Percutaneous Lung Biopsy with Pleural and Parenchymal Blood Patching: Results and Complications from 1,112 Core Biopsies

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ABSTRACT

Purpose: To evaluate the outcomes of computed tomography (CT) fluoroscopy-guided core lung biopsies with emphasis on diagnostic yield, complications, and efficacy of parenchymal and pleural blood patching to avoid chest tube placement.

Methods: This is a single-center retrospective analysis of CT fluoroscopy-guided percutaneous core lung biopsies between 2006 and 2020. Parenchymal blood patching during introducer needle withdrawal was performed in 74% of cases as a preventive measure, and pleural blood patching was the primary salvage maneuver for symptomatic or growing pneumothorax in 60 of 83 (72.2%) applicable cases.

Results: A total of 1,029 patients underwent 1,112 biopsies (532 men; mean age, 66 years; 38.6%, history of emphysema; lesion size, 16.7 mm). The diagnostic yield was 93.6% (1,032/1,103). Fewer complications requiring intervention were observed in patients who underwent parenchymal blood patching (5.7% vs 14.2%, $P < .001$). Further intervention was required in 83 of 182 pneumothorax cases, which included the following: (*a*) pleural blood patch (5.4%, 60/1,112), (*b*) chest tube placement without a pleural blood patch attempt (1.5%, 17/1,112), and (*c*) simple aspiration (0.5%, 6/1,112). Pleural blood patch as monotherapy was successful in 83.3% (50/60) of cases without need for further intervention. The overall chest tube rate was 2.6% (29/1,112). Emphysema was the only significant risk factor for complications requiring intervention ($P \leq .001$).

Conclusions: Parenchymal blood patching during introducer needle withdrawal decreased complications requiring intervention. Salvage pleural blood patching reduced the frequency of chest tube placement for pneumothorax.

ABBREVIATIONS

AE = adverse event, CT = computed tomography, ENB = electromagnetic navigational bronchoscopy, FNA = fine needle aspiration

Image-guided percutaneous needle lung biopsy is a widely accepted procedure for the diagnosis of a range of pulmonary lesions (1). Compared with electromagnetic navigational bronchoscopy (ENB), computed tomography (CT)-guided percutaneous biopsy can access virtually any anatomic location in the lung, does not require general anesthesia or heavy sedation, and has a high rate of tissue adequacy (1,2). Core biopsy and fine needle aspiration

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RESEARCH HIGHLIGHTS

- Percutaneous CT fluoroscopy-guided core lung biopsies performed with pleural and parenchymal blood patching techniques resulted in a low chest tube placement rate (2.6%, 29/1,112) and high diagnostic yield (93.6%, 1032/1103).
- 74% of patients underwent prophylactic parenchymal blood patching upon needle withdrawal, resulting in a lower complication rate of 5.7% compared with 14.2% in those without patching.
- Aspiration and pleural blood patching resolved 83.3% (50/60) of pneumothorax cases in which they were applied.
- Emphysema was the only significant risk factor for complications requiring intervention ($P \leq .001$).

(FNA) are the primary CT-guided percutaneous lung biopsy methods. In recent years, core biopsy has become the preferred technique over FNA because of higher diagnostic accuracy for benign lesions and an increased likelihood of specimen adequacy for molecular and genetic testing (3).

Despite the widespread application of CT-guided lung biopsies, the technique, specimen adequacy, and complication rates remain highly variable. Many centers routinely perform FNA, core biopsy, or both with a variety of devices, gauges, and number of cores and defer biopsies in cases with small targets or emphysema. There is also no consensus as to whether CT fluoroscopy or conventional CT guidance is superior, with many centers deferring the use of CT fluoroscopy due to concerns over operator radiation dose (4–6). As a result of this heterogeneity, there is a wide range in the diagnostic yield and reported complication rates. The most frequently observed complication after lung biopsy is pneumothorax, which is reported to occur in 10%–45% of procedures, with an overall chest tube rate of 0.7%–16% (5–14). The high rates of pneumothorax and chest tube placement after percutaneous biopsy have been used by some as justification for ENB over CT fluoroscopy-guided biopsy as the preferred first-line diagnostic procedure (15–17).

This is a single-center retrospective study of more than 1,000 patients performed using standardized imaging, biopsy devices, and pneumothorax salvage techniques. The study population included core biopsies only, CT fluoroscopy as the sole image-guidance technique, and parenchymal blood patching during the withdrawal of the introducer needle (18,19). Growing or symptomatic pneumothorax was initially treated with pleural blood patching for salvage (11). Thus, the hypothesis of this single-arm study is that a combination of procedural factors applied during core lung biopsies—CT fluoroscopic guidance, parenchymal blood patching, and pleural blood patching for pneumothorax salvage—results in a high diagnostic yield and low rate of chest tube placement compared with historical controls.

STUDY DETAILS

Study type: Retrospective, observational, cohort study

MATERIALS AND METHODS

This retrospective Health Insurance Portability and Accountability Act-compliant single-center study was performed under a waiver of informed consent from the University of Wisconsin Health Sciences institutional review board. All patients provided preprocedural written informed consent for the biopsy and further interventions if procedural complications were encountered.

Patient Selection

A retrospective review from an electronic database of all percutaneous CT fluoroscopy-guided lung biopsies performed between August 2006 and August 2020 was performed. Every CT fluoroscopy-guided percutaneous transthoracic core lung biopsy procedure from that time range was included for analysis. Prior proof of concept studies (11,18) on blood patching included up to 104 patients from this data set. Electronic medical records and CT images were reviewed to determine patient information, procedural data, and the presence of emphysema. Recorded data included age and sex of patient, lesion size and location, size of core biopsy device, number of passes, pathologic diagnosis, complications, and subsequent interventions. Additionally, medical records were reviewed to determine delayed complications within 30 days of the procedure and patient clinical outcome. Hemoptysis was defined as bloody expectorant requiring 2 or more pads to clear, and hemorrhage was defined as present when the amount of blood was greater than the expected small perinodular halo. Complications were graded as mild, moderate, or severe adverse event (AE) according to the established Society of Interventional Radiology criteria (20).

Mean patient age was 66 years (range, 18–92 years). More than half of the patient population (58.5%, 650/1,112) had an established history of cancer, and 38.6% (429/1,112) of patients had emphysema. The mean long-axis lesion diameter was 21.1 mm ± 15 (range, 4–124 mm; median, 16.7 mm); 63.8% (709/1,112) of lesions were ≤20 mm and 22.5% (250/1,112) were ≤10 mm. Patient and procedural characteristics are summarized in **Table 1**. The vast majority (96.6%, 1,074/1,112) of biopsies were performed with a 19-gauge introducer and 20-gauge core biopsy device, and the median number of passes was 3. A total of 38 procedures were performed with a 17-gauge introducer and an 18-gauge biopsy device.

Procedure

Procedures were performed at a single academic medical center by board-certified attending radiologists with 1–29

Table 1. Patient, Procedural, and Nodule Characteristics

Variable	n
Patient (N = 1,029)	
Sex	
Female (%)	497 (48.3)
Male (%)	532 (51.7)
Age (y)	
Mean	66 (12)
Range	18–92
Weight (kg)	80.3 (21.5)
Cancer history (%)	650 (58.5)*
Presence of emphysema (%)	429 (38.6)*
Lesion (N = 1,112)	
Median nodule diameter (mm)	16.7
Mean nodule diameter (mm)	21.1 (15.1)
≤5 mm (%)	8 (0.7)
>5 to ≤10 mm (%)	242 (21.8)
>10 to ≤20 mm (%)	459 (41.3)
>20 to ≤30 mm (%)	208 (18.7)
>30 to ≤50 mm (%)	137 (12.3)
>50 mm (%)	58 (5.2)
Located in the upper/middle lobe (%)	664 (59.7)
Located in the lower lobe (%)	434 (39)
Mediastinum (%)	14 (1.3)

Note–Values in parentheses are standard deviations unless otherwise indicated.
*Percentages of 1,112 procedures.

years of experience with lung biopsy along with senior radiology residents, abdominal imaging and interventional fellows, and interventional radiology fellows. Pathologists were not present for the procedure. The general technique with minor variations for operator preference and patient condition was as follows: procedures were performed under CT fluoroscopic guidance in intermittent mode (GE Medical Systems, Waukesha, Wisconsin). Buffered 1% lidocaine with 1:10,000 epinephrine was injected for local anesthesia just short of the pleural surface until a visible lens-shaped protrusion was noted. Moderate sedation was maintained with intravenous fentanyl (Hospira, Inc., Lake Forest, Illinois) and midazolam (Versed; Roche Laboratories, Nutley, New Jersey). Using intermittent CT fluoroscopic guidance, an introducer needle was advanced into the target lesion and cores obtained (Bard Monopty or Bard Max-Core; Becton, Dickinson and Company, Franklin Lakes, New Jersey). During the removal of the introducer needle, approximately 3–10 mL of autologous blood was injected into the pulmonary parenchyma along the needle track to reduce the incidence of pneumothorax using the previously described methods (18,19,21,22). The use of blood patching progressively increased over the duration of this study. After needle withdrawal, patients were rapidly placed biopsy side down, and a limited postprocedural CT was obtained to evaluate for immediate complications (23). Patients were transferred to a postprocedural nursing unit and monitored for at least 2–3 hours with a standard 1-hour postprocedural chest X-ray that was obtained regardless of the presence or absence of a pneumothorax or other complications.

Pneumothorax Management

For a growing or symptomatic pneumothorax, a pleural blood patch was attempted as the first-line therapy as described below (11). In a minority of cases, chest tube placement or simple aspiration without blood patch was the initial intervention based on physician preference, particularly early in the study. Patients who failed pleural blood patching due to the reaccumulation of an enlarging or symptomatic pneumothorax underwent the placement of a conventional chest tube (8–12-F pigtail) through a separate puncture, usually in the second or third intercostal space midclavicular line and directed toward the lung apex. Patients were then admitted to the hospital for air leak management.

Pleural Blood Patch as a Pneumothorax Salvage Technique

A straight 5-F multiside hole catheter (Yueh Centesis; Cook Medical) was placed into the pleural space with CT fluoroscopy guidance through the previously anesthetized rib space near the biopsy puncture site (**Fig a–f**). The catheter was ideally directed at an oblique angle to the lung surface to avoid puncture or injury to the lung during reinflation. The pneumothorax was then evacuated with wall suction. If the biopsy had not yet been completed, the procedure was finished, and then a median of 30 mL (range, 7–90 mL) of autologous blood was drawn from an existing intravenous line and injected rapidly into the pleural space, and the catheter was removed. The patient was immediately turned biopsy side down and observed on the CT table for 15 minutes. The patient was then moved to the recovery area on their side for 1 hour. A chest X-ray was used to confirm that there was no reaccumulation of the pneumothorax at 1 hour and 2–3 hours after biopsy. The reaccumulation of the pneumothorax generally prompted the placement of a chest tube and hospital admission until cessation of the air leak.

Statistical Analysis

For the univariate analyses, associations between categorical variables were tested using the chi-square test; if any of the cells had a count of <5, Fisher exact test was used. Continuous variables were compared using the *t* test. A multiple logistic regression for complication with intervention was fit against predictors such as patient age, sex, cancer/emphysema histories, lesion location/size, number of cores, core needle size, and pathology. Odds ratios and their 95% confidence intervals were obtained for each predictor. Demographic and clinical variables were also compared between patients with and without parenchymal blood

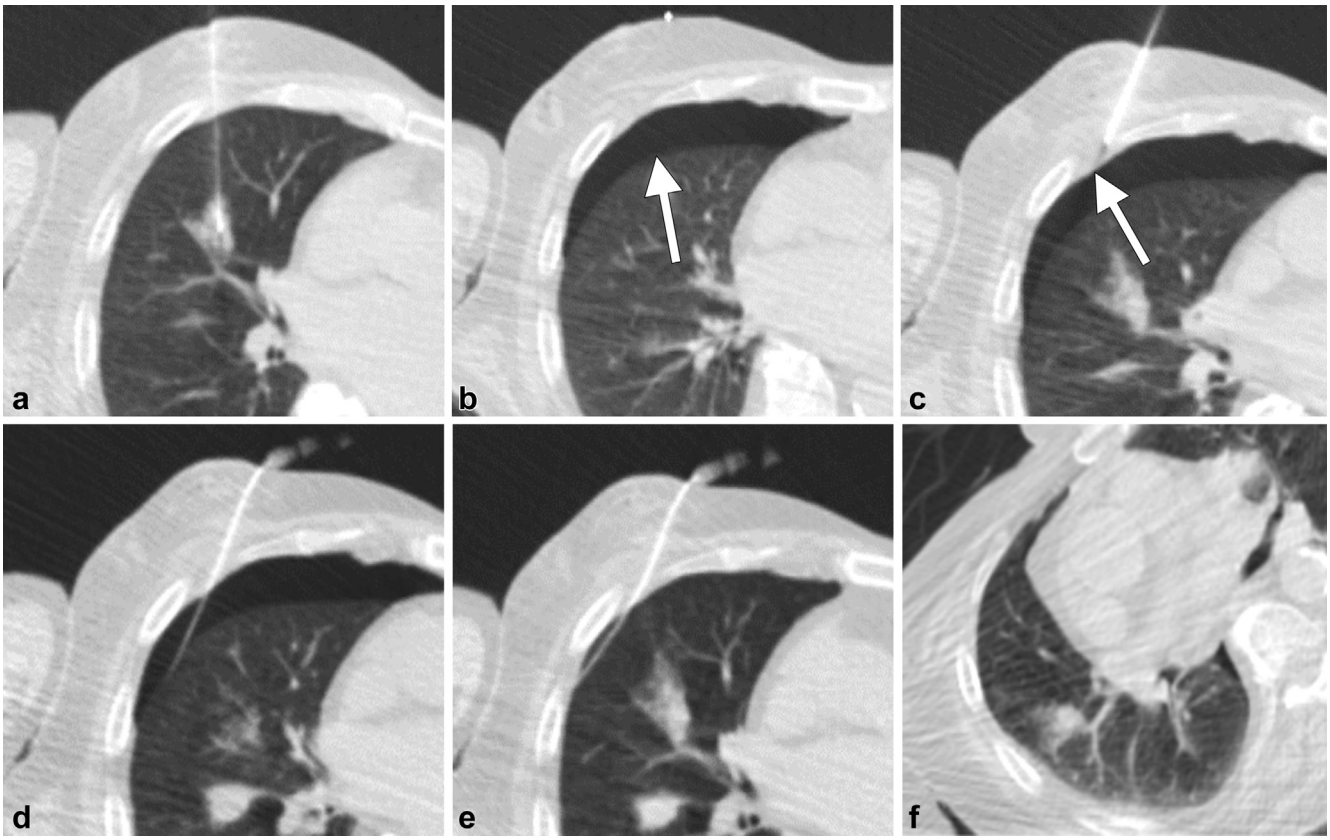

Figure. Pleural blood patch technique in a 70-year-old man undergoing biopsy of a pulmonary nodule in the right middle lobe. **(a)** Guide needle placed into the targeted mass. **(b)** A growing pneumothorax is detected after biopsy (white arrow). **(c)** Additional local anesthesia (1% lidocaine with epinephrine [1:100,000]) placed to the pleural surface. A skin puncture near the biopsy site is used for blood patching, and additional anesthesia is not always necessary. Note the slight intercostal tissue convexity (white arrow), which denotes adequate local anesthesia. **(d)** A straight 5-F multiside hole catheter (Yueh Centesis Catheter) is placed into the pleural space tangential to the lung surface to avoid injuring the lung during reinflation. **(e)** The pneumothorax is evacuated with wall suction, and 7–90 mL of autologous blood injected into the pleural space. **(f)** The catheter is removed, and the patient is immediately placed into the right lateral decubitus position for 15 minutes. Repeat scanning is performed before the patient is moved to the recovery area. If the pleural blood patch had failed with the reaccumulation of the pneumothorax, a conventional chest tube would have been placed in the second or third intercostal space midclavicular line, followed by hospital admission. The chest X-ray shows no reaccumulation of the pneumothorax 3 hours after biopsy (not shown). The patient was discharged the same day without sequela.

patching using a *t* test or chi-square/Fisher test, depending on the nature of the variable. Statistical significance was set at $P < .05$. All statistical analyses were performed in R version 3.6.3 (Foundation for Statistical Computing, Vienna, Austria).

RESULTS

A total of 1,029 patients (497 women, 532 men) who received 1,112 CT fluoroscopy-guided percutaneous transthoracic core lung biopsy procedures were included for analysis.

Lung adenocarcinoma was the most common malignant diagnosis in 28.8% (320/1,112) of cases, followed by benign or infectious/inflammatory in 21.4% (238/1,112) and metastases in 15.9% (177/1,112). The overall diagnostic yield was 93.6% (1,032/1,103), which increased with the lesion size. The 9 procedures where tissue was sampled for genetic testing only were excluded from the analysis of diagnostic

Table 2. Complication Rates for All Procedures (N = 1,112)

Complication	n	%
None	868	78.1
All complications	244	21.9
Pneumothorax	182	16.4
Requiring further intervention	83	7.5
Not requiring further intervention	99	8.9
Requiring chest tube placement	27	2.4
Hemorrhage	51	4.6
Requiring further intervention	0	0.0
Hemoptysis	7	0.6
Requiring further intervention	0	0.0
Hemothorax with chest tube	1	0.1
Hydropneumothorax with chest tube	1	0.1
Acute anterior CP and bleeding	1	0.1
Air embolus	1	0.1

Note–Percentages are based on 1,112 procedures.
CP = chest pain.

Table 3. Pneumothorax Interventions (N = 83)

Intervention	n	%
Simple aspiration only	6	0.5
Aspiration and pleural blood patch	60	5.4
Did not require subsequent chest tube placement	50	4.5
Required subsequent chest tube placement	10	0.9
Immediate chest tube placement	17	1.5
Overall chest tube placement	29	2.6

Note–Percentages are based on 1,112 procedures. Overall chest tube placement included the hemothorax and hydropneumothorax that required intervention.

Table 4. Results of Univariate Analyses to Determine the Risk Factors for Complications Requiring Intervention

Variable	Complications that required intervention (n = 87)	No complication or intervention (n = 1,025)	*P* value
Patient factors			
Sex			.1*
Male	53	524	
Female	34	501	
Age (y)			.259*
≤60	19	288	
>60	68	737	
Emphysema			<.001*
Yes	56	373	
No	31	652	
Lesion size (mm)			.729†
≤10	17	233	
>10 to ≤20	36	423	
>20 to ≤30	21	187	
>30 to ≤50	9	128	
>50	4	54	
≤10	17	233	.582*
>10	70	792	
Lesion location			.494†
Upper and middle lobes	57	607	
Lower lobe	29	405	
Mediastinum	1	13	
No. of cores			.377‡
Mean ± SD	3.52 ± 1.86	3.34 ± 1.31	

SD = standard deviation.
*Chi-square test.
†Fisher exact test (cell size, <5).
‡*t* test.

Table 5. Multiple Logistic Regression for Complications that Required Further Intervention

Variable	Odds ratio	95% CI	*P* value
Age	0.99	(0.98,1)	.129
Sex (male vs female)	1.27	(0.95,1.69)	.112
Cancer history (yes vs no)	1.35	(0.99,1.84)	.056
Emphysema history (yes vs no)	1.24	(0.98,1.58)	.063
Location (upper/middle vs lower Lobe)	1.14	(0.85,1.54)	.386
Lesion size (mm)	0.99	(0.98,1.00)	.268
No. of cores	1.04	(0.94,1.15)	.425
Core needle size (20 vs 18 gauge)	1.09	(0.46,2.57)	.841
Indeterminate vs primary	1.16	(0.61,2.2)	.645
Infection/benign vs primary lung cancer	0.85	(0.57,1.25)	.402
Metastases vs primary lung cancer	0.72	(0.45,1.14)	.161
Nondiagnostic vs primary lung cancer	1.43	(0.85,2.46)	.178
Other malignancy vs primary lung cancer	0.53	(0.21,1.3)	.163

CI = confidence interval.

yield because standard pathology reports were not available. The diagnostic yield was 95.6% (815/853) for lesions > 10 mm and 86.8% (217/250) for lesions ≤ 10 mm ($P \leq .001$).

A parenchymal blood patch was performed in 77% (822/1,068) of patients. It is unknown whether a parenchymal blood patch was performed in 44 procedures because the data were not recorded on the day of procedure. Mild AEs were observed in 19.2% (214/1,112) of cases, moderate AEs were observed in 2.6% (29/1,112), and there was 1 case of a life-threatening event (air embolus) (Table 2). Pneumothorax was the most frequently observed complication at 16.4% (182/1,112) (Tables 2, 3), followed by pulmonary parenchymal hemorrhage (4.6%, 51/1,112) and hemoptysis (0.6%, 7/1,112). All cases of hemorrhage and hemoptysis resolved spontaneously with observation. Air embolus was encountered in 1 (0.1%) patient who was successfully treated with the emergent evacuation of a left ventricular air collection and subsequently discharged with no long-term sequela. In the entire population, 7.5% (83/1,112) required some form of intervention for pneumothorax, including immediate chest tube placement (1.5%, 17/1,112), simple aspiration (0.5%, 6/1,112), or aspiration followed by a pleural blood patch (5.4%, 60/1,112). A median of 30 mL (range, 7–90 mL) of blood was used for the pleural blood patch. The volume of pleural blood patch increased from the first 3 years of our experience until the most recent 3 years (mean volume from 2011 to 2013, 19 mL; mean volume from 2017 to 2019, 48 mL; $P \leq .001$), but there was no association between the injected volume and success of the blood patch.

Of the 60 pneumothorax cases where aspiration and a pleural blood patch were attempted, 83.3% (50/60) resolved without the need for a subsequent chest tube. Moreover, 16.7% (10/60) required a chest tube after aspiration and pleural blood patching failed to treat the pneumothorax. The overall chest tube rate was 2.6% (29/1,112), which included a hydropneumothorax and hemothorax.

The results from the univariate analyses are listed in Table 4. After adjusting for other predictors, the multiple

Table 6. Rate of Pneumothorax, Chest Tube Placement, and Pleural Blood Patch Success for Patients with Emphysema

Variable	Emphysema (n = 429)		No emphysema (n = 683)		*P* value
	n	%	n	%	
Pneumothorax	88	20.5	94	13.8	.004*
Chest tube	23	5.4	6	0.9	<.001*
Pleural blood patch	36	8.4	24	3.5	<.001*
No chest tube required	27	75	23	95.8	.04†
Required chest tube	9	25	1	4.2	

*Chi-square test.
†Fisher exact test (cell size < 5).

logistic regression indicated that the presence of emphysema ($P = .06$) and a history of cancer ($P = .06$) are borderline significant indicators for experiencing a complication that required intervention (Table 5). Patients with emphysema and those with a history of cancer were 1.24 and 1.35 times, respectively, as likely to experience a complication requiring intervention. Age, sex, lesion location, lesion size, number of passes, needle size, and diagnosis were not found to increase the likelihood of experiencing a complication with intervention. The rate of pneumothorax was higher in patients with emphysema than in those without (20.5% vs 13.8%, $P = .004$), and the success rate for pleural blood patching was lower for patients with emphysema than for patients without emphysema (75% vs 95.8%, $P = .04$; Table 6).

Compared with patients who did not receive a parenchymal blood patch (n = 246), those who received a parenchymal blood patch (n = 822) were less likely to have a complication requiring intervention (5.7% vs 14.2%, $P < .001$) and were slightly older (68.0 vs 65.5 years, $P = .008$). There was no statistically significant difference in sex, cancer history, and the frequency of emphysema between the 2 groups (Table 7).

Table 7. Demographic and Complication Comparisons between Patients with and without Parenchymal Blood Patching

Variable	Received parenchymal blood patch (n = 822)	Did not receive parenchymal blood patch (n = 246)	*P* value
Patient factors			
Sex			
Male	412 (50.1%)	140 (56.9%)	.072
Female	410 (49.9%)	106 (43.1%)	
Age (y)	68 (60,74)	65.5 (57,73)	.008
Cancer history			
Yes	483 (58.8%)	143 (58.1%)	.919
No	339 (41.2%)	103 (41.9%)	
Emphysema			
Yes	327 (39.8%)	91 (37%)	.4765
No	495 (60.2%)	155 (63%)	
Lesion location			
Upper and middle lobes	491 (59.7%)	147 (59.8%)	.0101
Lower lobe	327 (39.8%)	92 (37.4%)	
Mediastinum	4 (0.5%)	7 (2.8%)	
Lesion size ≥ 10 mm			
Yes	669 (81.4%)	220 (89.4%)	.0025
No	153 (18.6%)	26 (10.6%)	
Complication requiring intervention			
Yes	47 (5.7%)	35 (14.2%)	<.001
No	775 (94.3%)	211 (85.8%)	

Note–A total of 44 patients were excluded from the analysis because there was no record whether they received a parenchymal blood patch; continuous variables are summarized by median (interquartile range), and categorical variables are summarized by N (%).

DISCUSSION

Lung biopsy is a significant procedure that is used to inform treatment decisions for patients with pulmonary masses, particularly in the era of precision medicine (3,24). Earlier literature has been found to focus on a single technical improvement, often in limited patient populations (23,25). This study combines several recent innovations ranging from imaging guidance to postprocedural salvage techniques, and the cumulative effect is reported in a large patient population. The overall results demonstrate that CT fluoroscopy-guided core lung biopsies in a population consisting of 39% of patients with emphysema (Table 8) can result in a high diagnostic yield and a low rate of chest tube placement (5–14). The particular strengths of this study are the large sample size relative to other studies (Table 8) (5–14); limiting the patient population to core biopsy only, which reflects most modern practices; uniform procedural technique; and the use of blood patching.

Blood patches were used in this study for 2 different purposes; the parenchymal patch was a primary preventive

Table 8. Characteristics and Results of Studies Published after 2010 with At Least 150 Core Biopsy Procedures

Study (year)	Guidance method	No. of core biopsy procedures	Introducer needle size	Mean lesion size (mm)	Diagnostic accuracy/ yield (%)	Emphysema (%)	Blood patching (Yes/No)	Ptx rate (%)	Chest tube rate (%)	Hemoptysis (%)	Hemorrhage (%)	Hemothorax (%)
Hiraki et al (2010) (5)	CT fluoroscopy	1,098	19 gauge	22.7 ± 15	NS	29.2	No	42.3	5	NS	NS	NS
Wagner et al (2011) (11)	CT	463 (includes FNA)	19–21 gauge	group A: 15 ± 3 group B: 22 ± 15	NS	NS	Yes (pleural)	9.7 (required intervention)	4.1	NS	NS	NS
Mendiratta-Lala et al (2014) (7)	CT fluoroscopy	169	14–20 gauge (mean, 19 gauge)	NS	85.2	NS	No	40.8	5.9	NS	NS	1.8
Anzidei et al (2015) (13)	CT	342	14–21 gauge (mean, 18 gauge)	36	NS	NS	No	45.3	11.4	4.4	18.1	3.5
Kuban et al (2015) (6)	CT	1,002	18–19 gauge	24.78 ± 19.03 (includes FNA)	NS	9.9	No	30	16	NS	NS	NS
Mills et al (2017) (9)	CT	224	18 or 20 gauge	35 ± 25 (includes FNA)	97.4	20.6 (COPD)	No	19.1	2.2	NS	NS	NS
Tian et al (2017) (10)	CT	560	17 gauge	18 ± 6	94.6	9.5	No	10.4	0.7	20.9	NS	2
Huang et al (2019) (8)	CT	198	17 gauge	group A: 12.0 ± 3.2 group B: 36.9 ± 18.0	93.9	NS	No	38.4	1.5	11.1	62.1	1.5
Perl et al (2019) (12)	CT	868	13, 15, 17, 19 gauge	NS	NS	NS	Yes (parenchymal)	13.1	4.5	NS	NS	NS
Yoon et al (2019) (14)	CT fluoroscopy	963 (includes FNA)	NS	31 ± 19	NS	42.8	No	19.8	4.2	4.6	NS	NS
Zlevor et al (current study)	CT fluoroscopy	1,112	19 gauge	16.7 (median)	93.6	38.6	Yes (parenchymal/ pleural)	16.4	2.6	0.6	4.6	0.1

CT = computed tomography; COPD = chronic obstructive pulmonary disease; FNA = fine needle aspiration; NS = not specified; Ptx = pneumothorax.

measure to lower the pneumothorax rate (18,19), and the pleural patch was used to salvage a symptomatic or growing pneumothorax and to avoid chest tube placement (11). Various materials have been used for parenchymal track sealing with success, including autologous blood, clotted blood, gelfoam, saline, and polyethylene glycol (23). At the study center, fresh blood is favored due to ready availability, low expense, and the ability to inject as a liquid with clotting along the puncture track. Although a comparison between patients who received parenchymal blood patches and those who did not is not the primary focus of this study, the statistically significant decrease in complications in patients who received parenchymal blood patching (in a demographically similar population) further confirms the results of prior reports (12,18,19) and supports the routine use of parenchymal patching during introducer needle withdrawal after core needle lung biopsy. An earlier report by Graffy et al (18) described a decrease in the pneumothorax rate and the need for any pneumothorax intervention after either core or FNA lung biopsy. The current study builds on this work by limiting the patient population to core biopsy only (reflecting most modern practices) and reporting on the addition pleural blood patching to treat postprocedural pneumothorax (18).

Pleural blood patching is a simple and fast (<5 minutes) salvage maneuver used since 2008 to avoid chest tubes in the face of a growing or symptomatic pneumothorax (11,18). The technique was originally adopted from the thoracic surgery literature where large volume blood patching has been used with success to treat persistent postsurgical air leaks (26–28). The volumes of pleural blood used in the current study (median, 30 mL) were less than that used in prior surgical series (generally >100 mL) (27,28) under the presumption that a lesser volume of blood was required after biopsy due to a smaller hole in the lung surface. The overall success rate (ie, chest tube avoidance) for pleural blood patching in this study was high at 83%, with slightly lower rates for patients with emphysema (75%). Compared with biopsy studies in which pleural patching was not utilized, pleural blood patching in this study resulted in a low overall chest tube rate, particularly considering that the patient population had one of the highest reported rates of emphysema versus other modern lung biopsy studies (**Table 8**) (5–14). The effect of pleural blood patching is highlighted when comparing the results of this study (in which both parenchymal and pleural blood patches were routinely used) to those of Perl et al (12) (883 patients) in which parenchymal but not pleural blood patching was used in 419 patients. Although the overall rate of pneumothorax was higher in the current study than that of Perl et al (12) (16.4% vs 10.7%), the chest tube rate was lower (2.6% vs 3.1%), largely due to cases salvaged with pleural blood patching.

Indwelling chest tubes after lung biopsy are associated with substantial patient discomfort, require prolonged contact with the health care system as an inpatient or outpatient, and drive substantial increased health care costs with up to a 4-fold multiple (29–32). A simple pneumothorax without intervention does not increase costs, morbidity, or patient discomfort. Pleural blood patching as an initial therapeutic maneuver to avoid a chest tube is a fast and simple technique that does not even require additional local anesthesia, and patients are often unaware that an additional procedure is even taking place. There is no need for additional follow-up imaging after pleural blood patching besides standard postbiopsy chest X-rays.

A high rate of pneumothorax for percutaneous lung biopsy has been used as a justification for ENB as a first-line diagnostic procedure (15–17). There appears to be little doubt that the overall pneumothorax rate is lower for ENB than for percutaneous lung biopsy, but the difference in chest tube rates appears to be low. For example, the chest tube rate for this series is lower than reported in recent ENB studies (15,17) with a higher diagnostic yield (2.5% vs 2.7%–4.1% and 93%.6 vs 66%–70%, respectively). Note that this study is not a direct comparison between ENB and CT fluoroscopy-guided lung biopsy where the patient populations and targets may be different. However, the favorable results presented in this study are a reminder that percutaneous techniques continue to improve, and earlier justifications for ENB based on complication rates may no longer be valid.

Physician radiation exposure has prevented CT fluoroscopy from becoming the standard guidance modality for percutaneous lung biopsy at several centers despite the known potential benefits of shorter procedure times and fewer complications (6,8–13,33–35). It is significant to note that the procedures performed in this study used an intermittent mode rather than continuous CT fluoroscopy (36). Intermittent CT fluoroscopy limits patient and operator exposure while still providing near-real–time guidance. Although not a direct comparison of CT fluoroscopy versus conventional CT, the low complication rate and high diagnostic yield in this study may be partially due to the immediate feedback provided by a high number of low-dose CT fluoroscopy check scans allowing multiple rapid incremental repositions during needle placement.

The main limitation of this study was the retrospective single-center design. Another limitation was the lack of a standardized protocol for blood patch versus chest tube for initial pneumothorax management, particularly in the early study years. More recently, blood patching has become the initial treatment of choice at the study center because of the ease of application, speed, and an increasing recognition of effectiveness. The wide range of operator experience for trainees as the primary operator is another limitation and may contribute to an increased range of complications and outcomes. Lastly, this study excluded ultrasound-guided biopsies and FNA, which was preferred over core in the first half of the study period. The impact of these exclusions is unknown and beyond the scope of this study.

In summary, this large retrospective study of CT fluoroscopy-guided core lung biopsies demonstrates a high diagnostic yield and low chest tube rate compared with

historical controls. The results of this study lend further support for the routine use of parenchymal blood patching for pneumothorax avoidance and pleural blood patching for pneumothorax salvage.

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