

# Lung, Pleural, and Mediastinal Biopsies: From Preprocedural Assessment to Technique and Management of Complications

Natasha Larocque, MD, FRCPC<sup>1</sup> Olga R. Brook, MD<sup>2</sup>

<sup>1</sup>Department of Radiology, Hamilton General Hospital, McMaster University, Hamilton, Ontario, Canada

<sup>2</sup>Department of Radiology, Beth Israel Deaconess Medical Center, Boston, Massachusetts

Address for correspondence Natasha Larocque, MD, FRCPC, Department of Radiology, McMaster University, 237 Barton Street East, Hamilton, L8L 2X2, Canada (e-mail: Natasha.larocque@medportal.ca).

Semin Intervent Radiol 2022;39:218–225

## Abstract

### Keywords

- ▶ interventional radiology
- ▶ percutaneous lung biopsy
- ▶ pleural biopsy
- ▶ mediastinal biopsy

Biopsies of the lung, pleura, and mediastinum play a crucial role in the workup of thoracic lesions. Percutaneous image-guided biopsy of thoracic lesions is a relatively safe and noninvasive way to obtain a pathologic diagnosis which is required to direct patient management. This article reviews how to safely perform image-guided biopsies of the lung, pleura, and mediastinum, from the preprocedural assessment to reviewing intraprocedural techniques, and how to avoid and manage complications.

Percutaneous biopsy of the lung, pleura, and mediastinum is an important step in the workup of thoracic lesions. Image-guided percutaneous biopsy of thoracic lesions is a noninvasive and relatively safe method to obtain a pathologic diagnosis which is essential in directing patient management.

## Preprocedural Assessment

### Lesion Assessment

One of the first steps when a request has been placed to perform a percutaneous thoracic biopsy is to review the patient's imaging to assess if the lesion is amenable to image-guided sampling. For lung lesions, there is a definite relationship between nodule size and risk of malignancy.<sup>1</sup> Studies have shown that diagnostic accuracy declines in proportion to decreasing lesion size<sup>2</sup> and that the diagnostic yield is lower in lesions smaller than 1.5 cm,<sup>3</sup> which can be attributed to the technical difficulty in sampling smaller lesions. However, the diagnostic yield also decreases in larger lesions, reportedly lesions over 5.0 cm, due to necrosis.<sup>3</sup> To avoid sampling necrosis in these larger lesions, positron emission tomography–computed tomography is a valuable adjunct tool for preprocedural planning to assess for

areas of viable tissue that can be targeted for sampling to increase the diagnostic yield (▶**Fig. 1**).<sup>4–6</sup> Similarly, increased pleural thickness is associated with higher diagnostic yield in pleural biopsies (▶**Fig. 2**).<sup>7</sup> Lesion size does not seem to be a factor in the diagnostic yield of mediastinal mass biopsies.<sup>8</sup>

Another consideration is the location of the lesion. For lung biopsies, percutaneous image-guided biopsy is well suited for peripheral lesions, while bronchoscopy is preferred for central or perihilar lesions. If there are extrapulmonary sites of disease, biopsy of these lesions should be considered to more accurately stage the disease. Another advantage of image-guided percutaneous biopsy as compared with an endobronchial approach is the ability to use larger gauge coaxial needles which can provide more robust tissue samples, particularly in cases of lymphoma where larger amounts of tissue are needed as fine needle aspiration biopsy (FNAB) is not sufficient for subtyping lymphoma (▶**Fig. 3**).

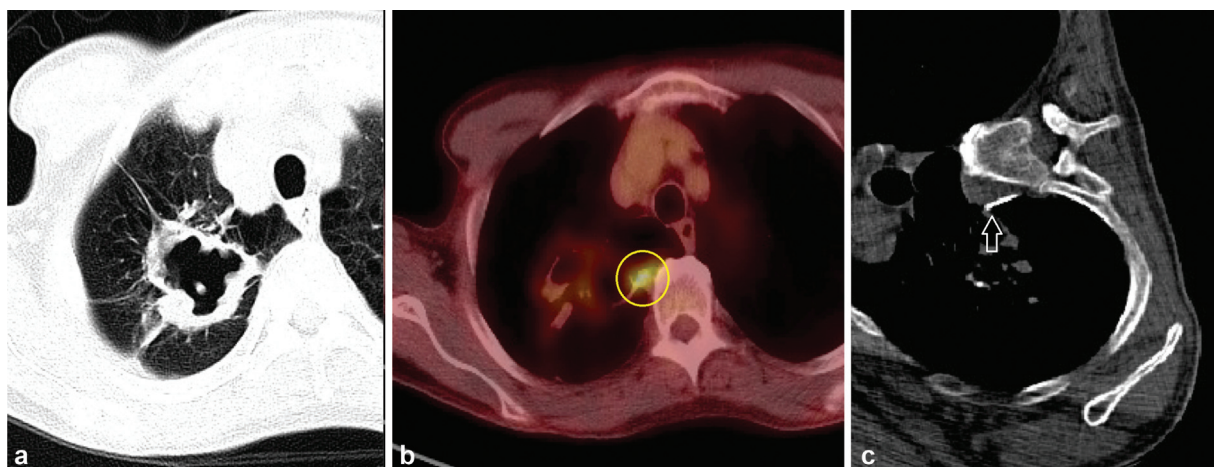
### Patient Selection

Once a patient is deemed a good candidate for percutaneous biopsy, a thorough preprocedural assessment is required.

Issue Theme Thoracic Interventions; Guest Editors, Claire S. Kaufman, MD and Charles E. Ray, Jr., MD, PhD, FSIR

© 2022. Thieme. All rights reserved. Thieme Medical Publishers, Inc., 333 Seventh Avenue, 18th Floor, New York, NY 10001, USA

DOI <https://doi.org/10.1055/s-0042-1751292>. ISSN 0739-9529.



**Fig. 1** A 67-year-old with a cavitary right upper lobe mass (a) underwent PET-CT that showed FDG uptake in the medial component of the mass (b, circle), which was then targeted for the biopsy (c; arrow—needle tip). Pathology revealed nonnecrotizing granulomas.

Regarding coagulation parameters, as per current guidelines, the INR should be less than 1.5, or should be corrected if above this level. The platelet count should be greater than 50,000/ $\mu$ L, and patients should be transfused if necessary. Plavix should be held for 5 days prior to the procedure; however, patients can continue aspirin. If patients are on a therapeutic dose of low-molecular-weight heparin, one dose should be held prior to the procedure.<sup>9</sup>

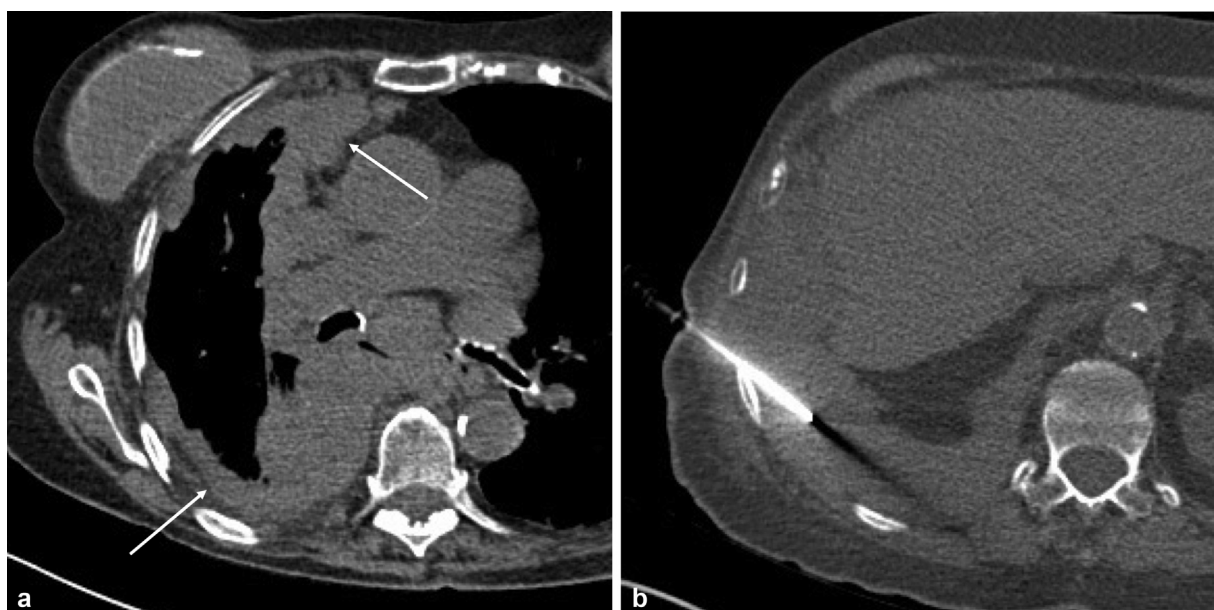
Some institutions perform prebiopsy pulmonary function testing (PFT) to assess a patient's ability to potentially withstand an iatrogenic pneumothorax.<sup>10,11</sup> Aspects of the PFT that are evaluated include the forced expiratory volume in 1 second, with absolute values of 0.8 to 1.5 L, or 30 to 50% predicated as minimum thresholds.<sup>10,11</sup> The transfer factor for carbon monoxide is also sometimes evaluated with ideal values between 30 and 50%.<sup>10</sup> Multidisciplinary patient assessment is recommended if PFT values are less than these

thresholds.<sup>11</sup> Interestingly, there is no association between PFT results and the risk for developing a pneumothorax<sup>12–15</sup>; therefore, many proceduralists do not routinely assess PFTs prior to the biopsy.

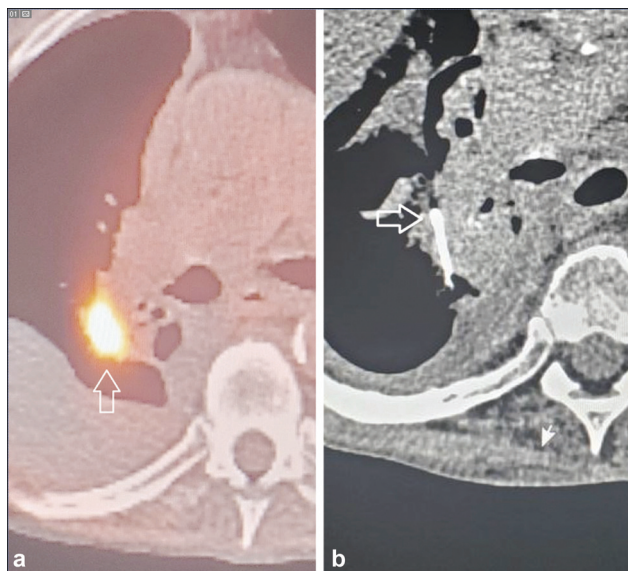
Relative contraindications to percutaneous thoracic biopsies include uncooperative patients, uncorrectable coagulopathy, severe respiratory compromise (e.g., severe emphysema or chronic obstructive pulmonary disease), pulmonary hypertension, and patients on positive pressure ventilation.<sup>4,16</sup>

### Procedural Technique

Moderate sedation is routinely used during percutaneous thoracic biopsies, which increases patient comfort as well as reduces the likelihood of extreme motion during the procedure. We routinely use a combination of fentanyl and midazolam for moderate sedation.



**Fig. 2** A 93-year-old man presented with recurrent right pleural effusion and irregular pleural thickening (a, arrows). The thickest region of pleural thickening was targeted for biopsy (b). Pathology was consistent with mesothelioma.



**Fig. 3** Patient with a right perihilar mass which was PET-CT avid (a, arrow). Bronchoscopic fine needle aspiration biopsy was nondiagnostic. Core biopsy samples were obtained under CT guidance (b; arrow—needle tip). Pathology was consistent with squamous cell carcinoma.

If multiple lung lesions are amenable for biopsy, it is typically preferable to target an upper lobe lesion, as there is less respiratory motion in the upper lobes compared with the lower lobes, which will make it easier to target the lesion and reduces risk of pneumothorax.

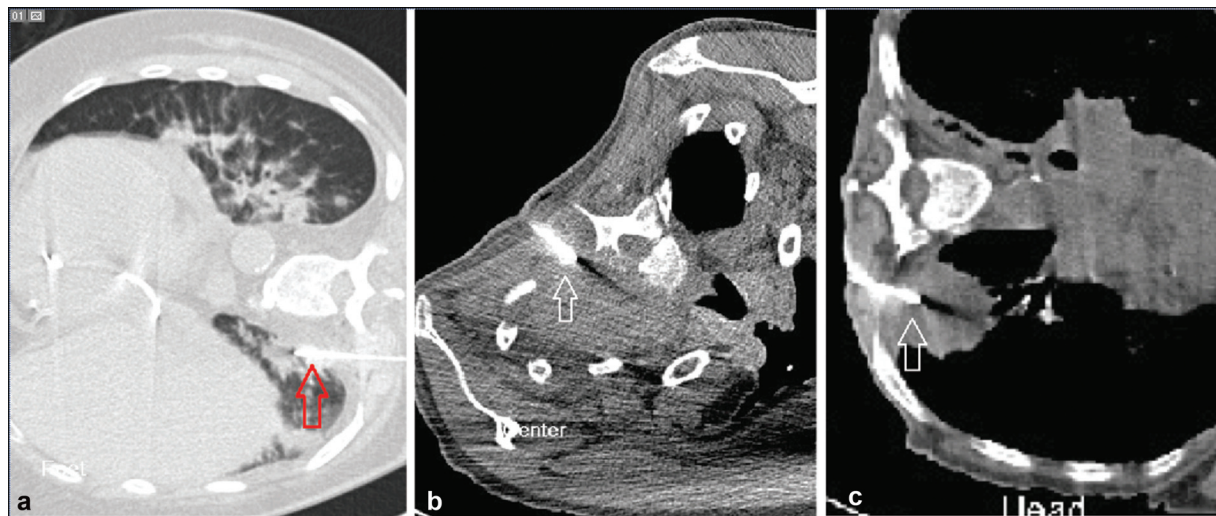
CT guidance with CT fluoroscopy is usually the modality of choice for image-guided percutaneous lung biopsy, as it allows near real-time visualization of the biopsy needle position, the target lesion, and important structures in between such as the pleura and pulmonary vessels.<sup>4,5,16</sup> We decrease the milliampere seconds (mAs) while using CT fluoroscopy during the procedure to lower radiation exposure to the patient and the operator. While standard

CT fluoroscopy for body application uses 50 mA, CT fluoroscopy in the lung can be utilized with lower exposure of 30 mA. Ultrasound (US) can also be used to safely target subpleural/peripheral lesions with the advantage of being more readily available than CT.<sup>17</sup>

Once the lesion for biopsy has been chosen, patient positioning needs to be considered. We suggest placing the patient in a lateral decubitus position (►Fig. 4), if tolerable by the patient, with the biopsy side down to decrease motion of the dependent lung and thus decrease the risk of pneumothorax,<sup>18–22</sup> and the operator working from either the front or the back. Another advantage of positioning the patient with biopsy side in the dependent position is decreased spillage of blood to the contralateral lung, if pulmonary hemorrhage occurs. The disadvantage of lateral decubitus positioning is that it can be difficult for patients to remain motionless, and thus supports should be provided as needed. Partial decubitus positioning, which is generally more convenient for patients, can be utilized to obtain the benefits of having the lung in a dependent position (►Fig. 5). Moreover, this positioning may open additional accesses for biopsy. Alternatively, supine or prone positioning could be used.

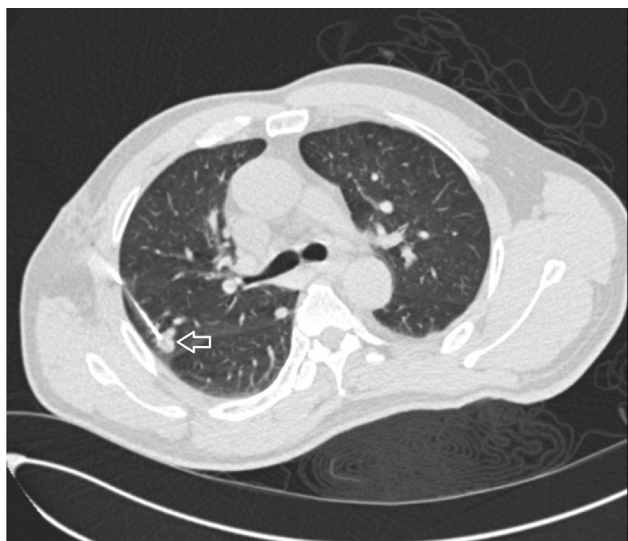
Next, a preprocedural CT scan, usually limited to the region of interest, is performed to localize the lesion. A marking grid could be placed on the patient prior to this scan to landmark. Alternatively, a landmark using the slice of interest on the preprocedural CT with a metallic marker can be utilized.

There are a few principles that should be adhered to when choosing a biopsy trajectory. First, one should choose the shortest path possible to the lesion, as a longer trajectory, usually intra-parenchymal distances of greater than 3 cm, increases the risk of pneumothorax.<sup>19</sup> Also, ideally, the pleura should be transgressed only once, and preferably crossed at a 90-degree angle, with avoidance of the fissures to decrease the chances of a pneumothorax.<sup>19</sup> For subpleural



**Fig. 4** The lateral decubitus position, with the biopsy side down, helps reduce motion and decreases the risk of an iatrogenic pneumothorax. Examples are shown in a 70-year-old patient with a new right lower lobe pulmonary nodule (a; arrow—biopsy needle), an 80-year-old man with a new left upper hemithorax mass post left upper lobectomy for squamous cell carcinoma (b; arrow—biopsy needle), and a 75-year-old woman with a left lower lobe mass (c; arrow—biopsy needle).





**Fig. 5** Partial decubitus position may provide some benefits of decreased motion due to partial effects of gravity, in addition to restricting spread of pulmonary hemorrhage, if it was to occur, to a single lung. Arrow—biopsy needle.

lesions, we try to plan for a trajectory that includes normal lung parenchyma to not lose access/positioning during biopsy needle exchanges and so that the pleura is transgressed only once. Any large bulla should also be avoided.

A preprocedural time-out is required for any interventional radiology procedure, which includes patient verification using two identifiers, verification of the correct procedure, identification of the correct biopsy site, as well as a review of patient allergies, medications, sedation plan, and laboratory tests. An important part of the time-out is to confirm lesion location as well as the number and media for the samples. For example, primary lung cancer now requires a large amount of material for genomic testing in addition to standard histopathological evaluation. We usually obtain at least four core biopsies which are placed in two separate formalin containers. Two to three core biopsies are more than sufficient for metastatic lung lesions, also placed in formalin. However, when lymphoma is in the differential, our protocol includes two to three cores into formalin for histopathological evaluation, two cores in Roswell Park Memorial Institution (RPMI) for flow cytometry, and another two cores for molecular genetics in RPMI for a total of six to seven cores. On the other hand, for culture, the specimen needs to be placed in a sterile container and not formalin.

After prepping the sterile field, and administering superficial and deep local anesthetic, our practice generally uses a 17/18G coaxial system to biopsy lung lesions. We use intermittent CT fluoroscopy to guide our biopsy needle, and try to advance the needle at end expiration during free breathing to make the fluoroscopic images reproducible. Breath-holding can be attempted if the patient is compliant, but in our experience it is not as reproducible as good timing during free breathing. It is important to use the minimum amount of moderate sedation required to optimize free-breathing, and reduce the sporadic respiration rates that can be displayed during sleep.

We suggest advancing the biopsy needle so that the outer stylet is just within the lesion. Studies have shown that the

diagnostic sensitivity increases with the higher number of passes performed.<sup>23,24</sup> Our practice does not routinely perform FNAB for lung lesions, as the diagnostic yield is lower than for core needle biopsy particularly in the diagnosis of benign lesions,<sup>3,25,26</sup> despite the higher risk for developing a pneumothorax.<sup>26</sup> Moreover, in the age of precision medicine, core biopsies allow for the characterization of tumor genomics which plays an increasingly important role in patient management. A recent study has shown that obtaining more than two core samples, and submitting samples in two cassettes improved tissue adequacy for molecular testing,<sup>27</sup> the latter of which is part of our routine practice.

### Considerations for Pleural and Mediastinal Biopsies

There are a few additional considerations for pleural and mediastinal biopsies.

For pleural-based lesions, US or CT could be used for imaging guidance with a meta-analysis showing no difference in diagnostic yield between these modalities.<sup>7,28</sup> For smaller pleural-based lesions, we will typically choose CT guidance to monitor for the development of an iatrogenic pneumothorax. Moreover, core needle biopsy is preferable over FNAB to increase the diagnostic yield (→Fig. 6).<sup>29</sup>

For mediastinal lesions, it is important to plan the biopsy trajectory carefully. Careful planning is required to avoid the internal mammary arteries (IMAs; →Fig. 7), and once within the mediastinum, CT fluoroscopy is judiciously used to avoid the thoracic aorta and pulmonary arteries. Hydrodissection can be used to form a biopsy plane between the IMA and sternum if required. Alternatively, a transsternal approach could be taken, which can be done manually or with the aid of a bone drill (→Fig. 8).

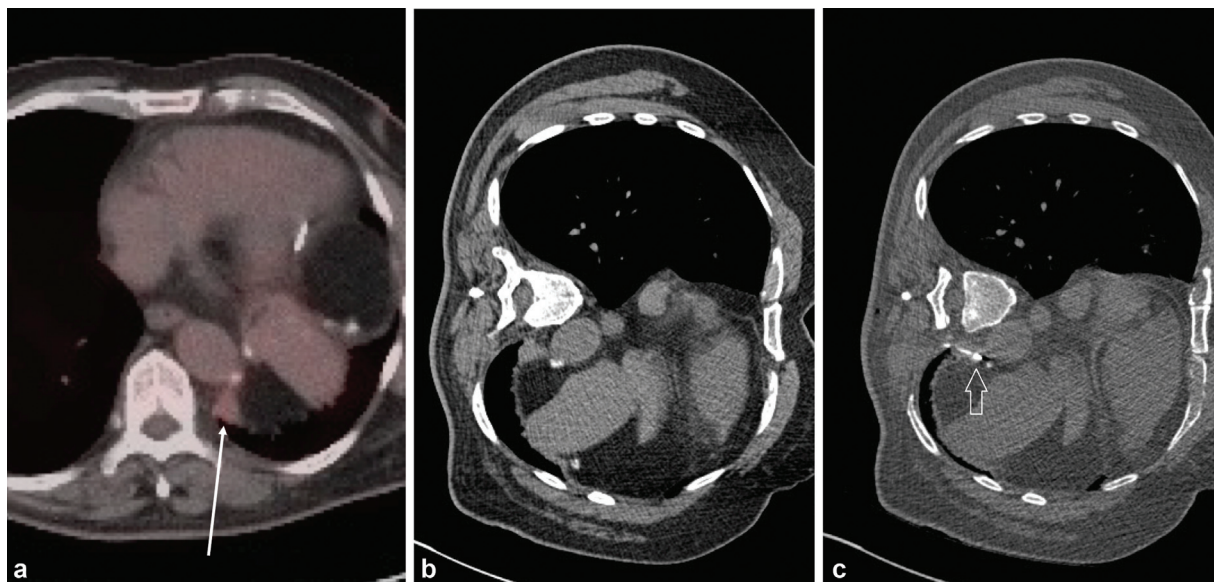
### Postprocedure Recovery

Once the procedure is finished, patients are asked to rest with the biopsy side down for 1 hour if tolerable. For patients without a pneumothorax on the postprocedural CT, we will monitor for 1 hour. If the patient is asymptomatic and if they score at least a 9 on the post anesthetic discharge score system,<sup>30</sup> then we will discharge the patient home. Studies have shown that a shortened observation period of 2 hours postprocedure without a routine chest radiograph in asymptomatic patients is safe.<sup>31</sup>

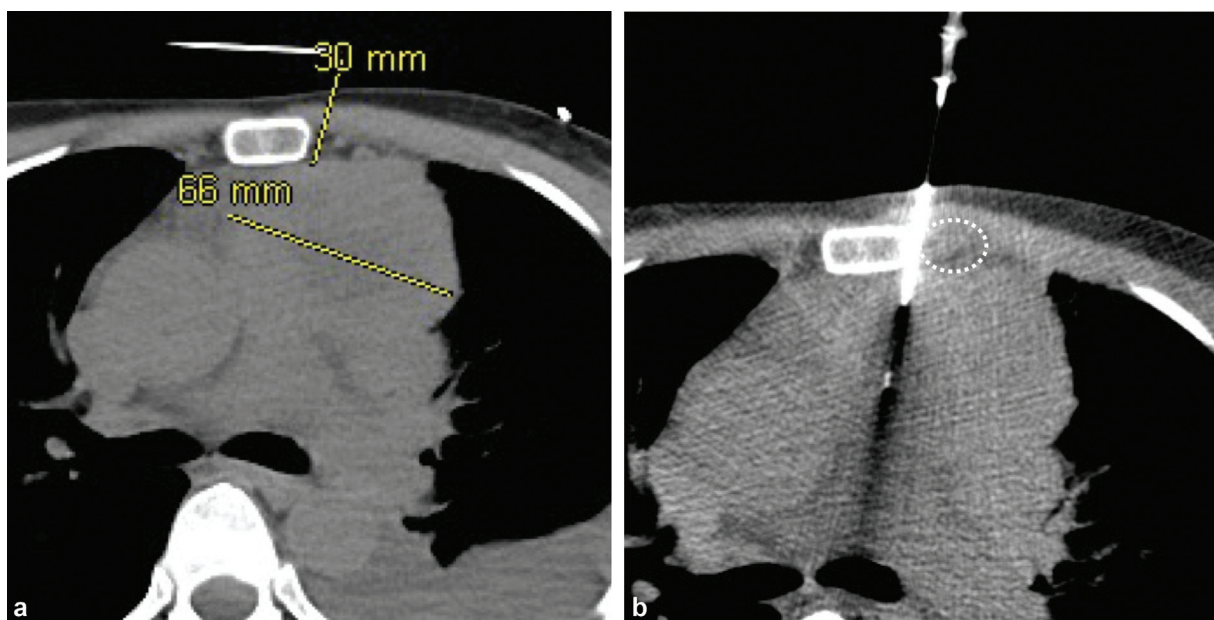
### Radiology–Pathology Correlation

Our institution runs weekly radiology–pathology rounds, where radiologists review the final pathology of any biopsy performed by our department. For cases where the pathology is indeterminate or discordant with the imaging findings, we will contact the referring provider with our recommendations such as repeat biopsy or obtaining follow-up imaging.

One of the major caveats is a pathology result showing organizing pneumonia. Even though organizing pneumonia exists, similar pathological findings can also be seen adjacent to tumors. Therefore, it is of utmost importance to correlate with the clinical history, imaging findings, and pathological findings to confirm concordance. In case of discordance,



**Fig. 6** A 73-year-old with a history of thymoma presents with new left pleural lesion which was mildly avid on PET-CT (a, arrow). Biopsy was performed in the left lateral decubitus position (b and c; arrow—needle tip) avoiding lung. Pathology demonstrated thymoma.



**Fig. 7** A 53-year-old patient with an anterior mediastinal mass (a). The window between the sternum and internal mammary vessels (dashed circle) is used to safely access the anterior mediastinal mass (b).

repeat biopsy with a slightly different approach is likely to be successful (→ Fig. 9). Therefore, discordant biopsy is *not* an indication for surgical biopsy.

## Complications

Complications for lung, pleural, and mediastinal biopsies are similar with pneumothorax and hemorrhage occurring most frequently.

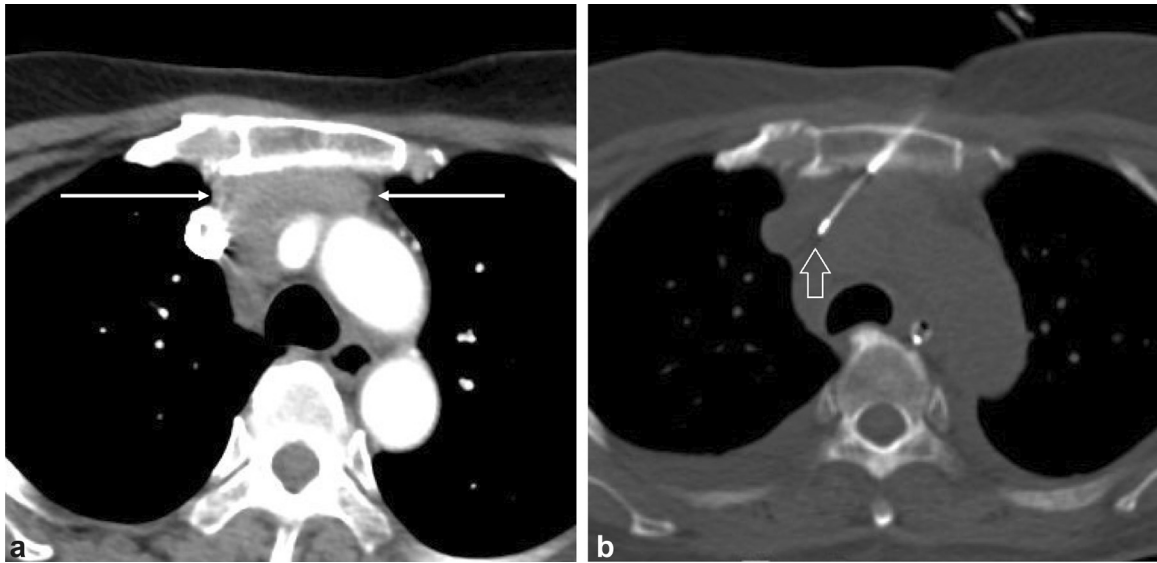
### Pneumothorax

Pneumothorax is a common complication of percutaneous thoracic biopsy with an average rate of approximately 26%,

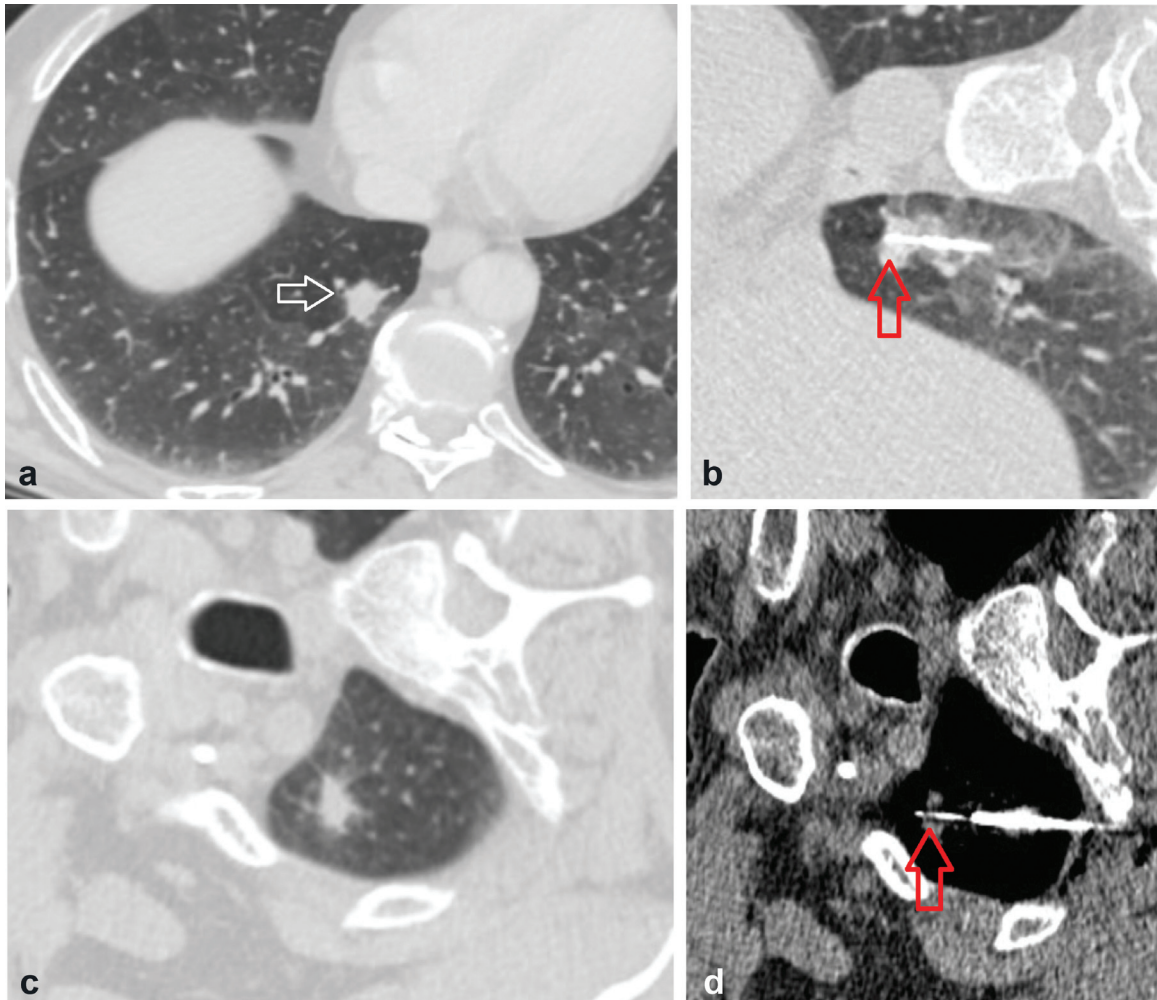
with pneumothoraxes requiring a chest tube in the 0 to 15% range.<sup>19</sup> If a pneumothorax is detected during the procedure, once sampling of the lesion of interest is completed, we will retract the coaxial needle to the pleural cavity and aspirate the pneumothorax using a three-way stopcock. If the pneumothorax does not respond to aspiration, recurs, or the patient is symptomatic, a chest tube will be placed. The chest tube can be small (e.g., 8–10 Fr), unless there is a concomitant hemothorax.

Some operators at our institution use a saline tract sealant which was shown in a meta-analysis to decrease the risk of chest drain insertion by ninefold.<sup>32</sup> Other techniques that can be employed to reduce the likelihood of chest drain





**Fig. 8** A 57-year-old patient with myasthenia gravis presented with an anterior mediastinal mass (a, arrows). Transsternal approach was utilized with an 11G coaxial bone biopsy set through and an 18G soft-tissue biopsy was obtained (b; arrow—18G needle).



**Fig. 9** A 61-year-old patient with chondrosarcoma presented with new pulmonary nodules (example shown in a, arrow). Percutaneous biopsy was performed (b; arrow—needle tip) in the right lateral decubitus position with pathology demonstrating organizing pneumonia. This was determined to be discordant with imaging and clinical characteristics and therefore a biopsy of a different pulmonary nodule (c) was performed (d; arrow—needle tip) which showed metastatic chondrosarcoma.

placement are to rapidly roll the patient biopsy-side down following the procedure, using a tract plug, or sealing the tract with a blood patch.<sup>32–34</sup>

Most pneumothoraxes occur immediately; however, delayed pneumothoraxes can also develop afterward, even up to 14 days postprocedure.<sup>35,36</sup> Female sex, the absence of emphysema, upper lobe location, and an increased number of pleural punctures are independent risk factors for the development of a delayed pneumothorax.<sup>35,36</sup> Delayed pneumothoraxes are clinically significant, as these patients are at a higher risk of needing a chest tube.<sup>35,36</sup>

In terms of postprocedure instructions, many centers will instruct patients to avoid scuba diving or flying for at least 72 hours post-biopsy; however, one study has shown that air travel can be safe in patients with pneumothoraxes as soon as 24 hours post-biopsy.<sup>37</sup>

Risk factors that increase the likelihood of pneumothorax include longer lesion depth ( $\geq 3$  cm), smaller lesion size ( $\leq 4$  cm), lesions without pleural contact, emphysematous lungs, larger needle gauge ( $\geq 18$ G), crossing fissures or bulla, multiple pleural punctures, and operator's experience.<sup>35,38,39</sup>

### Pulmonary Hemorrhage and Hemoptysis

Pulmonary hemorrhage is another commonly encountered complication. This manifests on imaging as perilesional ground-glass opacities. It is therefore critically important for the biopsy needle to be well positioned within the lesion of interest on the first pass because needle repositioning when pulmonary hemorrhage develops becomes nearly impossible due to obscuration of the underlying lesion, with the operator having to estimate lesion location based on landmarks.

The rate of pulmonary hemorrhage during biopsy has been reported in the 30 to 65% range.<sup>40,41</sup> Hemoptysis occurs much less frequently at approximately 2 to 10%.<sup>40,42</sup> Most cases of hemoptysis are self-resolving with hemoptysis requiring intervention seen in 0.1 to 1.6% of cases.<sup>40,42,43</sup> Risk factors for high-grade pulmonary hemorrhage include female sex, older age, emphysema, coaxial technique, non-subpleural location, lesion size of 3 cm or smaller, and subsolid lesions.<sup>38,40</sup>

### Air Embolus

Air embolus is an extremely rare complication with an estimate incidence of 0.08%, but it is clinically important to recognize due to its significant morbidity and mortality. A systematic review showed that 32% of patients with symptomatic air embolus survived with sequelae or passed away.<sup>44</sup> Strategies to avoid air embolus include always occluding the biopsy needle, for example, with the inner stylet, saline, or the operator's finger.<sup>16</sup>

Most patients who develop air embolus are immediately symptomatic with the most common symptoms including loss of consciousness, cardiac-related symptoms such as chest pain, or neurological symptoms such as motor weakness, dysarthria, and convulsions.<sup>44</sup> If a systematic air embolus is identified, the procedure should be immediately terminated and the patient placed in a left lateral decubitus

position, which is associated with favorable outcomes, to prevent air from passing from the right heart into the pulmonary arteries.<sup>44</sup> 100% supplemental oxygen should also be applied to decrease the air's nitrogen content. Air embolus can occur in any of the arterial or venous vasculature; however, air in the coronary arteries or intracranial spaces is associated with unfavorable outcomes.<sup>44</sup>

## Conclusion

Percutaneous image-guided biopsy is a relatively safe and accurate procedure to obtain a tissue diagnosis of thoracic lesions. In the age of precision medicine, core biopsies are increasingly performed to allow for characterization of tumor genomics, which plays an important role in patient management. Preprocedural planning is critical to promote safety of the procedure and avoid complications. Evidence-based strategies to avoid complications can be readily implemented during percutaneous biopsy to promote the safety of this procedure.

### Disclosures

The authors have no grants, disclosures, or any other conflicts of interests to declare.

### Conflict of Interest

None declared.

## References

- 1 MacMahon H, Naidich DP, Goo JM, et al. Guidelines for management of incidental pulmonary nodules detected on CT images: from the Fleischner Society 2017. *Radiology* 2017;284(01):228–243
- 2 Tsukada H, Satou T, Iwashima A, Souma T. Diagnostic accuracy of CT-guided automated needle biopsy of lung nodules. *AJR Am J Roentgenol* 2000;175(01):239–243
- 3 Priola AM, Priola SM, Cataldi A, et al. Accuracy of CT-guided transthoracic needle biopsy of lung lesions: factors affecting diagnostic yield. *Radiol Med (Torino)* 2007;112(08):1142–1159
- 4 de Margerie-Mellon C, de Bazelaire C, de Kerviler E. Image-guided biopsy in primary lung cancer: why, when and how. *Diagn Interv Imaging* 2016;97(10):965–972
- 5 Wu CC, Maher MM, Shepard JA. CT-guided percutaneous needle biopsy of the chest: preprocedural evaluation and technique. *AJR Am J Roentgenol* 2011;196(05):W511–W514
- 6 Purandare NC, Kulkarni AV, Kulkarni SS, et al. 18F-FDG PET/CT-directed biopsy: does it offer incremental benefit? *Nucl Med Commun* 2013;34(03):203–210
- 7 Park J, Park B, Lim JK, 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(03):699–706
- 8 Petranovic M, Gilman MD, Muniappan A, et al. Diagnostic yield of CT-guided percutaneous transthoracic needle biopsy for diagnosis of anterior mediastinal masses. *AJR Am J Roentgenol* 2015;205(04):774–779
- 9 Patel 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(06):727–736

- 10 Tavare AN, Hare SS, Miller FNA, Hammond CJ, 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(09):800–809
- 11 Manhire A, Charig M, Clelland C, et al; BTS. Guidelines for radiologically guided lung biopsy. *Thorax* 2003;58(11):920–936
- 12 Haramati LB, Austin JH. Complications after CT-guided needle biopsy through aerated versus nonaerated lung. *Radiology* 1991;181(03):778
- 13 Anderson CL, Crespo JC, Lie TH. Risk of pneumothorax not increased by obstructive lung disease in percutaneous needle biopsy. *Chest* 1994;105(06):1705–1708
- 14 Fish GD, Stanley JH, Miller KS, Schabel SI, Sutherland SE. Post-biopsy pneumothorax: estimating the risk by chest radiography and pulmonary function tests. *AJR Am J Roentgenol* 1988;150(01):71–74
- 15 Miller KS, Fish GB, Stanley JH, Schabel SI. Prediction of pneumothorax rate in percutaneous needle aspiration of the lung. *Chest* 1988;93(04):742–745
- 16 Winokur RS, Pua BB, Sullivan BW, Madoff DC. Percutaneous lung biopsy: technique, efficacy, and complications. *Semin Intervent Radiol* 2013;30(02):121–127
- 17 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(04):883–889
- 18 Appel E, Dommaraju S, Camacho A, et al. Dependent lesion positioning at CT-guided lung biopsy to reduce risk of pneumothorax. *Eur Radiol* 2020;30(11):6369–6375
- 19 Huo YR, Chan MV, Habib AR, Lui I, Ridley L. Pneumothorax rates in CT-guided lung biopsies: a comprehensive systematic review and meta-analysis of risk factors. *Br J Radiol* 2020;93(1108):20190866
- 20 Drumm O, Joyce EA, de Blacam C, et al. CT-guided lung biopsy: effect of biopsy-side down position on pneumothorax and chest tube placement. *Radiology* 2019;292(01):190–196
- 21 Rozenblit AM, Tuvia J, Rozenblit GN, Klink A. CT-guided transthoracic needle biopsy using an ipsilateral dependent position. *AJR Am J Roentgenol* 2000;174(06):1759–1764
- 22 Kinoshita F, Kato T, Sugiura K, et al. CT-guided transthoracic needle biopsy using a puncture site-down positioning technique. *AJR Am J Roentgenol* 2006;187(04):926–932
- 23 Beck KS, Kim TJ, Lee KY, Kim YK, Kang JH, Han DH. CT-guided coaxial biopsy of malignant lung lesions: are cores from 20-gauge needle adequate for histologic diagnosis and molecular analysis? *J Thorac Dis* 2019;11(03):753–765
- 24 Lim C, Lee KY, Kim YK, Ko JM, Han DH. CT-guided core biopsy of malignant lung lesions: how many needle passes are needed? *J Med Imaging Radiat Oncol* 2013;57(06):652–656
- 25 Anderson JM, Murchison J, Patel D. CT-guided lung biopsy: factors influencing diagnostic yield and complication rate. *Clin Radiol* 2003;58(10):791–797
- 26 Beslic S, Zukic F, Milisic S. Percutaneous transthoracic CT guided biopsies of lung lesions: fine needle aspiration biopsy versus core biopsy. *Radiol Oncol* 2012;46(01):19–22
- 27 Lin CY, Chang CC, Chu CY, et al. Computed tomography-guided transthoracic needle biopsy: predictors for diagnostic failure and tissue adequacy for molecular testing. *Front Med (Lausanne)* 2021;8:650381
- 28 Mei F, Bonifazi M, Rota M, et al. Diagnostic yield and safety of image-guided pleural biopsy: a systematic review and meta-analysis. *Respiration* 2021;100(01):77–87
- 29 Böcking A, Klose KC, Kyll HJ, Hauptmann S. Cytologic versus histologic evaluation of needle biopsy of the lung, hilum and mediastinum. Sensitivity, specificity and typing accuracy. *Acta Cytol* 1995;39(03):463–471
- 30 Chung F, Chan VW, Ong D. A post-anesthetic discharge scoring system for home readiness after ambulatory surgery. *J Clin Anesth* 1995;7(06):500–506
- 31 Ah-Lan KC, Nakhaei M, Camacho A, et al. Safely shortening the observation time after CT-guided lung procedures. *J Am Coll Radiol* 2021;18(08):1118–1127
- 32 Huo YR, Chan MV, Habib AR, Lui I, Ridley L. Post-biopsy manoeuvres to reduce pneumothorax incidence in CT-guided transthoracic lung biopsies: a systematic review and meta-analysis. *Cardiovasc Intervent Radiol* 2019;42(08):1062–1072
- 33 Clayton JD, Elicker BM, Ordovas KG, Kohi MP, Nguyen J, Naeger DM. Nonclotted blood patch technique reduces pneumothorax and chest tube placement rates after percutaneous lung biopsies. *J Thorac Imaging* 2016;31(04):243–246
- 34 Ahrar JU, Gupta S, Ensor JE, et al. Efficacy of a self-expanding tract sealant device in the reduction of pneumothorax and chest tube placement rates after percutaneous lung biopsy: a matched controlled study using propensity score analysis. *Cardiovasc Intervent Radiol* 2017;40(02):270–276
- 35 Bae K, Ha JY, Jeon KN. Pneumothorax after CT-guided transthoracic lung biopsy: a comparison between immediate and delayed occurrence. *PLoS One* 2020;15(08):e0238107
- 36 Choi CM, Um SW, Yoo CG, et al. Incidence and risk factors of delayed pneumothorax after transthoracic needle biopsy of the lung. *Chest* 2004;126(05):1516–1521
- 37 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(05):595–602.e1
- 38 Loh SEK, Wu DDF, Venkatesh SK, et al. CT-guided thoracic biopsy: evaluating diagnostic yield and complications. *Ann Acad Med Singap* 2013;42(06):285–290
- 39 Cox JE, Chiles C, McManus CM, Aquino SL, Choplin RH. Transthoracic needle aspiration biopsy: variables that affect risk of pneumothorax. *Radiology* 1999;212(01):165–168
- 40 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(01):287–296
- 41 Yeow KM, Su IH, Pan KT, et al. Risk factors of pneumothorax and bleeding: multivariate analysis of 660 CT-guided coaxial cutting needle lung biopsies. *Chest* 2004;126(03):748–754
- 42 Song YS, Park CM, Park KW, et al. Does antiplatelet therapy increase the risk of hemoptysis during percutaneous transthoracic needle biopsy of a pulmonary lesion? *AJR Am J Roentgenol* 2013;200(05):1014–1019
- 43 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(01):60–64
- 44 Lee JH, Yoon SH, Hong H, Rho JY, Goo JM. Incidence, risk factors, and prognostic indicators of symptomatic air embolism after percutaneous transthoracic lung biopsy: a systematic review and pooled analysis. *Eur Radiol* 2021;31(04):2022–2033