

Canadian Association of Radiologists/Canadian Association for Interventional Radiology/ Canadian Society of Thoracic Radiology Guidelines on Thoracic Interventions

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Abstract

Thoracic interventions are frequently performed by radiologists, but guidelines on appropriateness criteria and technical considerations to ensure patient safety regarding such interventions is lacking. These guidelines, developed by the Canadian Association of Radiologists, Canadian Association for Interventional Radiology and Canadian Society of Thoracic Radiology focus on the interventions commonly performed by thoracic radiologists. They provide evidence-based recommendations and expert consensus informed best practices for patient preparation; biopsies of the lung, mediastinum, pleura and chest wall; thoracentesis; pre-operative lung nodule localization; and potential complications and their management.

Résumé

Les interventions thoraciques sont souvent effectuées par des radiologistes, mais on manque d'orientations sur les critères d'adéquation et les considérations techniques pour garantir la sécurité des patients dans le cadre de telles interventions. Ces lignes directrices, élaborées par l'Association canadienne des radiologistes, l'Association canadienne pour la radiologie d'intervention et la Société canadienne de radiologie thoracique, portent principalement sur les interventions fréquemment exécutées par les radiologistes thoraciques. Elles fournissent des recommandations basées sur les données probantes et les meilleures pratiques renseignées par un consensus d'expert pour la préparation des patients, les biopsies du poumon, du médiastin, de l'espace pleural et de la paroi thoracique, la thoracocentèse, la localisation préopératoire de nodules pulmonaires, leurs complications possibles et leur gestion.

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Introduction

The Canadian Association of Radiologists (CAR), Canadian Association for Interventional Radiology (CAIR) and Canadian Society of Thoracic Radiology (CSTR) Working Group on Thoracic Interventions has compiled the following best practice guidelines focused on the interventions commonly performed by thoracic radiologists, rather than those more commonly performed by interventional radiologists. As such, ablation treatment of lung cancer and endovascular interventions are not discussed. Recommendations are based on a comprehensive literature review and are relevant to most practice settings in Canada. In cases where there is a paucity of data or low-quality evidence to support certain practices, the Working Group has provided recommendations based on available evidence and expert consensus.

Patient Preparation

Thoracic interventions can be safely performed on an outpatient basis.¹⁻³ Pre-emptive post-procedure admission can be considered for patients on home oxygen, those who live alone or in remote locations with limited at-home support or access to health care. In general, patients should be accompanied after discharge and have a reliable adult to stay with overnight in case of a delayed complication.

Biopsy of chest wall lesions and thoracentesis are low bleeding risk procedures and pre-procedure haematological testing is not required. If on anticoagulation medication, the International Normalized Ratio (INR) should be corrected to $\leq 2-3$ and platelet transfusion is recommended if the count is below $20 \times 10^9/L$. All other thoracic interventions are high bleeding risk procedures. Therefore, pre-procedure haematological testing (INR, platelet count and haemoglobin) is recommended.⁴ If elevated, the INR should be corrected to $\leq 1.5-1.8$ and platelet transfusion is recommended if the count is below $50 \times 10^9/L$. In the absence of risk factors, laboratory results within 3 months of biopsy are acceptable. Patients who are on anticoagulation and antiplatelet medications require pre-procedure thrombotic risk assessment and management of medications ([Supplementary Appendix A](#)). This should be done in consultation with the primary care provider, the physician who prescribed the medication, or a thrombosis or haematology service.⁴ Uncorrectable coagulopathy is an absolute contraindication for high bleeding risk procedures.

Pulmonary function tests (PFTs) are not routinely performed but can be considered in patients with severe COPD and interstitial lung disease (ILD).³ Thoracic interventions carry a very low risk of procedure-related infection. Routine antibiotic prophylaxis is not indicated.⁵ Patients undergoing

procedures to diagnose infection (empyema, lung biopsy for atypical infection) are often already on antibiotics.

On the day of the procedure, patients should be assessed by the radiologist performing the procedure to obtain informed consent, record pre-procedural vitals (heart rate, blood pressure, respiratory rate and oxygen saturation) and review recent laboratory values and medications ([Supplementary Appendix B](#)). Placement of an intravenous catheter is suggested to enable rapid administration of medication and fluid to treat complications such as pain, vasovagal reaction, or bleeding. Marking the side of the procedure in the supraclavicular fossa facilitates rapid identification of the side of the procedure for chest tube placement to treat a pneumothorax. Unless sedation is used, fasting before thoracic interventions is not required.

Biopsies

Lung

Image-guided percutaneous transthoracic needle biopsy (PTNB) is a well-known minimally invasive procedure in the diagnostic workup of thoracic lesions, performed by chest, general or interventional radiologists.⁶ The choice of imaging guidance modality, target lesion and approach is at the radiologist's discretion, taking into consideration patient safety, equipment availability, cytology/pathology and post-biopsy support. In general, targeting enlarging, peripheral and larger lesions, those in the upper lung zones and the non-necrotic hypermetabolic part of a lesion without crossing a fissure, vessel or bulla is preferred. Bronchoscopic biopsy is recommended for central lesions abutting or involving the central airways, endobronchial lesions and paratracheal and subcarinal lymph nodes.^{7,8} PTNB is not routinely recommended for patients with ILD due to lower diagnostic yield⁹; surgical lung biopsy has the highest diagnostic yield for ILD.¹⁰

Indications

1. Initial diagnosis of lesions suspicious for malignancy (imaging characteristics, patient age, smoking and family history of lung cancer, +/- Brock or Herder model).¹¹ Preoperative histologic confirmation of malignancy has been shown to significantly reduce the rate of unnecessary resection.¹²
2. Molecular analysis for initial assessment and re-biopsy for recurrent or progressive disease: the genetic profile of tumors provides options for management with targeted chemotherapy or immunotherapy and can change after initial treatment. For re-biopsy, either viable tissue of progressive disease from the primary lesion or a metastasis can be targeted.¹³

3. Multiple nodules in patients without known primary or single or multiple nodules in patients with more than one primary malignancy or when there was a long remission after treatment of primary cancer and tissue confirmation of metastases is required.
4. Research: to assess the efficacy of new drugs.
5. Persistent, non-resolving consolidation not diagnosed by clinical and laboratory investigations: diagnosis of non-infectious granulomatous disease or unusual fungal infections not responding to empiric antibiotic therapy in immunosuppressed patients.¹⁴ Mycobacterial infection can also be diagnosed in 80% of patients.¹⁵

Specific Situations

Cavitary Lesions. When feasible, the most hypermetabolic and thickest portion of the wall of the cavity should be targeted. Samples should be sent for microbiological evaluation when no malignant cells are identified on rapid on-site evaluation (ROSE).¹⁶ Core needle biopsy (CNB) is highly accurate for diagnosis of benign lesions.¹⁷

Small Nodules. While reasonable sensitivity and accuracy can be achieved for biopsy of small lung nodules (<10 mm),¹⁸ CNB or combination of Fine Needle Aspiration (FNA) + CNB appear to yield higher diagnostic accuracy than FNA alone.^{18,19} Several studies have shown reduced diagnostic accuracy for biopsy of small lung nodules <10 mm^{20,21} or <15 mm.^{22,23} Ability to perform PTNB on small lung nodules while maximizing diagnostic yield and minimizing complications varies across institutions according to local expertise.²⁴

Sub-Solid Lesions. The solid component of sub-solid nodules is an independent predictor of malignancy (Figure 1).²⁵ In

one study, the diagnostic accuracy of computed tomography (CT) analysis without PTNB was equivalent at predicting malignancy to preoperative PTNB of sub-solid nodules with a solid component measuring >5 mm.²⁶ In another study, of 356 sub-solid lung nodules, 330 (92.7%) were resected without preoperative PTNB and the rate of malignancy was 95.2% (314/330), for 242 part-solid and 72 pure ground-glass nodules.²⁷ Hence, some persistent sub-solid nodules with characteristic imaging features of primary lung adenocarcinoma, demonstrating growth and hypermetabolism on FDG-PET are surgically resected without PTNB.²⁸

Relative Contraindications to PTNB:

1. *Patient Limitations:* Unable to follow breath-hold instructions and maintain position.
2. *Lack of impact on patient management:* Biopsy results should guide management.
3. *FEV1 ≤35% predicted:* PFTs are rarely performed pre-biopsy and following this recommendation would eliminate many patients who could benefit from tissue diagnosis. In addition, hypoxaemia is not necessarily associated with a specific FEV1.^{29,30} and there is paucity of data to suggest a clear FEV1 threshold, below which biopsy should not be performed. No biopsy request should routinely be declined based on the severity of emphysema. Decision to proceed with biopsy should be decided after evaluation of the risks vs benefits.
4. *Single functional lung:* PTNB should only be considered when tissue diagnosis is absolutely necessary, ICU and surgical assistance are available and the biopsy can be performed by an experienced radiologist. In a study of 14 patients with prior pneumonectomy who underwent PTNB, Cronin reported a

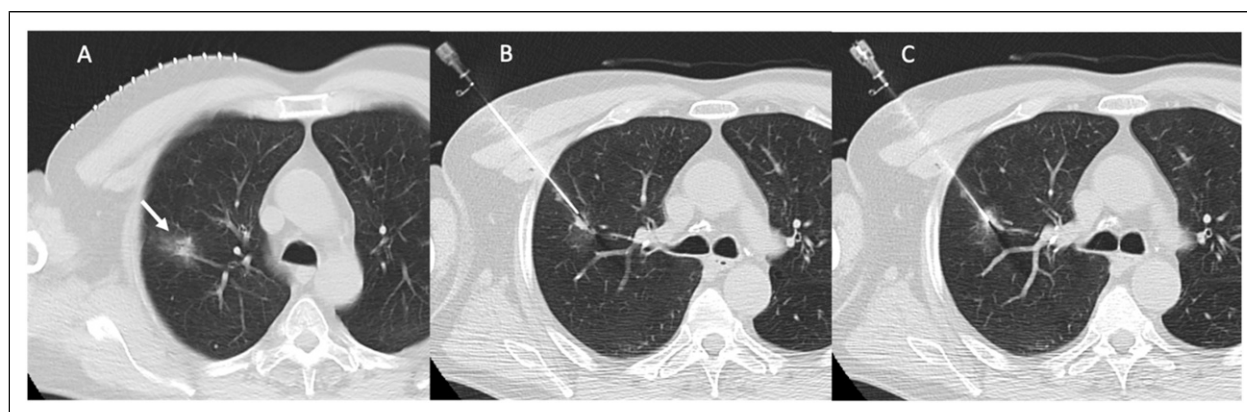


Figure 1. 72-year-old woman with incidental part-solid nodule in the right upper lobe suspicious for invasive adenocarcinoma targeted for tissue diagnosis with computed tomography-guided percutaneous transthoracic needle biopsy. (A) Radio-opaque grid over anterior chest wall in supine position for localization. Freezing needle should then be introduced to the subpleural space and local anaesthetic injected while patient suspends breathing (not shown). (B) Introducer placed just at the edge of the solid part of the nodule. (C) Fine needle aspiration or core biopsy needle is then inserted through the introducer, and biopsies are obtained from the solid component. Note the tip of the biopsy needle within the solid component of the nodule.

pneumothorax rate of 25%, but all were small and asymptomatic, and none required a chest drain.³¹

5. *Positive pressure ventilation:* Patients on positive pressure ventilation may have increased risk of pneumothorax³² and air embolism.³³⁻³⁵
6. *Pulmonary hypertension:* There is insufficient data to support an increased risk of haemorrhage.^{3,36,37} In a study of 74 patients with mild to moderate pulmonary hypertension, there was no difference in the rate of pulmonary haemorrhage, haemoptysis or haemothorax compared to a control group.³⁸ Another study showed no increased risk of pulmonary haemorrhage in patients with a dilated main pulmonary artery on CT.³⁹ Nevertheless, PTNB in patients with severe pulmonary hypertension should be considered with caution.
7. *Recent myocardial infarction:* There is insufficient data regarding a safe time interval to PTNB. If possible, a delay of 4–6 weeks is reasonable.^{3,40,41}

When there are safety concerns for PTNB, the risks and benefits of the procedure should be discussed at a multidisciplinary conference. Complete staging (CT abdomen, PET/CT) is suggested to identify safer biopsy sites, allow preliminary treatment planning and prognostication, and establish goals of care. Select patients with suspicious nodules who are at high risk of complications may be offered treatment without histologic confirmation.¹²

Imaging Modalities for Biopsy Guidance

Computed Tomography. This is the most commonly used modality.⁴²⁻⁴⁴ Advantages include the ability to target smaller, more central lesions, avoid fissures, bullae, vessels and the ability to target a specific part of a lesion, for example, the wall of a necrotic lesion or the solid component of a part-solid nodule and select the shortest biopsy trajectory.

Fluoroscopy. Fluoroscopy has a lower radiation dose and comparable accuracy and complication rate to CT.⁴⁵ Low cost, and real-time visualization of needle advancement are among other advantages. It has largely been replaced by CT but is still used in some centres to target larger lesions. Newer fluoroscopy units can perform cone beam CT to supplement fluoroscopic guidance or be used as stand-alone to guide lung biopsies.⁴⁶ Effective dose largely depends on tube voltage and the length of the procedure.

Ultrasound. This modality should be reserved for lung lesions abutting the pleura, pleural or chest wall lesions. Advantages are the lack of ionizing radiation, low cost, real-time visualization of needle advancement and low complication rate. In one study, the diagnostic yield was 89.5%.⁴⁷

Role of Fine Needle Aspiration vs Core Needle Biopsy. FNA is sufficient for diagnosis and immunohistochemical analysis of most malignancies. Rapid on-site evaluation (ROSE)

decreases the rate of non-diagnostic samples.⁴⁸ For lung cancer diagnosis, the sensitivity, specificity, accuracy and complication rate of FNA and CNB are comparable.⁴⁹ CNB should be considered at the time of initial biopsy when FNA does not yield adequate material after ROSE, or when ROSE is unavailable and when lymphoma or a benign diagnosis is suspected. Where ROSE is not available, CNB may be performed exclusively, without FNA.

For lymphoma, samples should be obtained for flow cytometry based on local laboratory protocols. In addition, CNB is recommended for sub-solid lesions with no or a very small solid component to improve diagnostic yield.⁵⁰ CNB may also be required to assess response to a new drug in a research study or when a specific molecular marker is required. The coaxial technique is recommended to allow multiple passes and reduce the number of pleural punctures. A 19 G introducer with a 21G needle for FNA and 20G for core is adequate in most cases. 18G core samples slightly increase the accuracy for the diagnosis of lymphoma.⁵¹ When CNB is performed, it is good practice to confirm the location of the cutting needle within the lesion prior to obtaining samples.

Post-Procedure Care. Patients should be transferred to an observation area, and remain on a stretcher, with the biopsy side down, when possible. Supplemental oxygen may improve patient comfort and maximize resorption of pneumothorax when present.⁵² A chest x-ray to exclude complications should be obtained within the range of 30¹–60 minutes post-biopsy, for stable, asymptomatic patients.

Complications and Management. Complications, risk factors and management recommendations are summarized in Table 1. Vasovagal reactions are not specific to PTNB and can usually be treated by raising the patient's legs and administering IV fluid. A Quality Improvement program should be in place to ensure high diagnostic yield and acceptable complication rates for any institution performing PTNB. The quality improvement thresholds provided by the Society of Interventional Radiology⁵³ should be used to trigger a review of procedures within the department.

Tumor Implantation Along Needle Tract and Pleural Recurrence. Following the report of a higher rate of pleural recurrence and one case of seeding along the needle biopsy tract during long-term follow-up of patients with Stage 1 lung cancer who had PTNB,⁵⁴ three systematic reviews and a meta-analysis were published with conflicting results. Wang et al.⁵⁵ and Li et al.⁵⁹ concluded that PTNB is not associated with an increase in total or pleural recurrence rate. However, for patients with subpleural lesions, PTNB did increase the risk of ipsilateral pleural recurrence. In Hong et al.'s systematic review and patient-level meta-analysis, the incidence of ipsilateral pleural recurrence in the PTNB group was higher than those in the other diagnostic procedures group for cases of isolated malignancy as well as concomitant metastases.⁷⁵

Table 1. Potential Common and Rare Complications From Thoracic Intervention Procedures.

Complication	Reported Prevalence Range	Prevention Measures	Management
Biopsy-related complications			
Pneumothorax	25.3%–25.9% ^{53,54}	<ol style="list-style-type: none"> 1. Avoid crossing fissure or bulla, and multiple pleural punctures; use coaxial technique 2. Tract sealing, rapid rollover to puncture site down, blood patch (parenchyma or pleural), deep expiration and breath-hold on needle extraction.⁵⁵ 	<ol style="list-style-type: none"> 1. If small, follow-up CXR to ensure stability before discharge 2. If large or if patient is symptomatic, pleural drainage catheter insertion (rate is 5.6–6.9%).^{53,54} Patients can be discharged with pleural drainage catheter connected to heimlich valve and instructions, to return for catheter removal 2 days later if bubble test is negative and patient is asymptomatic^{1,36}
Haemothorax	0.092% ⁵⁶ –6% ⁵⁷	<ol style="list-style-type: none"> 1. Check coagulation parameters, platelet count, and anticoagulation medications prior to biopsy 2. Avoid intercostal arteries (Doppler interrogation if using US; avoid subcostal groove) 3. Check preprocedural imaging to determine presence of vascular variants or potentially unexpected anatomical structures (e.g. herniated abdominal organs) 4. Fully automated biopsy needles have higher rates of haemothorax compared to semi-automated needles⁵⁷ 	<ol style="list-style-type: none"> 1. Urgent CT evaluation if haemothorax suspected 2. Urgent consultation with interventional radiology or thoracic surgery if arterial injury is suspected
Empyema	Unknown; exceedingly rare ⁵⁸	<ol style="list-style-type: none"> 1. Use sterile technique 2. Higher index of suspicion if biopsied focus returns infection <p>Usually small/ sub-lobar. Avoid crossing vessels. Risk factors are larger needle size, smaller lesion size, increased length of traversed lung, basal location of nodule and sub-solid nodule.⁵⁹ Haemorrhage along the needle tract has been shown to protect against pneumothorax due to blood patch⁶⁰</p>	<ol style="list-style-type: none"> 1. Monitor for signs of infection following biopsy 2. Contrast-enhanced CT if clinically suspected
Pulmonary haemorrhage	18.0% (13.4–23.8%) (CNB) 6.4% (2.5–15.2%) (FNA) ^{53,54}	<p>Avoid traversing large vessels and airways. Usually minimal and transient</p>	See Haemoptysis
Haemoptysis	4.1% (2.8–6.1%) (CNB) 1.7% (0.9–3.1%) (FNA) ^{53,54}	<p>Avoid traversing large vessels and airways. Usually minimal and transient</p>	<ol style="list-style-type: none"> 1. Patient reassurance and positioning with biopsy side down to protect contralateral airway 2. Increasing oxygen and suctioning as initial measure 3. If massive, selective intubation and embolization may be required
Mediastinal haematoma	0.9–1.2% ^{61,62}	<ol style="list-style-type: none"> 1. Prebiopsy CT with IV contrast to identify and avoid vessel 2. Blunt-tip cannula and saline injection to displace internal mammary artery 3. Cessation of anticoagulant/antiplatelet therapy 4. Needle size should be as small as possible without reducing diagnostic yield (typically 18G–20 G, but up to 16G)⁶³ 	<ol style="list-style-type: none"> 1. CT routinely performed 5–10 min post-biopsy to identify significant haemorrhage or enlarging haematoma 2. If present, multiphase CTA to identify source of haemorrhage 3. IR opinion regarding angiography and embolization or surgical consultation for haematoma causing significant mass effect or if too unstable for IR 4. IR and thoracic surgery consultation for intubation for haematoma causing tracheal compression 5. Code blue for unstable patients

(continued)

Table 1. (continued)

Complication	Reported Prevalence Range	Prevention Measures	Management
Chest wall haematoma	Rarely clinically significant. Likely similar to musculoskeletal biopsies; widely discrepant rates due to definition (minor bruising vs haematoma), up to 15.6% ⁶⁴ breast biopsies showed non-clinically significant rate of haematoma in 14.4%. ⁵⁶	1. Identify major arterial and venous structures by Doppler US 2. Expect more bleeding from vascular soft tissue masses	1. Most will resolve spontaneously without medical or surgical intervention 2. Superficial biopsied lesions may have more visible haematomas than deeper lesions 3. Manual compression can help achieve haemostasis 4. IR and thoracic surgery consultation 5. CT to assess extent, source and for baseline Manage according to cause. Pain medication, if required
Pain	Up to 20% ⁶⁵	Most commonly secondary to pneumothorax. Ensure adequate local anaesthesia, avoid inferior rib margin	
Chest wall tumor seeding	0.06%–0.2% ^{61–63,66}	Offer resection without biopsy when tissue diagnosis does not change management and findings are convincing for malignancy	
Systemic air embolism	Up to 4.8% (0.08% symptomatic) ⁶⁷	Risk factors are biopsy of cystic/cavitary lesions, emphysema, proximity to pulmonary vein, deep breathing, coughing during biopsy, positive pressure ventilation and prone position ^{33,67}	Right lateral decubitus or trendelenburg position, administer 100% O ₂ and hyperbaric O ₂ therapy. ^{33,67,68}
Death	Extremely rare, but limited prevalence data. ^{69,70}	Massive pulmonary hemorrhage, pulmonary venous air embolism and large haemothorax are potential causes of death	
Thoracentesis-related complications			
Pneumothorax	0.6 l–6.0% ⁷¹	Ultrasound guidance can help avoid puncturing the lung during thoracentesis. Factors reported to increase the risk of iatrogenic pneumothorax include underweight patients (defined as a BMI less than 18 kg/m ²), multiple needle passes, sampling of a small effusion, drainage of more than 1.5 L of fluid, and lack of operator experience	An ex-vacuo pneumothorax may occur due to negative pleural pressures causing an increased intrapleural gradient, resulting in accumulation of air in the pleural space. This type of pneumothorax rarely requires aggressive treatment. ⁷² In this scenario, patients should be observed for several hours and a chest x-ray obtained if new symptoms suggestive of pneumothorax develop. ⁷¹
Haemothorax	0.01% ⁷³	Use as small a needle as possible, avoid intercostal vessels by selecting lateral approach	Haemothorax should be suspected when a patient develops vital sign instability, a drop in haematocrit, or rapid pleural fluid re-accumulation following thoracentesis
Re-expansion pulmonary oedema	0.01–14% ⁷³	Remove less than 1.5 L if draining fluid quickly to reduce the risk of re-expansion pulmonary oedema	Supportive (oxygen, CPAP, mechanical ventilation) ⁷⁴

CT: computed tomography; IR: interventional radiology.

There are substantial limitations in the studies included in these reviews, such as small sample size, lack of consideration of type of cancer, tumor size, needle type and biopsy technique. Many studies also did not adjust for tumor location and distance from the pleura.¹²

Discharge Post PTNB. Early discharge post-PTNB is safe when the patient has someone to stay with them at home overnight and they live reasonably close to a hospital (e.g. within 1 hour to closest hospital). A study of 506 patients undergoing PTNB confirmed the safety of discharge 30 minutes post-biopsy for patients with no pneumothorax or 60 minutes post-biopsy if asymptomatic with a stable small pneumothorax.² The rate of delayed symptomatic pneumothorax was 1.4% and there were no deaths or other major complications.¹ Patients should be provided clear instructions regarding returning to hospital if new symptoms develop such as shortness of breath, chest pain or haemoptysis. It is important to explain the low risk of delayed pneumothorax. In patients discharged with a pleural drainage catheter in place, additional instructions regarding catheter care and when to return to hospital for catheter removal should also be provided. High risk patients, those with borderline lung function and significant co-morbidity or inadequate home support may be better served with overnight hospital admission for observation. Community hospitals in remote areas require surgical support from the closest tertiary care centres, in the event of severe post-biopsy complications in order to ensure patient safety. Please refer to [Supplementary Appendix C](#) for a sample post-biopsy and discharge instruction pamphlet.

Air Travel Post PTNB. Patients from remote areas may require air transportation to return to their community and a prolonged post-PTNB hospital stay is inconvenient and incurs additional costs. Overall, there is paucity of data to guide recommendations regarding air travel post-biopsy. According to Federal Aviation Administration regulation, cabin pressure in commercial aircrafts is maintained to 5000–8000 feet above sea level. At this altitude, a pneumothorax only expands by 30%. The British Thoracic Society Standards of Care Committee recommends a minimum delay of one week after full resolution of pneumothorax on chest x-ray and two weeks after a traumatic pneumothorax or uncomplicated thoracic surgery.⁷⁶ Tam et al⁷⁷ reported that 14 of 179 patients who underwent PTNB and traveled within 14 days of biopsy experienced respiratory symptoms. However, there were no adverse events even when there was small stable pneumothorax prior to air travel. The Alaska Native Medical Center (ANMC),⁷⁸ reviewed the air travel records of 80 patients with traumatic pneumothorax, and concluded air travel was safe for patients with no or a stable small pneumothorax as early as 48 hours post-trauma. After considering all the evidence, the working group recommends avoiding non-essential air travel for 5–7 days post-biopsy. For patients who must fly home after PTNB, the working group recommends a minimum delay of 48 hours for those without or with a small stable

pneumothorax. Modifications to these recommendations can be made for patients at particularly high risk for pneumothorax and who have significant co-morbidities or limited access to health care.

What to Do with a Non-diagnostic or Negative Biopsy Result. When FNA is performed, to minimize the rate of non-diagnostic biopsies, samples should be obtained with ROSE (where available); CNB can be performed during the same session if FNA is inconclusive. Samples should also be sent for microbiological analysis when infection is suspected. The rate of insufficient biopsies should be <10%.²⁸ The sensitivity for malignancy should range from 85 to 90% for lesions >2 cm.³ If a suspicious lesion is negative for malignancy with no definite benign diagnosis, a repeat biopsy is indicated. When the cytology result is ‘non-diagnostic’, the description of the findings in the report should be carefully reviewed and incorporated into the decision to proceed with a repeat biopsy. In one study, the overall rate of malignancy when the report included non-specific benign findings was only 20.6% while 91.1% of lesions were eventually shown to be malignant when the report quoted the presence of atypical cells.⁷⁹

Mediastinum

Imaging-guided transthoracic mediastinal biopsies are safe and effective minimally invasive procedures. The most common indications include suspected thymic neoplasm, lymphoma, germ cell tumor, metastases or lung cancer invading the mediastinum.⁸⁰ Benign lesions may also mimic malignancy such as infection and granulomatous disease.⁸⁰ CT guidance is the most common modality due to its efficacy, safety and wide availability.^{61,80,81} The diagnostic yield for mediastinal PTNB is 92% and accuracy is 94%.⁶³ Diagnostic yield is lower for residual lymphoma (57%) than for initial diagnosis or recurrence (90%).⁸⁰ CT also allows for identification of post-procedure complications ([Table 1](#)).

Initial preparation begins with reviewing relevant prior imaging including CT, MRI and PET CT to identify FDG avid solid areas to target. Cystic lesions such as typical pericardial cysts do not require biopsy while potential hydatid cysts carry risk of anaphylaxis if ruptured during biopsy.⁸²

Biopsy approach planning should include a contrast-enhanced CT to delineate anatomy, rule out vascular lesions and ensure the trajectory avoids vascular structures while targeting non-necrotic areas. An anterior parasternal extrapleural approach can target the anterior ([Figure 2](#)) or middle mediastinum.^{61,83} Occasionally, the only viable access is by a transpulmonary approach which carries risk of pneumothorax.⁶¹ A transsternal approach can avoid traversing the lung.⁸⁴ A perivertebral approach can target posterior mediastinal or subcarinal lesions.⁸³ A suprasternal or sub-xiphoid approach with needle and gantry angulation can be used to target superior mediastinal or more caudal lesions, respectively.⁸³

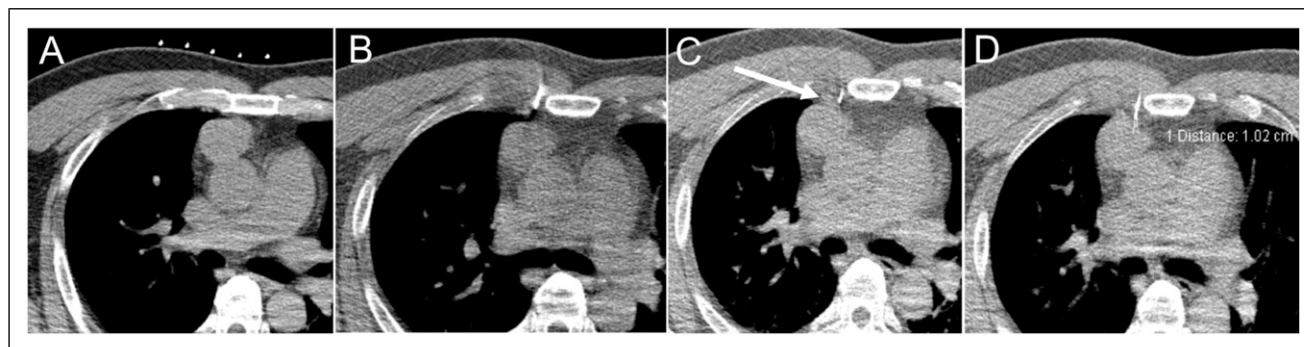


Figure 2. (A) Planning CT with laser light guidance and skin surface grid to identify skin entry location. (B) Under CT guidance, the coaxial introducer needle is advanced in a stepwise manner. (C) Saline can be injected (arrow) through the introducer to widen the mediastinal path or displace the mammary vessels. (D) Once the introducer is within the mass, core biopsies and fine needle aspiration may be performed. CT: computed tomography.

Needle length and size is selected based on lesion characteristics and is most commonly a coaxial technique. There is no difference in diagnostic yield between 18 and 20G needles.⁶³ For possible lymphoma, samples should be sent for flow cytometry, per local institutional protocols.

A post-procedure scan is performed to assess for complications such as haemothorax, mediastinal haemorrhage, pneumomediastinum, pulmonary haemorrhage or pneumothorax where transpulmonary approach was employed.

After biopsy, the patient is discharged to monitored nursing care for up to 2 hours and a chest x-ray is performed 30 minutes to 1 and 2-hours post-biopsy depending on radiologist preference. The patient is discharged home after radiologist reassessment, provided the post-biopsy chest x-ray shows no complication. Complication risks and management are outlined in [Table 1](#).

Pleura

Pleural biopsies can be undertaken for pleural thickening, focal pleural mass, or for microbiological analysis of suspected empyema. In contrast to lung biopsies, many pleural biopsies can be performed with ultrasound guidance rather than CT.

Advantages of ultrasound guidance include flexibility with patient positioning (sitting, prone, supine and lateral decubitus), the ability to compensate for respiratory and patient movement in real-time and the lack of radiation. In particular, lesions in the inferior chest that are more subject to movement with diaphragmatic excursion may benefit from ultrasound guidance due to real-time visualization.⁸⁵ A study performed at a Canadian institution also showed shorter procedure times and reduced wait times for ultrasound-guided biopsy as compared to CT, while showing similar diagnostic yield and pneumothorax rates.⁸⁶

Ultrasound-guided biopsy performs better when pleural thickening is larger and nodular in morphology.⁸⁷ In one study, a nearly 100% yield was achieved with pleural thickening >20 mm⁸⁸ and a recent study suggested that

optimal cut-off value for pleural thickening could be as little as 4.5 mm.⁸⁷ A smaller angle of incidence in relation to the pleura increases the length of fragment obtained, an important factor for smaller pleural lesions.⁸⁹ Depending on the patient's body habitus and lesion location, low-frequency (2–5 MHz) or high-frequency (5–10 MHz) probes can be utilized. Where safe to do so, a 16G rather than an 18G needle increases diagnostic yield particularly for mesothelioma.⁸⁹

Lesions without adequate peripheral pleural contact or without a transcutaneous ultrasound window (e.g. mediastinal pleural lesions) and those that may be obscured by ribs or other osseous structures are more amenable to biopsy under CT guidance. The technique for CT-guided biopsy is similar to lung biopsy. When pleural biopsy is unsuccessful or cannot be performed, surgical thoracoscopy may be considered.

Risks for pleural biopsy are similar to those of lung biopsy, including pneumothorax, haemothorax, infection and haematoma along the needle tract being the most common. Seeding of tumor along the needle tract, particularly in the setting of mesothelioma is a consideration.⁸⁹ Where there is clinical concern for this, consultation with surgical colleagues prior to biopsy is recommended. Preprocedural considerations and postprocedural monitoring are similar to those for lung biopsy, as described earlier.

Chest Wall

Neoplasms of the chest wall may arise from osseous structures or soft tissues and are a heterogeneous group of tumors that may be benign or malignant. Osseous malignancies include osteosarcoma, chondrosarcoma, Ewing sarcoma and myeloma, while soft tissue malignancies include undifferentiated pleomorphic sarcoma, liposarcoma, angiosarcoma and tumors of nerve sheath and cutaneous origins.⁹⁰ Chest wall invasion from intrathoracic malignancy, metastatic disease, melanoma and lymphoma would be other malignant considerations.⁹⁰

Options for tissue sampling include fine needle aspiration, core needle biopsy and surgical biopsy.⁹⁰ Consultation with

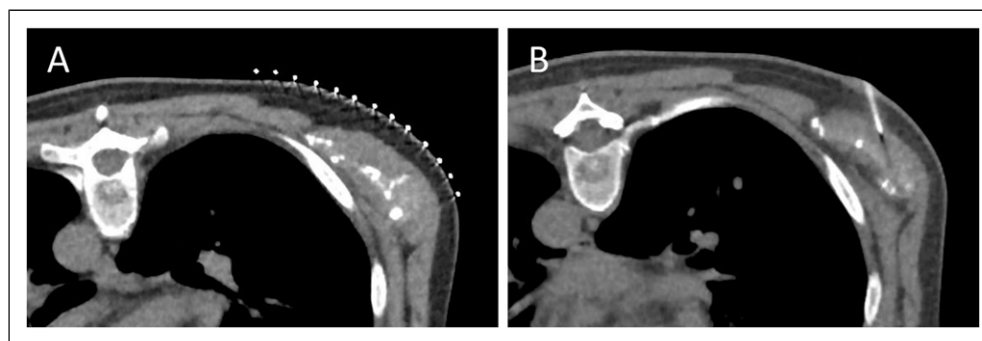


Figure 3. A right scapular biopsy in lung cancer metastasis. (A) Skin surface grid placed over the scapula following scout computed tomography image localization and laser light correlation. (B) After local anaesthetic, a 19G coaxial system is shown placed to the leading edge of the tumor deposit. Pathology demonstrated lung cancer metastasis (TTF-1 and CK-7 positive, p40 negative). Case courtesy of Dr Demetris Patsios.

surgical oncology prior to biopsy is imperative to avoid seeding of malignancy across tissue planes. Image guidance with ultrasound or CT can be used according to radiologist preference, with CT generally preferred for small masses near the lung and ultrasound for large masses well away from intrathoracic contents.⁹¹

For chest wall biopsies well away from the pleural surface (Figure 3), immediate complications tend to be minor and include postprocedural pain, haematoma and possibly infection. For biopsy of lesions closer to the pleura and lung, complications are similar to pleural and lung biopsies.

For lesions well away from the pleura and lung, there is a negligible risk of pneumothorax and a larger needle size should be considered to obtain larger cores for histopathologic analysis and avoid needle distortion or malfunction when targeting firm lesions. Biopsies can be performed with or without a coaxial needle system. For coaxial technique, the recommended needle size is up to 17G outer and 18G inner, but where safe to do so, up to 11G can be used.⁹²

Thoracentesis

Pleural effusions are a common manifestation of diseases localized to the pleura or underlying lung as well as multiple systemic conditions. Thoracentesis may be performed for either diagnostic or therapeutic purposes when respiratory function is impaired. Diagnostic thoracentesis is indicated when the underlying cause of the effusion is unclear or there is an unexplained lack of response to treatment.⁹³

Sampling of pleural fluid can allow for differentiation of a transudate from an exudate, as well as provide potential specific organisms in the case of empyema and identify the cell type of a malignant effusion. Common complications are listed in Table 1. Rare complications include injury to abdominal viscera and seeding along the needle tract in malignant effusions. There is a paucity of published data on recommended duration of outpatient monitoring post thoracentesis. Patient and institutional factors will likely influence

appropriate monitoring intervals. However, the Working Group recommends a post-thoracentesis monitoring period in the range of 30 minutes–1 hour, similar to lung biopsies for uncomplicated thoracentesis.

Ultrasound guidance improves the rate of successful thoracentesis and decreases the risk of iatrogenic pneumothorax. It is particularly useful in cases of small or loculated effusions, or in non-mobile supine patients in an ICU setting. Ultrasound has a higher sensitivity than CT in the identification of complex pleural effusions with septations or echogenic fluid.⁷¹

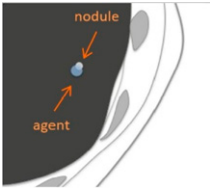
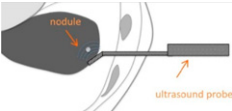
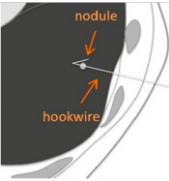
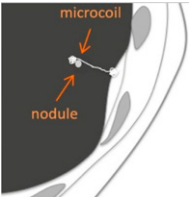
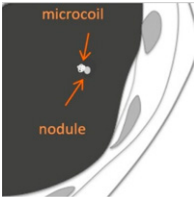
When possible, patients should be placed in an upright sitting position with arms elevated, or if unable, in a supine position with the ipsilateral arm raised over the head. This allows for maximal depth of the effusion in the lowest part of the chest. The procedure should be performed under site marking or direct visualization. If site marking is utilized, sampling must be performed immediately after, as any repositioning of the patient may result in fluid redistribution. Performing the procedure under direct visualization can be more technically challenging and has not been found to be associated with a lower rate of complications.⁹⁴ A lateral approach is preferred if there is sufficient fluid, as there is an increased risk of trauma to the intercostal vessels with a posterior or medial puncture.⁴⁰

For most diagnostic indications, a small gauge needle such as a 21 G needle connected to a 50 mL syringe is adequate to obtain a diagnostic sample. For therapeutic drainage of an uncomplicated effusion, a small size catheter of 5–6 F is usually adequate. Rapid removal of less than 1.5 L of fluid is recommended to avoid re-expansion pulmonary oedema.⁹⁴ For slow therapeutic drainage of complex effusions or intrapleural fibrinolytic therapy, a larger catheter size of up to 14 F can be used.⁹⁵

Pre-Operative Lung Nodule Localization

Many pre-operative lung nodule localization techniques have been developed over the last few decades, each with unique

Table 2. Pre-Operative Lung Nodule Localization Techniques and Common Advantages and Disadvantages.

Techniques				
Injection of Agents	Intraoperative Ultrasound	Hookwire	Microcoil (With Visceral Pleural Tagging)	Microcoil (Without Visceral Pleural Tagging)
				
Detection <ul style="list-style-type: none"> • Methylene blue – direct visualization • Contrast media/lipiodol – fluoroscopy • Radionuclides – scintillation counter Advantages <ul style="list-style-type: none"> • Minimizes pleural pain • Less costly • No dislodgement 	<ul style="list-style-type: none"> • Thoroscopic ultrasound in deflated lung 	<ul style="list-style-type: none"> • Palpation or fluoroscopy 	<ul style="list-style-type: none"> • Palpation or fluoroscopy 	<ul style="list-style-type: none"> • Palpation or fluoroscopy
Disadvantages <ul style="list-style-type: none"> • Diffusion of agents away from nodule • Restricts allowable time between CT localization procedure and VATS • Risk of stroke if communication with pulmonary veins • Radiation exposure from radionuclides 	<ul style="list-style-type: none"> • Avoids time and expense of pre-operative localization procedures • Can localize nodules in locations more difficult to place agents/hookwire/microcoil such as fissural, apical and diaphragmatic surfaces • Allow for characterization of vessels and lungs surrounding nodule 	<ul style="list-style-type: none"> • Able to tag the pleural surface • Allows surgeons to pull the nodule up from surrounding lung and aid in VATS excisional biopsy 	<ul style="list-style-type: none"> • Microcoil is soft and pliable causing less damage to lung even if dislodged • Fibre coating on the microcoils induces coagulation and increases adhesion of the to the lung tissue • Lower risk of microcoil dislodgement than hookwire 	<ul style="list-style-type: none"> • Same as microcoil with pleural tagging • In addition, not tagging the pleural surface decreases procedure time, risk of dislodgement and pleural pain • Does not limit surgeon to a particular surgical path
Disadvantages <ul style="list-style-type: none"> • Must completely collapse lung to visualize nodule • Lengthen surgery time since collapsing lung can take 30–150 min • Lungs with extensive emphysema are more difficult to collapse, difficult to visualize nodule 	<ul style="list-style-type: none"> • High incidence of preoperative wire dislodgement • Associated pneumothorax, pulmonary haemorrhage, pleural pain • Risk of air embolism • Limits surgeon to a particular surgical path 	<ul style="list-style-type: none"> • Microcoil dislodgement but lower risk than hookwire • Limits surgeon to a particular surgical path 	<ul style="list-style-type: none"> • Microcoil dislodgement but lower risk than hookwire 	<ul style="list-style-type: none"> • Microcoil dislodgement but lower risk than hookwire

Figures prepared by Dr. Lan Chau Kha

CT: computed tomography; VATS: video-assisted thorascopic surgery.

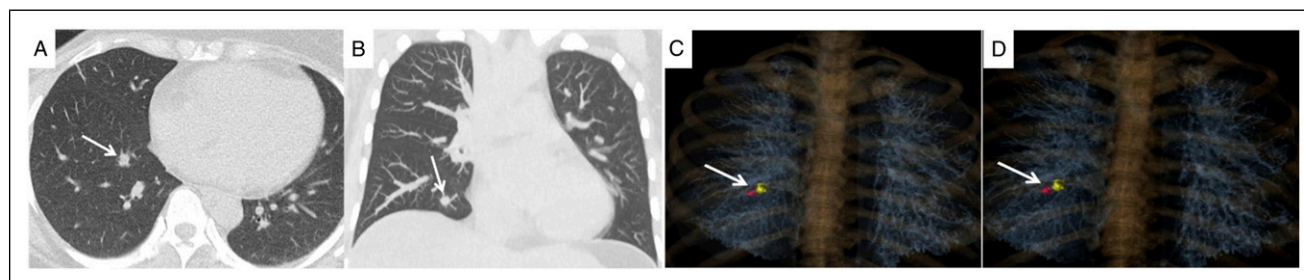


Figure 4. 44-year-old woman with treated breast cancer. (A and B) A new solid nodule was identified on surveillance CT as shown on axial lung windows and coronal MIP images. (C) After a non-diagnostic biopsy, a microcoil was deployed under CT guidance, posterior and medial to the nodule as shown on volume rendered image. (D) Repeat CT chest two weeks later, on the day of resection, demonstrates stable position of the microcoil, with no interval migration or dislodgement (D). The target nodule is shown in red (arrow) and the microcoil is shown in yellow (both C and D). Pathologic evaluation confirmed breast metastasis. CT: computed tomography.

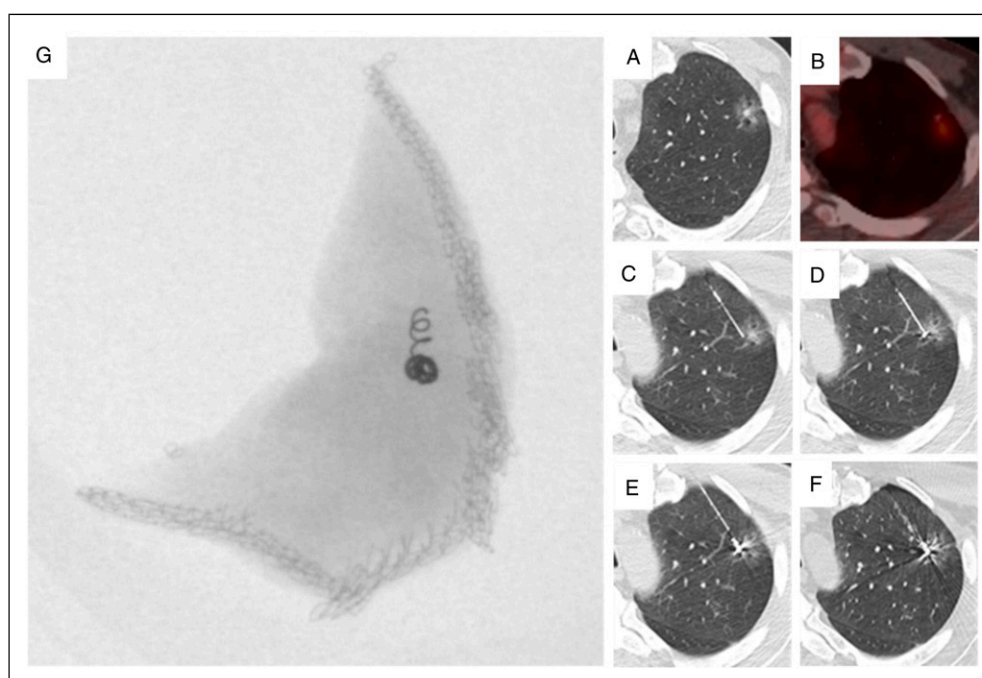


Figure 5. 64-year-old man with video-assisted thoracoscopic surgical resection of a left upper lobe pT2a, N0, M0 invasive adenocarcinoma (acinar predominant). (A). A sub-solid left upper lobe nodule (arrow) was detected on lung screening CT. (B). PET/CT revealed this nodule had an SUV of 2.7. The patient underwent pre-operative microcoil localization. (C). A 22-gauge Chiba Sugai needle with centimetre markers (Cook Canada, Stouffville, Ontario, Canada) was removed and placed on the sterile tray. An 80-mm-long 0.018-inch-diameter fibre-coated platinum microcoil (VortX 18, Diamond Shape; Boston Scientific, Cork, Ireland) was loaded into the needle and pushed using the 0.018-inch wire that comes with the microcoil package. A hemostat was then used to mark the pusher wire at two locations: (1) the length necessary to eject 30-mm of the microcoil and (2) the length necessary to eject the entire 80-mm microcoil from the introducer needle. (C) The introducer needle tip was then placed adjacent but deep to the nodule (arrow). (D) The tip of the stiff end of the pusher wire was then placed at the 5-cm mark from the tip of the introducer needle ensuring 3 cm of the microcoil which was ejected. E. As the microcoil position was correct, the remainder of the microcoil was deployed by inserting the stiff end of the guidewire to the second hemostat where the remainder of the coil was deployed in the lung parenchyma (arrow). The empty introducer needle and guidewire assembly were then withdrawn. It is also possible to deploy the entire length of the microcoil at the deep margin of the target nodule, for greater simplicity and faster procedural time. 3D reconstructions help the thoracic surgeons localize the microcoil in relation to the target nodule and plan the size of the resection volume and surgical approach. (F) A post-procedure thin section limited CT was performed to document the final position of the microcoil relative to the nodule and to assess for the presence of haemorrhage/pneumothorax. (G) A perioperative specimen radiograph was obtained confirming microcoil resection. Pathology confirmed negative surgical margins. CT: computed tomography.

Table 3. Summary of Key Recommendations.

Topic	Recommendation	Additional Comments
Appropriateness criteria	It is important to ensure that the thoracic biopsy or other intervention will have impact on patient management	Criteria are evolving for scenarios where treatment can be initiated without tissue diagnosis of lung cancers. This requires further clarification and study
Patient safety	A safety checklist is recommended to make sure all elements are in place for optimal patient preparation, procedural and post discharge requirements	There are variations across different practice settings. However, a general safety checklist is provided in the Supplementary Appendix
Post biopsy travel	Non-essential air travel should be avoided for 5–7 days post-biopsy. For patients who must fly home after percutaneous transthoracic needle biopsy, the working group recommends a minimum delay of 48 hours for those without or with a small stable pneumothorax	This recommendation is based on expert consensus rather than evidence due to paucity of data on this topic
Technical considerations and complications	Radiologists performing thoracic interventions should be aware of technical considerations to ensure patient safety as well as diagnostic yield or therapeutic success (such as in thoracentesis), etc. Knowledge of common complications, how to prevent and manage them is critical for anyone performing thoracic interventions	Table 1 summarizes the common complications, prevention measures and management
Discordant biopsy results	When the biopsy results are discordant with the imaging features of the target lesion, a standard operating procedure should be in place to flag discordant results and outline next steps in management for the referring physician	It is good practice to document on the procedural report the histopathology results of the biopsy and next management steps where appropriate
Quality improvement	A quality improvement program should be in place that facilitates monitoring of diagnostic yield and complication rates	An audit should be performed if diagnostic yield and complication rates fall outside acceptable ranges to identify potential underlying causes and solutions

strengths, limitations and safety profile.⁹⁶ Some of the more commonly used pre-operative lung localization techniques are summarized in [Table 2](#), along with technique-specific complications and limitations. Common complications resulting from wire localizations and their management are the same for lung biopsies ([Table 1](#)).

Mayo et al⁹⁷ first described the microcoil technique that involves percutaneous placement of one end of a microcoil adjacent to the target lung nodule and the other end marking the visceral pleural surface.⁹⁷ This allows the surgeon to localize the microcoil using fluoroscopy in addition to direct visualization of the visceral pleural marker during video-assisted thoracoscopic surgery.⁹⁸ A widely-used modification of this technique involves placement of the entire microcoil adjacent to the target nodule or alternatively, with the distal portion of the coil marking the deepest aspect of the nodule and the proximal portion marking the superficial aspect ([Table 2](#)). This shortens the CT procedure time, reduces patient radiation exposure while maintaining a similar safety profile. This modification also allows the surgeon to use a preferred surgical trajectory for resection rather than being constrained by the microcoil insertion trajectory.⁹⁹ Ideally, the microcoil insertion is followed by surgical resection on the same day. However, this can pose logistical challenges for coordination. In one Canadian centre, >200 microcoils were placed between 1 day and 2 weeks prior

to surgery with a similar success rate and safety profile (unpublished data). A systematic review and meta-analysis of hookwire, microcoil and lipiodol nodule localization techniques found microcoil and lipiodol to have the highest (97–99%) successful localization rates with microcoils having the best safety profile.¹⁰⁰ Fiducial marker placement using gold seeds has similar success rates, but vascular embolization has been reported,¹⁰¹ while microcoil shape and haemostatic fibre coating eliminate this possibility due to promotion of thrombosis.⁹⁷ Long-term outcomes and disease-free survival have also been excellent with the microcoil technique.¹⁰²

Refer to [Figures 4](#) and [5](#) for more information about this technique; see [Supplementary Appendix D](#) for a video related to this technique.

Conclusion

These guidelines describe best practice recommendations for thoracic interventions commonly performed by radiologists based on current evidence and standards ([Table 3](#)). Future revision and updates will occur as new techniques and innovations develop, and as the boundaries between thoracic and interventional radiology subspecialties become even more blurred with variation in job descriptions across different practice settings.

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Supplemental Material

Supplemental material for this article is available online.

References

- Dennie CJ, Matzinger FR, Marriner JR, Maziak DE. Trans-thoracic needle biopsy of the lung: Results of early discharge in 506 outpatients. *Radiology*. 2001;219:247-251.
- Tavare AN, Creer DD, Khan S, Vancheeswaran R, Hare SS. Ambulatory percutaneous lung biopsy with early discharge and heimlich valve management of iatrogenic pneumothorax: More for less. *Thorax*. 2016;71:190-192.
- Manhire A, Charig M, Clelland C, et al. Guidelines for radiologically guided lung biopsy. *Thorax*. 2003;58:920-936.
- Patel IJ, Rahim S, Davidson JC, et al. Society of interventional radiology consensus guidelines for the periprocedural management of thrombotic and bleeding risk in patients undergoing percutaneous image-guided interventions—Part II: Recommendations. *J Vasc Interv Radiol*. 2019;30:1168-1184.
- Chehab MA, Thakor AS, Tulin-Silver S, et al. Adult and pediatric antibiotic prophylaxis during vascular and IR procedures: A society of interventional radiology practice parameter update endorsed by the cardiovascular and interventional radiological society of Europe and the Canadian association for interventional radiology. *J Vasc Interv Radiol*. 2018;29:1483-1501.
- Guibert N, Pradines A, Favre G, Mazieres J. Current and future applications of liquid biopsy in nonsmall cell lung cancer from early to advanced stages. *Eur Respir Rev*. 2020;29:190052. doi: [10.1183/16000617.0052-2019](https://doi.org/10.1183/16000617.0052-2019)
- Detterbeck FC, Lewis SZ, Diekemper R, Addrizzo-Harris D, Alberts WM. Executive summary: Diagnosis and management of lung cancer, 3rd ed: American College of Chest Physicians evidence-based clinical practice guidelines. *Chest*. 2013;143:7S-37S.
- Scottish Intercollegiate Guidelines Network, Healthcare Improvement Scotland. *Management of Lung Cancer: A National Clinical Guideline*; 2014.
- Padrão E, Rodrigues M, Guimarães S, et al. Diagnostic yield of computed tomography-guided transthoracic lung biopsy in diffuse lung diseases. *Respiration*. 2018;96:455-463.
- Pastre J, Khandhar S, Barnett S, et al. Surgical lung biopsy for interstitial lung disease. Safety and feasibility at a tertiary referral center. *Ann Am Thorac Soc*. 2021;18:460-467.
- British Thoracic Society. *PN Risk Calculator. Better Lung Health for All*. <https://www.brit-thoracic.org.uk/quality-improvement/guidelines/pulmonary-nodules/pn-risk-calculator/>. Accessed February 13, 2022.
- Callister MEJ, Baldwin DR, Akram AR, et al. British Thoracic Society guidelines for the investigation and management of pulmonary nodules. *Thorax*. 2015;70(suppl 2):ii1-ii54.
- Kim L, Tsao MS. Tumour tissue sampling for lung cancer management in the era of personalised therapy: What is good enough for molecular testing? *Eur Respir J*. 2014;44:1011-1022.
- Kropshofer G, Meister B, Lass-Flörl C, Crazzolara R. Why is biopsy of suspected fungal lung lesions necessary? *Med Mycol Case Rep*. 2013;2:141-143.
- Beck KS, Han DH, Lee KY, Kim SJ. Role of CT-guided transthoracic biopsy in the diagnosis of mycobacterial infection. *J Investig Med*. 2019;67:850-855.
- Kiranantawat N, Petranović M, McDermott S, et al. Feasibility and accuracy of CT-guided percutaneous needle biopsy of cavitary pulmonary lesions. *Diagn Interv Radiol*. 2019;25:435-441.
- Shin KE, Park JS, Lee JW. Diagnostic accuracy of CT-guided core needle biopsy for thin-walled cavitary pulmonary lesions. *Am J Roentgenol*. 2021;216:369-375.
- Choi SH, Chae EJ, Kim J-E, et al. Percutaneous CT-guided aspiration and core biopsy of pulmonary nodules smaller than 1 cm: analysis of outcomes of 305 procedures from a tertiary referral center. *AJR Am J Roentgenol*. 2013;201:964-970.
- Yamagami T, Iida S, Kato T, Tanaka O, Nishimura T. Combining fine-needle aspiration and core biopsy under CT fluoroscopy guidance: A better way to treat patients with lung nodules? *AJR Am J Roentgenol*. 2003;180:811-815.
- Wallace MJ, Krishnamurthy S, Broemeling LD, et al. CT-guided percutaneous fine-needle aspiration biopsy of small (≤ 1 -cm) pulmonary lesions. *Radiology*. 2002;225:823-828.
- Hiraki T, Mimura H, Gobara H, et al. CT fluoroscopy-guided biopsy of 1,000 pulmonary lesions performed with 20-gauge coaxial cutting needles. *Chest*. 2009;136:1612-1617.
- Li H, Boisselle PM, JO S, Trotman-Dickenson B, McLoud TC. Diagnostic accuracy and safety of CT-guided percutaneous needle aspiration biopsy of the lung: Comparison of small and large pulmonary nodules. *AJR Am J Roentgenol*. 1996;167:105-109.
- Yeow K-M, Tsay P-K, Cheung Y-C, Lui KW, Pan KT, Chou ASB. Factors affecting diagnostic accuracy of CT-guided coaxial cutting needle lung biopsy: Retrospective analysis of 631 procedures. *J Vasc Interv Radiol*. 2003;14:581-588.
- Yeow K-M, Su I-H, Pan K-T, et al. Risk factors of pneumothorax and bleeding: Multivariate analysis of 660 CT-guided coaxial cutting needle lung biopsies. *Chest*. 2004;126:748-754.

25. Henschke CI, Yankelevitz DF, Mirtcheva R, McGuinness G, McCauley D, Miettinen OS. CT screening for lung cancer: Frequency and significance of part-solid and nonsolid nodules. *AJR Am J Roentgenol*. 2002;178:1053-1057.
26. Lee SM, Park CM, Song YS, et al. CT assessment-based direct surgical resection of part-solid nodules with solid component larger than 5 mm without preoperative biopsy: Experience at a single tertiary hospital. *Eur Radiol*. 2017;27:5119-5126.
27. Cho J, Ko S-J, Kim SJ, et al. Surgical resection of nodular ground-glass opacities without percutaneous needle aspiration or biopsy. *BMC Cancer*. 2014;14:838.
28. Yoon SH, Lee SM, Park CH, et al. 2020 Clinical practice guideline for percutaneous transthoracic needle biopsy of pulmonary lesions: A consensus statement and recommendations of the Korean Society of Thoracic Radiology. *Korean J Radiol*. 2021;22:263-280.
29. Ardestani ME, Abbaszadeh M. The association between forced expiratory volume in one second (FEV1) and pulse oximetric measurements of arterial oxygen saturation (SpO2) in the patients with COPD: A preliminary study. *J Res Med Sci*. 2014;19:257-261.
30. Momany S, Ismail M, Wardeh G, Al-Shrouf A, Khan M. Relationship between hypoxemia and FEV1 in patients with chronic obstructive pulmonary disease (COPD). *Chest*. 2003;124:169S.
31. Cronin CG, Sharma A, Digumarthy SR, et al. Percutaneous lung biopsy after pneumonectomy: Factors for improving success in the care of patients at high risk. *AJR Am J Roentgenol*. 2011;196:929-934.
32. de Lassence A, Timsit J-F, Tafflet M, et al. Pneumothorax in the intensive care unit: Incidence, risk factors, and outcome. *Anesthesiology*. 2006;104:5-13.
33. Freund MC, Petersen J, Goder KC, Bunse T, Wiedermann F, Glodny B. Systemic air embolism during percutaneous core needle biopsy of the lung: Frequency and risk factors. *BMC Pulm Med*. 2012;12:2.
34. Franke M, Reinhardt HC, von Bergwelt-Baildon M, Bangard C. Massive air embolism after lung biopsy. *Circulation*. 2014;129:1046-1047.
35. Um S-J, Lee S-K, Yang DK, et al. Four cases of a cerebral air embolism complicating a percutaneous transthoracic needle biopsy. *Korean J Radiol*. 2009;10:81-84.
36. Sargent EN, Turner AF, Gordonson J, Schwinn CP, Pashky O. Percutaneous pulmonary needle biopsy report of 350 patients. *Am J Roentgenol*. 1974;122:758-768.
37. Khouri N, Stitik F, Erozan Y, et al. Transthoracic needle aspiration biopsy of benign and malignant lung lesions. *Am J Roentgenol*. 1985;144:281-288.
38. Digumarthy SR, Kovacina B, Otrakji A, Lanuti M, Shepard JAO, Sharma A. Percutaneous CT guided lung biopsy in patients with pulmonary hypertension: Assessment of complications. *Eur J Radiol*. 2016;85:466-471.
39. Tai R, Dunne RM, Trotman-Dickenson B, et al. Frequency and severity of pulmonary hemorrhage in patients undergoing percutaneous CT-guided transthoracic lung biopsy: Single-institution experience of 1175 cases. *Radiology*. 2016;279:287-296.
40. Semark A, Rodseth RN, Biccadd BM. When is the risk acceptable to proceed to noncardiac surgery following an acute myocardial infarction? *Minerva Anesthesiol*. 2011;77:64-73.
41. Eagle KA, Berger PB, Calkins H, et al. ACC/AHA guideline update for perioperative cardiovascular evaluation for noncardiac surgery—Executive summary a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to update the 1996 guidelines on perioperative cardiovascular evaluation for noncardiac Surgery). *Circulation*. 2002;105:1257-1267.
42. Lee C, Guichet PL, Abtin F. Percutaneous lung biopsy in the molecular profiling era: A survey of current practices. *J Thorac Imaging*. 2017;32:63-67.
43. Tavare AN, Hare SS, Miller FNA, Hammond C, Edey A, Devaraj A. A survey of UK percutaneous lung biopsy practice: Current practices in the era of early detection, oncogenetic profiling, and targeted treatments. *Clin Radiol*. 2018;73:800-809.
44. Jo Y, Han DH, Beck KS, Park JS, Kim TJ. Practice pattern of transthoracic needle biopsy: 2016 survey in the members of Korean Society of Thoracic Radiology. *Korean J Radiol*. 2017;18:1005-1011.
45. Kurban LA, Gomersall L, Weir J, Wade P. Fluoroscopy-guided percutaneous lung biopsy: A valuable alternative to computed tomography. *Acta Radiol*. 2008;49:876-882.
46. Lee SM, Park CM, Lee KH, Bahn YE, Kim JI, Goo JM. C-arm cone-beam CT-guided percutaneous transthoracic needle biopsy of lung nodules: Clinical experience in 1108 patients. *Radiology*. 2014;271:291-300.
47. Portela-Oliveira E, Souza CA, Gupta A, Bayanati H, Inacio J, Rakhra K. Ultrasound-guided percutaneous biopsy of thoracic lesions: High diagnostic yield and low complication rate. *Clin Radiol*. 2021;76:281-286.
48. Nasuti JF, Gupta PK, Baloch ZW. Diagnostic value and cost-effectiveness of on-site evaluation of fine-needle aspiration specimens: Review of 5, 688 cases. *Diagn Cytopathol*. 2002;27:1-4.
49. Yao X, Gomes MM, Tsao MS, Allen C, Geddie W, Sekhon H. Fine-needle aspiration biopsy versus core-needle biopsy in diagnosing lung cancer: A systematic review. *Curr Oncol*. 2012;19:16-27.
50. Kim TJ, Lee J-H, Lee C-T, et al. Diagnostic accuracy of CT-guided core biopsy of ground-glass opacity pulmonary lesions. *AJR Am J Roentgenol*. 2008;190:234-239.
51. Hu Q, Naushad H, Xie Q, Al-Howaidi I, Wang M, Fu K. Needle-core biopsy in the pathologic diagnosis of malignant lymphoma showing high reproducibility among pathologists. *Am J Clin Pathol*. 2013;140:238-247.
52. Cormier Y, Laviolette M, Tardif A. Prevention of pneumothorax in needle lung biopsy by breathing 100% oxygen. *Thorax*. 1980;35:37-41.
53. Gupta S, Wallace MJ, Cardella JF, Kundu S, Miller DL, Rose SC. Quality improvement guidelines for percutaneous needle biopsy. *J Vasc Interv Radiol*. 2010;21:969-975.

54. Matsuguma H, Nakahara R, Kondo T, Kamiyama Y, Mori K, Yokoi K. Risk of pleural recurrence after needle biopsy in patients with resected early stage lung cancer. *Ann Thorac Surg.* 2005;80:2026-2031.
55. Wang T, Luo L, Zhou Q. Risk of pleural recurrence in early stage lung cancer patients after percutaneous transthoracic needle biopsy: A meta-analysis. *Sci Rep.* 2017;7:42762.
56. Chetlen AL, Kasales C, Mack J, Schetter S, Zhu J. Hematoma formation during breast core needle biopsy in women taking anti-thrombotic therapy. *AJR Am J Roentgenol.* 2013;201:215-222.
57. Foremny GB, Pretell-Mazzini J, Jose J, Subhawong TK. Risk of bleeding associated with interventional musculoskeletal radiology procedures. A comprehensive review of the literature. *Skeletal Radiol.* 2015;44:619-627.
58. Cheng T, Cheng Q, Wan H. A case of a pleural empyema secondary to a percutaneous lung biopsy. *Chest.* 2016;149:A107.
59. Li H, Chen R, Zhao J. Correlation between percutaneous transthoracic needle biopsy and recurrence in stage I lung cancer: A systematic review and meta-analysis. *BMC Pulm Med.* 2020;20:198.
60. De Filippo M, Saba L, Silva M, et al. CT-guided biopsy of pulmonary nodules: Is pulmonary hemorrhage a complication or an advantage? *Diagn Interv Radiol.* 2014;20:421-425.
61. Navin PJ, Eickstaedt NL, Atwell TD, et al. Safety and efficacy of percutaneous image-guided mediastinal mass core-needle biopsy. *Mayo Clin Proc Innov Qual Outcomes.* 2021;5:1100-1108.
62. Kulkarni S, Kulkarni A, Roy D, et al. Percutaneous computed tomography-guided core biopsy for the diagnosis of mediastinal masses. *Ann Thorac Med.* 2008;3:13-17.
63. Lee HN, Yun SJ, Kim JI, Ryu CW. Diagnostic outcome and safety of CT-guided core needle biopsy for mediastinal masses: A systematic review and meta-analysis. *Eur Radiol.* 2020;30:588-599.
64. Shif Y, Kung JW, McMahon CJ, et al. Safety of omitting routine bleeding tests prior to image-guided musculoskeletal core needle biopsy. *Skeletal Radiol.* 2018;47:215-221.
65. Winn N, Spratt J, Wright E, Cox J. Patient reported experiences of CT guided lung biopsy: A prospective cohort study. *Multidiscip Respir Med.* 2014;9:53.
66. Heerink WJ, de Bock GH, de Jonge GJ, Groen HJM, Vliegenthart R, Oudkerk M. Complication rates of CT-guided transthoracic lung biopsy: Meta-analysis. *Eur Radiol.* 2017;27:138-148.
67. Monnin-Bares V, Chassagnon G, Vernhet-Kovacsik H, et al. Systemic air embolism depicted on systematic whole thoracic CT acquisition after percutaneous lung biopsy: Incidence and risk factors. *Eur J Radiol.* 2019;117:26-32.
68. Sheth RA, Baerlocher MO, Connolly BL, et al. Society of interventional radiology quality improvement standards on percutaneous needle biopsy in adult and pediatric patients. *J Vasc Interv Radiol.* 2020;31:1840-1848.
69. Richardson CM, Pointon KS, Manhire AR, Macfarlane JT. Percutaneous lung biopsies: A survey of UK practice based on 5444 biopsies. *Br J Radiol.* 2002;75:731-735.
70. Tomiyama N, Yasuhara Y, Nakajima Y, et al. CT-guided needle biopsy of lung lesions: A survey of severe complication based on 9783 biopsies in Japan. *Eur J Radiol.* 2006;59:60-64.
71. Jany B, Welte T. Pleural effusion in adults-etiology, diagnosis, and treatment. *Dtsch Arzteblatt Int.* 2019;116:377-386.
72. Cantey EP, Walter JM, Corbridge T, Barsuk JH. Complications of thoracentesis: Incidence, risk factors, and strategies for prevention. *Curr Opin Pulm Med.* 2016;22:378-385.
73. Ault MJ, Rosen BT, Scher J, Feinglass J, Barsuk JH. Thoracentesis outcomes: A 12-year experience. *Thorax.* 2015;70:127-132.
74. Verhagen M, van Buijtenen JM, Geeraedts LMG. Reexpansion pulmonary edema after chest drainage for pneumothorax: A case report and literature overview. *Respir Med Case Rep.* 2015;14:10-12.
75. Hong H, Hahn S, Matsuguma H, et al. Pleural recurrence after transthoracic needle lung biopsy in stage I lung cancer: A systematic review and individual patient-level meta-analysis. *Thorax.* 2021;76:582-590.
76. British Thoracic Society Standards of Care Committee. Managing passengers with respiratory disease planning air travel: British Thoracic Society recommendations. *Thorax.* 2002;57:289-304.
77. Tam A, Singh P, Ensor JE, et al. Air travel after biopsy-related pneumothorax: is it safe to fly? *J Vasc Interv Radiol.* 2011;22:595-602.
78. Sacco F, Calero KR. Safety of early air travel after treatment of traumatic pneumothorax. *Int J Circumpolar Health.* 2014;73:24178. doi:10.3402/ijch.v73.24178
79. Chae KJ, Hong H, Yoon SH, et al. Non-diagnostic results of percutaneous transthoracic needle biopsy: A meta-analysis. *Sci Rep.* 2019;9:12428.
80. de Margerie-Mellon C, de Bazelaire C, Amorim S, et al. Diagnostic yield and safety of computed tomography-guided mediastinal core needle biopsies. *J Thorac Imaging.* 2015;30:319-327.
81. Protopapas Z, Westcott JL. Transthoracic hilar and mediastinal biopsy. *Radiol Clin North Am.* 2000;38:281-291.
82. Kuzucu A, Ulutas H, Reha Celik M, Yekeler E. Hydatid cysts of the lung: Lesion size in relation to clinical presentation and therapeutic approach. *Surg Today.* 2014;44:131-136.
83. Gupta S, Seaberg K, Wallace MJ, et al. Imaging-guided percutaneous biopsy of mediastinal lesions: Different approaches and anatomic considerations. *Radiographics.* 2005;25:763-786; discussion 786-788.
84. Gupta S, Wallace MJ, Morello FA, Ahrar K, Hicks ME. CT-guided percutaneous needle biopsy of intrathoracic lesions by using the transsternal approach: Experience in 37 patients. *Radiology.* 2002;222:57-62.
85. Jarmakani M, Duguay S, Rust K, Conner K, Wagner JM. Ultrasound versus computed tomographic guidance for percutaneous biopsy of chest lesions. *J Ultrasound Med.* 2016;35:1865-1872.
86. Mychajlowycz M, Alabousi A, Mironov O. Ultrasound-versus CT-guided subpleural lung and pleural biopsy: An analysis of wait times, procedure time, safety, and diagnostic adequacy. *Can Assoc Radiol J.* 2021;72:883-889. doi:10.1177/0846537120939073
87. Park J, Park B, Lim J-K, et al. Ultrasound-guided percutaneous needle biopsy for small pleural lesions: Diagnostic yield and

- impact of CT and ultrasound characteristics. *AJR Am J Roentgenol*. 2021;217:699-706.
88. Zhang Y, Tang J, Zhou X, Zhou D, Wang J, Tang Q. Ultrasound-guided pleural cutting needle biopsy: Accuracy and factors influencing diagnostic yield. *J Thorac Dis*. 2018;10:3244-3252.
 89. Isus G, Vollmer I. Ultrasound-guided interventional radiology procedures in the chest. *Radiologia*. 2021;63:536-546.
 90. Carter BW, Benveniste MF, Betancourt SL, et al. Imaging evaluation of malignant chest wall neoplasms. *Radiographics*. 2016;36:1285-1306.
 91. Souza FF, De Angelo Andrade M, Smith A, Dei Santi DB. Clinical utility of image-guided chest wall mass biopsy: Results in 28 patients. *Cancer Imaging*. 2011;11:42-47.
 92. Kachroo P, Pak PS, Sandha HS, et al. Chest wall sarcomas are accurately diagnosed by image-guided core needle biopsy. *J Thorac Oncol*. 2012;7:151-156.
 93. Hooper C, Lee YCG, Maskell N, et al. Investigation of a unilateral pleural effusion in adults: British Thoracic Society pleural disease guideline 2010. *Thorax*. 2010;65:ii4-ii17.
 94. Brogi E, Gargani L, Bignami E, et al. Thoracic ultrasound for pleural effusion in the intensive care unit: A narrative review from diagnosis to treatment. *Crit Care*. 2017;21:325.
 95. Light RW. Pleural controversy: Optimal chest tube size for drainage. *Respirol Carlton Vic*. 2011;16:244-248.
 96. Donahoe LL, Nguyen ET, Chung T-B, et al. CT-guided microcoil VATS resection of lung nodules: A single-centre experience and review of the literature. *J Thorac Dis*. 2016;8:1986-1994.
 97. Mayo JR, Clifton JC, Powell TI, et al. Lung nodules: CT-guided placement of microcoils to direct video-assisted thoracoscopic surgical resection. *Radiology*. 2009;250:576-585.
 98. Powell TI, Jangra D, Clifton JC, et al. Peripheral lung nodules: Fluoroscopically guided video-assisted thoracoscopic resection after computed tomography-guided localization using platinum microcoils. *Ann Surg*. 2004;240:481-489.
 99. Kha L-CT, Hanneman K, Donahoe L, et al. Safety and efficacy of modified preoperative lung nodule microcoil localization without pleural marking: A pilot study. *J Thorac Imaging*. 2016;31:15-22.
 100. Park CH, Han K, Hur J, et al. Comparative effectiveness and safety of preoperative lung localization for pulmonary nodules: A systematic review and meta-analysis. *Chest*. 2017;151:316-328.
 101. McDermott S, Frenk NE, Fintelmann FJ, et al. Preoperative CT-guided fiducial marker placement for surgical localization of pulmonary nodules. *Radiol Cardiothorac Imaging*. 2022;4:e210194.
 102. Rodrigues JCL, Pierre AF, Hanneman K, et al. CT-guided microcoil pulmonary nodule localization prior to video-assisted thoracoscopic surgery: Diagnostic utility and recurrence-free survival. *Radiology*. 2019;291:214-222.

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