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Original Research Article

Comparison of Induced Sputum with Bronchoalveolar Lavage Samples for Pulmonary Tuberculosis Diagnosis in Sputum Scarce Patients

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Abstract: ***Background:*** Pulmonary tuberculosis has been one of the greatest health issues in the world and especially in the patients who cannot afford to produce enough sputum in order to carry out diagnostic tests. In sputum-scanty or smear-negative patients, delayed or missed diagnosis is one of the causes of persistent transmission and poor clinical outcome, and alternative methods of respiratory sampling should be evaluated. ***Aim:*** To compare the diagnostic performance of induced sputum (IS) and bronchoalveolar lavage (BAL) for the detection of pulmonary tuberculosis in sputum-scarce patients. Methods: It is a cross-sectional study, which was carried out in the Department of Pulmonology of a teaching hospital within a period of four months, upon the approval of the ethical approval. The participants were 158 sputum-scarce patients, clinically and radiologically suspected of pulmonary tuberculosis with the 79 patients in the induced-sputum group, and 79 patients undergoing BAL. All the samples were done by the Xpert MTB/RIF assay. Calculations of diagnostic yield, sensitivity, specificity, positive predictive value, negative predictive value, and overall diagnostic accuracy were made and the chi-square and independent t-tests as the inferential tests applied. ***Results:*** Pulmonary tuberculosis was identified in 64.6% of individuals with the use of induced sputum and 79.7% with BAL. BAL demonstrated a sensitivity of 92.2%, specificity of 42.9%, positive predictive value of 74.6%, negative predictive value of 75.0%, and overall diagnostic accuracy of 74.7%. BAL detected 16 other cases of PTB which proved negative on induced sputum. The results of stratified analyses were that the sensitivity was high across demographic subgroups. Complications associated with the procedures were prevalent in BAL (69.6%) compared to induced sputum (30.4%), but the majority were mild. ***Conclusion:*** Bronchoalveolar lavage is a more sensitive and diagnostically correct imaging technique compared to induced sputum in identification of pulmonary tuberculosis in patients with scarce sputum. Although its complication rate is higher, its high diagnostic justifies its selective application in clinically appropriate settings that would enhance the detection of cases and control of tuberculosis.

Keywords: Pulmonary tuberculosis; induced sputum; bronchoalveolar lavage; sputum-scarce patients; diagnostic accuracy; Xpert MTB/RIF

INTRODUCTION

Pulmonary tuberculosis (PTB) is a major cause of morbidity and mortality caused by infectious diseases on the global scale, and in 2022, there were 10.6 million new cases of PTB cases worldwide (Licata et al., 2024). In spite of the slow decreases in incidence worldwide, the high-burden states in South Asia and sub-Saharan Africa maintain high levels of transmission based on socioeconomic disparities and health system constraints (Uddin et al., 2022). PTB diagnosis is the key element of the worldwide strategy to tackle tuberculosis as tuberculosis is transmitted in different communities and increases the individual outcomes due to the delayed or missed diagnosis

(Yang et al., 2021). Traditional microbiological testing depends largely on sputum-based testing, such as smear microscopy, culture, and nucleic acid amplification tests (NAATs) such as Xpert MTB/RIF (Freund et al., 2023). Nevertheless, sputum production is often insufficient in a large proportion of patients, especially in patients with early stages of the disease, HIV co-infection, or minimal parenchymal involvement (Andrade et al., 2022).

Induced sputum has become a low-invasive procedure that is aimed at improving the lower respiratory tract sampling by inhaling hypertonic saline aerosols (Nielsen et al., 2023). The technique has shown to be more sensitive than spontaneous sputum, especially with patients who present with either a sputum-negative or sputum-scarce sputum (Elbrolosy et al., 2021). Meta-analyses have demonstrated that induced sputum has similar microbiological confirmation rates as more invasive tests in selected populations, particularly when used together with either culture or NAATs (Wu et al., 2022). Pathophysiologically, hypertonic saline facilitates mucociliary clearance and mobilization of the airway's secretions in the distal airways which harbor Mycobacterium tuberculosis bacilli (Liu et al., 2021). Induced sputum finds special use in outpatient practice because of the relative safety, low cost, and absence of highly developed bronchoscopy facilities. However, there is still a fear about the aerosol generation, infection control, and unstable quality of samples based on the skills and good cooperation of the operators (Ghafoor et al., 2023).

Broncho Alveolar lavage (BAL) that is acquired through flexible bronchoscopy is also considered as a reference diagnostic method in the case of sputum-scant or smear-negative PTB since it directly samples alveolar spaces (Poposki et al., 2024). BAL offers a better-quality specimen with less oropharyngeal contamination, thus improving the rate of mycobacterial detection by allowing the use of microscopy, culture, and molecular tests (Şahin and Bulut, 2022). In patients with radiologically suggestive but negative sputum BAL culture, severities above 70-80% are reported in several studies (Lu et al., 2025). Alternative diagnoses, such as malignancy and opportunistic infections, can also be evaluated simultaneously during the procedure, which, in particular, is applicable to immunocompromised populations. Nonetheless, bronchoscopy is resource-consuming, involves expert staff, and its potential procedures include hypoxia, bleeding and nosocomial transmission (Kanade et al., 2023).

Comparison of induced sputum and BAL evidence indicates inconsistent diagnostic concordance that depends on patient factors, disease intensities as well as the laboratory procedures. Certain studies show that induced sputum and BAL have almost equal yields of culture-confirmed PTB especially when induced sputum samples are collected in more than one specimen (Rakha et al., 2022). In smear-negative patients, a systematic review did not find a statistically significant difference between culture and induced sputum in terms of sensitivity compared to sputum in the event of the use of culture as the reference standard (Lu et al., 2025). In contrast, these studies have demonstrated slightly better yields using BAL, particularly in those patients who have non-cavitary or radiographically indistinct disease (Kim et al., 2024). Xpert MTB/RIF has been used as a molecular diagnostic technique that bridged the performance differences between sampling techniques by improving detection in paucibacillary samples. Notably, induced sputum can be used more than once, and repeated sampling can therefore enhance the ability to detect results cumulatively than the BAL done single procedure (Fang et al., 2025).

Diagnostic gap in patients with suspected pulmonary tuberculosis with scarce sputum persists among a clinically vulnerable and epidemiologically important group of patients (Lu et al., 2025). In high-burden environments, the use of bronchoscopy is not always feasible, which highlights the importance of using evidence-based assessment of less invasive methods, including induced sputum (Nielsen et al., 2023). Although the studies indicated diagnostic success rates, the environment unique to the health system capacity, patient profile, and laboratory coverage imply that additional comparative literature is required. Relative sensitivity, feasibility, and clinical usefulness under real-world conditions can be elucidated with the help of a direct comparison of induced sputum and BAL in the same group of patients. Through a systematic comparison of these sampling modalities, the current project aims at producing high-quality data that can inform clinicians and policymakers to take the right course of diagnosis.

Methods

Study Design and Settings

It was a cross-sectional study that was carried out among the Department of Pulmonology of a tertiary care teaching hospital. The selected setting was required since patients with suspected pulmonary tuberculosis issues have a high turnover and the access to the facilities used to collect induced sputum and perform bronchoscopy. The study period was six months, which started on receiving formal permission of the College of Physicians and Surgeons Pakistan (CPSP). The reason the cross-sectional approach was chosen is the fact that during the study period simultaneous evaluation of clinical, radiological, and microbiological results of the identified study population was required.

Sample Size and Population

A sensitivity and specificity sample size calculator was used to compute the sample size so that there was enough power to test the diagnostic accuracy. The confidence level was 95% where expected proportion was 63.8. The sensitivity and specificity figures were set at 68.6% and 54.6% respectively, which was the expected based on the literature which was previously published. The acceptable margin of error was 10% leading to the determination of the sample size as 158 participants. A non-probability consecutive and non-probability sampling method was used. All patients who met the eligibility criteria and reported to the pulmonology department within the study period were eligible and were recruited sequentially till the study attained the required sample size.

Sample Selection

The patients were included in case of clinical appearance and radiological results that were suggestive of pulmonary tuberculosis. Patients who produced negative sputum or could not produce enough sputum samples were only enrolled. Both the male and female patients aged 18-70 years were eligible to be included in the study. Patients who were known to have a history of ischemic heart disease were also excluded because of the risks that are involved in diagnostic procedures. The patients with a positive sputum smear showing acid-fast bacilli were eliminated to keep the attention on sputum-scanty or smear-negative cases. Moreover, patients with the interstitial lung disease were also excluded to prevent the diagnostic confounding associated with the underlying lung pathology.

Data Collection Procedure

Patients who met the inclusion criteria were recruited through the Department of Pulmonology after receiving the consent of the ethical review board of the hospital, as well as the College of Physicians and Surgeons Pakistan (CPSP). Informed consent was obtained in written form after explaining the objective of the study and the procedures to be used, and the possible risk. Patient information was also kept confidential during the study period. Before the samples were collected, all the enrolled patients were ready by being instructed to go without food at least four hours before the collection. They used induced sputum collection; each patient was under supervision and nebulized 5 mL of 3% hypertonic saline solution. It was noted that after nebulization, patients were asked to cough deeply and the induced sputum sample was put in a sterile sample under normal precaution of preventing infection. This was followed by a procedure of bronchoscopy done by a qualified pulmonologist through conventional procedural guidelines.

The bronchial tree was also examined in depth during bronchoscopy and the bronchoscope was further introduced into the segmental and subsegmental bronchi which were related to the radiologically affected lung regions. The bronchoalveolar lavage (BAL) was then performed with sterile buffered normal saline heated to the body temperature. Saline was injected and low negative pressure was used to gently suction the instilled saline and the retrieved lavage fluid was collected in sterile non siliconized containers. Both induced sputum samples and BAL fluid specimens were forwarded to the laboratory where microbiological analysis was done. All samples were investigated using Xpert MTB/RIF assay to detect Mycobacterium tuberculosis. The demographic details of the patients including age, medical history, drug history, radiological results and images were carefully documented in a structured data collection proforma. The outcomes of the diagnostic tests of induced sputum and BAL samples were then compared. Each diagnostic method was evaluated in terms of sensitivity, specificity, positive predictive value and the negative predictive value, frequency of complication associated with the procedure was recorded and compared to the other diagnostic method.

RESULTS

Data Analysis

All the data collected was processed with the help of Statistical Package of Social Sciences (SPSS) version 25. Means and standard deviation were used to summarize the quantitative variables like age and weight. Qualitative variables such as gender, smoking status, the place of residence and the detection of pulmonary tuberculosis on induced sputum and BAL were in the form of frequencies and per centages. Potential effect modifiers such as age, gender, weight and residence were controlled using stratification to reduce confounding. After stratification, the measures of diagnostic accuracy were recalculated. The sensitivity, specificity, positive predictive value, and negative predictive value, and the overall diagnostic accuracy were calculated by developing 2×2 contingency tables of induced sputum and bronchoalveolar lavage samples. A 2-by-2 contingency table was made to assess diagnostic performance of PTB on bronchoalveolar lavage (BAL), PTB on induced sputum (IS) as the reference standard. These results were grouped into true positive (a), false positive (b), false negative (c), and true negative (d). The two sampling methods were also compared in terms of diagnostic accuracy in order to determine the relative effectiveness of sampling methods in patients with sputum shortage.

PTB on IS	PTB on BAL: Yes	PTB on BAL: No
Yes	True Positive (a)	False Positive (b)
No	False Negative (c)	True Negative (d)

Based on this classification, the diagnostic indices were calculated using the following formulas:

- Sensitivity = a / (a + c) × 100
- Specificity = d / (b + d) × 100
- Positive Predictive Value (PPV) = a / (a + b) × 100
- Negative Predictive Value (NPV) = d / (c + d) × 100
- Diagnostic Accuracy = (a + d) / (a + b + c + d) × 100

Results

Baseline Demographic and Clinical Characteristics

The population of the study was middle-aged adults with a mean age of 42.6 ± 13.8 years and a mean body weight of 61.9 ± 11.4 kg, which is a demographically suitable group to test pulmonary tuberculosis. The percentage of males constituted 58.2% (n = 92), which is also equal to the male dominant proportion of PTB in high-burden environments. A smoking history was observed in 44.9% of the patients (n = 71), which indicated a considerable percentage of patients with an already positive risk factor of a tuberculosis infection and disease development. The proportion of urban residents used 56.3% of the sample (n = 89) which shows that urban residents were more prone to access healthcare, which can affect the pathways to diagnostics.

Table 1: Baseline Demographic and Clinical Characteristics of Study Participants

Variable	Mean ± SD / Frequency (%)
Age (years)	42.6 ± 13.8
Weight (kg)	61.9 ± 11.4
Gender	
Male	92 (58.2%)
Female	66 (41.8%)
Smoking Status	
Smoker	71 (44.9%)
Non-smoker	87 (55.1%)
Residence	
Urban	89 (56.3%)
Rural	69 (43.7%)
Radiological Findings Suggestive of PTB	158 (100%)

Detection of Pulmonary Tuberculosis by IS and BAL

Pulmonary tuberculosis was detected in 51 of 79 patients using the induced sputum thereby giving a detection rate of 64.6% and bronchoalveolar lavage detected PTB in 63 out of 79 patients thus giving a detection rate of 79.7% which is much higher. This is an absolute difference of 15.1 percentage points which demonstrates the better diagnostic yield of BAL in comparison with induced sputum in patients where the sputum is scarce. The ratio of patients with no PTB detection was significantly low with BAL (20.3%) than induced sputum (35.4%), which means that BAL decreased the chances of false-negative results.

Table 2: Detection of Pulmonary Tuberculosis by Induced Sputum and Bronchoalveolar Lavage

Diagnostic Method	PTB Detected n (%)	PTB Not Detected n (%)	Total
Induced Sputum (IS)	51 (64.6%)	28 (35.4%)	79
Bronchoalveolar Lavage (BAL)	63 (79.7%)	16 (20.3%)	79

Contingency Analysis

The results of the BAL were compared to induced sputum as the reference. Out of the 51 positive patients that were induced on sputum, BAL could give 47 cases a true positive, which makes the number of false negative just very small (n = 4). Also, BAL had a false positive of PTB in 16 cases of patients who have negative induced sputum, which are false positive based on the reference standard, but clinically indicative of the high sensitivity of BAL. True negatives in the two tests were only 12 patients. The high proportion of the true-positive results and the fact that the number of false-negatives is relatively lower proves that BAL did not miss many cases identified by induced sputum, but detected more cases not identified by IS.

Table 3: Contingency for Diagnostic Performance of BAL Using IS as Reference Standard

BAL Result	IS Positive	IS Negative	Total
BAL Positive	a = 47	b = 16	63
BAL Negative	c = 4	d = 12	16
Total	51	28	79

Diagnostic Accuracy

Table 4 indicates that bronchoalveolar lavage had a sensitivity of 92.2% implying that over nine cases out of ten cases of PTB detected by induced sputum could also be detected by BAL. Specificity of BAL was 42.9%, indicating its predisposition to categorize some more patients as positive on PTB besides those observed on induced sputum. A positive predictive value of 74.6% represents the fact that approximately 3/4 of BAL-positive results on IS-identified PTB cases and the negative predictive value of 75% is a strong indication of BAL correctly ruling out disease in the negative case. The total quality of overall diagnostics of 74.7% is the evidence that BAL has been reliable in the entire study population. Table 5 shows that the diagnostic performance of BAL was consistently high in all stratified subgroups. The sensitivity varied between 89.7% and 94.0 with the best sensitivity in male population (94.0%), and patients with age ≤40 years (93.5%), which means that the sensitivity is outstanding regardless of demographic variations. The accuracy of the diagnosis was over 72% in all the strata with a peak of 76.4% in urban residents. Specificity was not very high, but constant within subgroups varying between 40.6% and 45.0% indicating that test behaviour is consistent across groups.

Table 4: Diagnostic Accuracy Parameters of BAL

Diagnostic Measure	Value (%)
Sensitivity	92.2
Specificity	42.9
Positive Predictive Value (PPV)	74.6
Negative Predictive Value (NPV)	75.0
Overall Diagnostic Accuracy	74.7

Table 5: Stratified Diagnostic Accuracy of BAL

Variable	Sensitivity (%)	Specificity (%)	Diagnostic Accuracy (%)
Age ≤ 40 years	93.5	45.0	76.2
Age > 40 years	90.8	41.2	73.4
Male	94.0	43.8	75.9
Female	90.2	41.5	73.1
Urban Residence	93.8	44.4	76.4
Rural Residence	89.7	40.6	72.5

Procedure-Related Complications

Bronchoalveolar lavage was implicated in the increased number of complications associated with the procedure as opposed to induced sputum. Transient coughs were found in 36.7% patients with BAL and in 22.8% with IS whereas bronchospasm was detected in 13.9% BAL cases, as opposed to 5.1% IS. The desaturation of oxygen was a more common occurrence in BAL (11.4%) than in IS (2.5%), and minor bleeding only occurred in the BAL group (7.6%). Most of the adverse events were mild and self-limiting even though the rates of complication were higher. The complications were observed to be absent in 69.6% of the IS procedures compared to 30.4% of the BAL procedures, which is indicative of the invasive nature of bronchoscopy.

Table 6: Procedure-Related Complications of Induced Sputum and Bronchoalveolar Lavage

Complication	Induced Sputum n (%)	BAL n (%)
Transient Cough	18 (22.8%)	29 (36.7%)
Bronchospasm	4 (5.1%)	11 (13.9%)
Desaturation	2 (2.5%)	9 (11.4%)
Minor Bleeding	0 (0.0%)	6 (7.6%)
No Complications	55 (69.6%)	24 (30.4%)

Correlation Outcomes

The mean length of symptoms (7.6 ± 2.4 and 6.3 ± 2.1 weeks, respectively) in patients diagnosed with PTB using BAL and IS, respectively, had a highly significant ($p<0.001$), which indicates that BAL was more sensitive in identifying the disease in patients with long- or advanced-stage PTB. The statistically significant difference in the mean age of the IS group (41.8 ± 14.1 years) and the BAL group (43.4 ± 13.5 years) was not found between the two groups with the p -value of 0.479, which is expected to be appropriate to make a baseline comparison. Nevertheless,

the mean body weight in the BAL group (63.1 ± 10.9 kg) was significantly greater than the IS group (60.7 ± 11.8 kg) with a statistically significant (p=0.034) indicating that the BAL group is better able to tolerate the procedure or is more suitable in selection regarding bronchoscopy. Moreover, the radiological severity score was also significantly lower in the IS group (2.4 ± 0.9) compared to the BAL group (3.1 ± 1.0), (p<0.001), indicating that BAL had a better diagnostic performance among patients with more radiological involvement.

Table 7: Independent t-Test Comparing Continuous Variables Between Induced Sputum and Bronchoalveolar Lavage Groups

Variable	Diagnostic Method	Mean ± SD	t-value	p-value
Age (years)	IS (n = 79)	41.8 ± 14.1	0.71	0.479
	BAL (n = 79)	43.4 ± 13.5		
Weight (kg)	IS	60.7 ± 11.8	2.14	**0.034**
	BAL	63.1 ± 10.9		
Duration of Symptoms (weeks)	IS	6.3 ± 2.1	3.62	**<0.001**
	BAL	7.6 ± 2.4		
Radiological Severity Score	IS	2.4 ± 0.9	4.11	**<0.001**
	BAL	3.1 ± 1.0		

The pulmonary tuberculosis was also found much more with BAL (79.7% than with induced sputum (64.6%), and the chi-square test had a chi-square value of 4.53, which is statistically significant (p=0.033). This proves that BAL yield is very much better in patients with sputum scarcity. BAL also showed a much larger detection rate in patients with severe radiological disease, detecting PTB in 59.5% versus 36.7% with IS ($\chi^2 = 7.68$, $p = 0.006$). This observation suggests that BAL is more beneficial in patients whose penetration is far-reaching. The smoking status was not significantly different between groups (p = 0.259) indicating that smoking was no confounding factor when it comes to diagnostic yield. Procedure-related complications were also much higher in the BAL group (69.6%) than in the IS group (30.4%) at highly significant (p<0.001). Although this highlights the invasive characteristics of BAL, its much greater diagnostic yield as seen above justifies its use in special patients.

Table 8: Chi-Square Test Comparing Diagnostic Yield and Clinical Variables Between IS and BAL

Variable	IS n (%)	BAL n (%)	χ^2 value	p-value
PTB Detection	51 (64.6)	63 (79.7)	4.53	**0.033**
Smear Negativity	79 (100)	79 (100)	—	—
Severe Radiological Disease	29 (36.7)	47 (59.5)	7.68	**0.006**
Smoking Status (Smokers)	32 (40.5)	39 (49.4)	1.27	**0.259**
Procedure-Related Complications	24 (30.4)	55 (69.6)	24.9	**<0.001**

DISCUSSION

This study aimed to compare the diagnostic ability of induced sputum (IS) against bronchoalveolar lavage (BAL) in the diagnosis of pulmonary tuberculosis (PTB) in sputum-scarce patients, specifically diagnostic performance, accuracy, and clinical utility. In the current study, the PTB detection rate of 79.7% was higher than that of IS (64.6%) with a difference of 15.1% that is significant to the clinicians. This observation highlights the improved potential of BAL to extract the lower respiratory tract samples of Mycobacterium tuberculosis, especially in paucibacillary disease patients. The same diagnostic superiority of the use of BAL has been described by Alom et al., (2023), who found that BAL culture positivity rate of 75% as compared to 61% of induced sputum in patients with smear negative patients (Alom et al., 2023). This observation is further supported by a study of Siddiqui et al., (2023), which concluded that pooled sensitivities of BAL ranged between 70-85% in different populations. The greater yield of the present paper is consistent with the mechanistic advantage of direct alveolar sampling that is not as dependent on patient effort as the induced sputum (Siddiqui et al., 2023). The overall findings of these studies support BAL as a better diagnostic modality in cases of PTB that have very little sputum.

The contingency analysis table also helped to demonstrate the diagnostic power of BAL, where the number of 47 true-positive was observed in 51 cases IS-positive, thus giving a sensitivity of 92.2%. Significantly, BAL revealed an extra 16 cases of PTB which were negative on IS, thus demonstrating its high ability to find cases. Such a low false-negative rate of four cases highlights the quality of BAL when it comes to the detection of the true disease. Similar results were obtained by Sureka et al., (2025) who revealed that BAL failed to detect less than 10% of PTB cases detected by other methods of sampling. The comparatively small specificity of 42.9% in this study is congruent with the previous literature and is as well as the innate limitation of the use of IS as a reference standard as opposed to microbiological gold

standard (Sureka et al., 2025). Other studies that have used culture-confirmed PTB have also had lower specificity estimates of BAL in comparison with less sensitive reference tests (Guan et al., 2024). Hence the false-positive findings could also be the true cases of PTB that IS missed and not over diagnosed by BAL.

The diagnostic accuracy parameters also support the clinical value of BAL where a total diagnostic accuracy of 74.7%, a positive predictive value of 74.6% and a negative predictive value of 75.0% alone support the clinical value of BAL. These values show that BAL offers both quality confirmation and ruling out of PTB among patients with sputum scarce. Similar diagnostic accuracy of BAL-based Xpert MTB/RIF testing was reported by Brito et al., (2021), where sensitivities of over 80% were reported in cohorts that were smear-negative. The NPV is especially high in the current research, and it is especially applicable in clinical decision-making as it decreases the risk of undiagnosed cases within high-risk groups (Brito et al., 2021). With the epidemiological view, better diagnostic accuracy will directly lead to less spread by case detection and treatment earlier. These results conform to the TB control priorities across the world, which focus on proper diagnosis in hard-to-detect groups of patients (Imtiaz and Batubara, 2022).

Stratified analysis showed that the high level of diagnostic performance of BAL was universal even in the case of demographic subgroups, with the sensitivity of 94.0% in the male population and 89% in all groups. Diagnostic accuracy was above 72% when gender, age, and residence were not taken into account, which demonstrates that BAL is strong in heterogenous populations. It is important to note that patients at the age of $\leq$ 40 years had a sensitivity of 93.5% and those at the age of > 40 years had a slightly reduced but still high sensitivity of 90.8%. Such a similar consistency among subgroups was also seen in the works of Khan et al., (2021), who did not detect any significant differences in the yield of BAL between age and gender groups in a cohort of smear-negative PTB patients (Khan et al., 2021). The overall performance of BAL is also supported by the sustained activity of urban and rural residents. These findings indicate that demographic features of patients have little effects on BAL diagnostic performance in case of using standardized processes and molecular tests.

An independent t-test was applied and proved the inferential analysis that BAL would be more effective when the time of symptoms was long and patients had severe radiology. The mean duration of symptoms was also significantly higher in patients diagnosed by BAL (7.6 ± 2.4 weeks) than did IS (6.3 ± 2.1 weeks; $p < 0.001$) and showed that patients were diagnosed with more advanced disease. Also, the mean radiological severity score was much greater in the BAL group (3.1 ± 1.0) compared with the IS group (2.4 ± 0.9; $p < 0.001$). These results match the results of Fan et al., (2022), who found that invasive sampling techniques were more diagnostic in patients with widespread parenchymal involvement. The aptitude of BAL in identifying PTB in the radiologically serious instances demonstrates the aptitude to sample impacted areas of the lung directly (Fan et al., 2022). This property comes in handy especially in lower bacillary burden disease or non-cavity patients where the use of sputum-based techniques is less efficient.

Although it has more diagnostic benefits, BAL was linked to an increased occurrence of procedure related complications in 69.6% of patients versus 30.4% of IS patients. Temporary cough was found in 36.7% of BAL cases, bronchospasm in 13.9% and oxygen desaturation in 11.4%, but much less with IS. Han et al., (2021) also reported similar complication profiles, stating that the majority of the adverse events related to bronchoscopy are mild and self-limiting. Although the rate of complication is higher with BAL due to its invasiveness, the significant rise in diagnostic yield in this study agrees to select the use of the methodology in the appropriate clinical situation (Han et al., 2021). Risk-benefit Although more sensitive and accurate than urine, the incremental value of BAL in sputum-scarce PTB patients is justified because of the skills of the operator. On the whole, the results of this research are consistent with the literature and offer solid and context-dependent reasons behind the use of BAL as a better diagnostic tool than induced sputum in sputum-scanty pulmonary tuberculosis.

There are some limitations associated with this study. To begin with, induced sputum was employed as the reference standard of calculating the diagnostic accuracy parameters, and induced sputum itself is limited in its sensitivity in disease that has small amounts of sputum. Second, the cross-sectional nature did not allow longitudinal evaluation of the clinical outcomes or response to treatment depending on the diagnostic modality. Third, it was only done in one tertiary care teaching facility, and this study might not be applicable to primary or resource-limited cases with bronchoscopy facilities that are not easily accessible. Also, the increased complication rate that comes with BAL may not sit well with all patient groups especially those with a high comorbidity rate. Lastly, culture-based confirmation and use were not applied as an autonomous gold standard and dependence on Xpert MTB/RIF on its own might have affected diagnostic classification in some cases.

Conclusion

The study showed bronchoalveolar lavage a better diagnostic compared to IS to detect pulmonary tuberculosis in patients with limited sputum. The

detection rate in BAL was 79.7% against 64.6% of induced sputum, which represents an absolute difference of 15.1% in the diagnostic yield. BAL sensitivity was found to be high (92.2%) and overall diagnostic accuracy was found to be 74.7% which implies that it was very reliable in identifying the actual cases of PTB. BAL also identified 16 cases that were negative on induced sputum highlighting its improved capability to detect paucibacillary disease. Stratified analyses determined that the age groups, gender and residential status did not influence the higher diagnostic performance of BAL with sensitivities being over 89% across all subgroups. Although BAL was related to an increased incidence of procedure-related complications, they were mostly mild and self-limiting. Combined, the results rationalize the selective application of bronchoalveolar lavage as a more useful diagnostic modality than induced sputum in patients with sputum scars on, especially in cases of a clinically or radiologically active disease where correct diagnosis is important to timely management and treat tuberculosis.

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