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Review

CT-guided transthoracic needle biopsy: How we do it☆

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ABSTRACT

CT-guided transthoracic needle biopsy is a well-established method for diagnosing pulmonary lesions. However, despite extensive literature on the subject, many aspects of the procedure remain unexamined in large controlled trials. Consequently, practices vary across centers due to differences in local facilities, operators' preferences, and experience. This article summarizes the essential steps of CT-guided transthoracic needle biopsy, covering patient selection to technical tips and tricks, complication management, and rapid onsite cytology evaluation. The techniques described here are based on years of clinical practice, research findings, and close collaboration with colleagues from various specialties, aiming to maximize tissue retrieval while minimizing complications. Moreover, given the growing importance of molecular analyses in the diagnosis and management of lung cancer, this article provides a concise and practical guide on proper biopsy specimen handling.

1. Patient selection and preprocedural imaging evaluation

The decision to refer a patient with a pulmonary lesion for transthoracic needle biopsy (TTNB) instead of bronchoscopy, excision, or surveillance depends on the pre-test likelihood of malignancy, potential procedural risks, and patient preferences [1–3]. At our tertiary center for lung tumor management, TTNB candidates are evaluated by a multidisciplinary board or referred directly for radiology consultation. The main reasons for referral include (a) suspected malignancy in general or lung cancer screening populations (Rete Italiana Screening Polmonare; ClinicalTrials.gov ID, NCT05766046), (b) the need for tissue sampling to reassess molecular profiling in cases with advanced progressive cancers, and (c) persistent or increasing opacities with uncertain causes, despite extensive assessments. TTNB is preferred when a lesion is inaccessible by bronchoscopy or no other safer biopsy targets (e.g., superficial lymph nodes) are available. For intrapulmonary lesions, when bronchoscopy fails or is deemed unsuitable, TTNB is considered an excellent option, even if the target is centrally located within the lung.

Radiologists carefully review available imaging data and clinical information to assess the rationale and feasibility of TTNB, considering factors that may affect or contraindicate the procedure. These factors include:

- Risk factors for significant pneumothorax, such as destructive emphysema, extensive interstitial lung disease [4,5], and perifissural lesion location [6,7].
- The presence of major vessels adjacent to or embedded within the lesion, which increases the risk of clinically significant hemorrhage.
- Lesion proximity to the heart or costophrenic sulci, as motion in these locations often challenges targeting of the intended area and increases the risk of inadvertently puncturing nearby structures.
- Small lesion size (e.g., <10 mm), which may decrease diagnostic accuracy [8–10], although no critical size has been established below which TTNB should be avoided.

At this preprocedural stage, additional investigations can help refine the presumptive diagnosis and optimize TTNB planning. PET/CT, often performed before the decision to obtain tissue for diagnosis, helps

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pinpoint disease locations; assess lesion malignancy; differentiate viable tissue from necrosis, collapsed lung, and fibrosis; and identify the most metabolically active lesions in cases with multiple lung lesions [11,12]. Contrast-enhanced CT can also aid in identifying vital targetable tissue and visualizing vessels along the needle path and within the target, helping to avoid injury to intralesional vessels (for instance, hypertrophic vasculature in large lesions) or suspected vascular malformation.

Lesion location and size are key factors in selecting optimal image guidance for TTNB. We typically use US guidance for peripheral lung and pleural lesions $\geq$ 1 cm when an adequate acoustic window is available. This approach offers real-time needle visualization, low cost, portability, potential time savings, and no radiation exposure. Our experience, consistent with the literature, suggests that US guidance is as safe and accurate as, or possibly superior to, CT guidance for peripheral TTNBs [13,14]. However, US guidance has drawbacks. In particular, when pneumothorax occurs–a condition detected on US by the absence of the sliding sign [15]–the loss of the acoustic window can compromise procedural success. Moreover, operators may avoid US guidance for subpleural lesions, opting instead to include lung parenchyma in the needle trajectory to reduce the risk of pleural seeding. This approach is supported by a possible increased risk of pleural recurrence when TTNB targets subpleural primary lung cancer [16], yet this association remains controversial [17]. For all pulmonary lesions other than those abutting the pleura, CT remains the preferred guidance modality for TTNB.

The following sections outline the local workflow of CT-guided TTNB. The main steps, from procedure selection to complication management, are summarized in Fig. 1.

2. Operating room

Before performing TTNB, operators must ensure that the CT scan room is properly equipped to address potential complications. Essential equipment includes an oxygen supply, airway suction devices, pneumothorax drainage materials, and a crash cart. At our institution, thoracic surgeons, bronchoscopists, and resuscitation teams are on call to aid in complication management. For high-risk cases, such as patients with prior pneumonectomy or contralateral massive pleural effusion, these specialists may assist the interventional radiologist and radiology nursing staff from the procedure's outset.

3. Preprocedural tests

Proper preprocedural coagulation management is essential in TTNB. The Cardiovascular and International Radiological Society of Europe (CIRSE) recommends assessing bleeding history via structured questionnaires rather than routine coagulation screening [18], while the 2019 Society of Interventional Radiology (SIR) guidelines advise testing International Normalized Ratio (INR) and platelet count for all high-bleeding-risk procedures, including TTNB [19].

In our practice, patients with comorbidities are often screened for coagulopathy for other medical reasons. When no prior testing is available, we omit coagulation laboratory assessments in low-risk cases, such as young patients with no bleeding history. Otherwise, coagulation parameters are routinely checked and corrected as needed. Among candidates for TTNB on antithrombotic therapy, anticoagulants and antiplatelet agents are withheld and reinitiated per current recommendations [18,19]. A multidisciplinary approach remains crucial for managing these cases.

Although no specific pulmonary function thresholds contraindicate TTNB, preprocedural pulmonary function tests are desirable, as obstructive pulmonary dysfunction increases the risks of pneumothorax and the need for drainage [1,20,21]. For patients with forced expiratory volume in one second (FEV_1) values $<$ 35 % of the predicted values, the benefits and risks of TTNB are thoroughly assessed by a multidisciplinary team according to the guidelines [1]. Patients with respiratory failure who require noninvasive ventilation or intubation are generally excluded from TTNB.

4. Patient preparation

Before initiating TTNB, patients in our institution are asked to sign a written informed consent form indicating their understanding of the procedural steps and related risks. We emphasize treating "the patient as a partner," a principle critical for procedural success. Effective communication about the importance of patient cooperation is prioritized, as it may enhance the likelihood of a successful outcome.

To ensure that the target lesion is in a predictable position during TTNB, patients are instructed to breathe gently and hold their breath consistently during scanning or needle manipulation, avoiding deep inhalations or expirations. For less cooperative patients and those with larger lesions (e.g., >2 cm) in the upper lobes, where respiratory movement is less pronounced, free quiet breathing can be an alternative [22]. TTNB is discouraged in individuals unable to remain still or with irregular breathing, as uncontrolled motion can affect both safety and accuracy due to needle dislodgement.

Patients must fast for 4–6 h before the procedure. The preprocedural checklist includes intravenous access (18–20 gauge) and a pulse oximeter on the patient's finger to monitor oxygen saturation during TTNB and recovery. Local anesthesia is typically sufficient for TTNB, with conscious sedation reserved for anxious patients to promote regular breathing and minimize motion. If coughing occurs, a suppressant may be administered, but persistent coughing warrants postponing the procedure to avoid excessive risk of complications.

5. Procedure technique

Our institution has implemented the PEARL protocol [23], which involves positioning biopsy-side down (i.e., lesion and needle tract below the left atrium), needle removal during expiration, autologous blood patch sealing, rapid rollover, and pleural patching. While most PEARL steps can be consistently applied, the biopsy-side down position may not always provide the optimal needle trajectory. Operators should prioritize positioning that shortens the needle path and avoids major vessels, fissures, emphysema, and pulmonary regions affected by interstitial lung disease when feasible. In cases of extensive lung parenchymal disruption, the importance of planning needle trajectories that minimize or avoid lung traversal cannot be overemphasized (Fig. 2).

Previous lung surgery also informs TTNB planning. When bilateral lesions are accessible, targeting the surgical side may reduce the risk of hemothorax and pneumothorax due to postoperative adhesions [24,25]. However, needle entry at the thoracotomy incision site should be avoided to prevent scarring that could hinder needle manipulation.

All procedural steps follow a "move off and scan" approach to minimize radiation exposure. After positioning the patient according to the planned needle trajectory, ensuring comfort and alignment, a low-dose volumetric CT scan is used to identify the optimal needle entry point and mark the skin using the grid method. The site is then sterilized and draped, and local anesthesia (10–20 mL of 2 % lidocaine buffered with sodium bicarbonate) is administered. The needle tip is advanced to the pleura while avoiding major vessels (Fig. 3). For patients with extensive emphysema or interstitial lung disease, the anesthetic needle tip is kept slightly more superficial to reduce the risk of early pneumothorax. Throughout the application of anesthesia and subsequent steps, needle advancement is monitored using sequential CT scans, with volumetric scans reserved for oblique approaches requiring multiplanar reconstruction to refine the entry and angulation (Fig. 4). Intravenous contrast agent may occasionally be administered to delineate vascular structures in the needle path, especially when variations from diagnostic CT arise due to changes in patient positioning or breath-holding.

The local technical parameters of the non-contrast volumetric and sequential CT protocols are summarized in Table 1.

Over the last two decades, the core needle biopsy (CNB) has become

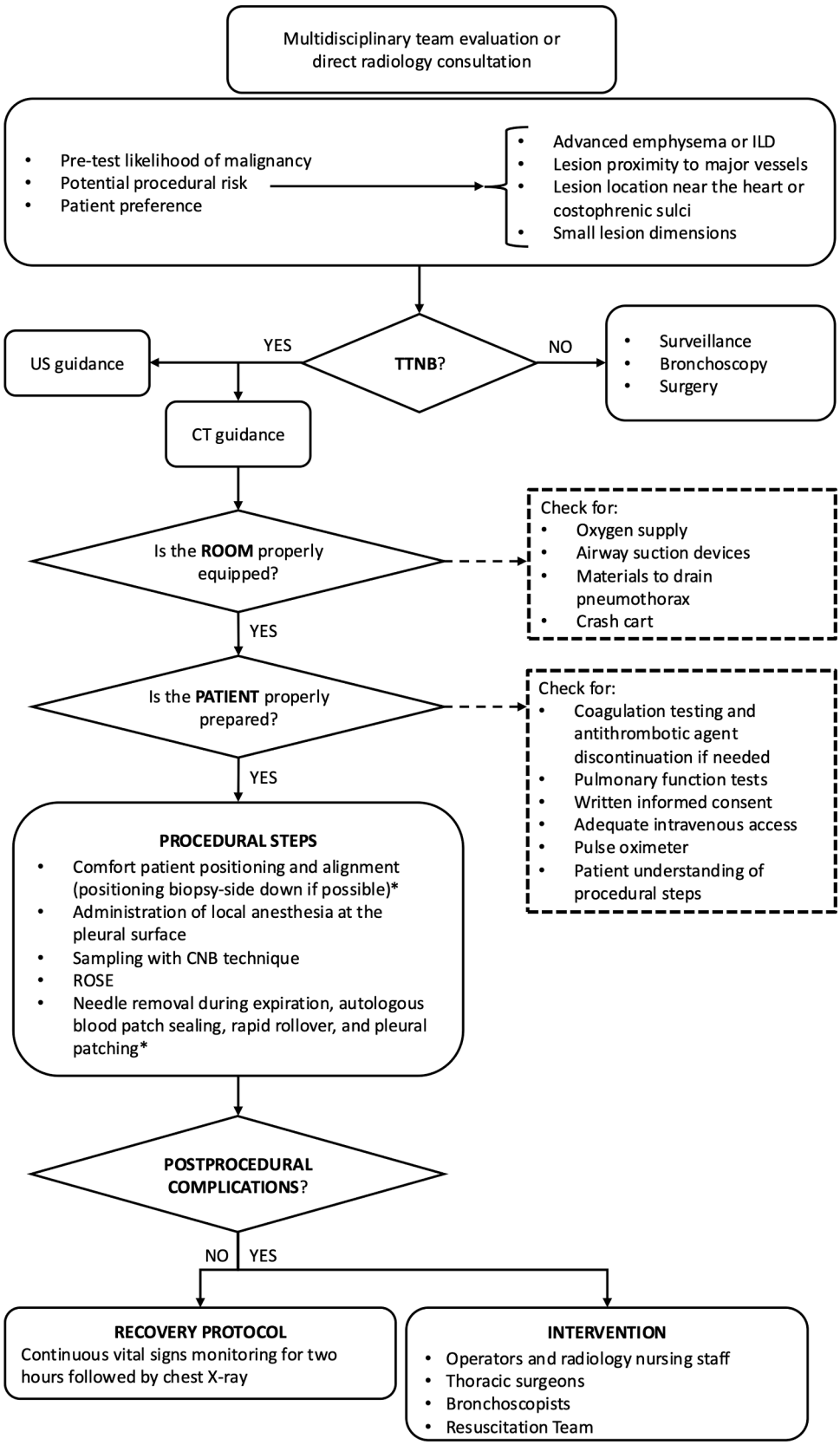

Fig. 1. Local workflow for transthoracic needle biopsy. *According to the PEARL protocol [23]. Abbreviations: CNB, core needle biopsy; ILD, interstitial lung disease; ROSE, rapid on-site evaluation; TTNB, transthoracic needle biopsy.

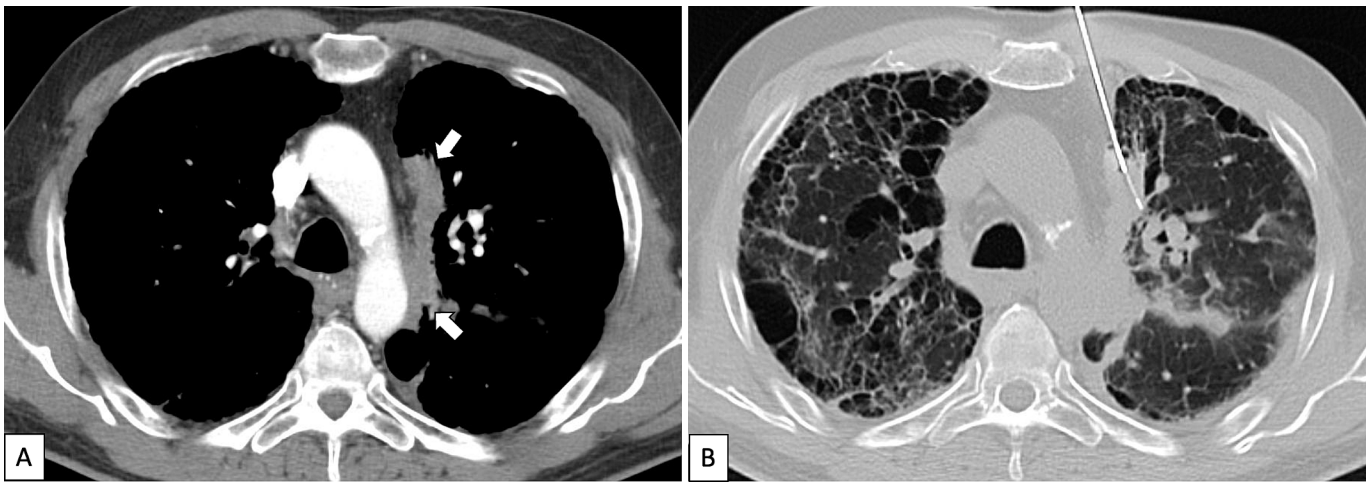

Fig. 2. A. Contrast-enhanced CT of a left paramediastinal solid tissue (arrows) referred for transthoracic needle biopsy. B. The CT-guided biopsy procedure was planned to minimize needle traversal of confluent emphysema by crossing the anterior mediastinum. The final diagnosis was lung adenocarcinoma.

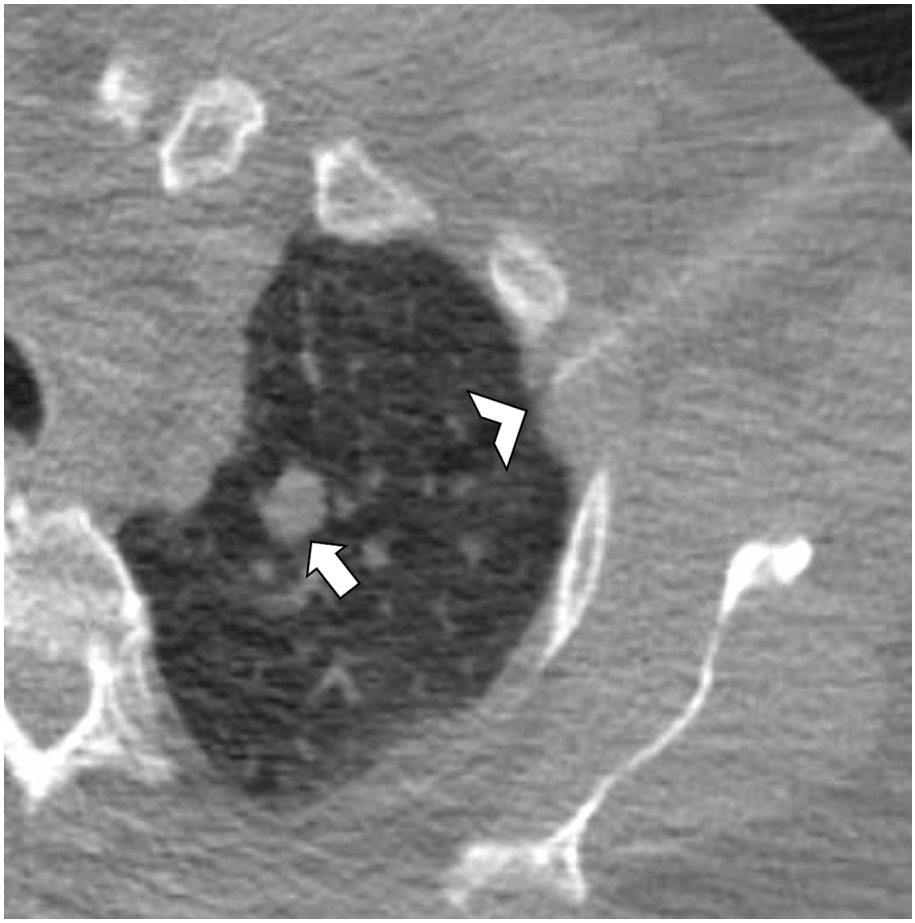

Fig. 3. Anesthesia administration during a CT-guided transthoracic core needle biopsy of a solid nodule located in the left upper lobe (arrow). The needle trajectory was oriented toward the target, and anesthesia was delivered at the pleural surface (arrowhead) without penetrating the lung parenchyma.

favored over fine needle aspiration (FNA) for TTNB due to its numerous advantages. Despite the slightly increased risk of complications [26], CNB allows multiple samplings with a single pleural transgression, offers more consistent pathology interpretation, improves the characterization of small and benign lesions [27,28] and hematologic malignancies [29], and yields a higher proportion of samples suitable for molecular testing [30].

At our institution, a 17-gauge coaxial introducer (5, 10, or 15 cm in length) is typically paired with an 18-gauge semi-automatic Tru-Cut needle. The introducer's path is planned in alignment with the anesthetic needle trajectory and advanced incrementally through the chest wall until it reaches the pleura. In cases with short skin-to-pleura distance, where chest wall stabilization may not be sufficient to secure the introducer, wet gauze or a sterile drape fashioned as a needle holder can

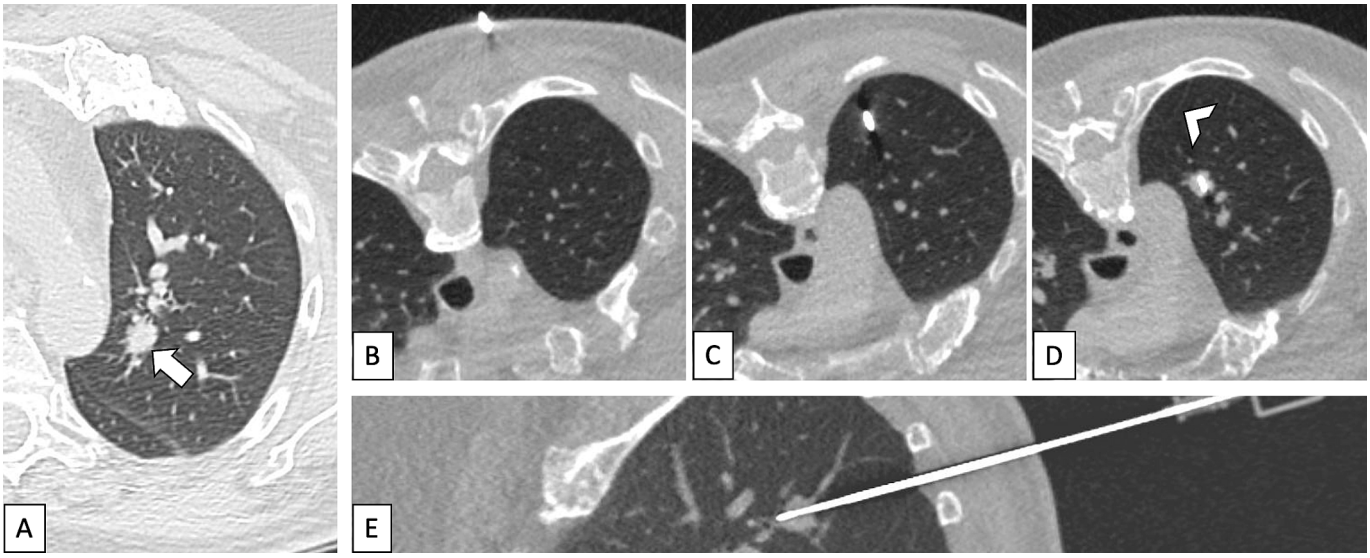

Fig. 4. A-E. CT-guided transthoracic core needle biopsy of a central solid nodule located in the left upper lobe (arrow). B-D. Axial images from the up (B) to the bottom (D) depict an oblique approach, which was adopted to avoid interception of the nearby fissure (arrowhead) and vessels. E. Volumetric acquisition was performed to assess the oblique needle course and proper groove positioning within the lesion. The final diagnosis was lung adenocarcinoma.

Table 1
CT scan parameters for transthoracic needle biopsy.

	Volumetric scanning*	Sequential scanning
Tube voltage (kVp)#	100	80
Tube current (mAs)#	30	30
Rotation time (sec)	0.5	0.5
Pitch	1.0	NA
Slice thickness (mm)	1.0	2.0
Interval (mm)	0.5	2.0
Reconstruction algorithm	Intermediate sharp	Intermediate sharp
Window width§	1600	2300
Window level§	−600	−140
Matrix	512x512	512x512

* Refers to the immediate preprocedural and postprocedural scans. The field of view for the preprocedural scan is usually restricted to the target area, whereas the immediate postprocedural scan includes the entire chest. If an oblique needle approach is necessary, volumetric scans are also performed during the procedure, lowering the tube voltage to 80 kVp and adjusting window width and level as needed.

Adaptation may be needed for overweight and obese patients. Further intraprocedural changes may be performed upon operator judgment.

§ May require intraprocedural adjustments to optimize target and needle visualization.

provide added stability.

When inserting the coaxial needle into the lung, a rapid advancement of at least 1.5–2 cm beyond the pleural surface is recommended to prevent needle slippage back into the pleural space. For subpleural lesions, adequate lung parenchyma should lie between the entry point and the lesion to allow corrective manipulation if needed. If insufficient parenchyma exists, adjustments (for instance, because of target misalignment caused by respiratory motion) may require multiple pleural passes, increasing injury risk. In such cases, transfixing the lesion with the guiding needle, pulling it back to the center of the intended area, and sampling with the cutting needle is one option. Alternatively, the introducer tip can be positioned near the pleura, with the cutting needle advanced directly into the target (Fig. 5). This technique minimizes overshooting the target and reduces the need for pull-back repositioning to align the biopsy groove. A similar approach has been proposed using CT fluoroscopy guidance, achieving a high diagnostic yield for subpleural nodules, even if they are small in dimensions [31]. Despite its advantages of continuous needle monitoring and real-time manipulation in response to respiratory movements, this technique involves increased radiation exposure compared with conventional CT guidance.

Our Tru-Cut needles offer biopsy sample lengths of 20 and 10 mm. The 20 mm length is generally preferred to maximize tissue acquisition, while the 10 mm length is reserved for patients at high risk for cutting vessels near or within the target lesion and to avoid taking large amounts of normal parenchyma when targeting a small lesion. Procedure planning must account for the gap between the inner needle and outer cannula tips in most coaxial needles to avoid unintended overadvancement (Fig. 6). Accurate positioning of the biopsy groove requires careful evaluation of lesion morphology and functional imaging to ensure traversal of viable tissue, particularly in the following scenarios:

- Lesions associated with cystic airspaces or cavitations: Aligning the needle throw with the wall thickening or dominant mural nodule (tangential approach) is preferred [32] (Fig. 7). If the lesion is small and alignment becomes challenging, encompassing the air component within the biopsy groove may still maintain safety and diagnostic accuracy [33,34] (Fig. 8).
- Sub-solid nodules: The most solid component should be included within the biopsy groove (Fig. 9). Accurate needle positioning is crucial, as supervening hemorrhage can obscure the target and hinder additional sampling.
- Heterogeneous masses: Functional imaging can help target the areas of areas with the highest metabolic uptake for sampling (Fig. 10).

Whenever feasible, we aim to collect at least two samples. More core biopsy samples can often be obtained without compromising safety [35]. However, the final number of samples depends on clinical context, lesion characteristics, and procedural complications. Rapid on-site evaluation (ROSE), detailed later in the manuscript, may also affect the number of samples. In high-risk cases or surgical candidates, a single adequate sample may suffice. Conversely, additional samples may be taken for large, easily accessible lesions after ROSE confirmation of specimen adequacy.

6. Complications

Meta-analyses and retrospective studies of large cohorts report

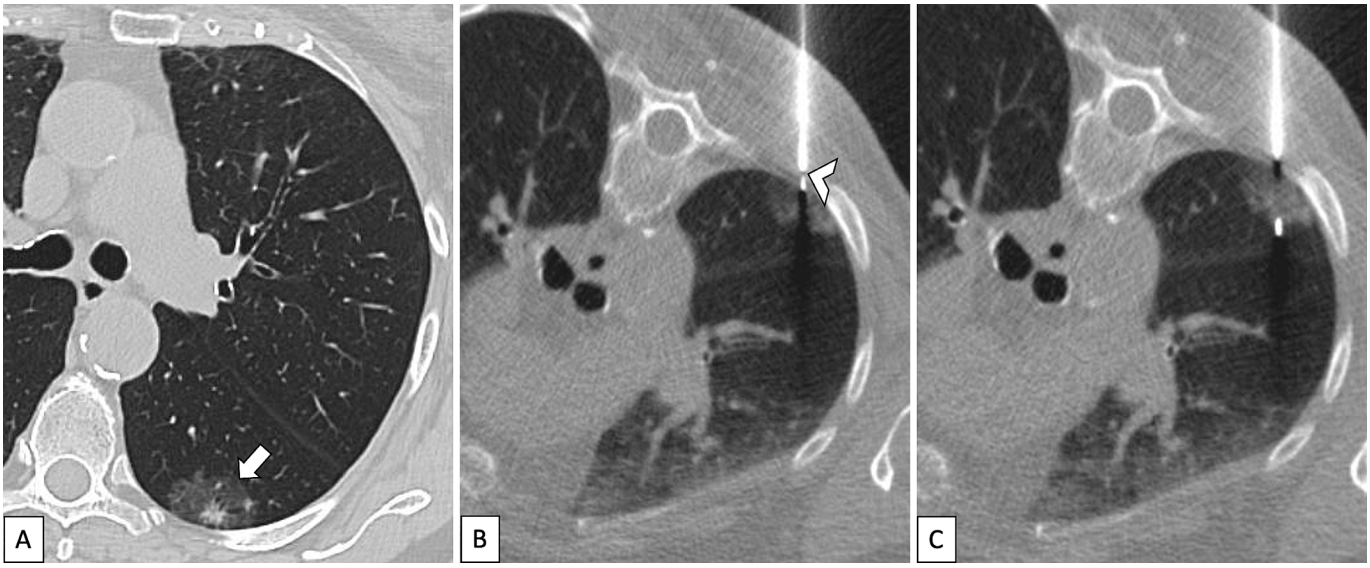

Fig. 5. A-C. CT-guided transthoracic core needle biopsy of a subpleural subsolid nodule located in the left lower lobe (arrow). B. The introducer tip (arrowhead) was positioned near the pleural surface. C. Then, the cutting needle was directly advanced through the pleura into the target, avoiding the need for pull-back repositioning and minimizing the risk of hemorrhage obscuring the target due to coaxial needle introduction into the lung parenchyma. The final diagnosis was lung adenocarcinoma with lepidic growth.

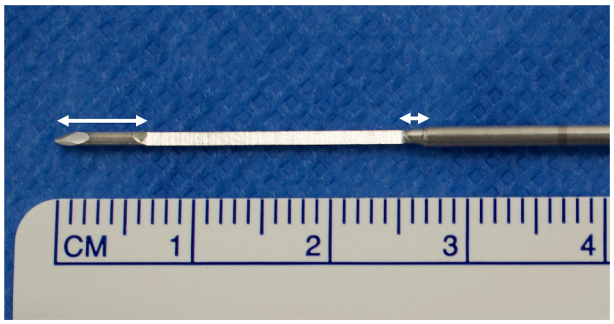

Fig. 6. 18-gauge cutting needle extremity. Operators should be aware of the death spaces (double arrows) that exceed the length of the groove to avoid unintended over-advancement of the needle during the procedure.

pneumothorax incidence of approximately 15–25 % [7,26,36–40], with chest tube placement required in 3–7 % of cases [7,26,39]. Small pneumothoraces during the procedure can be monitored via serial intraprocedural CT scans. If no significant enlargement is noted, and the patient remains clinically stable, tissue sampling may proceed, particularly for pleural-adjacent lesions (Fig. 11). Conversely, manual air aspiration using a tube extension, three-way valve, and 50-mL Luer-lock syringe through the introducer can be effective. Following aspiration, sampling may proceed, followed by a pleural blood patch (autologous blood injection) performed before introducer withdrawal under forced expiration to minimize the risk for chest tube placement [23,41]. Persistent or rapidly recurring pneumothoraces despite intervention necessitate chest tube insertion, with occasional help of thoracic surgeons if needed.

If a significant pneumothorax develops only after introducer removal, the patient is positioned supine, and a 14-gauge 5 cm cannula is used for manual aspiration and pleural blood patching. If this approach fails, chest tube placement is required.

Supplemental oxygen at 4–6 L/min via nasal cannula is administered after pneumothorax detection.

Pulmonary hemorrhage, the most common TTNB bleeding complication, occurs in approximately 20 % of procedures [42] and often does not require intervention. Hemoptysis, occurring in 0.1–1.6 % of cases [37,43], mandates immediate needle removal, patient positioning on the lesion side, and airway clearance via oral suction. Hemoptysis is often self-limiting due to the pulmonary vessels' low-pressure system. Severe bleeding requires bronchoscopy and resuscitation team consultation, possibly leading to intubation.

Hemothorax, a rare complication following TTNB (0.1–0.2 % of cases) [37,42,44], may result from needle interception of extrapulmonary vessels (e.g., intercostal or internal mammary vessels) or from traversing a pulmonary branch, with consequent blood extravasation into the needle tract. Any supervening hemothorax is monitored using serial intraprocedural CT scans, with contrast-enhanced acquisition to identify the bleeding site if rapid progressive enlargement is noted (Fig. 12). Small, self-limiting hemothoraces (<300 mL) are managed conservatively, while larger ones necessitate supportive care and possible thoracic surgeon involvement [45]. In our experience, vessel embolization or urgent thoracotomy are exceedingly rare.

Systemic air embolism, occurring in < 0.1 % of cases [46], is possibly linked to direct air introduction into the pulmonary vein through a hollow biopsy needle or broncho-venous fistula formation [47]. Preventative measures include avoiding the procedure in patients with uncontrolled cough or who are on positive ventilation and favoring ipsilateral decubitus positioning [48,49]. Symptoms range from none to neurological manifestations such as dizziness, aphasia, loss of consciousness, hemiparesis, and cardiac arrest [46]. Management involves supportive care for symptom presentation, oxygen administration, Trendelenburg positioning, and hyperbaric treatment [3,46]. In > 3,000 TTNBs performed at our institution in the past decade, no symptomatic air embolisms have been documented, although asymptomatic cases may be underreported [50].

7. Postprocedural recovery

Following TTNB, patients undergo 2h of continuous vital sign monitoring, followed by chest radiography. If no complications arise, outpatients are discharged on the same day, and inpatients return to their hospital rooms. Both outpatients and inpatients are otherwise managed according to the standard of care.

Given the risks of delayed complications [1,51], outpatients are instructed to contact or return to the hospital if they experience breathlessness, chest pain, or hemoptysis. For patients with severe

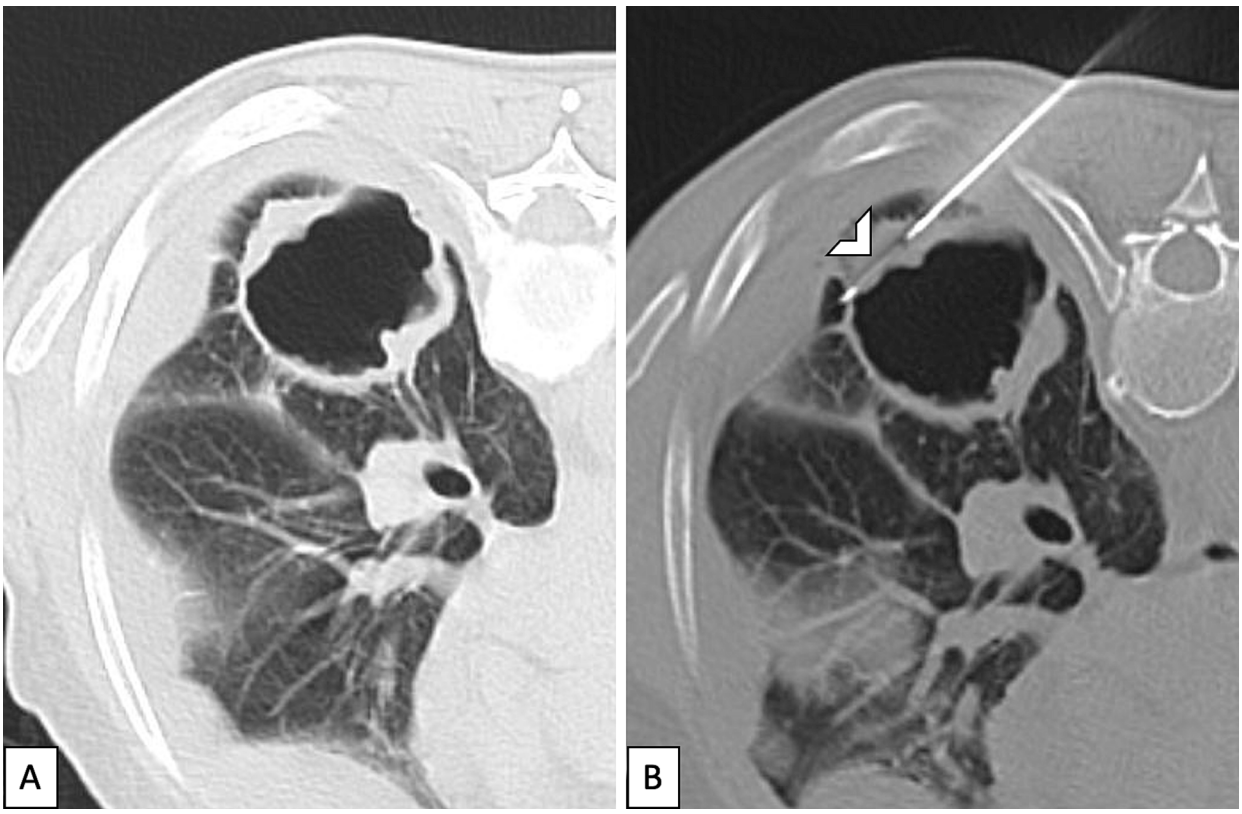

Fig. 7. A-B. CT-guided transthoracic core needle biopsy of a cavitary lesion located in the right lower lobe. B. The biopsy groove (arrowhead) was aligned with the wall thickening to maximize tissue sampling (i.e., tangential approach). The final diagnosis was non-small cell lung cancer favor squamous carcinoma.

comorbidities or inadequate home support, inpatient management is preferred over same-day discharge.

8. ROSE and postprocedural tissue management

In TTNB, ROSE can enhance diagnostic accuracy and optimize successful molecular analyses without compromising safety [52,53]. However, its adoption depends on institutional resources and logistics due to its demands for time, financial resources, and trained personnel. Moreover, ROSE lacks robust statistical evidence of efficacy to support its widespread recommendation.

At our institution, ROSE has been implemented over the last two decades and involves a cytopathologist or well-trained cytotechnologist during sampling, who 1) macroscopically evaluates biopsy specimens, 2) creates touch preparations on a glass slide, 3) rapidly stains the slide, 4) microscopically evaluates cellular adequacy without requiring a precise diagnosis, and 5) provides specimen fixation after touch imprinting by placing the sample between two sponges in a bio-cassette. This is immediately put into a container filled with neutral 10 % buffered formalin to prevent rapid tissue protein and nucleic acid degradation [54] and then transported to the pathology laboratory at room temperature.

9. Final histological evaluation and molecular testing

Diagnostic evaluation follows the latest World Health Organization (WHO) guidelines for thoracic tumors in small biopsy samples [55]. When morphology is not straightforward (e.g., poorly differentiated non-small cell lung cancer), immunohistochemical staining may become necessary to establish a diagnosis. This analysis is performed using small panels to conserve tissue for molecular analysis [54].

The assessment of molecular biomarkers is required in selected cases, such as to inform treatment selection at the time of recurrence or progression [56]. The European Society for Medical Oncology (ESMO) 2024 recommendations prioritize testing the molecular status of at least nine main biomarkers (epidermal growth factor receptor [EGFR], B-Raf proto-oncogene, serine/threonine kinase [BRAF], Kirsten rat sarcoma viral oncogene homolog [KRAS], mesenchymal-epithelial transition factor [MET], erb-b2 receptor tyrosine kinase 2 [ERBB2], anaplastic lymphoma kinase [ALK], ROS proto-oncogene 1, receptor tyrosine kinase [ROS1], rearranged during transfection [RET], and neurotrophic receptor tyrosine kinase [NTRK]) and programmed death-ligand 1 (PD-L1) protein expression. This panel may be extended to include additional markers based on the findings of emerging clinical trials [57]. We typically employ a next-generation sequencing (NGS) panel including 50 genes, with a turnaround time of 4–7 working days between the biopsy and molecular results.

10. Nondiagnostic samples

TTNB has a negative predictive value of only 51 % for diagnosing malignancies [58]. Therefore, nondiagnostic TTNBs, defined as pathologic results that are neither malignant nor specifically benign, require careful evaluation to prevent delayed diagnosis and treatment. At our institution, these nondiagnostic cases are typically reviewed by a multidisciplinary team to determine whether to repeat the procedure, perform excision, or monitor, depending on concern regarding a false-negative result. Key factors in this decision include the pre-test probability of malignancy, confidence in the biopsy groove positioning during sampling, and the potential risks of monitoring versus treatment or re-biopsy. The pathological features of the sample also influence the management of nondiagnostic TTNBs, as the malignancy risk varies across nondiagnostic categories, with a higher risk associated with atypical cells and a lower risk with nonspecific benignities (e.g., granulomatous inflammation) and insufficient specimens [59,60].

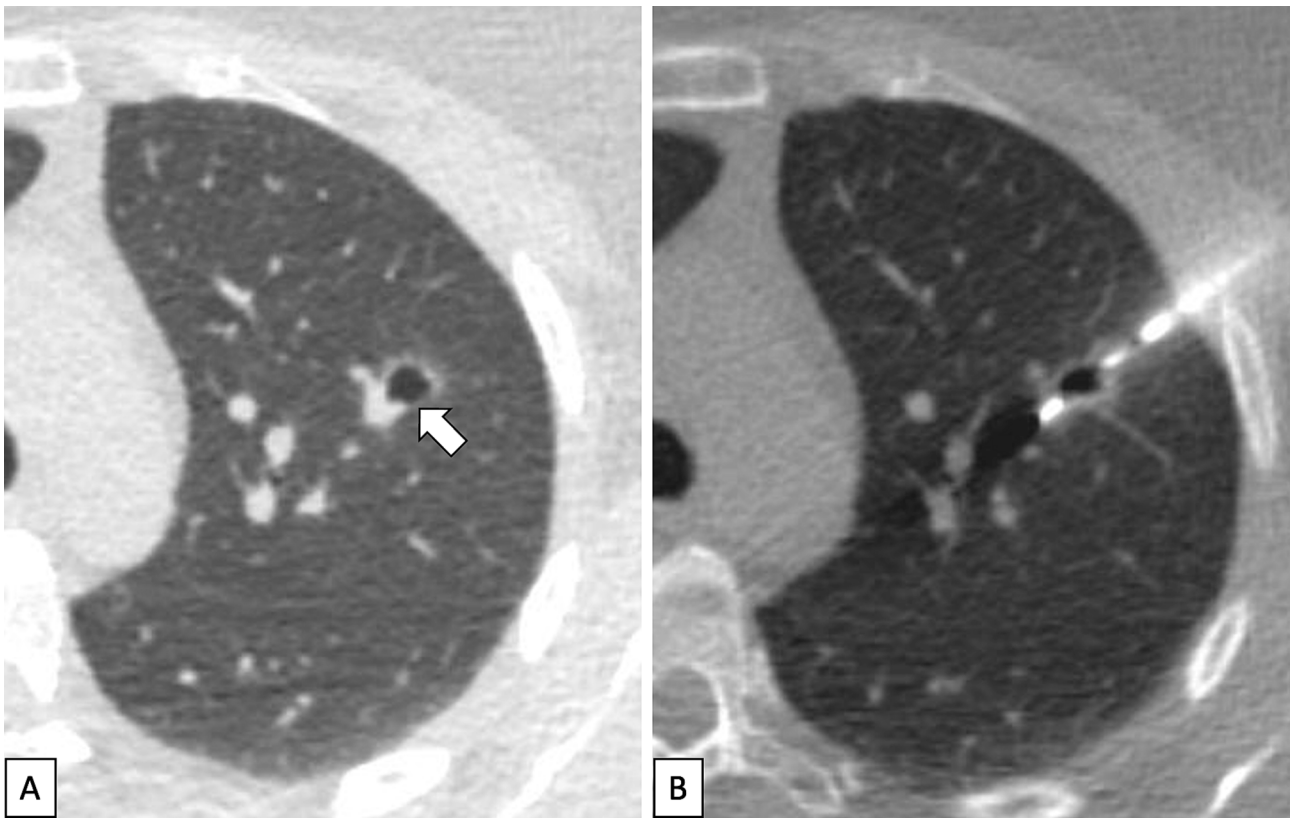

Fig. 8. A-B. CT-guided transthoracic core needle biopsy of unilocular cystic airspace lesion located in the left upper lobe (arrow). B. Given the challenges in adopting a tangential approach due to small lesion dimensions, the lesion was transfixed, including both the circumferential thickening and the airspace within the biopsy groove. The final diagnosis was lung adenocarcinoma.

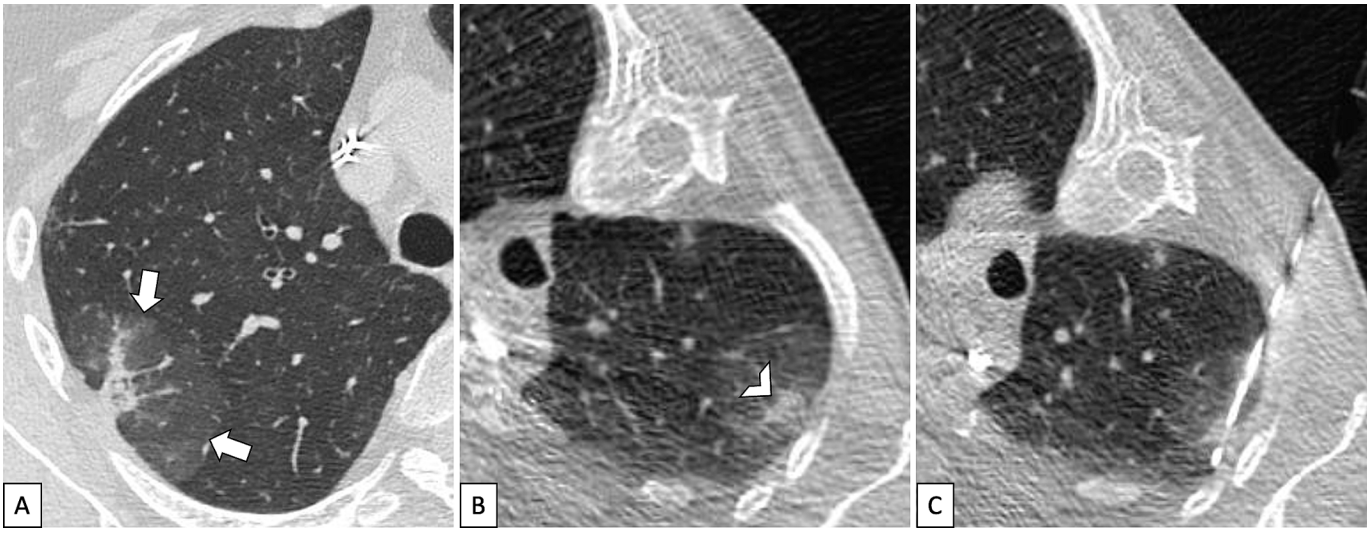

Fig. 9. A-C. CT-guided transthoracic core needle biopsy of a part-solid nodule located in the right upper lobe (arrows). B, C. The patient was positioned with the biopsy-side down, targeting the solid component (arrowhead). The final diagnosis was lung adenocarcinoma with lepidic growth.

11. Future perspectives

Novel methods such as radial endobronchial ultrasound (r-EBUS), virtual bronchoscopy (VB), electromagnetic navigation (EMN), and robot-assisted bronchoscopy (RAB) have improved bronchoscopic sampling of peripheral pulmonary lesions, prompting reconsideration of the role of TTNB [38,61]. Prospective studies are required to clarify the impacts of these technologies [62]. TTNB remains pivotal in complementing bronchoscopy for tissue sampling, driven by the increasing detection of pulmonary nodules and the need for tumor biomarker assessment [63–65]. TTNB offers equal or higher diagnostic yield compared with bronchoscopy, with success rates > 90 % [33,38,66], and requires less expensive equipment. While bronchoscopy is often viewed as safer, TTNB-related adverse events, such as perilesional hemorrhage and self-limiting pneumothorax, typically do not affect patient management [26]. According to existing

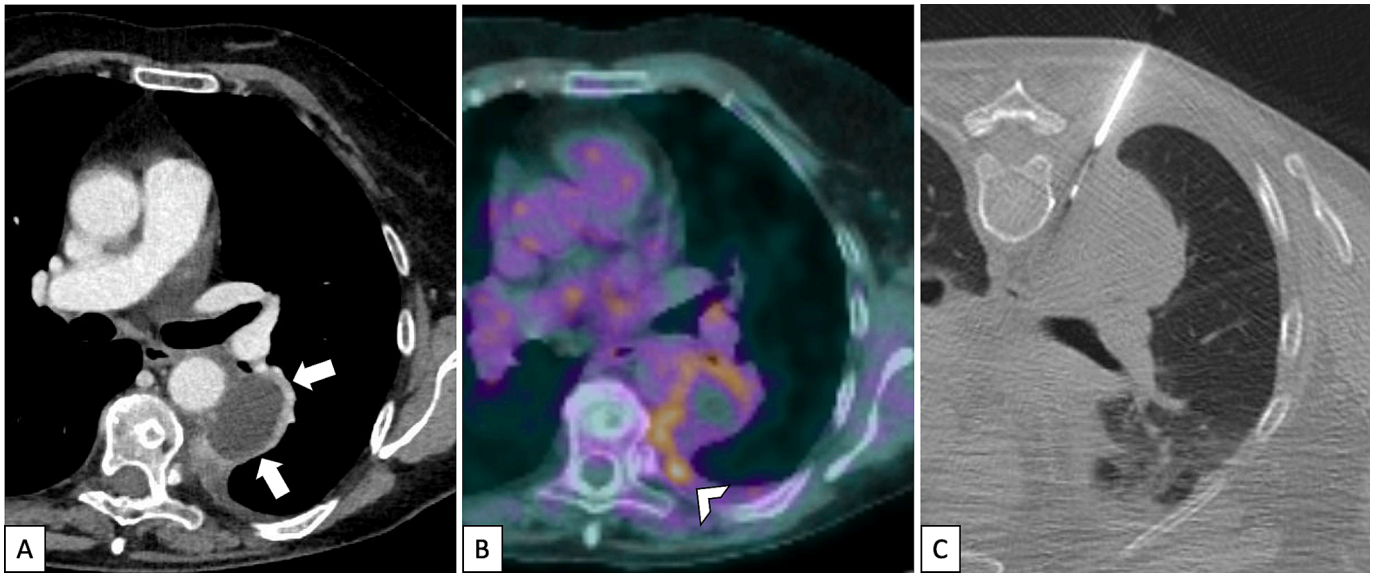

Fig. 10. A. Contrast-enhanced CT of a heterogeneous mass with large hypodense core and peripheral enhancing tissue abutting the left paravertebral region and posterior mediastinum (arrows). B. 18^{F}-FDG PET/CT showed abnormal peripheral metabolic activity (arrowhead), suspected of malignancy. C. The patient was referred for CT-guided transthoracic needle biopsy. The procedure was performed by comparing contrast-enhanced CT, functional imaging, and intraprocedural plain low-dose scans side by side to target the area with the highest metabolic uptake. The biopsy suggested epithelioid mesothelioma, later confirmed by surgery.

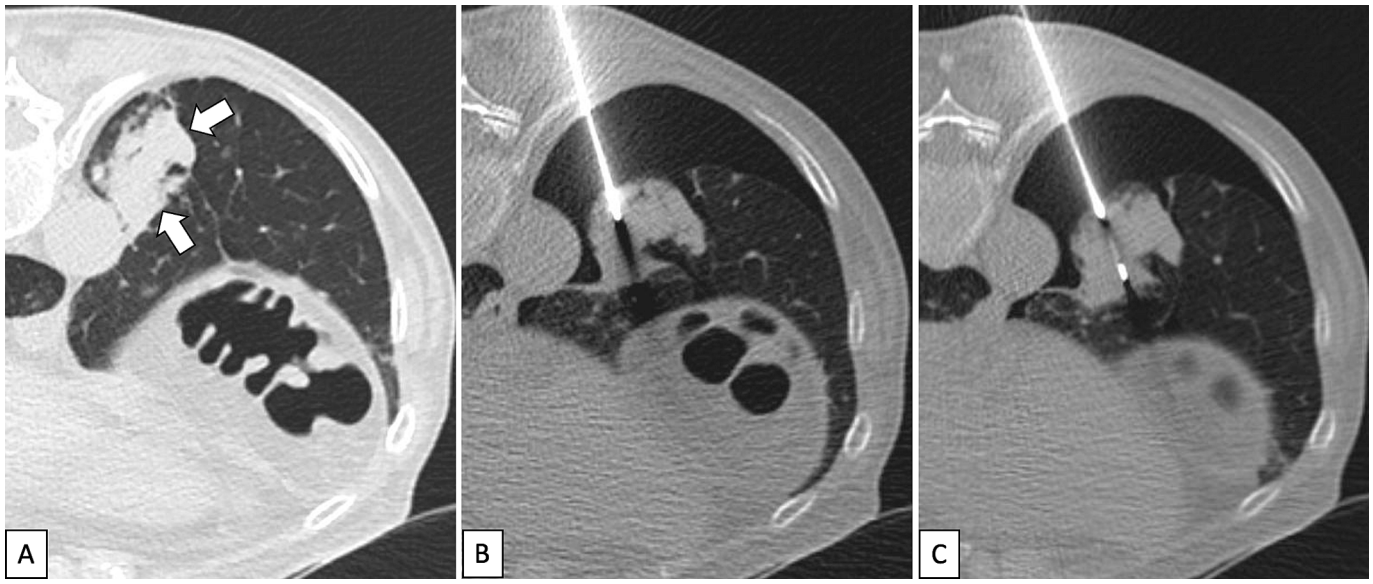

Fig. 11. A-C. CT-guided transthoracic core needle biopsy of a left lower lobe mass (arrows). B, C. A pneumothorax occurred after the coaxial needle introduction yet remained substantially stable over the course of the procedure, enabling proper groove positioning and successful sampling. The final diagnosis was lung adenocarcinoma.

recommendations [67], future studies may classify these events as expected procedure-related occurrences rather than true complications, thus mitigating long-standing concerns regarding TTNB safety.

Advances in TTNB technologies, including navigation systems and fusion techniques [68–70], may assist target lesions otherwise challenging to sample using conventional guidance, such as those that require an oblique approach or where viable tissue is unevenly distributed. These methods could enhance TTNB's diagnostic performance while maintaining safety and minimizing radiation exposure. However, further research is needed to assess their impact and feasibility in clinical practice.

12. Conclusions

TTNB remains essential for diagnosing pulmonary lesions. Radiologists play a key role in multidisciplinary teams regarding patient selection, evaluating TTNB feasibility, and planning procedures to maximize tissue sampling while ensuring patient safety. Collaboration with specialists is essential for managing complications and handling tissues appropriately. Careful revision of the procedure, along with a comprehensive assessment of the pre-test probability of malignancy and sample pathologic characteristics, is key to avoiding delayed treatment and diagnosis in nondiagnostic TTNBs.

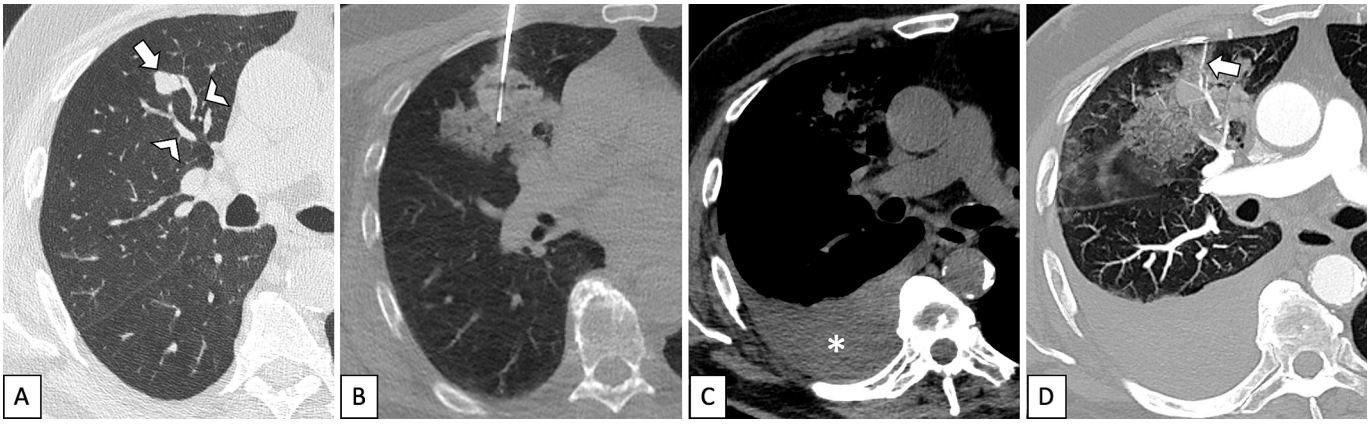

Fig. 12. A-D. CT-guided transthoracic core needle biopsy of solid nodule located in the right upper lobe (arrow in A), surrounded by vessels (arrowheads). B. The needle transfixed the lesion and intercepted adjacent vessels, with consequent circumscribed parenchymal hemorrhage. C. After needle removal, a hemothorax rapidly accumulated (asterisk). D. A contrast-enhanced CT was immediately performed to identify the site of bleeding, depicting active blood extravasation along the needle tract (arrow) into the pleural space. The biopsy revealed poorly differentiated non-small cell carcinoma, not otherwise specified.

CRediT authorship contribution statement

Maurizio Balbi: Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Conceptualization. **Luisella Righi:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Conceptualization. **Noemi Cristina Culasso:** Writing – review & editing, Writing – original draft, Visualization, Methodology. **Marta Bignoli:** Writing – review & editing, Visualization. **Rouslan Senkeev:** Writing – review & editing, Visualization. **Ludwig Federico Garello:** Writing – review & editing, Visualization. **Damiano Carota:** Writing – review & editing, Writing – original draft, Visualization. **Simona Sobrero:** Writing – review & editing, Visualization, Methodology. **Silvia Novello:** Writing – review & editing, Supervision, Methodology. **Andrea Veltri:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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