

Original article

Conventional flexible bronchoscopy versus radial endobronchial ultrasound (R-EBUS)-guided bronchoscopy under fluoroscopy: A retrospective study at Phrapokklao Hospital, Chanthaburi, Thailand

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Abstract

Background: Conventional flexible bronchoscopy is widely used for evaluating peripheral pulmonary lesions; however, its diagnostic yield remains limited. Although radial endobronchial ultrasound (R-EBUS) combined with fluoroscopic guidance may improve lesion localization and tissue acquisition, real-world comparative data from provincial tertiary-care centers are scarce.

Objectives: To compare the diagnostic yield of conventional flexible bronchoscopy and R-EBUS-guided bronchoscopy under fluoroscopic guidance for peripheral pulmonary lesions and identify patient-, lesion-, and procedure-related factors associated with diagnostic success.

Methods: We conducted a retrospective observational study at a provincial tertiary-care hospital in Eastern Thailand. Adult patients undergoing diagnostic bronchoscopy for peripheral pulmonary lesions between October 2023 and October 2025 were included. Diagnostic yield was defined according to contemporary ATS/ACCP Delphi consensus criteria. Univariable and multivariable logistic regression analyses were performed to evaluate factors associated with diagnostic yield, and Firth penalized logistic regression used as confirmatory analysis to address potential sparse-data bias.

Results: A total of 102 patients were analyzed, including 66 who underwent conventional bronchoscopy and 36 who underwent R-EBUS-guided bronchoscopy under fluoroscopic guidance. The final procedure-level diagnostic yield was higher, but not significantly different, in the R-EBUS with fluoroscopy group than in the conventional group (75.0% vs. 60.6%; $P = 0.14$). After adjusting for clinically relevant lesion-related factors, R-EBUS-guided bronchoscopy under fluoroscopic guidance was independently associated with higher diagnostic yield (adjusted odds ratio [OR] 3.72, 95% confidence interval [CI] 1.12–12.38, $P = 0.03$). Presence of a computed tomography (CT) bronchus sign was the strongest, most consistent predictor of diagnostic success across all models (adjusted OR 31.33, 95% CI 8.43–116.52, $P < 0.001$). Confirmatory Firth penalized regression yielded consistent estimates in direction and magnitude.

Conclusion: In this real-world provincial tertiary-care setting, R-EBUS-guided bronchoscopy under fluoroscopic guidance was independently associated with higher diagnostic yield after accounting for lesion accessibility, particularly presence of a CT bronchus sign. Lesion-related factors, especially bronchial anatomy, play a central role in determining diagnostic success and should be carefully assessed when selecting bronchoscopic techniques in resource-limited settings.

Keywords: Bronchoscopy, diagnostic yield, fluoroscopy, peripheral pulmonary lesion, radial endobronchial ultrasound.

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Pulmonary lesions, particularly lung cancer, remain a major global health burden and are the leading cause of cancer-related mortality worldwide. ⁽¹⁾ Accurate pathological diagnosis is crucial because early detection and treatment significantly improve survival outcomes. ⁽²⁾ Although computed tomography (CT) has increased detection of small and peripheral pulmonary lesions, obtaining a definitive tissue diagnosis for such lesions still poses a significant clinical challenge. ⁽³⁾

Conventional flexible bronchoscopy has long been a standard diagnostic tool due to its safety, widespread availability and minimally invasive nature. ⁽⁴⁾ However, its diagnostic yield for peripheral pulmonary lesions, particularly small nodules or lesions without a CT bronchus sign, is limited, with reported yields of 50.0%–60.0%. ^(4,5) Thus, to improve lesion localization and sampling accuracy, adjunctive bronchoscopic imaging techniques have been developed. For instance, fluoroscopy-guided bronchoscopy was introduced to enhance real-time visualization of biopsy instruments and lesion targeting. Previous studies have shown that fluoroscopic guidance may improve the diagnostic yield compared with conventional bronchoscopy alone, especially for larger lesions. ^(3,6) However, its benefit is reduced in small or low-contrast lesions and accompanied by concerns on radiation exposure. ⁽⁷⁾

Radial endobronchial ultrasonography (R-EBUS) enables cross-sectional ultrasonographic imaging of peripheral lung lesions. ^(8,9) A recent meta-analysis found diagnostic yields of 70.0%–75.0% with R-EBUS-guided bronchoscopy. However, performance declines with small lesions, ground-glass opacities, or limited real-time confirmation during biopsy. ⁽¹⁰⁾

Combining R-EBUS with fluoroscopic guidance could integrate accurate lesion localization with real-time confirmation of biopsy instrument position and may further improve diagnostic yield ^(11–13); however, direct comparisons against conventional bronchoscopy without fluoroscopy remain scarce. ⁽¹⁴⁾

In October 2024, Phrapokklao Hospital, a provincial tertiary referral center in Eastern Thailand, introduced R-EBUS-guided bronchoscopy under fluoroscopic guidance into routine clinical practice. Evidence from resource-limited provincial centers, where general pulmonologists perform diagnostic bronchoscopy rather than interventional specialists, is still scarce. Therefore, we aimed to conduct a retrospective study to compare diagnostic yield,

defined according to the American Thoracic Society and American College of Chest Physicians (ATS/ACCP) Delphi consensus, ⁽¹⁵⁾ between conventional flexible bronchoscopy and R-EBUS-guided bronchoscopy under fluoroscopic guidance at Phrapokklao Hospital. We also assessed patient, lesion, and procedure-related factors influencing diagnostic yield to guide the evidence-based implementation of advanced diagnostic bronchoscopy in resource-constrained provincial tertiary-care settings.

Materials and methods

Study design and setting

This retrospective observational study was conducted at Phrapokklao Hospital, a provincial tertiary referral center in Eastern Thailand. This study was designed and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines. We first reviewed medical records of patients who underwent diagnostic bronchoscopy for pulmonary lesions between October 1, 2023, and October 31, 2025, corresponding to one year before and another after the introduction of radial endobronchial ultrasonography and fluoroscopic guidance in October 2024. The institutional ethics committee approved the study protocol and waived the requirement for informed consent due to the retrospective nature of the research. The study protocol was registered with the Thai Clinical Trials Registry (TCTR identification number: TCTR20260222002).

Participants

Consecutive patients undergoing diagnostic flexible bronchoscopy at the study center were screened for eligibility. Patients were eligible if they met all following criteria: (1) adults ≥ 18 years; (2) diagnostic bronchoscopy to obtain a pathological diagnosis for a suspected peripheral pulmonary lesion; and (3) bronchoscopic sampling regardless of final pathological outcome, including cases yielding nondiagnostic results. Patients were excluded if their target lesion was directly visible endobronchially on initial inspection, no bronchoscopic tissue sampling was attempted, or bronchoscopy was performed for nondiagnostic reasons. Retention of nondiagnostic cases as eligible subjects, rather than treating them as exclusion events, was implemented in accordance with 2024 ATS/ACCP Delphi consensus criteria to prevent ascertainment bias in the estimation of diagnostic yield.

Index test and comparator

The index test was R-EBUS-guided bronchoscopy under fluoroscopic guidance. Bronchoscopic procedures were conducted using a flexible bronchoscope (Olympus BF-H190; outer diameter, 4.9 mm) with a radial ultrasound probe advanced through the working channel to localize peripheral pulmonary lesions. After ultrasonographic confirmation of the lesion position, transbronchial sampling with fluoroscopic guidance was performed to confirm appropriate instrument placement during tissue acquisition.

The comparator was conventional flexible bronchoscopy without ultrasonographic or fluoroscopic guidance. Routine clinical practice involved performing conventional bronchoscopy using either a Fuji EB-589S bronchoscope (with an outer diameter of 5.1 mm) or an Olympus BF-H190 bronchoscope. Sampling techniques included transbronchial biopsy brushing and bronchoalveolar lavage as clinically appropriate.

All patients underwent pre-procedural chest CT using a standard institutional protocol with a slice thickness of 3 mm. Lesion size was assessed on axial CT images by measuring the maximum diameter and the mean 2D diameter, derived from the longest and shortest axial measurements of the target lesion. CT findings, including patterns of abnormalities, density, location, and presence of a bronchus sign, were recorded and reviewed before bronchoscopy to guide procedural planning.

A dedicated bronchoscopy suite housed a single experienced general pulmonologist (the principal investigator) who performed all bronchoscopic procedures under conscious sedation and local anesthesia. Trained bronchoscopy nurses assisted the pulmonologist. This single-operator approach effectively eliminated interoperator technical variability and interrater confounding. Patients were assigned to each group based primarily on the technology availability at our center. The conventional group comprised historical controls treated before clinical introduction of R-EBUS and fluoroscopy. After implementation of these advanced modalities in October 2024, the R-EBUS-guided technique with fluoroscopy became standard practice for all suspected peripheral pulmonary lesions endobronchially invisible.

Reference standard and outcome definition

The reference standard was the histopathological or cytopathological evaluation of bronchoscopic specimens from both index and comparator bronchoscopic procedures, considered part of routine clinical practice.

The primary outcome was diagnostic yield, defined according to the ATS/ACCP Delphi consensus statement⁽¹⁵⁾ as the proportion of bronchoscopic procedures establishing a specific malignant or benign diagnosis sufficient to guide clinical management, divided by the total number of procedures. Diagnostic yield was determined solely based on the pathological results of the bronchoscopic procedure and not modified by follow-up findings.

A diagnostic result was defined as histopathological or cytopathological confirmation of malignancy or a specific benign condition. A nondiagnostic result was suggestive but not definitive findings, including atypical or suspicious cells, acute or chronic nonspecific inflammation, necrosis, reactive or normal tissue, blood only, or insufficient tissue for diagnosis, regardless of subsequent clinical or radiological outcomes.

Statistical analysis

Baseline characteristics are summarized using the mean and SD for continuous variables and frequency with percentage for categorical variables. Comparisons between bronchoscopic techniques were performed using the Student's *t*-test or Chi-square test, as appropriate.

The primary analysis assessed the association between bronchoscopic technique and diagnostic yield using logistic regression. Univariable logistic regression analyses were first performed to identify factors associated with diagnostic yield. Then, variables considered clinically relevant or demonstrating a univariable association ($P < 0.10$) were entered into a multivariable logistic regression model to estimate adjusted odds ratios (ORs) with 95% confidence intervals.

Given the retrospective nature of the study, no formal *a priori* sample size calculation was performed; the analysis included all consecutive eligible patients identified within the prespecified study period.

Given the modest sample size and potential for sparse-data bias, Firth penalized logistic regression was performed as a confirmatory analysis to assess the robustness of multivariable findings. Adjusted ORs from multivariable models were graphically displayed using a forest plot to facilitate comparison of effect estimates across covariates.

All statistical tests were two-sided, and a P -value < 0.05 was considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics, version 28.0 (IBM Corp., Armonk, NY, USA) and Stata Statistical Software: Release 19 (StataCorp LLC, College Station, TX, USA).

Results

Study population and baseline characteristics

A total of 102 patients, comprising 66 patients who underwent conventional flexible bronchoscopy and 36 patients who underwent R-EBUS-guided bronchoscopy under fluoroscopic guidance, were included in the final analysis (**Figure 1**). Baseline patient and lesion characteristics stratified by bronchoscopic technique are summarized in **Table 1**.

Most baseline characteristics were comparable between groups. Patients in the conventional bronchoscopy group were more frequently male than those in the R-EBUS with fluoroscopy group (59.1% vs. 36.1%, $P = 0.03$). The mean maximum lesion diameter was significantly larger in the conventional bronchoscopy group compared with the R-EBUS with fluoroscopy group (38.1 ± 15.7 mm vs. 32.0 ± 13.6 mm, $P = 0.04$). Upper-lobe lesions predominated in both groups, and $>50\%$ lesions demonstrated a CT

bronchus sign. Most lesions in both groups were solid or mass-like in appearance on chest CT.

Bronchoscopic diagnostic outcomes

Table 2 shows bronchoscopic diagnostic outcomes according to technique. Transbronchial lung biopsy was performed in all patients, with selective bronchoalveolar lavage and bronchial brushing based on clinical indications.

The transbronchial biopsy diagnostic yield was 55.9% overall, with a higher yield in the R-EBUS with fluoroscopy group than in the conventional bronchoscopy group (66.7% vs. 50.0%, $P = 0.11$). Pathological diagnoses from biopsy were predominantly malignant, particularly adenocarcinoma. The distribution of pathological diagnoses, including nondiagnostic results, did not significantly differ between techniques (overall $P = 0.65$).

Bronchoalveolar lavage was performed in 98 of 102 patients, yielding a diagnostic result in 28.6% of cases, with no significant difference between techniques (29.2% vs. 27.3%, $P = 0.84$). Bronchial brushing was performed only in 4 patients, having a diagnostic result in 75.0% of cases, without significant differences between groups.

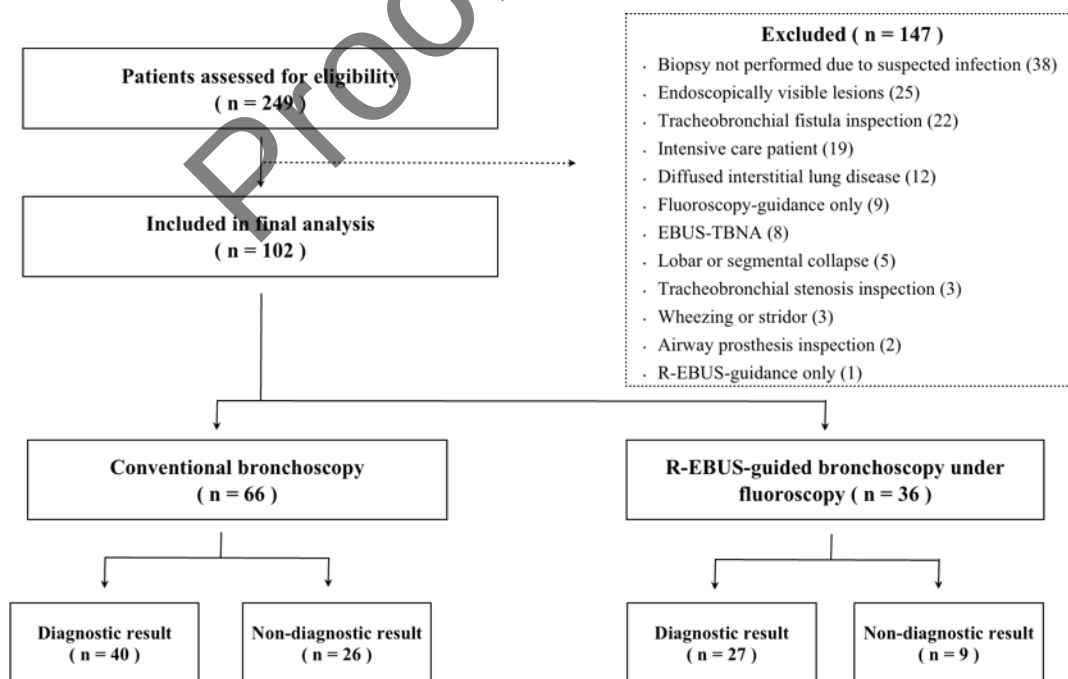


Figure 1. Study flow diagram outlining patient selection, inclusion and exclusion criteria, and the final analytic cohort. A total of 102 patients were included in the final analysis, comprising 66 patients who underwent conventional flexible bronchoscopy and 36 patients who underwent radial endobronchial ultrasound (R-EBUS)-guided bronchoscopy under fluoroscopic guidance.

Table 1. Baseline characteristics of the study population according to bronchoscopic technique.

Characteristics	Overall (n = 102)	Conventional (n = 66)	R-EBUS + fluoroscopy (n = 36)	P-value
Patient characteristics				
Age (years), mean $\pm$ SD	63.6 $\pm$ 12.4	63.5 $\pm$ 12.3	63.8 $\pm$ 12.6	0.92
Male sex, n (%)	52 (51.0)	39 (59.1)	13 (36.1)	0.03
Used tobacco, n (%)	24 (23.5)	16 (24.2)	8 (22.2)	0.82
COPD, n (%)	9 (8.8)	7 (10.6)	2 (5.6)	0.49
Lesion location (CT)				
Right upper lobe, n (%)	25 (24.5)	13 (19.7)	12 (33.3)	0.43
Right middle lobe, n (%)	7 (6.9)	6 (9.1)	1 (2.8)	
Right lower lobe, n (%)	25 (24.5)	17 (25.8)	8 (22.2)	
Left upper lobe, n (%)	23 (22.5)	15 (22.7)	8 (22.2)	
Lingual lobe, n (%)	4 (3.9)	4 (6.1)	0 (0.0)	
Left lower lobe, n (%)	18 (17.6)	11 (16.7)	7 (19.4)	
Lesion location (upper vs. non-upper lobes)				
Upper lobes lesion, n (%)	48 (47.1)	28 (42.4)	20 (55.6)	0.20
Non-upper lobes lesion, n (%)	54 (52.9)	38 (57.6)	16 (44.4)	
Radiologic lesion characteristics				
Bronchus sign presence, n (%)	55 (53.9)	37 (56.1)	18 (50.0)	0.56
Longest diameter, mm, mean $\pm$ SD	35.9 $\pm$ 15.2	38.1 $\pm$ 15.7	32.0 $\pm$ 13.6	0.040
Longest lesion diameter (cut-off 30 mm)				
< 30 mm, n (%)	38 (37.3)	22 (33.3)	16 (44.4)	0.27
$\geq$ 30 mm, n (%)	64 (62.7)	44 (66.7)	20 (55.6)	
Lesion type				
Solid/mass, n (%)	87 (85.3)	55 (83.3)	32 (88.9)	0.57
Non-solid/subsolid, n (%)	15 (14.7)	11 (16.7)	4 (11.1)	

P-values were calculated using Pearson's Chi-square test or the Fisher-Freeman-Halton exact test with Monte Carlo simulation, as appropriate. COPD, chronic obstructive pulmonary disease; R-EBUS, radial endobronchial ultrasound; SD, standard deviation.

At the procedure level, the final diagnostic yield was 65.7% overall. The R-EBUS-guided bronchoscopy under fluoroscopy group achieved a higher final diagnostic yield (75.0%) compared to the conventional bronchoscopy group (60.6%). However, this difference was not statistically significant ($P = 0.14$).

Table 3 summarizes results from univariable and multivariable logistic regression analyses evaluating factors associated with diagnostic yield. In univariable analyses, presence of a CT bronchus sign and solid or mass-type lesions were significantly associated with higher diagnostic yield, whereas bronchoscopic technique and lesion size showed nonsignificant trends.

Then, two multivariable models were constructed. Model 1 included bronchoscopic technique, bronchus sign, lesion size (>30 mm), and lesion type based on clinical relevance and univariable screening. In this model, both R-EBUS-guided bronchoscopy under fluoroscopic guidance and presence of a bronchus sign remained independently associated with higher diagnostic yield (adjusted OR 3.72, 95% CI 1.12–12.38, $P = 0.03$; and adjusted OR 31.33, 95% CI 8.43–116.52, $P < 0.001$, respectively), whereas lesion size

and lesion type were not. Model 2 was additionally adjusted for sex and showed a weaker association between bronchoscopic technique and diagnostic yield; the bronchus sign remained a consistent independent predictor.

Confirmatory analysis

Given the modest sample size and the potential for sparse-data bias, Firth penalized logistic regression was performed as a confirmatory analysis (**Table 4**). The results were consistent with those of the standard multivariable model, with R-EBUS-guided bronchoscopy under fluoroscopic guidance remaining independently associated with higher diagnostic yield compared with conventional bronchoscopy (adjusted OR 3.33, 95% CI 1.05–10.52; $P = 0.04$). The presence of a CT bronchus sign was a strong predictor of diagnostic yield (adjusted OR 23.71, 95% CI 7.01–80.17; $P < 0.001$), whereas lesion size >30 mm and solid or mass-type lesion morphology were not significantly associated with diagnostic yield after this adjustment. **Figure 2** illustrates the concordance of adjusted effect estimates between standard and Firth models.

Table 2. Bronchoscopic diagnosis outcomes according to technique.

Diagnostic outcome	Overall (n = 102)	Conventional (n = 66)	R-EBUS+ fluoroscopy (n = 36)	P-value
Final diagnostic yield	67/102 (65.7%)	40/66 (60.6%)	27/36 (75.0%)	0.14
(Procedure-level)				
BAL diagnostic yield	28/98 (28.6%)	19/65 (29.2%)	9/33 (27.3%)	0.84
Bronchial brushing diagnostic yield	3/4 (75.0%)	0/1 (0.0%)	3/3 (100.0%)	0.25
Transbronchial biopsy diagnostic yield	57/102 (55.9%)	33/66 (50.0%)	24/36 (66.7%)	0.11
Pathological diagnosis from biopsy				
Adenocarcinoma	38 (37.3%)	22 (33.3%)	16 (44.4%)	
Metastatic carcinoma	6 (5.9%)	3 (4.5%)	3 (8.3%)	
Squamous cell carcinoma	3 (2.9%)	2 (3.0%)	1 (2.8%)	
Granulomatous disease	5 (4.9%)	3 (4.5%)	2 (5.6%)	
Other specific benign pathology	5 (4.9%)	3 (4.5%)	2 (5.6%)	
Non-diagnostic	45 (44.1%)	33 (50.0%)	12 (33.3%)	0.65

BAL, bronchoalveolar lavage

Table 3. Factors associated with diagnostic yield.

Variable	Univariable OR (95% CI)	P-value	Model 1 aOR (95% CI)	P-value	Model 2 aOR (95% CI)	P-value
Bronchoscopic technique						
R-EBUS+fluoroscopy vs. Conventional	1.95 (0.79–4.80)	0.15	3.72 (1.12–12.38)	0.03	2.91 (0.82–10.30)	0.10
Male sex	0.48 (0.21–2.11)	0.09			0.31 (0.09–1.07)	0.06
Used tobacco	0.83 (0.32–2.16)	0.71				
COPD	0.38 (0.10–1.52)	0.17				
Upper-lobe location	1.55 (0.68–3.54)	0.30				
Bronchus sign presence	24.70 (7.57–80.64)	<0.001	31.33 (8.43–116.52)	<0.001	36.49 (9.10–146.36)	<0.001
Longest diameter ≥ 30 mm	2.07 (0.89–4.79)	0.09	1.46 (0.46–4.64)	0.52	1.63 (0.48–5.49)	0.43
Solid/mass lesion	3.52 (1.14–10.90)	0.03	4.00 (0.78–20.36)	0.10	3.06 (0.59–15.82)	0.18

Variables with $P < 0.10$ in univariable analysis or clinical relevance were considered for multivariable analysis.**Model 1 variables:** technique, bronchus sign, lesion size, lesion type**Model 2 variables:** Model 1 + sex

aOR, adjusted odds ratio; CI, confidence interval; COPD, chronic obstructive pulmonary disease; OR, odds ratio; R-EBUS, radial endobronchial ultrasound.

Table 4. Multivariable and Firth penalized logistic regression analyses for factors associated with diagnostic yield.

Variable	Adjusted OR (95% CI)	P-value	Firth adjusted OR (95% CI)	P-value
R-EBUS+fluoroscopy vs. Conventional	3.72 (1.12–12.38)	0.03	3.33 (1.05–10.52)	0.04
Bronchus sign presence	31.33 (8.43–116.52)	<0.001	23.71 (7.01–80.17)	<0.001
Longest diameter > 30 mm	1.46 (0.46–4.64)	0.52	1.42 (0.47–4.32)	0.53
Solid/mass lesion	4.00 (0.78–20.36)	0.10	3.53 (0.75–16.69)	0.11

- Odds ratios (ORs) were estimated using multivariable logistic regression.

- The multivariable model included bronchoscopic technique, bronchus sign, and lesion size (>30 mm) based on clinical relevance and prior analyses.

- Firth penalized logistic regression was performed as a confirmatory analysis to reduce small-sample and separation bias.

- Confidence intervals (CIs) are 95%.

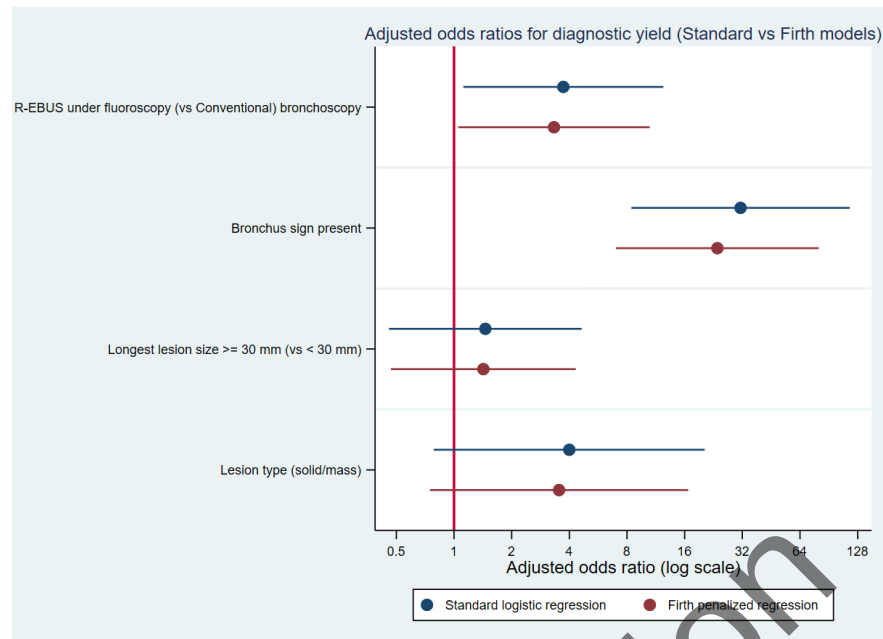


Figure 2. Forest plot showing adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for factors associated with final diagnostic yield. Estimates are derived from multivariable logistic regression (standard model) and confirmatory Firth penalized logistic regression. Odds ratios are displayed on a logarithmic scale. Wide confidence intervals for some predictors reflect limited precision due to sample size and event distribution and should be interpreted cautiously.

Discussion

In this single-center retrospective study at a provincial tertiary-care hospital, we compared the diagnostic yield of conventional flexible bronchoscopy and R-EBUS-guided bronchoscopy under fluoroscopic guidance for peripheral pulmonary lesions. At the procedure level, R-EBUS with fluoroscopy demonstrated a higher, but not significantly different, final diagnostic yield than conventional bronchoscopy (75.0% vs. 60.6%) in the unadjusted analysis. After adjustment for clinically relevant lesion-related factors, R-EBUS-guided bronchoscopy under fluoroscopy was independently associated with higher diagnostic yield, while presence of a CT bronchus sign emerged as the strongest, most consistent predictor of diagnostic success across models.

The diagnostic yield of conventional bronchoscopy in this study is consistent with prior reports, in which yields range from 35.0% to 83.0% depending on lesion characteristics and procedural approach.⁽³⁾ The relatively high yield in our cohort may be partly explained by the predominance of larger lesions, as nearly two-thirds had a maximum diameter ≥ 30 mm, a factor consistently associated with improved diagnostic success in conventional bronchoscopic biopsy.⁽³⁾ Similarly, the diagnostic yield of R-EBUS-

guided bronchoscopy under fluoroscopic guidance in our study aligns with recently reported pooled estimates of 70.0%–75.0%.⁽¹⁰⁾ Despite limited direct head-to-head comparisons, our findings are consistent with evidence supporting the incremental value of combining radial ultrasound with fluoroscopic guidance in selected lesions.^(6, 10) Further, the distribution of pathological diagnoses in our cohort was comparable between techniques and consistent with prior research, supporting the external validity of our results.^(5, 6, 13)

Beyond bronchoscopic technique, lesion-related factors played a pivotal role in determining diagnostic yield. Among all evaluated variables, presence of a CT bronchus sign was the most robust predictor of diagnostic success. Previous studies have demonstrated that a bronchus leading directly to the target lesion substantially increases the likelihood of successful transbronchial sampling, particularly in image-guided and R-EBUS-guided procedures,^(16–18) a finding reinforced by meta-analysis.^(10, 13) Further, lesion size has traditionally been associated with diagnostic yield, with larger lesions generally yielding higher success rates.^(3, 5) The anatomical mechanism driving this size-yield relationship was classically described by Tsuboi, *et al.*, who demonstrated a direct correlation between tumor size and airway multiplicity. In their seminal study, they observed that 62.5% of

tumors smaller than 3 cm were supplied by merely a single airway. Conversely, they found that lesions measuring 3 cm or larger involved multiple bronchial branches in 60.0% of cases, an anatomical feature that inherently facilitated transbronchial instrument access.⁽¹⁸⁾ In our cohort, the association between lesion size and diagnostic yield was weaker after adjusting for the bronchus sign and other covariates, suggesting that bronchial anatomy and lesion accessibility may be more influential than size alone, consistent with Yuan, *et al.*⁽¹⁹⁾ Lesion morphology demonstrated only a modest association with diagnostic yield after multivariable adjustment, indicating that lesion type alone is insufficient to predict diagnostic success without considering accompanying bronchial anatomy.

With respect to procedure-related factors, the role of bronchoscopic technique warrants careful interpretation. Although R-EBUS-guided bronchoscopy under fluoroscopic guidance demonstrated a higher crude diagnostic yield than conventional bronchoscopy, this difference was not significant before adjustment. However, accounting for lesion-related factors resulted in R-EBUS with fluoroscopy being independently associated with higher diagnostic yield, suggesting that baseline differences in lesion accessibility may have masked procedural benefit in the unadjusted comparison. The sensitivity of this association to model specification highlights the challenge of disentangling technique-related effects from lesion accessibility in retrospective analyses and underscores the potential for residual confounding. The attenuation of the bronchoscopic technique effect in Model 2 ($P=0.10$) after further adjusting for sex most likely reflects loss of statistical precision from over-parameterization in a modest sample size, rather than true confounding by sex, as patient sex is not an established determinant of bronchoscopic lesion accessibility. Despite this, confirmatory penalized regression analysis produced effect estimates that aligned with the primary adjusted model's direction. This supports the robustness of the observed association.

This study has several strengths. It reflects real-world practice in a provincial tertiary-care hospital where diagnostic bronchoscopy is performed by a general pulmonologist rather than interventional specialists, addressing an important evidence gap in resource-limited settings. Further, diagnostic yield was defined using contemporary ATS/ACCP Delphi

consensus criteria, enhancing methodological rigor and comparability.⁽¹⁵⁾ In addition, use of both standard and penalized regression analyses strengthened the validity of our findings in the context of a modest sample size. Limitations include its retrospective design, potential selection bias, differences in sex distribution and lesion size between groups, incomplete data on the exact number of biopsy samples and the specific size or type of biopsy forceps used, and differential bronchoscope utilization between cohorts. Specifically, the R-EBUS-guided cohort exclusively used the Olympus BF-H190 (outer diameter: 4.9 mm), whereas the conventional cohort used either a Fuji EB-589S (outer diameter: 5.1 mm) or an Olympus BF-H190 (outer diameter: 4.9 mm). This differential allocation may be a potential source of residual technical confounding that could not be fully controlled. Given that all procedures were performed by a single operator, it is important to acknowledge the potential temporal bias introduced by the learning curve during R-EBUS's initial institutional adoption phase with fluoroscopy. The R-EBUS cohort was the first year of institutional adoption, starting in October 2024. Procedural inexperience during this phase may have attenuated the diagnostic yield of R-EBUS with fluoroscopy, suggesting that the reported independent benefit (adjusted OR 3.72) is a conservative estimate of its true utility with increasing operator proficiency. Although the single-center design may limit generalizability, consistency with multicenter observational studies and metaanalyses supports external validity.

Conclusion

Our findings suggest that careful pre-procedural assessment of lesion-related factors, particularly presence of a CT bronchus sign, may be as critical as the choice of bronchoscopic technique for optimizing diagnostic yield. In resource-limited settings, selective use of R-EBUS-guided bronchoscopy under fluoroscopic guidance for lesions with favorable bronchial anatomy may help maximize diagnostic success while maintaining procedural efficiency. Prospective, multicenter studies with standardized technique allocation are warranted to further clarify the independent contribution of bronchoscopic techniques to diagnostic yield.

Author contributions

BS contributed substantially to the concept and design of this study, the acquisition of data, reviewing the literature, and the analysis and interpretation of data, and drafted the manuscript. KE, ID, and SS contributed to the interpretation of data and revised the manuscript critically for important intellectual content. All authors approved the final version submitted for publication and took responsibility for statements made in the published article.

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Conflict of interest statement

All authors have completed and submitted the International Committee of Medical Journal Editors Uniform Disclosure Form for Potential Conflicts of Interest. All authors declare that they have no conflicts of interest.

Data sharing statement

All data generated or analyzed in the present study are included in the published article. Further details are available for non-commercial purposes from the corresponding author upon reasonable request.

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