lesion and to determine the optimal entry site for the needle. The important factors in choosing an access route include avoiding chest wall vessels such as subclavian, internal mammary, intercostal, and intrapulmonary vessels. It is also important to minimize pleural transgression by performing a single pleural puncture and avoiding fissures if possible. Large bullae should also be avoided.

If biopsy is being performed for a lesion of mixed CT attenuation, biopsy should be targeted

toward the solid component of the nodule or mass. Similarly, if there is central necrosis, biopsy should be directed at the wall of the lesion [7].

5.2.4 Anesthesia

Adequate pleural anesthesia is a primary point of a successful biopsy, as patient's comfort and cooperation. Placement of the coaxial needle is essential for achieving pleural anesthesia and optimal trajectory for needle placement into the target lesion.

Anesthesia of the parietal pleura requires the precise placement of the needle tip in an extrapleural location immediately adjacent to and superficial to the parietal pleura while avoiding both the underlying parietal and visceral pleura, which if violated increases the risk of an early pneumothorax.

The costal and diaphragmatic parietal pleuras are innervated by the overlying intercostal nerve, which means that inadequate anesthesia is characterized by significant pain and discomfort [8]. Local analgesics are used like lidocaine 1% (most common) and bupivacaine (for longer onset and duration).

Systemic analgesia like paracetamol or opioids (fentanyl, morphine) could be used in uncollaborative patient with severe pain.

5.2.5 Devices and Techniques

The needle selected depends upon lesion characteristics, type/amount of tissue required, and operator preference. Biopsy needles can be divided into two groups: **aspiration needles** for retrieval of specimens for cytologic evaluation, and **core biopsy needles** for retrieval of specimens for histologic evaluation.

- **Aspiration Needle (FNAB)**: FNAB is a minimally invasive procedure that is performed using a 21-, 23-, or 25-gauge needle attached to a 10 cm 3 syringe. Aspiration needles are thin walled and flexible, and are used for obtaining specimens for cytologic or microbiologic evaluation (Fig. 5.1). However, because the needles are flexible, they can easily bend or deflect off course; such effects are magnified when using a longer needle. The needle is introduced into the lesion and moved several times, dislodging cells, which are aspirated and deposited into glass slides. Direct smears

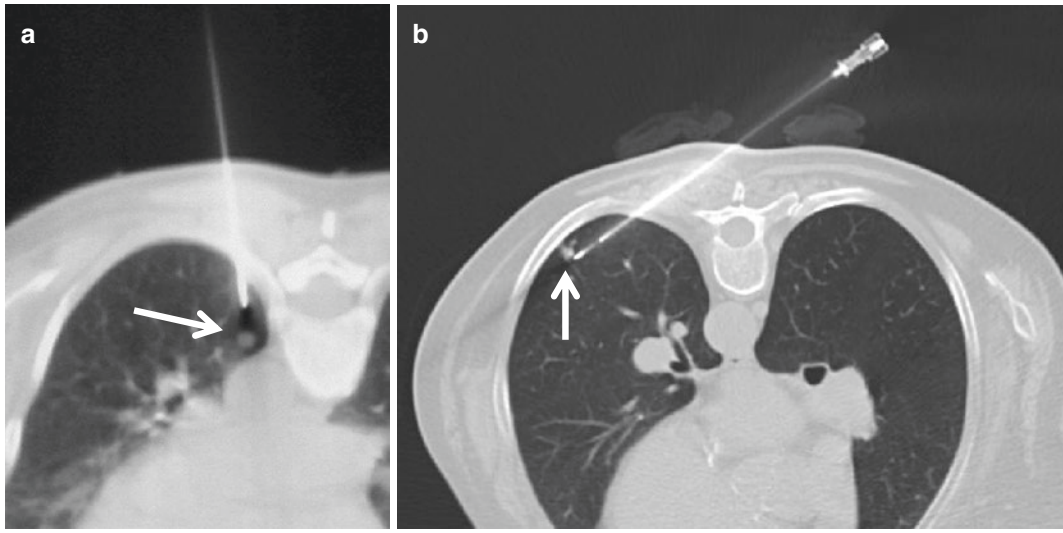

Fig. 5.1 Axial CT images show two different cases of FNAB of 5 mm nodules (*arrows*) located in the left lung both reached with posterior approach (*arrows*)

are made manually and fixed in alcohol for staining using the Papanicolaou or hematoxylin and eosin (H&E) method and then air-dried for staining using the Diff-Quik method for conventional cytological examination. By changing the direction of the needle during aspiration, different sites in the target area can be evaluated [9]. Aspiration needles are useful for making diagnoses of epithelial carcinomas (adenocarcinoma or squamous cell carcinoma) because these diagnoses can be made on cytological analysis alone. Today, though, the diagnosis is not limited to cell type, but includes evaluation of tumor markers and analysis of tumor mutational status, which require procurement of additional tissue. In cases where cytologic sampling may have been adequate in the past, histologic sampling may be required to have sufficient tissue for analysis [10].

- **Core Needle Biopsy (CNB)**: Automated core biopsy needles are generally used to obtain tissue for histologic evaluation. The automated devices obtain higher quality and more intact core biopsy samples than obtained with manual needles (Fig. 5.2). Use of an automated biopsy device may improve results if a pathologist is not on-site at the time of biopsy because, depending on tumor type, the needle will obtain similar core samples that are free of crush injury sometimes imparted by smaller conventional needles. Currently, side-cutting biopsy guns are available in a variety of sizes, ranging from 20 gauge (the smallest) to 14 gauge (the largest). Usually, 2–4 cores of tissue are obtained from the lesion. For conventional pathological examination, the samples are fixed in formalin, routinely processed, and embedded in paraffin.

FNAB and CNB are complementary techniques for evaluating the lesion of interest; both have distinct advantages and limitations. FNAB is the preferred method in technically challenging sites such as those close to major blood vessels or neurovascular bundles. In addition, FNAB is the preferred method for obtaining material for microbiologic culture studies from lesions that are thought to be infectious.

CNB samples invariably contain more tissue than do FNAB samples, making ancillary studies possible.

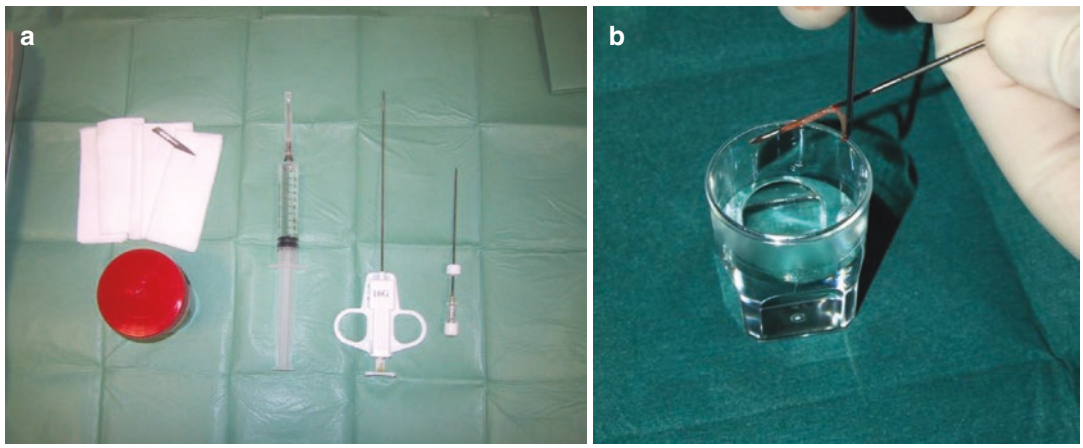

Fig. 5.2 The pictures show the set for a lung biopsy which includes several surgical gauze, a syringe with local anesthetic, a surgical scalpel, and a biopsy needle (**a**). High-quality core biopsy sample obtained using a 16-gauge automated biopsy device (**b**)

5.3 CT-Biopsy Procedure

After appropriate patient positioning, a radiopaque marker is placed on the patient's skin over the area of interest. During suspended respiration, a short spiral CT scan of the region of interest is obtained, and from these images an appropriate table position and needle trajectory are chosen. The shortest straight pathway from the skin to the lesion is preferred over a longer oblique pathway, and ideally the needle should cross the pleura at a 90° angle rather than at an oblique angle. The depth from the skin entry site to the lesion is then measured.

Next, the patient is moved back into the CT gantry to the desired table position. With the use of the gantry laser light to delineate the Z-axis position, and the radiopaque skin marker to reference the *X*-axis position, the needle entry site is marked with indelible ink on the patient's skin.

The skin site is prepped and draped using sterile technique. Palpation of underlying structures to determine the contour of the ribs or the location of adjacent skeletal structures is helpful. For local anesthesia, a 27-gauge or similar needle is used to inject 1% or 2% lidocaine into the skin and subcutaneous tissues, followed by deeper infiltration of the intercostal muscles.

The biopsy needle is inserted through the dermatotomy into the subcutaneous tissues. All needle movements should be performed with patient's respiration suspended. When advancing the needle, it is important to maintain the same trajectory with each movement, as even slight deviations of the needle at the skin or within the subcutaneous tissues will produce marked deviation at a deeper level. The needle is advanced to the level of the pleura, and the needle position and angle are verified with a short-segment CT (typically obtained using a sequential technique). Next, the needle is advanced in one motion through the pleura to the prescribed depth. Afterwards, the patient may breathe quietly, and the needle should be allowed to sway to and fro with respiratory motion; the needle should not be held or fixed during respiration, as this will cause a lacerating effect on the pleura with each breath.

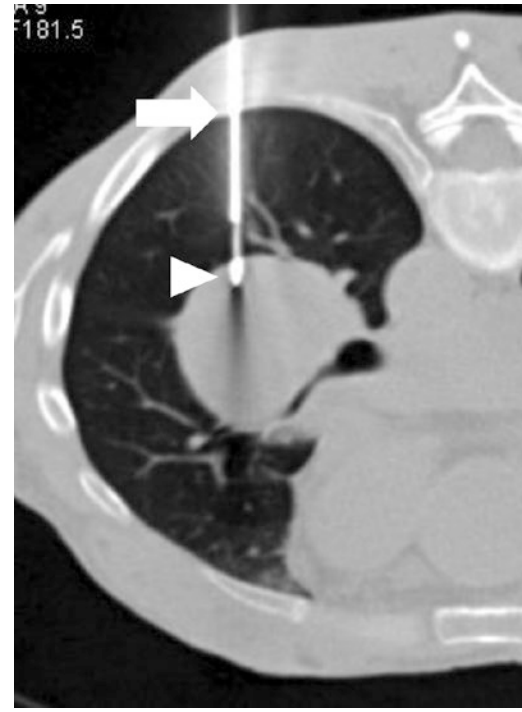

Fig. 5.3 Axial CT image shows a central mass in the left lung. CNB was performed using a posterior approach. The needle crosses the pleura approximately at a 90° (*arrow*). The tip of the needle is in the mass ready for biopsy (*arrowhead*)

Confirmation of needle tip position must be performed before aspirating or cutting (Fig. 5.3). After needle tip position within the lesion is confirmed, a tissue sample may be obtained. If an aspiration or a cutting needle is used, the inner stylet is removed from the needle and the cannula quickly covered to block entry of air into the needle.

5.4 US-Guided Biopsy Procedure

Ultrasound-guided TNB is limited to regions that provide an adequate acoustic window to the lesion and is best suited for peripheral pulmonary or mediastinal masses that abut the pleura. The affected region is studied using US (usually from 1 to 5 MHz) convex probe parallel to the ribs in

the intercostal spaces. Local anesthesia is used in every case through local subcutaneous injection (10–20 mL xylocaine 2% or lidocaine).

The core biopsy needle having a size of 16-, 18-, or 20-G needle, length of 20 cm, and core length of 10, 15, or 20 mm is chosen according to the size and type of the lesion. The needle is placed into the biopsy gun and the puncture is performed using continuous visual control on the monitor.

After the puncture the needle is removed and compression is applied at the puncture site. When the tissue sample is considered sufficient, no further punctures are performed and the sample is placed in a tube containing 4% formaldehyde and is sent to the pathological department. Chest radiograph is performed after the biopsy to rule out any complications (i.e., pneumothorax). Generally all patients are observed for at least 12 h after the procedure up to 1 week to detect any complications [11].

5.4.1 Complications

Some complications could occur after a lung biopsy procedure. The most common complications are pneumothorax and bleeding. Although most patients can tolerate a small pneumothorax or mild hemorrhage, when performing TNB in high-risk patients with significant cardiopulmonary disease or single functional or anatomic lung, even a small pneumothorax or mild hemorrhage may cause significant respiratory compromise.

- **Pneumothorax**: PNX is the most common complication of transpulmonary biopsy (TNB). The reported incidence ranges from 0% to 61%. Factors reported to be associated with a higher incidence of pneumothorax and chest tube insertion include obstructive airway disease, increased lesion depth, decreased lesion size, a small angle of the needle with the thoracic pleura, multiple pleural punctures, fissure and bulla transgression, small and deeply situated lesions, longer procedure duration, and operator inexperience [12]. Some studies suggest no difference in pneumothorax rate between larger and smaller needles [13]. Pneumothoraces can occur during or immediately after the procedure, which is why it is important to perform a CT scan of the region following removal of the needle (Fig. 5.4) If the patient develops a pneumothorax during or after TTNB, the patient should immediately be placed biopsy-side down, and oxygen via nasal cannula or facemask should be administered at 2–4 L/min. If the biopsy needle is still within the thorax, manual aspiration of the PNX may be performed (Fig. 5.5). Aspiration of excess pleural air results in improved apposition of the visceral and parietal pleura, minimizing the need for chest tube

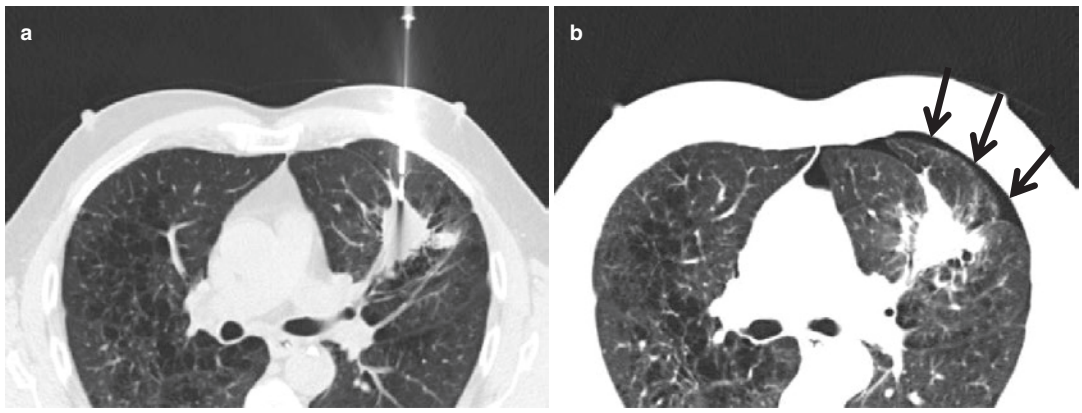

Fig. 5.4 Axial CT images show a mass in the left lung in patient with severe emphysema. The needle is positioned for biopsy (**a**). Axial CT image shows small pneumothorax immediately after the procedure (*arrows*) (**b**)

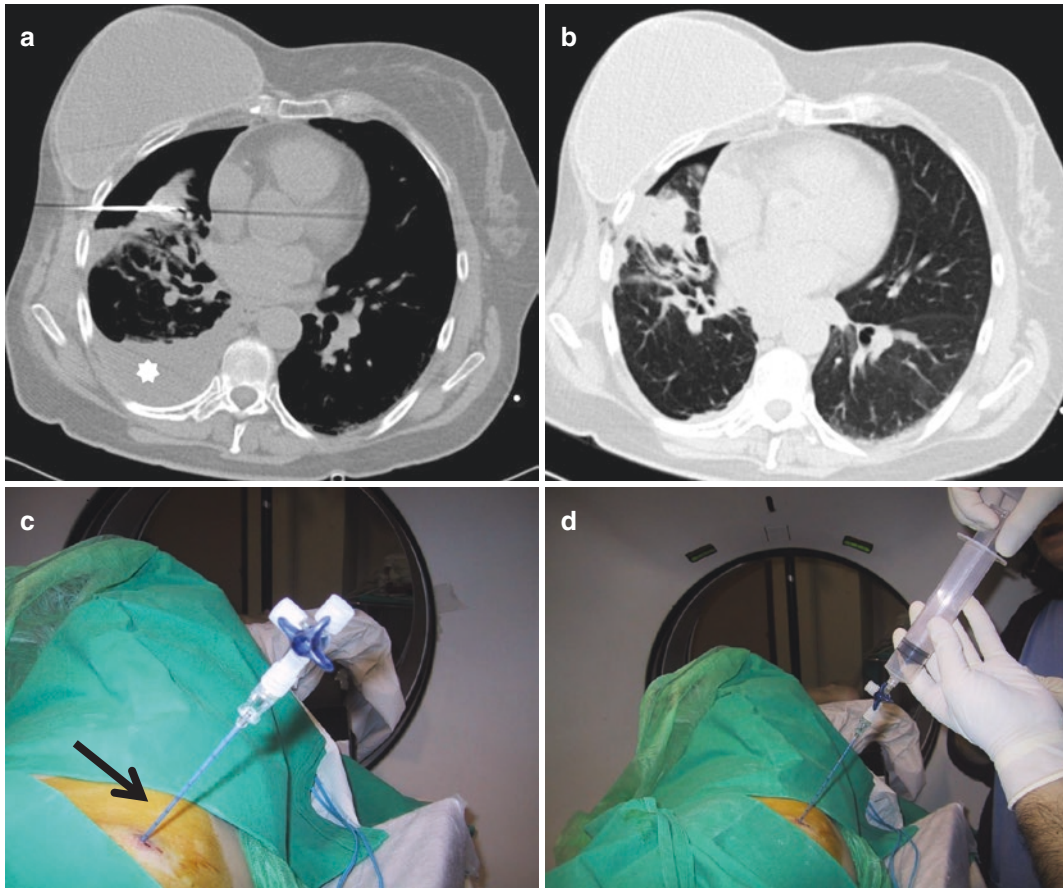

Fig. 5.5 Axial CT image shows a pneumothorax during biopsy of the right lung metastasis (**a**) immediately drained with a catheter directly in the CT room (*arrow*) (**c**, **d**). Axial CT image after drainage of the pneumothorax and pleural effusion (*) which was already present before the biopsy (**b**)

insertion. Long-term pleural drainage may be required for a persistent air leak despite conservative management, or for a large (>20–30%) or symptomatic pneumothorax. A small-gauge drainage catheter (<16-French) can be placed in a relatively quick and safe manner using either a direct trocar method versus guide wire approach. Typically, a pneumothorax is drained via the second or third intercostal space on the medioclavicular line, and an effusion is drained via the sixth or seventh intercostal space on the midaxillary line. Once in place, the catheter can be connected to chest drainage systems such as Pleur-evac suction or to a Heimlich valve depending on the rate of air leak (techniques) [14].

- **Hemoptysis and Pulmonary Hemorrhage**: Hemorrhage, with or without hemoptysis, is the second most common complication of TNB. Although most bleeding is self-limited, hemorrhage is considered to be the most dangerous potential complication of percutaneous lung biopsy. The use of fine needles for aspiration and biopsy has reduced the incidence of significant bleeding to 0–10% with most series reporting an incidence of less than 5%. In addition, small-gauge (18–20-gauge) automated cutting needles are now widely avail-

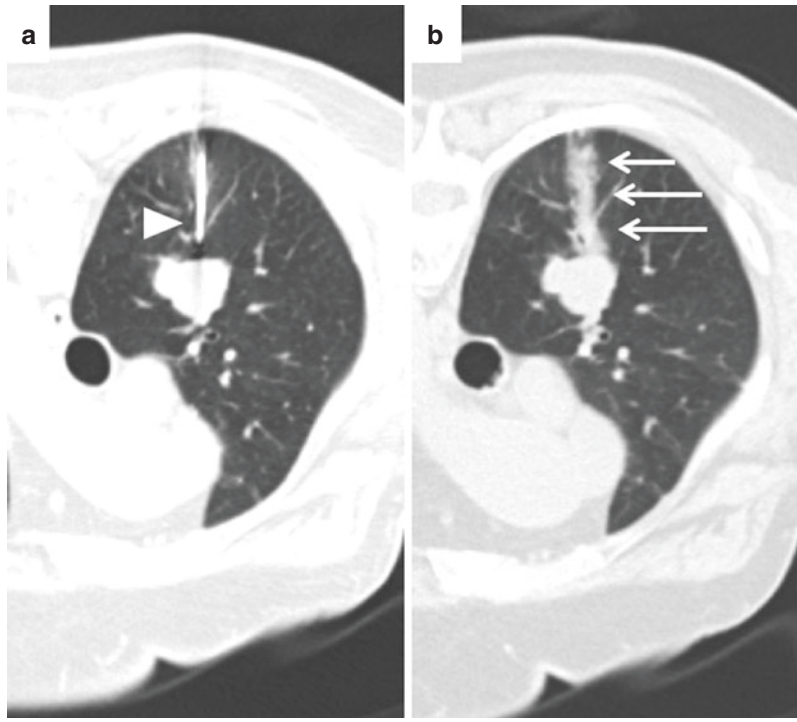

Fig. 5.6 Axial CT image shows the needle positioned for lung biopsy (*arrowhead*) (**a**). After removing the needle a hemorrhage occurs in his trajectory (*arrows*) (**b**)

able and do not appear to be associated with a significantly increased risk of hemorrhage compared with aspirating needles, particularly when their use is confined to lesions in the peripheral third of the lung [15]. Hemorrhage is characterized by the development of perilesional or in the path airspace and ground-glass opacities on CT; sometimes it can occur also in the pathway of the needle (Fig. 5.6). Most episodes of parenchymal hemorrhage or hemoptysis will settle spontaneously. However, if the patient is hemodynamically unstable, appropriate fluid resuscitation ± blood transfusion is required. Rarely, bronchial or pulmonary transcatheter arterial embolization is required. Hemoptysis is often associated with coughing secondary to airway irritation. Severe coughing can result in pleural laceration and increases the risk of a pneumothorax. If pulmonary venous damage has occurred, the swings from negative (inspiration) to positive (coughing) intrathoracic pressure increase the risk for air embolism and Trendelenburg positioning may be added to facilitate clearance of blood and reduce the risk of an air embolus reaching the cerebral circulation [16].

- **Infection**: Rarely infection can be introduced into the lung lesion secondary to the biopsy procedure. Management: Appropriate antibiotic treatment.
- **Failure**: If insufficient tissue cores are obtained, histology can be inconclusive and thus no diagnosis is made. In this case it is necessary to repeat the percutaneous biopsy. To avoid this situation an inspection of the tissue cores at the time of the biopsy procedure is recommended in order to ensure sufficient tissue volume. To reduce the number of inadequate biopsy it is preferable to

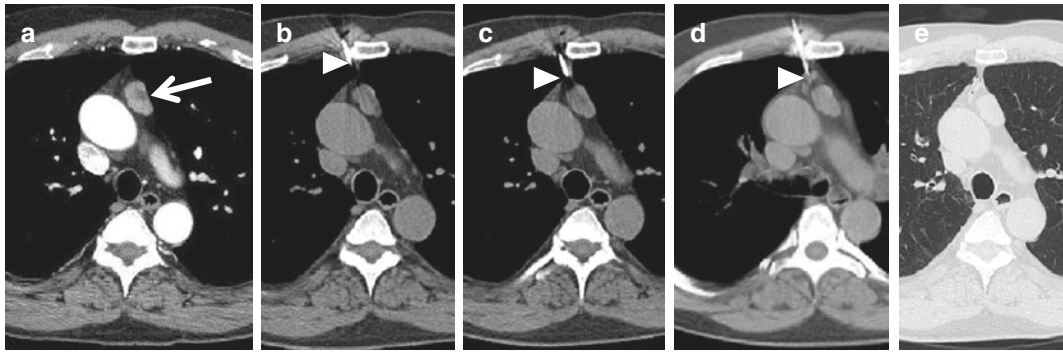

Fig. 5.7 Axial CT image shows a mass into the anterior mediastinum on the left (*arrow*) (**a**). The needle is positioned between the sternum and right mammary vessels avoiding the lung parenchyma (*arrowheads*) (**b**–**d**). CT image acquired immediately after procedure doesn't show any sign of pneumothorax (**e**)

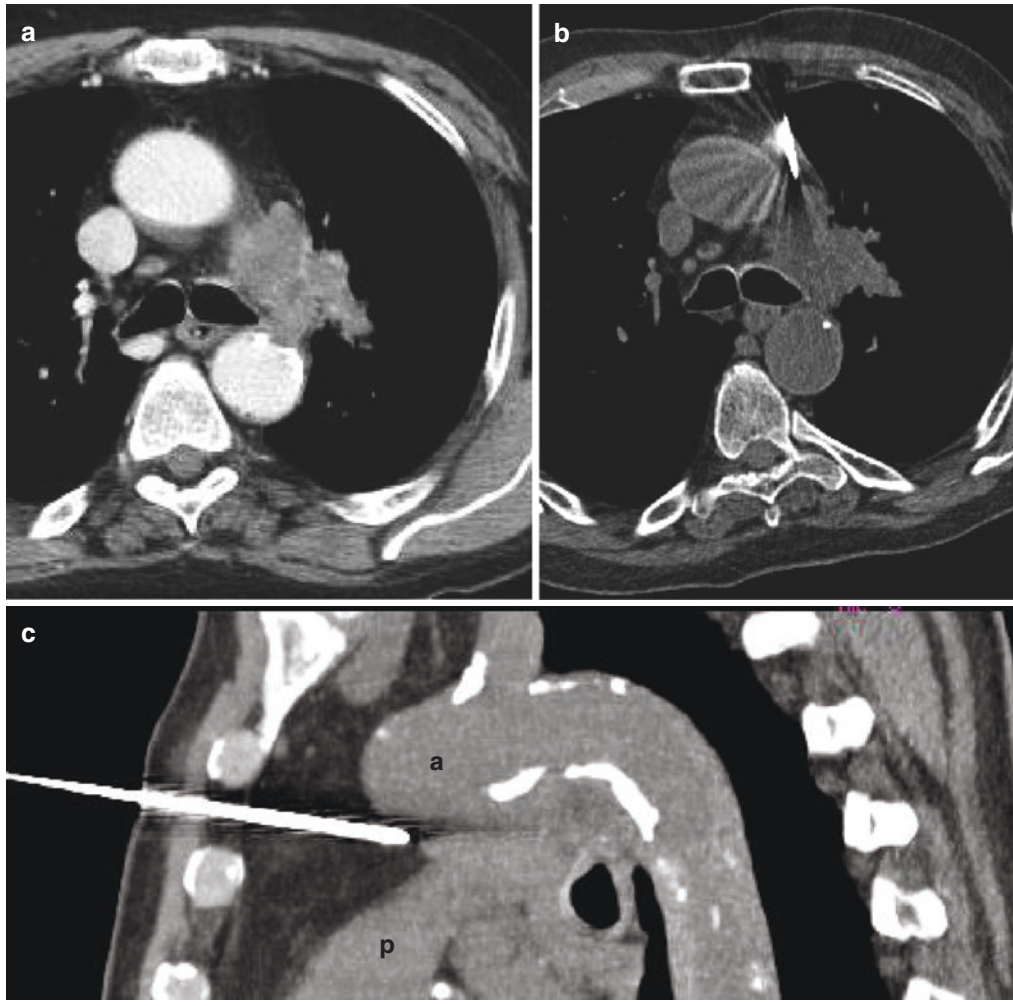

Fig. 5.8 Axial CT image shows a metastasis of NSCLC in the aortopulmonary window (*arrow*) (**a**). The needle is inserted with parasternal approach trough the mediastinal fat (*arrowheads*) (**b**). Sagittal CT volumetric reconstruction images show the tip of the needle into the mass (m) below to the aorta (a) and above to the pulmonary artery trunk (**c**, **d**)

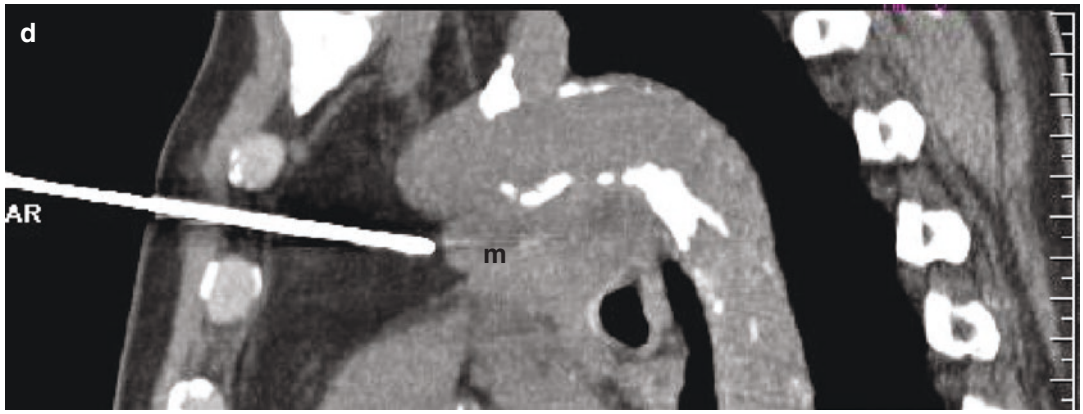

Fig. 5.8 (continued)

acquire more than one specimen in the same session using the same cannula adequately oriented.

- **Air Embolism**: Rare complication due to puncture of a pulmonary vein with air being sucked in and embolizing to the systemic circulation via the left heart, resulting in symptoms resembling those of stroke, transient ischemic attack, seizure, or cardiopulmonary collapse. Management: Remove the biopsy needle, place the patient in the supine position, and administer 100% oxygen. Hyperbaric oxygen therapy is recommended. A diagnosis may be established by performing immediate brain or cardiac CT to search for intravascular air bubbles.

5.5 Mediastinum

5.5.1 Anatomic and Technical Considerations

5.5.1.1 Parasternal Approach

A direct mediastinal approach involves placement of the biopsy needle through an extrapleural space medial to the lung to avoid traversal of the lung and the pleura. The needle can be advanced through or lateral to the sternum, through the posterior paravertebral space, through the suprasternal notch, or through the subxiphoid space.

In the parasternal approach the needle is inserted lateral to the sternum and advanced through the parasternal muscles and mediastinal fat into the target lesion (Fig. 5.7). The internal mammary blood vessels are located on either side of the sternum; the artery is usually situated lateral to the vein (Fig. 5.8).

Occasionally, the space between the lateral edge of the sternum and the internal mammary vessels may be too small to allow safe parasternal needle placement. Placing the patient in a lateral decubitus position may cause the mediastinum to shift laterally toward the dependent side, bringing the lesion or the mediastinal fat into direct contact with the parasternal chest wall and allowing the needle access to the lesion. Alternatively, saline solution ("salinoma") or diluted contrast medium can be injected to create an artificial extrapleural path for needle placement. The use of US guidance is generally limited to biopsies of large anterior mediastinal lesions [17].

5.5.1.2 Paravertebral Approach

The paravertebral approach allows access to posterior mediastinal lesions and is used mostly for biopsy of subcarinal lesions from the right side. For the paravertebral approach, the patient is generally placed in the prone position; patients who are unable to lie prone may be placed in a prone oblique or lateral decubitus position. The needle is advanced immediately lateral to the vertebral

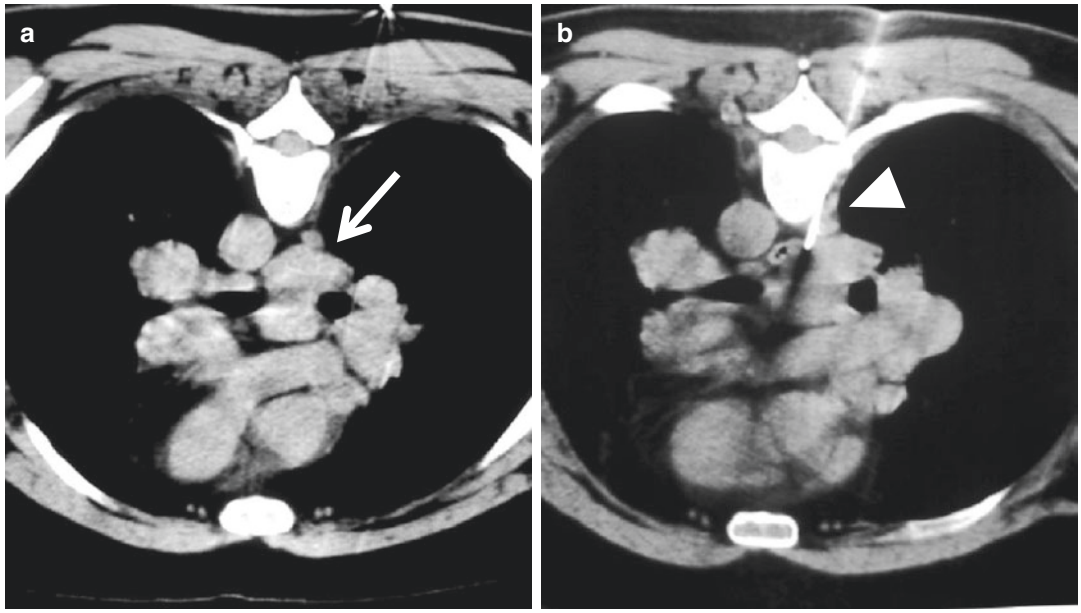

Fig. 5.9 Axial CT image shows a mass in the subcarinal space (*arrow*) (**a**). The needle is positioned with posterior approach between the endothoracic fascia and the parietal pleura (*arrowhead*) (**b**)

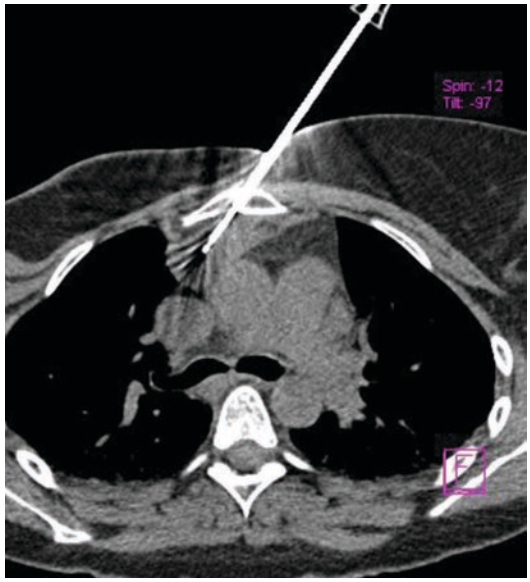

Fig. 5.10 The axial CT image shows a retrosternal mass. The needle is positioned with trans-sternal approach with oblique pathway to get biopsy avoiding mediastinal vessels

body between the endothoracic fascia and the parietal pleura (Fig. 5.9).

In most patients, injection of 10–20 mL of saline solution is sufficient to achieve adequate mediastinal widening; however, larger volumes may be required. The injection of saline solution also displaces mediastinal structures, such as the azygos vein, esophagus, nerves, and vertebral blood vessels, from the needle's path [17].

5.5.1.3 Trans-Sternal Approach

The trans-sternal approach is used for biopsy of lesions that are not safely accessible by the parasternal approach. To reach the target a cannula adequately oriented is previously positioned across the sternum. Through the cannula the biopsy needle is inserted and the sample is taken (Fig. 5.10). The entire procedure can be performed in local anesthesia but the anesthetic infiltration of the periosteum is required to avoid pain during and after biopsy. The use of a hammer can help to push the needle crossing the sternum.

There are some other techniques due to mediastinal biopsy, like the following:

- **Suprasternal Approach**
  The suprasternal approach is another alternative method for obtaining tissue samples for cytologic or histologic diagnosis of mediasti-

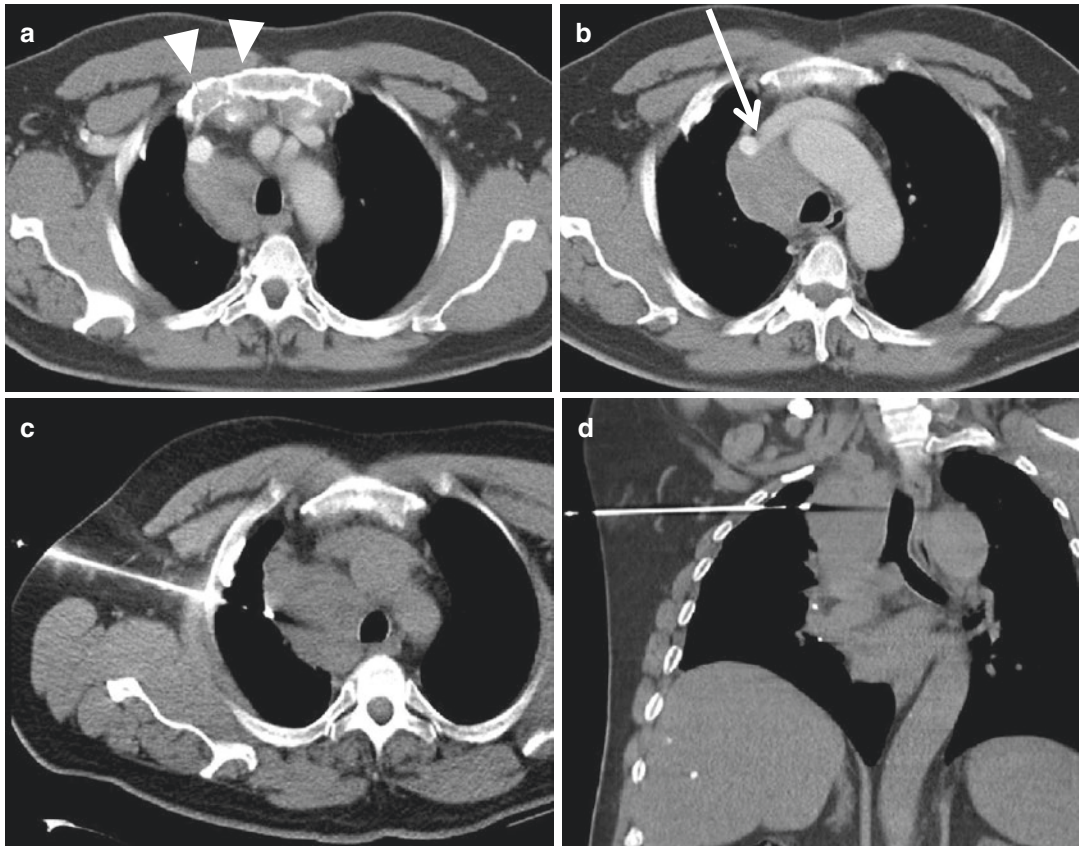

Fig. 5.11 The interposition of the sternum (*arrowheads*) or the major vascular structures (*arrow*) (**a**) obstacles the extrapleural biopsy of the mediastinal mass (**b**). The biopsy was performed using a transpulmonary approach (**c**, **d**)

nal lesions. The use of the suprasternal approach for US- and CT-guided biopsy is taken into consideration to reach small retrosternal lesions located in the anterior and middle mediastinum. A direct mediastinal approach, which enables extrapleural needle placement, is the preferred method to avoid the risk of pneumothorax especially for patients affected by BPCO or other emphysematous conditions. Patients have to be positioned on their back with their head hyperextended. Hemorrhagic complications are rare and are due to an unaspected vascular puncture.

– **Transpulmonary Approach**
The transpulmonary approach is usually used to biopsy lesions inaccessible with an extrapleural approach (Fig. 5.11). This approach involves transgression of the lung and visceral pleura by the biopsy needle and the major limitation is the pneumothorax which is more frequent with respect to the biopsy of the lung because the needle passes the parietal and visceral pleura to reach the mediastinum. The injection of physiological saline solution in the subpleural space in the point of insertion of the needle can help to reduce the pneumothorax rate.

– **Approach Through the Pleural Space**
CT guidance is usually used to perform the mediastinum biopsy through pleural space and the needle can be advanced increasing the pleural space by injection of saline or through a preexistent pneumothorax or pleural effusion. In the preexistent pleural effusion US guidance can be used to advance the needle and to reach the target through the pleural space. In the posterior

mediastinal mass a paravertebral approach with patient prone can be used. The pleural fluid can be used as an "acoustic window" for needle placement. During mediastinal biopsy through the pleural space an inadvertently puncture of the visceral pleura can occur with consequent pneumothorax.

5.6 Drainage

Chest drainage procedures can be classified based on the anatomical regions of the pleural space, lung parenchyma, and mediastinum.

Placing an image-guided percutaneous chest catheter is an important alternative to surgically placed chest tubes because of the advantage of precise placement under image guidance (US or CT) and small caliber of the catheter (5–14 F versus approximately 24 F for chest tubes).

Most common indications are pleural space: pleural effusion, pneumothorax, empyema, or infection, and lung parenchyma and mediastinum: abscess.

5.6.1 Pleural Space

- **Pleural Effusion**: Defined as accumulation of fluid in the pleural space. Intrapleural pressure is lower than the interstitial fluid pressure of the pleural tissues, favoring flow of fluid into the pleural space. The protein and cellular concentration in this fluid is typically low because pleural fluid is effectively a filtrate. Normally, the influx of fluid into the pleural space is balanced by its removal via the lymphatic system. In certain clinical conditions, the balance between the secretion and absorption can be disturbed and fluid may accumulate in the pleural space. In disease states, the normal composition of pleural fluid is altered, which allows for diagnosis via pleural fluid analysis. Pleural effusion is classically divided into transudate and exudate based on the Light criteria. The Light criteria consist of measurement of the lactate dehydrogenase (LDH) and protein concentration in the pleural fluid and serum.
- **Pneumothorax**: PNX is an imaging finding and clinical condition in which air accumulates within the pleural space. Pneumothoraces can be either spontaneous, associated with underlying lung disease (lymphangioleiomyomatosis, blebs, etc.), or the result of traumatic injury to the chest wall, pulmonary parenchyma, or airways. Traumatic pneumothorax most often results from penetrating or blunt trauma; spontaneous pneumothorax may be divided into a primary form (rupture of an apical intrapleural bleb) and a secondary form, which is associated with underlying parenchymal lung disease.
- **Empyema**: This is a collection of purulent fluid in the pleural space. The most common cause is pneumonia. Lung abscess, bronchopleural fistula, esophageal perforation, postsurgical complications, and trauma may also result in empyema. Along with antibiotic therapy and treatment of the underlying disease process, early and complete drainage of the infected fluid is considered essential in the successful management of empyema [18].

5.6.2 Intervention

- **Thoracentesis**: Although the procedure can be performed at bedside without imaging guidance, it is generally recommended to use ultrasonographic guidance to avoid potential complications, most of all in pediatric patients. Once the patient is best positioned for the procedure, ultrasound can be used to determine the optimal needle trajectory to the effusion. Use of the lower frequency 3–5 MHz probe offers a wider depth of field and a more global view of the lung and the effusion [19]. There is a method for estimating the size of the pleural effusion in medical intensive care unit patients. An equation was described between the volume of the effusion and the separation distance between the lung and the outer parietal pleura as *the effusion size (cc) = 20 × separation*

(sep) in mm; here the separation (sep) was identified as the maximal separation distance between the parietal and visceral pleura during end expiration [20]. There are two options for positioning of the patient for the thoracentesis procedure. An upright position is traditionally preferred by many clinicians, with the patient leaning forward on a support. This allows access to the posterior approach to thoracentesis. The supine position, allowing a lateral approach to the chest cavity, may be employed in patients unable to sit up. This would be a similar position to that used for the typical placement of a chest tube. Optimally, the head of the bed should be elevated in this position to facilitate the drainage of the pleural fluid inferiorly and to accumulate the effusion closer to the location of standard needle placement [21]. Once the optimal needle puncture location is determined by using ultrasound, it is important to use a liberal amount of local anesthesia to provide maximal patient comfort during the procedure. For a simple diagnostic thoracentesis, a 20-gauge needle and syringe is generally sufficient for fluid collection. For greater volume drainage, a specific thoracentesis kit has the benefit of a plastic catheter that can be advanced over a metal trocar. Removing the metal trocar immediately as the pleural effusion is entered, while simultaneously advancing the flexible plastic catheter, will have the benefit of decreasing the risk of injury to the lung. When ready to proceed, one should advance the needle into the pleural space while simultaneously drawing back with the plunger of the syringe. Once pleural fluid is flowing into the syringe, adequate fluid (usually 20–30 cc) should be removed and sent for the usual laboratory studies [22].

- **Chest Drain Insertion**: The preferred position for drain insertion is on the bed, slightly rotated, with the arm on the side of the lesion behind the patient's head to expose the axillary area. In fact the most common position for chest tube insertion is in the midaxillary line. For apical pneumothoraces the second intercostal space in the midclavicular line is sometimes chosen but is not recommended routinely as it may be uncomfortable for the patient and may leave an unsightly scar. The majority of physicians now use smaller catheters (10–14 French) and studies have shown that these are often as effective as larger bore tubes and are more comfortable and better tolerated by the patient [23]. As a chest drain may potentially be in place for a number of days, aseptic technique is essential to avoid wound-site infection or secondary empyema. After local anesthesia the tube will be positioned and the incision for insertion of the chest drain should be similar to the diameter of the tube being inserted. If possible, the tip of the tube should be aimed apically to drain air and basally for fluid. Two sutures are usually inserted—the first to assist later closure of the wound after drain removal and the second, a stay suture, to secure the drain [24].

5.7 Lung and Mediastinum

Abscess: A lung abscess usually results from aspiration of anaerobic oropharyngeal bacteria into gravity-dependent portions of the lung, most often the posterior segments of the upper lobes and the superior segments of the lower lobes. Mediastinal abscesses are a rare and potentially fatal condition; common etiologies of mediastinal abscess include head and neck infections that descend into the mediastinum, trauma, and postsurgical. Bronchial obstruction due to malignancy, inflammation, or foreign body is also an important risk factor for development of lung abscess because it impairs effective clearing of aspirated oropharyngeal fluid.

Current first-line therapy for lung abscess is an antibiotic therapy directed at the suspected causative organisms.

5.7.1 Intervention

When nonresponsive to antibiotics, postural drainage, and bronchoscopic drainage, image-guided catheter drainage allows high success rate of more than 70% after 10–15 days of drainage [25]. If the abscess abuts the pleura, the catheter can be placed without lung parenchymal transgression.

It typically involves the use of 7–14 F (French) catheter for drainage and Seldinger technique. Ideally, insertion should be in the "triangle of safety," an area bordered by the lateral edge of the latissimus dorsi, the lateral border of the pectoralis major muscle, and a line superior to the horizontal level of the nipple.

Principals steps of Seldinger technique [26]:

1. Insert an introducer needle into the pleural space and confirm that either fluid or air is returned. If this does not occur, do not proceed.
2. If fluid or air is returned, the syringe is removed.
3. Insert the guide wire through the introduced needle into the pleural space.
4. The introducer needle is then removed, leaving the guide wire in position.
4. Pass the dilators sequentially over the guide wire to dilate the tract in a slight twisting action. Never use the force.
5. Remove the dilator.
6. Pass the chest tube into the pleural space over the guide wire.
7. Remove the guide wire and any tube stiffeners, leaving the chest tube in place.
8. Secure the tube in place with a suture, dress with gauze, connect the drainage system, obtain a chest radiograph to confirm the tube position, assess lung expansion, and monitor the initial drainage from the tube.

Complications:

- Hemorrhage.
- Pneumothorax, rare and usually from air introduced during procedure: This will resolve with the catheter in place.
- Lung injury can lead to bleeding into bronchial tree and aspiration into contralateral side. If bleeding appears in endotracheal tube or expectorate, place patient ipsilateral side down. Extremely rare with imaging guidance.

5.8 Lung and Soft-Tissue Ablation

Interventional radiology offers also some therapeutic opportunities with the use of radiofrequency ablation (RF), microwave ablation (MW), cryoablation, etc. In particular lung cancer has been the most common target of this procedures;

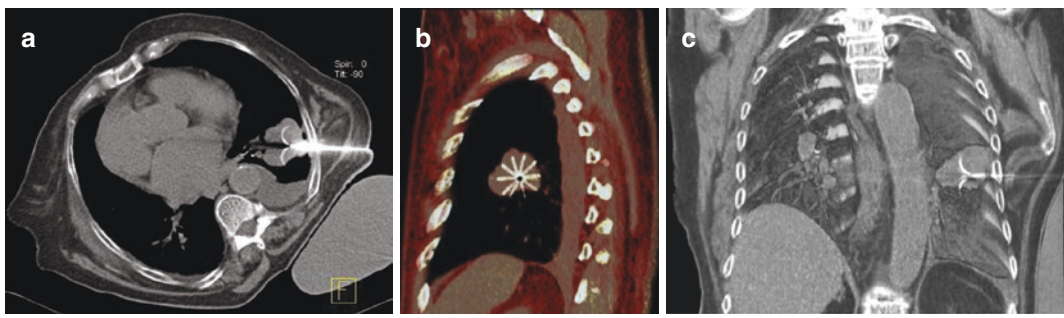

Fig. 5.12 Axial CT image shows a NSCLC in 71-year-old man treated with RFA using an umbrella-shape device (**a**). The coronal and sagittal volumetric reconstructions show the correct central position of the device into the mass (**b**, **c**)

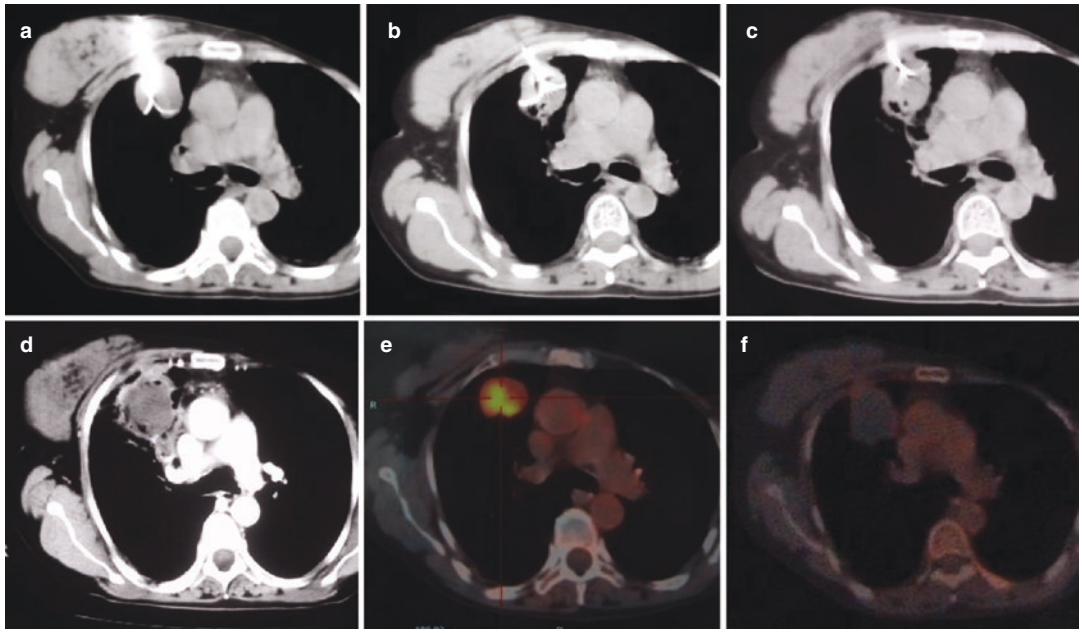

Fig. 5.13 Successful RFA of a breast cancer lung metastasis ineligible for surgery. The RF device is positioned in three different depths (**a**–**c**). Contrast CT image acquired after ablation shows lack of contrast enhancement of the tumor (**d**). 2 months later, the follow-up PET-CT image shows complete loss of 18F-FDG avidity indicative of metabolic response to treatment (*arrow*) (**e**, **f**)

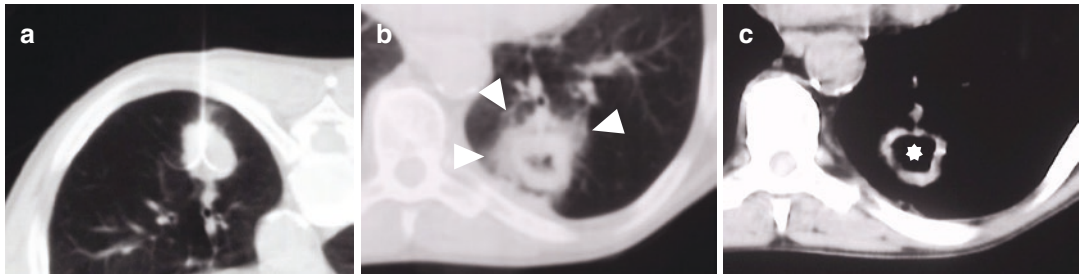

Fig. 5.14 Patient with NSCLC on the left lung. Axial CT image shows the device positioned into the tumor with posterior approach (*arrow*) (**a**). Immediately after the treatment a ground-glass opacity is visible around the tumor (*arrowheads*) (**b**). Cavitation of the mass 1-month follow-up (*) (**c**)

actually surgical resection remains the gold standard of therapy in early-stage non-small cell lung cancer (NSCLC), being the only therapeutic option with proven long-term cure and survival, reserved for only stage I–II of the disease [27]. Thermal ablation has recently been advocated as an alternative treatment, especially in patients with early-stage disease who are not surgical candidates.

5.9 Radiofrequency Ablation

Radiofrequency ablation (RFA) uses a high-frequency current to heat and coagulate tissues. An alternating electrical current of usually 500 kHz with a power of up to 200 Watts is applied to the target lesion by means of an electrode. The therapeutic range for RFA is quite narrow: between 65 C and 105 C, in

which protein denaturation takes place, leading to coagulative necrosis [28]. Radiofrequency ablation is indicated in patients for whom treatment of lung cancer is expected to convey a survival benefit and/or improved quality of life [29].

RFA is usually reserved for patients with early stage I or II NSCLC, in whom a surgical resection is contraindicated. RFA can also be suitable in patients with advanced disease who responded to chemo/radiotherapies, but who have a persistent peripheral focus of disease. RFA has also been used in isolated recurrence of NSCLC in postsurgical patients in whom further surgery is contraindicated. Patients with limited peripheral lung metastases can also be suitable candidates for RFA treatment provided that the primary cancer is controlled [30]. Large tumors (usually >5 cm), proximity to major pulmonary vessels or major bronchus, hilar tumors, and more than three tumors in one lung are usually contraindicated for RFA treatment.

Virtually all cases of RFA are carried out under CT guidance, even though there have been reports of US being used if the target lesion is in contact with the parietal pleura [31]. The aim is to achieve complete ablation of the tumor along with a parenchymal margin of 0.5 cm to 1 cm. Differently from the liver the ablation of

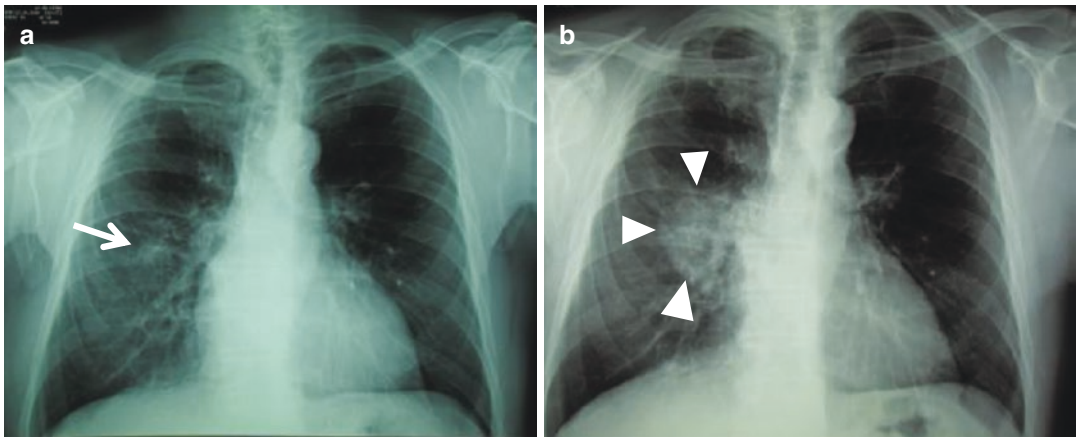

Fig. 5.15 Patient with perihilar NSCLC of right lung treated with RFA. X-ray image shows a nodular opacity (*arrow*) (**a**). X-ray image acquired 24 h after ablation shows large ground-glass opacity which completely covers the tumor (*arrowheads*) (**b**)

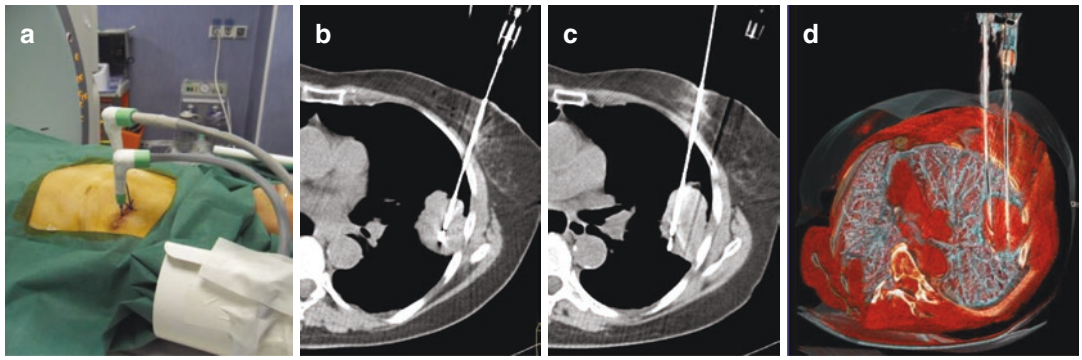

Fig. 5.16 MWA of a NSCLC to the left lung in a 64-year-old woman not candidate for surgery. Two antennas are inserted percutaneously with CT guidance (**a**–**c**). The volumetric reconstruction shows the two antennas correctly positioned parallel into the mass (**d**)

needle track is usually not. During the procedure the use of computerized tomography reconstructions allows to see if the tumor is completely covered by the treatment (Fig. 5.12). In large tumors the multiple positioning of the RF electrode can be used to better treat the mass (Fig. 5.13a–c). Post-procedure care usually involves repeat imaging of the chest to assess the presence of any pneumothorax and a 24-h observation period [29].

RFA often induces an inflammatory reaction in the surrounding lung parenchyma, which may appear as ground-glass opacification or even consolidation on imaging. In several cases cavitation of the mass can occur (Fig. 5.14). Most centers use a 1-month follow-up CT scan as baseline, because the high-density treated area is usually larger than the initial tumor [31]. CT scans are repeated at 3 months, 6 months, and then every 6 months post-procedure.

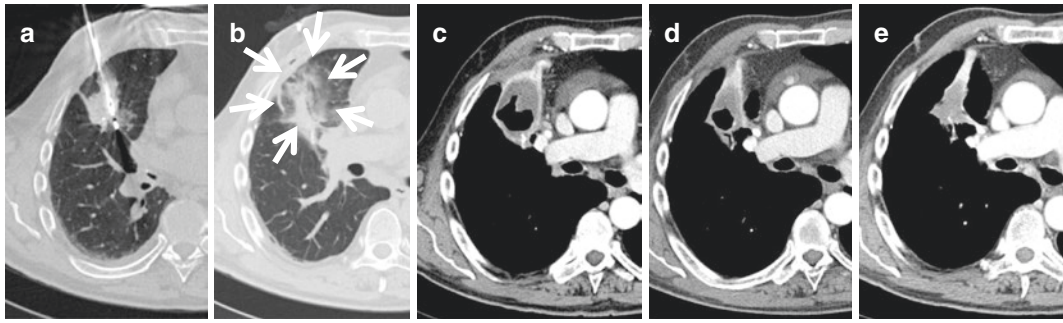

Fig. 5.17 MWA of a NSCLC to the right lung in a 69-year-old man. Axial CT image shows the antenna positioned into the mass with anterior approach (**a**). Ground-glass opacity around the tumor immediately after ablation (*arrows*) (**b**). Progressive reduction in size of the cavitated area and no contrast enhancement at 3-, 6-, and 12-month follow-up confirm the success of the treatment (**c**–**e**)

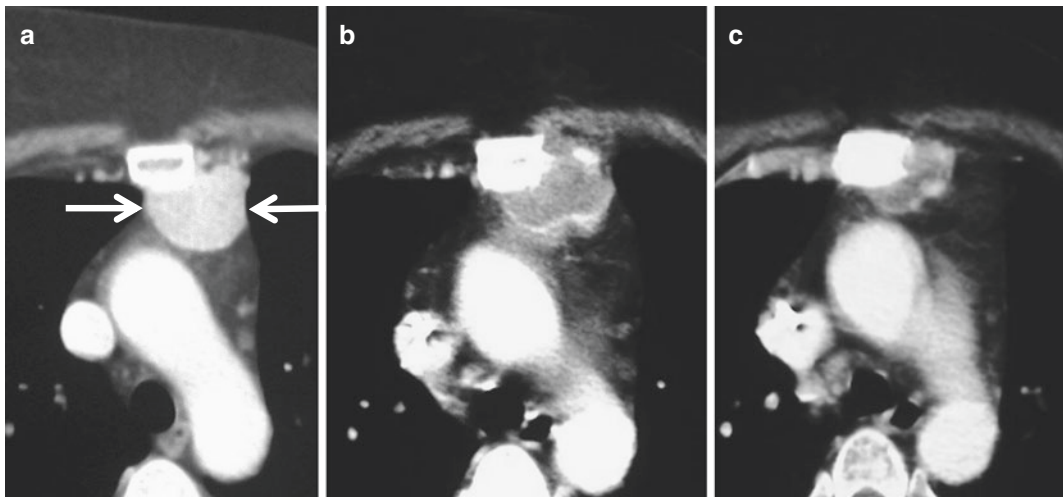

Fig. 5.18 MWA of a breast cancer metastasis in the anterior mediastinum of a 70-year-old woman. Contrast CT image shows a 5 cm soft tissue of high density (*arrows*) (**a**). Contrast CT images show downsizing and lack of contrast enhancement of the mass at 3- and 6-month follow-up (**b**, **c**)

Sometimes PET-FDG scan is required by oncologists to check if the tumor has been completely destroyed by the ablation (Fig. 5.13f). Before discharge the patient usually acquires an X-ray of the thorax to check complications and to evaluate the treated area which appears as a large ground-glass opacity around the lesion (Fig. 5.15).

The most common complications encountered with RFA treatment are pneumothorax and pleural effusion, most of which are usually small and self-limiting. Management of this complications is the same as that in the lung biopsy.

5.10 Microwave Ablation

MW basically uses dielectric hysteresis to produce heat. During the application of electromagnetic waves (usually at 900–2500 MHz), the polar water molecules are forced to realign constantly with the oscillating electric field, increasing their kinetic energy and converting this energy into heat which increases tissue temperatures to cytotoxic levels. Unlike from RFA that results in heating in tissues adjacent to the electrode, in MWA direct "radiating" heating occurs in the volume of tissues around the antenna. Moreover, MWA is able to produce a larger heating zone with higher temperature and more rapidly than RF. The microwave system consists of a generator connected to an antenna through a coaxial transmission line. The delivery of electromagnetic energy from the generator to the antenna is usually via a coaxial transmission line. However, a major disadvantage is due to the fact that the smaller the cable diameter, the more the power loss and resulting cable heating. MWA is usually carried out in a similar fashion to RFA, under conscious sedation and local anesthesia and CT or US guidance.

The mean tumor diameter was 3.0 cm and the mean ablation diameter obtained was 4.0 cm. Histological analysis of the ablated specimens showed marked coagulation necrosis and complete thermocoagulation and absence of any viable tumor [32]. To control the size of coagulative necrosis we can change the coagulative performance using different power levels and different exposure times. In large masses MWA can be performed simultaneously using two coaxial antennas (connected with two generators) to obtain a major necrosis

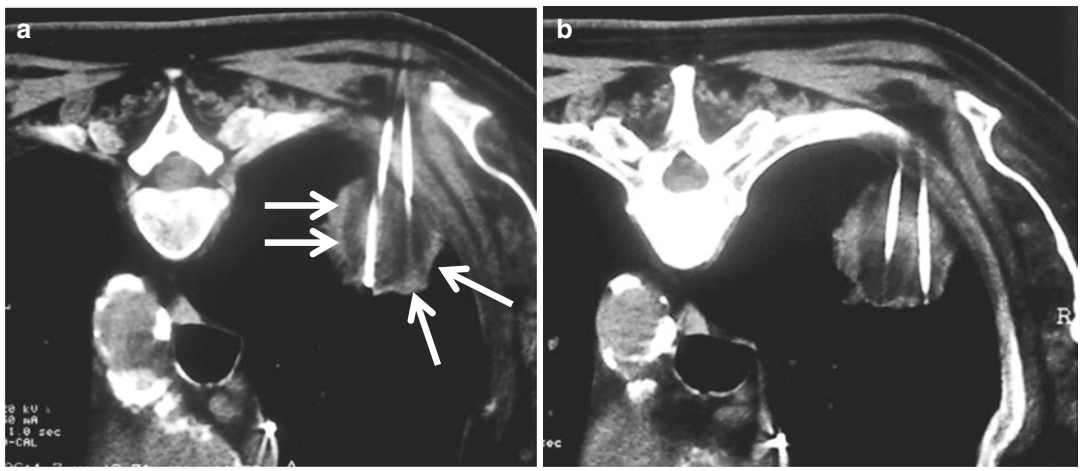

Fig. 5.19 Cryoablation of a NSCLC of a 77-year-old man. Axial CT image shows the cryoprobes into the tumor during the freezing phase. The formation of *ice ball* appears as an ovoid, well-delimitated hypodense area around the needles into the tumor (*arrows*) (**a**, **b**)

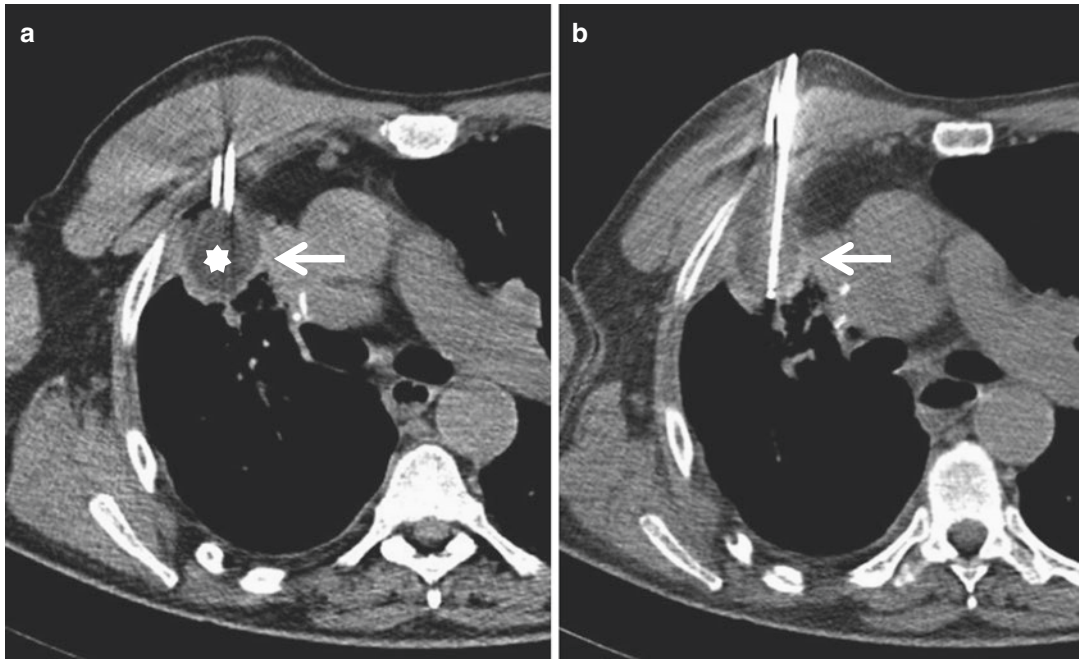

Fig. 5.20 Cryoablation of a NSCLC in a 65-year-old man after a previous superior lobectomy. The axial CT images acquired during the freezing phase show a well-delimited ice ball (*) into the tumor in contact to the superior vena cava (*arrows*) (**a**, **b**)

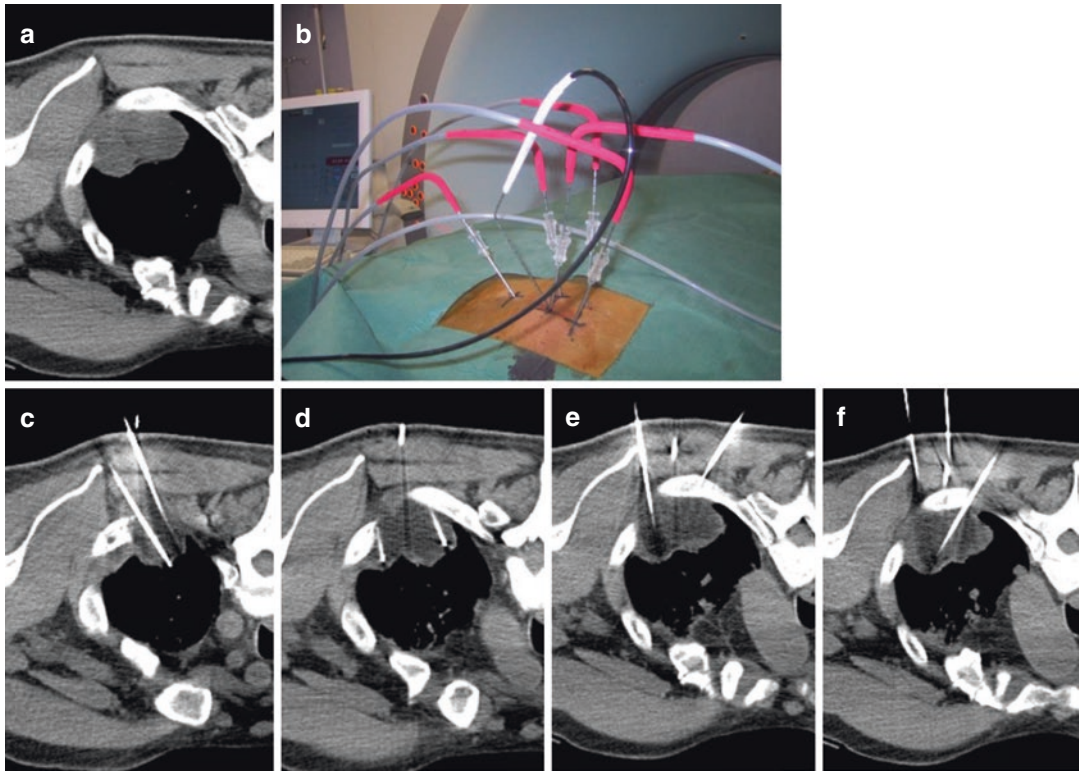

Fig. 5.21 Axial CT image shows a 54-year-old man who presented a strong pain due to pleural and infiltration of a rib by a large metastasis of liposarcoma (**a**) treated with insertion of 5 cryoprobes and a thermosensor (**b**–**f**)

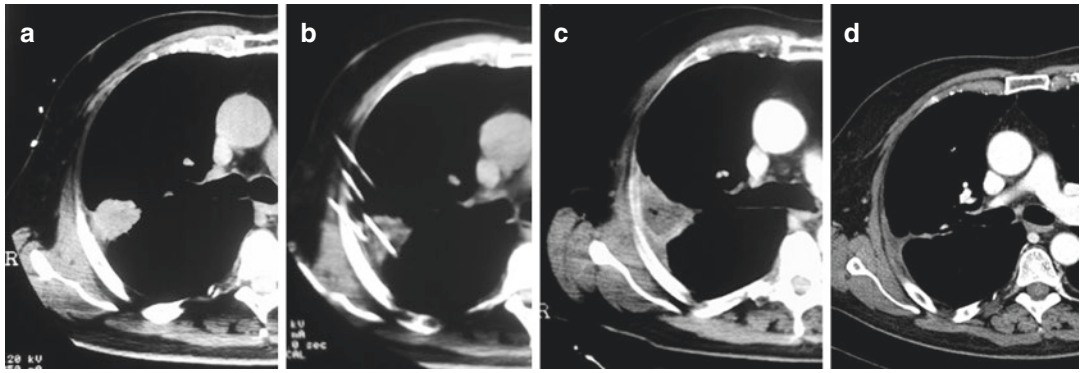

Fig. 5.22 Successful CRA of a large colorectal lung metastasis in patient ineligible for surgery. Axial CT image shows a 3.7 cm metastasis in the right lung (**a**) treated with 4 cryoprobes (**b**). Contrast axial CT image acquired after 1 month shows lack of enhancement and initial reduction in size of the lesion (**c**) which evolved in a scar after 20-month follow-up (**d**)

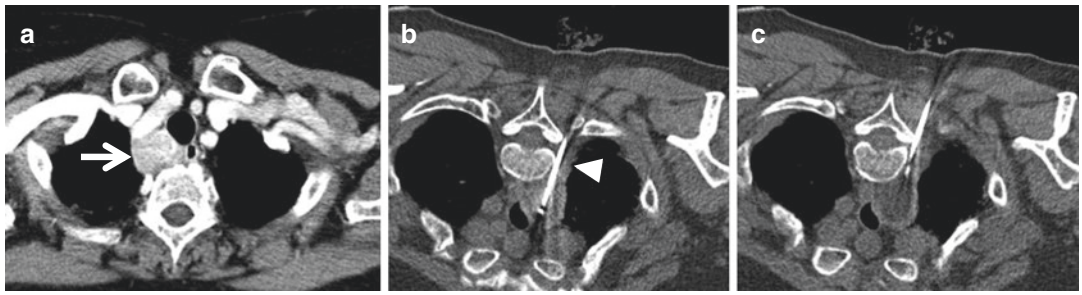

Fig. 5.23 Contrast axial CT image shows a 64-year-old woman who presents a mediastinal metastasis of thyroid carcinoma (*arrow*) (**a**). Axial CT image shows the cryoprobe into the mass, positioned with paravertebral approach between thoracic fascia and parietal pleura (*arrowhead*) (**b**)

area in very short time (Fig. 5.16). Follow-up CT scans were performed at 1-, 3-, and 6-month interval, and the mean follow-up period was 10 months [33]. Stable or reduction in size and absence of tumor enhancement CT images are considered indicative of complete tumor necrosis. Cavitation, similar to RFA, can occur after MWA and usually does not require any intervention. The evolution consists of a slow but progressive reduction in size of the mass (Fig. 5.17). Also mediastinal tumors can be treated with MWA and the evolution of the tissue mass is similar to lung tumors (Fig. 5.18).

5.10.1 Complications

Hemoptysis, skin burns, pneumothorax, and infections are uncommon but possible complications which can occur after MWA of the lung. A rare but serious complication is the bronchopleural fistula after MWA which consists of a direct communication of pleural cavity and the bronchial tree. The fistula usually spontaneously closes itself but sometimes the suture of the bronchial defect is necessary.

5.10.2 Cryoablation

Like RFA and MWA, cryoablation is performed under image guidance, most commonly CT or US. Cryoablation uses extreme cold to cause tissue destruction. Modern cryoablation systems utilize specialized probes to deliver cycles of argon and helium gases to, respectively, freeze and thaw targeted tissues. The procedure relies upon the rapid decompression (Joule–Thomson effect) of argon and helium gases circulating

inside the probe. Depending on the distance from the needle, the effect of the ice is different. Temperatures ranging between 40° and 20° below zero result in intracellular ice formation with membrane rupture and cell death. With temperatures above 20° below zero we have resulting supercooling of the tissues without intracellular ice formation. Apoptosis is possible but inconstant and we need to repeat the cycles. Cellular damage occurs via a complex combination of cellular damage during a freezing and thawing cycle. Direct cell injury occurs via a combination of metabolic disruptions, cell dehydration, and formation of intracellular ice crystals which disrupts organelles and cell membranes and leads to cell death [34]. Cryoablation may be superior to RFA as larger ablation margins can be obtained, multiple applicators can be used, and it has been associated with less pain. Visualization of the ablation zone is another distinct advantage of cryoablation, which is seen as an "ice ball" on CT scans (Fig. 5.19) particularly useful during the treatment of tumors closed to major vascular structures (Fig. 5.20). However, for tumors adjacent to or contacting large vascular structures, such as the aorta or main pulmonary artery, a triple-freezing protocol is generally preferred to overcome sink effect of blood flow and to obtain larger ablation. Cryoablation also preserves the underlying collagenous architecture of the target tissues [35]. Cryoablation is a method which can also be used to treat lung lesions with severe pain due to pleural infiltration or involvement of the thoracic wall (Fig. 5.21). Potential risks and complications of pulmonary cryoablation are essentially those deriving from percutaneous interventional treatment such as local hematomas, pneumothorax, pleural effusion, and pulmonary bleeding. The use of thin needles to perform the ablation allows to reduce the number and severity of complications [36]. Compared to the lesions treated RFA or MWA the transformation of the lung lesion treated with cryoablation is similar. There is lack of contrast enhancement after 1 month followed by a scar evolution after a few months' follow-up (Figs. 5.22 and 5.23).

References

1. Gupta S. Role of image-guided percutaneous needle biopsy in cancer staging. Semin Roentgenol. 2006;41:78–90.
2. Collins JM, Kriegshauser JS, Leslie KO. CT-guided biopsy of perivascular tumor encasement using simultaneous IV contrast enhancement. Am J Roentgenol. 2009;193:W283–7.
3. Ahrar K, Gupt S, editors. Percutaneous image-guided biopsy. New York: Springer; 2013.
4. Pate IJ, Davidson JC, Nikolic B, et al. Standards of practice committee, with cardiovascular and interventional radiological Society of Europe (CIRSE) endorsement. Consensus guidelines for periprocedural management of coagulation status and hemostasis risk in percutaneous image-guided interventions. J Vasc Interv Radiol. 2012;23(6):727–36.
5. Manhire A, Charig M, Clelland C, et al. Guidelines for radiologically guided lung biopsy. Thorax. 2003;58(11):920–36.
6. Khadadah ME, Muqim AT, Al-Mutairi AD, et al. Closed percutaneous pleural biopsy. A lost art in the new era. Saudi Med J. 2009;30(6):793–7.
7. Winokur RS, Pua BB, Sullivan BW, Madoff DC, FSIR. Percutaneous lung biopsy: technique, efficacy, and complications. Semin Interv Radiol. 2013;30:121–7.
8. Ahrar K, Gupta S, editors. Percutaneous image-guided biopsy. New York: Springer; 2014. Chapter 11
9. Frable WF. Fine needle aspiration biopsy techniques. In: Bibbo M, Wilbur D, editors. Comprehensive cytopathology. 3rd ed. Philadelphia: Saunders, Elsevier; 2008. p. 579–98.
10. Solomon SB, Zakowski MF, Pao W, et al. Core needle lung biopsy specimens: adequacy for EGFR and KRAS mutational analysis. AJR Am J Roentgenol. 2010;194(1):266–9.
11. Morvay Z, Szabó E, Tiszlavicz L, Furák J, Troján I, Palkó A. Thoracic core needle biopsy using ultrasound guidance. Ultrasound Q. 2001;17:113–21.
12. Moore EH, Shepard JO, McLoud TC, et al. Positional precautions in needle aspiration lung biopsy. Radiology. 1990;175:733–5.
13. Swischuk JL, Castaneda F, Patel JC, et al. Percutaneous transthoracic needle biopsy of the lung: review of 612 lesions. J Vasc Interv Radiol. 1998;9(2):347–52.
14. Aziz A, Ashizawa K, Nagaoki K, Hayashi K. High resolution CT anatomy of the pulmonary fissures. J Thorac Imaging. 2004;19:186–91.
15. Arakawa H, Nakajima Y, Kurihara H, et al. CT-guided transthoracic needle biopsy: a comparison between automated biopsy gun and fine needle aspiration. Clin Radiol. 1996;51(7):503–6.
16. Wallace AB, Suh RD. Percutaneous transthoracic needle biopsy: special considerations and techniques used in lung transplant recipients. Semin Interv Radiol. 2004;21(4):247–5.

17. Ahrar K, Gupta S, editors. Percutaneous image-guided biopsy. New York: Springer; 2014. p. 119.
18. Light RW. Parapneumonic effusions and empyema. ClinChestMed. 1985;6(1):55–62.
19. Feller-Kopman D. Ultrasound-guided thoracentesis. Chest. 2006;129(6):1709–14.
20. Balik M, Plasil P, Waldauf P, et al. Ultrasound estimation of volume of pleural fluid in mechanically ventilated patients. Intensive Care Med. 2006;32(2):318–21.
21. Nicolaou S, Talsky A, Khashoggi K, Venu V. Ultrasound-guided interventional radiology in critical care. Crit Care Med. 2007;35(supplement 5):S186–97.
22. Sikora K, Perera P, Mailhot T, Mandavia D. Ultrasound for the detection of pleural effusions and guidance of the thoracentesis procedure. ISRN Emergency Medicine. 2012;2012:676524.
23. Patz EF, Goodman PC, Erasmus JJ. Percutaneous drainage of pleural collections. J Thorac Imaging. 1998;13(2):83–92.
24. Laws D, Neville E, Duffy J, on behalf of the British Thoracic Society Pleural Disease Group, a subgroup of the British Thoracic Society Standards of Care Committee. BTS guidelines for the insertion of a chest drain. Thorax. 2003;58(Suppl II):ii53–9.
25. Ghaye B, Dondelinger RF. Image guided thoracic interventions. Eur Respir J. 2001;17:507–28.
26. Heunks L, Demoule A, Windisch W. Pulmonary emergencies. Sheffield: ERS; 2016. p. 230–9.
27. National Lung Cancer Audit – LUCADA.
28. Nikfarjam M, Muralidharan V, Christophi C. Mechanisms of focal heat destruction of liver tumors. J Surg Res. 2005;127(2):208–23.
29. Hiraki T, Gobara H, Mimura H, Toyooka S, Fujiwara H, Yasui K, et al. Radiofrequency ablation of lung cancer at Okayama University Hospital: a review of 10 years of experience. Acta Med Okayama. 2011;65(5):287.
30. Abbas G, Pennathur A, Landreneau RJ, Luketich JD. Radiofrequency and microwave ablation of lung tumors. J Surg Oncol. 2009;100(8):645–50.
31. Ambrogi MC, Fanucchi O, Cioni R, Dini P, De Liperi A, Cappelli C, et al. Longterm results of radiofrequency ablation treatment of stage I non-small cell lung cancer: a prospective intention-to-treat study. J Thorac Oncol. 2011;6(12):2044–51.
32. Simon CJ, Dupuy DE, Mayo-Smith WW. Microwave ablation: principles and applications. Radiographics. 2005;25(suppl 1):S69–83.
33. Wolf FJ, Grand DJ, Machan JT, DiPetrillo TA, Mayo-Smith WW, Dupuy DE. Microwave ablation of lung malignancies: effectiveness, CT findings, and safety in 50 patients1. Radiology. 2008;247(3):871.
34. Gage AA, Baust J. Mechanisms of tissue injury in cryosurgery. Cryobiology. 1998;37(3):171–86.
35. Wang H, Littrup PJ, Duan Y, Zhang Y, Feng H, Nie Z. Thoracic masses treated with percutaneous cryotherapy: initial experience with more than 200 procedures. Radiology. 2005;235(1):289.
36. Pusceddu C, Sotgia B, Fele RM, Melis L. CT-guided thin needles percutaneous cryoablation (PCA) in patients with primary and secondary lung tumors: a preliminary experience. Eur J Radiol. 2013;82(5):e246–53.