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ORIGINAL ARTICLE

Comparison of Computed Tomography and Ultrasonography as A Guide Method in 20-Gauge Transthoracic Fine Needle Biopsies

Ayla Türkar

Department of Radiology, Sureyyapasa Chest Diseases and Thoracic Surgery Training and Research Hospital, İstanbul, Türkiye

Abstract

Introduction: The goal of this study is to compare computed tomography (CT) and ultrasonography (USG) in transthoracic biopsies as a guide method.

Methods: A total of 152 patients, consisting of 121 men and 31 women, underwent a 20-Gauge (20-G) fine needle aspiration biopsy. CT in 83 patients and USG in 69 patients were chosen as the guide method. The mean age of the patients was 66±10 (CT guidance group was 67±9, USG guidance group was 64±11), and the median lesion size was 65 mm (interquartile range [IQR] 45-80 mm). All lesions were chosen pleural-based and larger than 2 cm. Thus, the risks of major complications, especially pneumothorax and hemorrhage, and the difficulties in reaching the lesion were minimized, and it was aimed to investigate the contribution of the chosen guide method to the diagnosis. The advantages and disadvantages of both techniques were investigated.

Results: While CT-guided biopsies had a diagnostic accuracy rate of 87.9%, a sensitivity of 87.3%, and a specificity of 100%, USG-guided biopsies had a diagnostic accuracy rate of 82.6%, a sensitivity of 82.1%, and a specificity of 100%.

Discussion and Conclusion: The necrosis content of the lesion is the primary factor reducing the success rate of both techniques. It causes more failures under ultrasonography guidance.

Keywords: Computed tomography; Transthoracic biopsy; Ultrasonography.

Lung cancer is the most common cancer in men and the second most common cancer in women after breast cancer, which is responsible for %18 of all cancer-related deaths [1]. After the suspected lesion is detected, a correct diagnosis is very crucial for effective treatment. There are several well-defined and accepted methods such as mediastinoscopy, endobronchial ultrasonography, and bronchoscopy which are primarily preferred for centrally located masses, and transthoracic needle biopsy for peripherally located masses to make an accurate and safe diagnosis.

Transthoracic needle biopsies, a highly successful and conventional method in diagnosing lung lesions, have been used for decades and were first described by Nordenström B. in 1965 [2]. Today, the most common guiding methods used by interventional radiologists are computed tomography (CT), ultrasonography (USG), and fluoroscopy. The most common and well-known complications related to the procedure are pneumothorax and hemorrhage [3]. There are also findings showing that pneumothorax and chest tube placement rates can be reduced with methods such as intraparenchymal blood patches added to the

Correspondence: Ayla Türkar, M.D. Department of Radiology, Sureyyapasa Chest Diseases and Thoracic Surgery Training and Research Hospital, İstanbul, Türkiye
Phone: +90 216 421 42 00 **E-mail:** aylack2002@yahoo.com
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standard procedure in recent years [4,5].

It is known that cavitation and necrosis in lung lesions reduce the accuracy of transthoracic needle biopsy results. In lesions with these features, the literature findings on the diagnostic results of CT and USG guidance are limited. There are various opinions about the success of the guide method. The effects of factors such as lesion size, presence of necrosis, and distance from pleura on the diagnosis are frequently investigated. In addition, when choosing a fine needle or core biopsy, both have advantages and disadvantages. Moreover, the thickness of the needle can be another factor affecting success.

Materials and Methods

This retrospective and single-center study was conducted on 152 patients in the Radiology Clinic of Süreyyapaşa Chest Diseases and Thoracic Surgery Training and Research Hospital between 2019-2022. Since the study is retrospective, there is no requirement for an informed consent form. The ethics committee report approved by the hospital with protocol code 116.2017.R-246 is available. This study was conducted in accordance with the Declaration of Helsinki.

Patients: All patients with lung lesions who had consulted the radiologist for transthoracic fine needle biopsy (TTFNB) procedure for diagnosis were included in the study.

Interventions: TTFNB with a 20-G needle.

Radiologist: All features of lesions such as size, necrosis, and cavitation existence were evaluated, and all biopsies were performed by the same interventional radiologist with 5-8 years of experience.

Guidance decision of USG and CT definition: CT images of all patients were evaluated before the biopsy. PET/CT images were out of the evaluation. Thoracic USG control for the suspicious lesion was performed by the same radiologist. While on CT images, the necrotic area is detected as a lower density than the lesion, USG shows a heavy content cystic area without vascularization. Needle biopsy from areas with these features was avoided. Although it is pleural-based, CT was chosen as the guiding method to provide better anatomical orientation since 7 patients required intervention with a long trace through lateral due to scapular superposition (Fig. 1). While CT is mainly chosen as the guiding method in lesions smaller than 3 cm (3:1), USG is primarily preferred in lesions larger than 7 cm (2.5:1). Thus, while the guide method of 55 patients was selected according to partial selection bias, the method to be used in the other 97 patients was determined randomly.

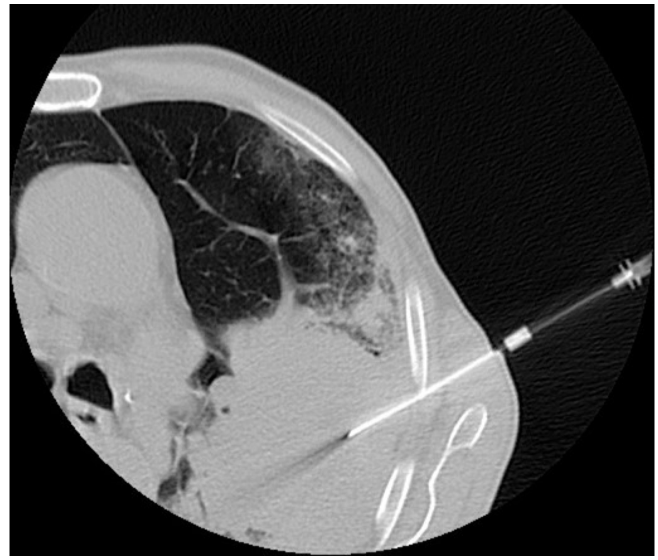

Figure 1. The gross lesion was diagnosed as squamous cell carcinoma, and a CT-guided biopsy was performed because adequate sonographic orientation could not be achieved due to the scapula, although it was pleural-based.

In this research, only pleural-based lesions larger than 2 cm were included to focus on the diagnostic contribution of the selected guide method. Thus, the purpose of this research is to select the most appropriate guide method for each patient according to factors such as the presence of necrosis and cavitation, lesion size, and location by minimizing the possibility of major complications and the difficulties in reaching the lesion.

16-MDCT (Toshiba Medical Systems, Tokyo, Japan) or 128-MDCT (Philips Medical Systems, Amsterdam, Netherlands) were used in CT-guided biopsies, and images with a cross-sectional thickness of 4 mm were obtained. In some patients, 2 mm slice thickness was used for additional imaging in cases such as narrow intercostal space or proximity to major structures. A Mindray ultrasonography device (Mindray Medical Systems, Shenzhen, Guandong, China) was used in USG-guided biopsies. In both methods, first of all, patients were placed in a supine or prone position according to the location of the lesion. No sedation was applied. Pain control was achieved by applying 5-10 ml of local anesthetic only to the area where the intervention was planned, starting from the skin towards the pleura. A 100 or 150 mm long 20-G fine needle (Chiba) was used in all lesions, and only one intervention was performed. After the material was placed in a %20 formol-alcohol mixture, three pathologists in our hospital made a randomized evaluation. The on-site pathologist did not accompany the team during the procedure.

Malignant pathology reports in which subtype could be performed or could not be performed but could be detected as small cell or non-small cell carcinoma, and benign pathology reports including infection findings were considered successful procedures.

Statistical Analysis

The Statistical Package for Social Sciences (SPSS) version 20.0 software (IBM Corp.; Armonk, NY, USA) was used. Patients' demographics and all clinical data were summarized using descriptive analysis. Student's T-test, used for continuous variables (i.e., age), showed that they were distributed normally in both groups. The results obtained from the Student's T-test were reported as mean±standard deviation (S.D.). If the groups were distributed non-normally, the nonparametric Mann-Whitney U test and Kolmogorov-Smirnov test were used, and the results obtained were reported as median and interquartile range. Dichotomous values (gender, tumor size group, diagnostic presence, type of lesion characteristics [cavity, necrosis, both cavity and necrosis]) were compared using the chi-squared test. If n was below 5, Fisher's exact test was used, and values were reported as numbers and percentages. Patients were grouped according to CT or USG guidance and diagnostic presence or absence. Two groups were compared according to recorded values. Multi-logistic regression analysis was done to define the diagnostic findings. Statistically significant variables were included in the model following univariate analysis. P-value<0.05 was accepted as statistically significant.

Results

The mean (±standard deviation) age of CT-guided and USG-guided groups were 67±9 versus 64±11, p=0.15 respectively. Median size of lesions were 65 mm (IQR; 45-80) with a minimum of 22 mm and a maximum of 140 mm. The median size of CT-guided lesions were 52.5 mm (IQR; 40-75), while USG-guided lesions were 75 mm (IQR; 50-90). In both groups, two lesions were in the form of consolidation and those were excluded when calculating the median values of lesion size. Of the 83 lesions in which CT-guided transthoracic fine needle aspiration biopsy was performed, 69 were diagnosed as malignant, and the pathology results of 10 patients were not diagnostic. Of 69 lesions performed with USG-guided biopsy, 55 were found to be malignant, and the pathology results of 12 patients were not diagnostic. The lesion was reported as infective in 4 patients with CT-guided biopsy and 2 patients with USG-guided biopsy, and they were included in the correctly diagnosed group. The pathology result of one of the USG-guided biopsies was reported as histiocytic cells and was diagnosed with histiocytosis X after lobectomy. Another patient whose pathology was reported as necrotic debris and caseous necrosis was diagnosed with vasculitis after further examination. Although the biopsy results led to the diagnosis in these two patients, they were included in the unsuccessful procedure group since the definitive diagnosis could not be made. In a patient who underwent USG-guided biopsy and reported squamous cell carcinoma, the pathological diagnosis was corrected as adenocarcinoma after segmentectomy, and the subtype was misdiagnosed with a fine needle.

Comparisons of patients according to demographic characteristics and tumor location are shown in Table 1.

In both groups, 20 of the pathology results of 22 non-diagnostic lesions were later found to be malignant by other methods such as wedge biopsy, mediastinoscopy, and lobectomy. One lesion was diagnosed as histiocytosis X, and one lesion was diagnosed as vasculitis. Of the 10 undiagnosed lesions under the CT guidance, 5 had necrosis, one had cavitation, and one was hard and fibrotic.

Table 1. Patients' comparisons according to demographics and tumor locations

	Computed Tomography, N=83	Ultrasonography, N=69	p
Sex, Male, n (%)	70 (15.7)	51 (73.9)	0.11
Age over 65, n (%)	51 (61.4)	38 (55.1)	0.43
Lesion size above 3 cm, n (%)	68 (81.9)	64 (92.8)	0.049
Right lung, n (%)	47 (56.6)	32 (46.4)	0.21
Lower lobe locations, n (%)	33 (39.8)	35 (20.3)	0.18
Pneumothorax, n (%)	2 (2.4)	0	-

Table 2. Diagnostic performance of transthoracic fine needle biopsy when presence of cavity-necrosis, cavity, and necrosis alone by using guidance of computerized tomography and ultrasound scanner.

	Computed Tomography, N (%)	Ultrasonography, N (%)
Non diagnostic Results	N=10	N=12
Cavity and necrosis	1 (10.0)	2 (16.6)
Cavity	1 (10.0)	2 (16.6)
Necrosis	5 (50.0)	10 (83.3)
Diagnostic Results	N=73	N=57
Cavity and necrosis	9 (12.3)	2 (3.5)
Cavity	13 (17.8)	5 (8.7)
Necrosis	22 (30.1)	14 (19.1)

There was no necrosis or cavitation in the other 3 lesions. Of the 12 undiagnosed lesions under USG guidance, 10 had necrosis and 2 had cavitation (Table 2), as one of the lesions containing cavitation belonged to the patient who was later diagnosed with vasculitis. One lesion without necrosis or cavitation belonged to the patient who was later diagnosed with histiocytosis X.

According to the current findings; accuracy, sensitivity, and specificity for CT-guided fine needle biopsies were 87.9%, 87.3%, and 100%, respectively, while they were 82.6%, 82.1%, and 100% for those guided by USG.

The presence of necrosis in undiagnosed lesions was 68.1%, while this rate was 27.6% in diagnosed lesions. It is seen that the presence of necrosis in the lesion significantly reduces the success of diagnosis. While there was 50% necrosis in CT-guided unsuccessful procedures, this rate was 83.3% in USG-guided unsuccessful procedures.

The presence of cavitation was 13.6% in undiagnosed lesions, 12.8% in diagnosed lesions, and the presence of both necrosis and cavitation was 13.6% and 8.4% in undiagnosed and diagnosed lesions, respectively.

Minimal pneumothorax was developed in only 2 biopsies performed under CT guidance as a complication and no chest tube placement or treatment was required, while no complication was developed under USG guidance. Since the parenchyma was not passed, no major hemorrhage developed in either guide method.

Table 3. Comparing the patients according to diagnosis obtained from transthoracic fine needle biopsy.

	Diagnosis		p
	Absent, N=22	Present, N=130	
Male, N (%)	18 (81.8)	103 (79.2)	0.78
Guidance of TTFNB, N (%)			
CT	10(45.5)	73(56.2)	0.35
USG	12(54.5)	57(43.8)	
Age over 65, N (%)	12 (54.5)	77 (59.2)	0.68
Lesion size over 3 cm, N (%)	20 (90.9)	112 (86.2)	0.54
Left lung lesions, N (%)	7 (31.8)	66 (50.8)	0.10
Right lung lesions, N (%)	15 (68.2)	64 (49.2)	
Lower lobe lesions N (%)	13 (59.1)	55 (42.3)	0.14
Lesion nature, N (%)			
Cavity	3 (13.6)	18 (13.8)	>0.99
Necrosis	15 (68.2)	36 (27.7)	<0.001
Cavity and Necrosis	3 (13.6)	11 (8.5)	0.43

TTFNB: Transthoracic fine needle biopsy; CT: Computed tomography; USG: Ultrasonography.

Table 4. Logistic regression of the factors affecting the non-diagnostic lung pathologies by transthoracic fine needle biopsy (enter method)

	Odds Ratio	95% Confidence Interval		p
		Lower	Upper	
Male gender	1.05	0.28	3.87	0.94
Age < 65	1.80	0.63	5.14	0.27
USG guided TTFNB	1.41	0.50	3.99	0.52
Presence of necrosis	5.74	2.04	16.18	0.001
Lesion present right side	2.68	0.93	7.74	0.07
Lesion present lower lobe	2.07	0.75	5.70	0.16
Lesion size < 3 cm	0.92	0.16	5.33	0.92

USG: Ultrasonography; TTFNB: Transthoracic fine needle biopsy.

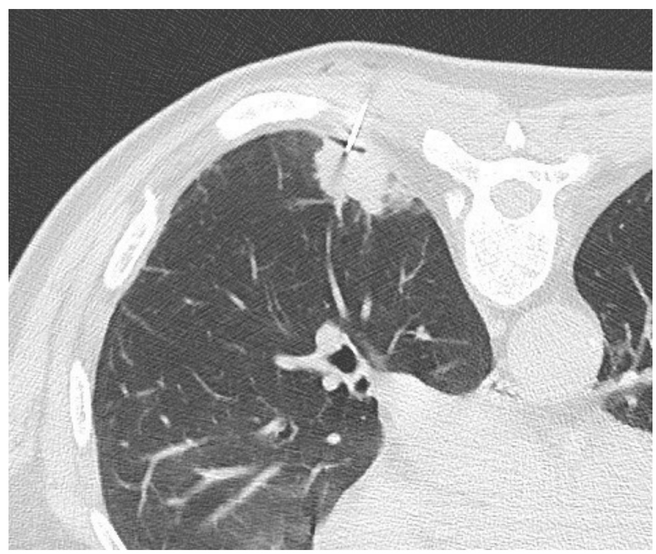

Figure 2. Minimal pneumothorax due to respiratory movement despite being pleural-based.

Discussion

The advantages and disadvantages of both CT and USG as guiding methods will be discussed. The findings of this study revealed that when adequate anatomical orientation can be obtained through sonography, USG guidance should be favored to protect the patient from unnecessary radiation exposure. In situations where reaching the lesion will be difficult, better anatomical orientation is required, and necrosis or cavitation is present, CT guidance is more appropriate to reduce the risk of potential complications and improve diagnosis.

A definitive pathological diagnosis is required for the determination of treatment protocols in lung cancers. Needle biopsies are frequently preferred due to their high

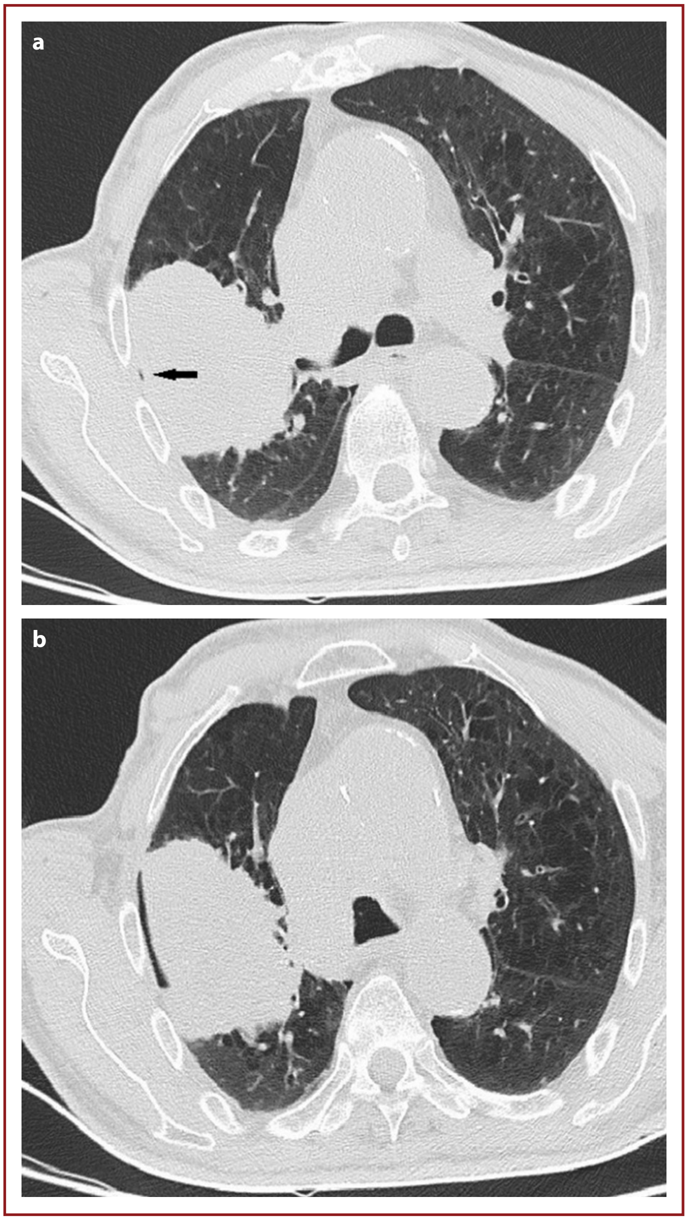

Figure 3. (a, b) Millimetric bleb (arrow) despite having a wide pleural-base **(a)**. Self-limiting pneumothorax after TTFNB **(b)**.

contribution to the diagnosis and acceptable complication rates. Correct selection of the guide method, fine needle or core needle, and needle thickness to be used are important in terms of diagnostic accuracy and complication rates [6,7]. However, only fine needle biopsies with a 20-G needle thickness were included in this study.

The most common complication of TTFNB is pneumothorax if the lesion is not pleural-based, and chest tube insertion may be required if it is large and symptomatic. Another common complication is hemorrhage. Rarely, air embolism, needle track metastasis, and death can be seen [8]. In the study by Soylemez Wiener et al. [9], the rate of pneumothorax due to the procedure was 15-25%, while the need for chest tube insertion was 4-6%, and the rate of severe hemorrhage was found to be about 1%, except for the hemorrhage in the needle tract, which is frequently seen. In the study of Boskovic et al., [10] the rate of pneumothorax was reported as a wide range of 9-54%. While the diagnostic success of fine needle and core needle biopsy are close to each other in some studies [11], the core needle is found to have higher accuracy in some studies [12]. On the contrary, studies show that fine needle biopsies have fewer complications and higher accuracy rates than core needle biopsies if the procedure is accompanied by a pathologist [13]. In addition, the selected needle thickness in the procedure can be a determining factor in both diagnosis and complication rates. In a study by Kuban et al., [14] it was determined that the risk of pneumothorax increased when the needle thickness increased. In a study by Moore et al.,[15] no significant difference was found between the risk of complications and needle thickness. In addition, the increase in needle thickness did not increase the diagnostic accuracy. However, in that study, a pathologist accompanied for cytological evaluation during the procedure, and while the requirement for multiple passes is higher in needles with less thickness, one pass was mostly sufficient in biopsies performed with 18-G needles. The size of the lesion is also one of the main factors determining diagnostic success. While the diagnosis rate is low and the risk of complications is high in nodules smaller than 1 cm [16], the diagnostic accuracy increases significantly in nodules larger than 1 cm [17]. Particularly, lesions larger than 3 cm are a predictor of diagnostic success [18]. In our study, a lesion smaller than 3 cm does not seem to decrease the chance of diagnosis (Tables 3 and 4). Although there are studies suggesting CT, because it is difficult to reach small lesions with USG, Jarmakani et al. [19] state that there is no correlation between lesion size and diagnostic accuracy in terms of USG and CT guidance.

Similarly to the literature, it is found that the main factor reducing diagnostic success was the presence of necrosis. The presence of necrosis reduces the success rate in both methods ($p<0.001$). Especially when USG is chosen as the guiding method, it is thought to be the main factor in the lower accuracy and sensitivity ratio compared to CT since it can be radiologically more difficult to distinguish between viable and necrotic tissue. For this reason, CT may be more appropriate as the guide method to be chosen in necrotic masses. However, the lower chance of success in USG-guided biopsies may also be due to the higher median size of the lesions than CT-guided lesions.

Because it is expected that the content of necrosis is much more in large malignant tumors. On the contrary, there are some studies stating that USG is more successful because it provides real-time imaging in the presence of necrosis [20]. In another study, the accuracy and sensitivity of USG were found to be higher than CT in pleural-based lesions, especially if the lesion size is large and the length of the mass contacting the pleura (lesion-pleura contact arc length) is more than 4 cm. However, in this study, thicker needles were used in USG-guided procedures compared to CT-guided procedures [21].

In our study, CT was found to have greater accuracy and sensitivity than USG, with respective values of 87.9%, 87.3% for CT, and 82.6%, 82.1% for USG. Similarly, in a comprehensive meta-analysis study, CT guidance was found to be superior to USG, and the accuracy and sensitivity of CT were 92.1%, while the accuracy and sensitivity of USG were reported as 88.7% and 91.5% [22].

Pneumothorax is an extremely rare complication in pleural-based lesions. In our study, minimal pneumothorax was developed in 2 cases which were both performed under CT guidance, and a chest tube placement was not needed. One of them was smaller than 3 cm, while the other was larger than 7 cm. The reason for this was that the parenchyma was traversed due to the respiratory movement during the pass of the needle in the small lesion (Fig. 2), while the subpleural millimetric air cyst was accompanied by the larger lesion (Fig. 3).

Pneumothorax did not develop in any of the USG-guided procedures. The reason for this was thought to be an advantage that parenchymal transition could be avoided since respiratory movement could be seen in real-time with USG. Similarly, Lee et al. [23] reported that USG is safer and has a lower complication rate in peripheral lesions larger than 1 cm. However, in smaller lesions or especially if the length of the lesion contacting the pleura is narrow, it was thought that it would be safer to prefer CT guidance primarily. In addition, CT is preferred in lesions where access is restricted due to rib or scapula superposition, and in lesions close to vital structures such as the aorta and pulmonary artery, to provide better anatomical orientation, while in suitable lesions, it may be more appropriate to try USG-guided biopsy first to protect the patient from exposure to radiation due to the procedure.

The study has some limitations. First, it is a single-center study and has a retrospective nature. However, the center where the study was conducted is one of the biggest chest diseases research hospitals and all patients in the study were generalizable, even though the sample size is not large enough. Secondly, although the randomized selection was applied to a large extent when allocating patients for CT or USG guidance, the selection of the radiologist according to the known literature data was based on lesion size and localization, which may lead to selection bias in some patients. Beyond that, TTFNB already has basic criteria that radiologists have to follow up in addition to the selection of CT and USG guidance.

Conclusion

This study showed that diagnostic accuracy and sensitivity are slightly higher in CT-guided transthoracic fine needle aspiration biopsies than in USG-guided. Therefore, the guide method to be chosen should be decided after a detailed evaluation for each lesion, and the most appropriate method should be selected.

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Ethics Committee Approval: This retrospective and single-center study was conducted on 152 patients in the Radiology Clinic of Sureyyapasa Chest Diseases and Thoracic Surgery Training and Research Hospital between 2019-2022. Since the study is retrospective, there is no requirement for an informed consent form. The ethics committee report approved by the hospital with protocol code 116.2017.R-246 is available. This study was conducted in accordance with the Declaration of Helsinki.

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References

1. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, et al. Global cancer statistics 2020: GLOBOCAN Estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin 2021;71:209–49. [CrossRef]
2. Nordenström B. A new technique for transthoracic biopsy of lung changes. Brit J Radiol 1965;38:550–3. [CrossRef]
3. Yeow KM, Su IH, Pan KT, Tsay PK, Lui KW, Cheung YC, et al. Risk factors of pneumothorax and bleeding: Multivariate analysis of 660 CT-guided coaxial cutting needle lung biopsies. Chest 2004;126:748–54. [CrossRef]
4. Wagner JM, Hinshaw JL, Lubner MG, Robbins JB, Kim DH, Pickhardt PJ, et al. CT-guided lung biopsies: Pleural blood patching reduces the rate of chest tube placement for postbiopsy pneumothorax. AJR Am J Roentgenol

2011;197:783–8. [CrossRef]
5. Malone LJ, Stanfill RM, Wang H, Fahey KM, Bertino RE. Effect of intraparenchymal blood patch on rates of pneumothorax and pneumothorax requiring chest tube placement after percutaneous lung biopsy. AJR Am J Roentgenol 2013;200:1238–43. [CrossRef]
6. Chae KJ, Hong H, Yoon SH, Hahn S, Jin GY, Park CM, et al. Non-diagnostic results of percutaneous transthoracic needle biopsy: A Meta-analysis. Sci Rep 2019;9:12428. [CrossRef]
7. Lima CD, Nunes RA, Saito EH, Higa C, Cardona ZJ, Santos DB. Results and complications of CT-guided transthoracic fine-needle aspiration biopsy of pulmonary lesions. J Bras Pneumol [Article in Portuguese] 2011;37:209–16. [CrossRef]
8. Chung T. Fine needle aspiration of the solitary pulmonary nodule. Semin Thorac Cardiovasc Surg 2002;14:275–80. [CrossRef]
9. Wiener RS, Wiener DC, Gould MK. Risks of transthoracic needle biopsy: How high? Clin Pulm Med 2013;20:29–35. [CrossRef]
10. Boskovic T, Stanic J, Pena-Karan S, Zarogoulidis P, Drevelegas K, Katsikogiannis N, et al. Pneumothorax after transthoracic needle biopsy of lung lesions under CT guidance. J Thorac Dis 2014;6(Suppl 1):99–107.
11. Calle ASM, Navarro N, Inchaurraga I, Furest I, Lera B, Moragon EM. CT-guided transthoracic fine-needle aspiration vs core needle biopsy in diagnosis of lung cancer: A retrospective comparison of diagnostic accuracy. Eur Respir J 2016;48:PA3860
12. Anzidei M, Porfiri A, Andrani F, Di Martino M, Saba L, Catalano C, et al. Imaging-guided chest biopsies: Techniques and clinical results. Insights Imaging 2017;8:419–28. [CrossRef]
13. Capalbo E, Peli M, Lovisatti M, Cosentino M, Mariani P, Berti E, et al. Trans-thoracic biopsy of lung lesions: FNAB or CNB? Our experience and review of the literature. Radiol Med 2014;119:572–94. [CrossRef]
14. Kuban JD, Tam AL, Huang SY, Ensor JE, Philip AS, Chen GJ, et al. the effect of needle gauge on the risk of pneumothorax and chest tube placement after percutaneous computed tomographic (CT)-guided lung biopsy. Cardiovasc Intervent Radiol 2015;38:1595–602. [CrossRef]
15. Moore W, Sawas A, Lee C, Ferretti J. Needle gauge and cytological yield in CT-guided lung biopsy. Int Sch Res Notices 2011;2011:970813. [CrossRef]
16. Ng YL, Patsios D, Roberts H, Walsham A, Paul NS, Chung T, et al. CT-guided percutaneous fine-needle aspiration biopsy of pulmonary nodules measuring 10 mm or less. Clin Radiol 2008;63:272–7. [CrossRef]
17. Ohno Y, Hatabu H, Takenaka D, Higashino T, Watanabe H, Ohbayashi C, et al. CT-guided transthoracic needle aspiration biopsy of small (< or=20 mm) solitary pulmonary nodules. AJR Am J Roentgenol 2003;180:1665–9. [CrossRef]
18. Lin CY, Chang CC, Chu CY, Huang LT, Chung TJ, Liu YS, et al. Computed tomography-guided transthoracic needle biopsy: Predictors for diagnostic failure and tissue adequacy for molecular testing. Front Med (Lausanne) 2021;8:650381. [CrossRef]
19. 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;35:1865–72. [CrossRef]
20. Pan JF, Yang PC, Chang DB, Lee YC, Kuo SH, Luh KT. Needle aspiration biopsy of malignant lung masses with necrotic centers. Improved sensitivity with ultrasonic guidance. Chest 1993;103:1452–6. [CrossRef]
21. Yamamoto N, Watanabe T, Yamada K, Nakai T, Suzumura T, Sakagami K, et al. Efficacy and safety of ultrasound (US) guided percutaneous needle biopsy for peripheral lung or pleural lesion: Comparison with computed tomography (CT) guided needle biopsy. J Thorac Dis 2019;11:936–43. [CrossRef]
22. DiBardino DM, Yarmus LB, Semaan RW. Transthoracic needle biopsy of the lung. J Thorac Dis 2015;7(Suppl 4):304–16.
23. Lee MH, Lubner MG, Hinshaw JL, Pickhardt PJ. Ultrasound guidance versus CT guidance for peripheral lung biopsy: Performance according to lesion size and pleural contact. AJR Am J Roentgenol 2018;210:110–117. [CrossRef]