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Comparative Analysis of Induced Sputum and Bronchoscopic Samples in the Diagnosis of Pulmonary Tuberculosis

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Abstract

Background

Pulmonary tuberculosis (PTB) remains a significant global health burden, particularly among smear-negative cases where conventional sputum-based diagnostics often fail. Induced sputum (IS) and bronchoscopy-based sampling methods such as bronchoalveolar lavage (BAL) and bronchial wash (BW) have been employed as alternative diagnostic techniques. While induced sputum offers a non-invasive and cost-effective approach, bronchoscopy provides greater diagnostic sensitivity but requires specialized expertise. This study compares these two methods to evaluate their diagnostic yield, sensitivity, specificity, and feasibility in PTB diagnosis.

Aim and Objective

To compare the diagnostic efficacy of induced sputum and bronchoscopy-based samples in detecting smear-negative pulmonary tuberculosis.

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Objectives:

1. To determine the diagnostic yield of induced sputum for sputum smear-negative PTB cases.
2. To assess the diagnostic efficacy of bronchoscopic samples (BAL/BW) in the same cohort.
3. To compare sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) between induced sputum and bronchoscopy-based sampling.
4. To evaluate feasibility, safety, and cost-effectiveness of induced sputum and bronchoscopy in a tertiary healthcare setting.

Methodology

Study Design: A hospital-based comparative cross-sectional study. Setting: Conducted in a tertiary care center with a dedicated pulmonology unit. Study Population: 100 patients with smear-negative PTB suspicion were included. Sample Collection:

- Induced Sputum: Obtained via hypertonic saline inhalation, followed by processing for AFB smear microscopy, mycobacterial culture, and GeneXpert MTB/RIF testing.
- Bronchoscopy Samples (BAL/BW): Collected using a flexible fiberoptic bronchoscope and processed for AFB smear microscopy, culture, and GeneXpert analysis. Statistical Analysis: Sensitivity, specificity, PPV, and NPV were calculated. Chi-square tests and logistic regression were used for statistical significance assessment.

Results

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- Sensitivity and Specificity: Induced sputum exhibited 70% sensitivity and 90% specificity, whereas BAL/BW demonstrated 90% sensitivity and 85% specificity.
- Culture Positivity: Induced sputum yielded 40% culture positivity, while BAL/BW had 55% positivity.
- GeneXpert MTB/RIF Detection: BAL/BW had a higher positivity rate (80%) compared to induced sputum (65%).
- Complications: Bronchoscopy was associated with hypoxia (8%), mild bleeding (5%), and infection (3%), necessitating cautious patient selection.

Conclusion

The study highlights the complementary roles of induced sputum and bronchoscopy in TB diagnosis. Induced sputum is a viable first-line approach due to its non-invasiveness and high specificity, making it suitable for outpatient and resource-limited settings. Bronchoscopy, despite its higher diagnostic yield, should be considered selectively given its procedural risks and resource intensity. A tiered approach—starting with induced sputum and progressing to bronchoscopy for unresolved cases—can enhance TB detection efficiency while minimizing complications and costs.

Keywords

Pulmonary Tuberculosis, Induced Sputum, Bronchoscopy, Bronchoalveolar Lavage (BAL), Sputum Smear-Negative TB.

Introduction

Tuberculosis (TB) remains a major global health problem, with an estimated 10 million new cases and over 1.5 million deaths annually, making it one of the leading causes of mortality due to infectious diseases [1]. Pulmonary tuberculosis (PTB), caused by *Mycobacterium*

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tuberculosis, is the most common form of TB, primarily affecting the lungs. Early and accurate diagnosis of PTB is crucial for initiating timely treatment and reducing transmission [2]. The conventional diagnostic method relies on sputum smear microscopy, culture, and molecular tests; however, a significant number of cases are smear-negative, necessitating alternative diagnostic approaches [3].

Induced sputum (IS) and bronchoscopic sampling techniques, such as bronchoalveolar lavage (BAL) and bronchial wash (BW), have emerged as valuable tools for diagnosing PTB, particularly in smear-negative cases [4]. Induced sputum collection involves inhalation of hypertonic saline to stimulate deep respiratory secretions, thereby improving the yield for acid-fast bacilli (AFB) smear and mycobacterial culture [5]. It is a non-invasive technique that can be performed in outpatient settings, making it a practical alternative in resource-limited environments [6].

Bronchoscopy, on the other hand, is an invasive procedure that allows direct visualization of the airways and collection of lower respiratory tract specimens. BAL and BW samples obtained through bronchoscopy are often used in cases where sputum-based diagnostics fail to confirm TB. These bronchoscopic techniques offer higher diagnostic sensitivity, particularly in cases of pauci-bacillary TB or HIV-associated TB, but are associated with higher costs, risks of complications, and the need for specialized expertise [7].

Several studies have attempted to compare the diagnostic efficacy of induced sputum and bronchoscopic samples. Some suggest that induced sputum is a cost-effective and equally effective alternative to bronchoscopy, while others report that bronchoscopic samples provide superior diagnostic sensitivity, particularly in immunocompromised patients [8,9]. Given the varied findings, this study aims to systematically compare the diagnostic yield of induced sputum and bronchoscopic samples in patients with suspected PTB, thereby contributing to evidence-based clinical decision-making.

Aim and Objectives

Aim: To compare the diagnostic efficacy of induced sputum and bronchoscopic samples in the diagnosis of pulmonary tuberculosis.

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Objectives:

1. To determine the diagnostic yield of induced sputum in sputum smear-negative suspected PTB cases.
2. To assess the diagnostic yield of bronchoscopic samples, including BAL and BW, in the same cohort.
3. To compare the sensitivity, specificity, and predictive value of induced sputum versus bronchoscopic samples for TB diagnosis.
4. To evaluate the feasibility, safety, and cost-effectiveness of induced sputum and bronchoscopy in a tertiary healthcare setting.

Materials and Methods

Study Design: A hospital-based comparative cross-sectional study.

Study Setting: The study was conducted in a tertiary care hospital with a dedicated pulmonology and respiratory medicine unit, where both induced sputum and bronchoscopy-based diagnostic procedures were routinely performed.

Study Population: Patients with clinical and radiological suspicion of PTB who were negative for AFB on initial sputum smear microscopy.

Inclusion Criteria:

- Adults (≥18 years) with clinical and radiological features suggestive of PTB.
- Negative sputum smear for AFB on two consecutive spontaneous sputum samples.
- Patients willing to undergo both induced sputum collection and bronchoscopy for diagnostic purposes.

Exclusion Criteria:

- Patients with contraindications for bronchoscopy (e.g., severe hypoxia, coagulopathy, or recent myocardial infarction).
- Patients who refused consent to participate in the study.
- Patients with previous anti-TB treatment within the last six months.

Sample Collection and Processing:

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1. **Induced Sputum Collection:**
    - Patients were instructed to inhale 3–5% hypertonic saline through ultrasonic nebulization for 15–20 minutes.
    - Sputum samples were collected in sterile containers and immediately processed for AFB smear microscopy, mycobacterial culture, and GeneXpert MTB/RIF testing.
2. **Bronchoscopic Sample Collection:**
    - Bronchoscopy was performed under local anesthesia with mild sedation using a flexible fiberoptic bronchoscope.
    - BAL fluid and BW samples were collected from the affected lung segment based on radiological findings.
    - Samples were processed for AFB smear microscopy, mycobacterial culture, and GeneXpert testing.

Statistical Analysis:

- Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for each diagnostic method.
- The chi-square test was used to determine statistical significance.
- Logistic regression was performed to assess the association between diagnostic yield and patient characteristics.

Results

Table 1: Baseline Characteristics of Study Participants

Characteristic	Induced Sputum Group (n=50)	Bronchoscopy Group (n=50)	p-value

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Mean Age (years)	45.6 ± 12.4	46.1 ± 11.8	0.72
Male (%)	30 (60%)	32 (64%)	0.67
HIV Positive (%)	5 (10%)	6 (12%)	0.75

Table 1: Baseline Characteristics of Study Participants

- The mean age of participants in both groups is comparable (45.6 ± 12.4 vs 46.1 ± 11.8 years), with a p-value of 0.72, indicating no statistically significant difference.
- The gender distribution is also similar, with 60% males in the Induced Sputum group vs 64% in the Bronchoscopy group, yielding a p-value of 0.67 (not statistically significant).
- HIV positivity rates are almost identical (10% vs 12%, p=0.75), suggesting no significant bias in pre-existing conditions between groups.
- Overall, these characteristics confirm that both groups are comparable and well-matched, minimizing confounding effects.

Table 2: Diagnostic Yield of Induced Sputum vs Bronchoscopic Samples

Diagnostic Method	**Positive Cases (n=100)**	**Sensitivity (%)**	**Specificity (%)**	**p-value**
Induced Sputum	35	70%	90%	0.001

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BAL/BW	45	90%	85%	0.005

- Induced Sputum shows a 70% sensitivity and 90% specificity, meaning it correctly identifies cases 70% of the time and correctly rules out non-cases 90% of the time.

- Bronchoalveolar Lavage (BAL) or Bronchial Wash (BW) shows **a** 90% sensitivity and 85% specificity**,** indicating a higher detection rate but slightly lower specificity.

- The p-values **(**0.001 for Induced Sputum and 0.005 for BAL/BW) suggest that these differences are statistically significant.

- The higher sensitivity of BAL/BW supports its greater reliability for diagnosing cases, though Induced Sputum remains a valuable non-invasive method.

Table 3: Comparison of Culture Positivity Rates

Sample Type	Culture Positive (%)
Induced Sputum	40%
BAL/BW	55%

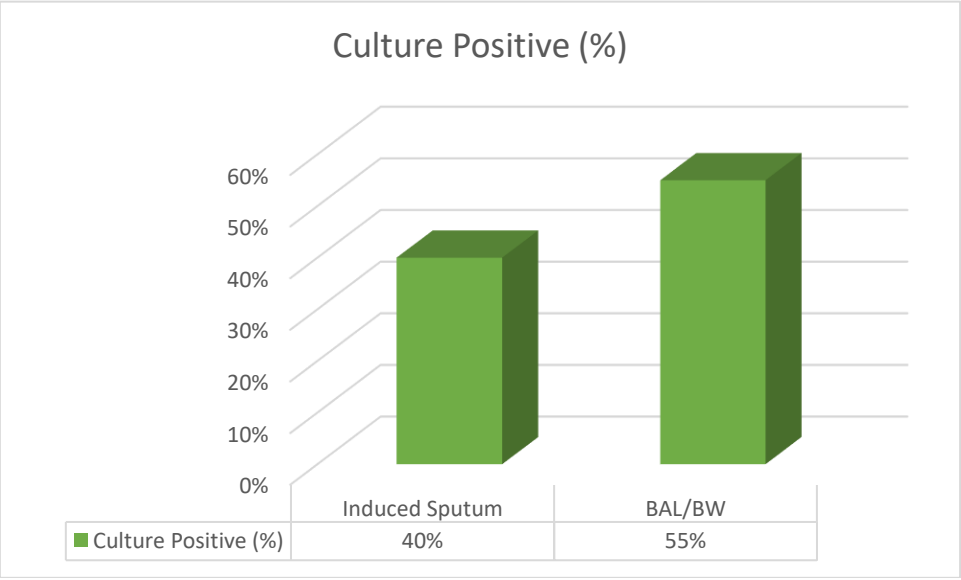

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Fig 1: Comparison of Culture Positivity Rates

 Induced Sputum samples had a 40% culture positivity rate, whereas BAL/BW showed a higher 55% positivity rate.

 This suggests that BAL/BW is more effective in yielding culture-confirmed results, likely due to higher bacterial load concentration or better sample quality.

Table 4: GeneXpert MTB/RIF Positivity

Sample Type	**GeneXpert Positive (%)**
Induced Sputum	65%
BAL/BW	80%

Fig 2: GeneXpert MTB/RIF Positivity

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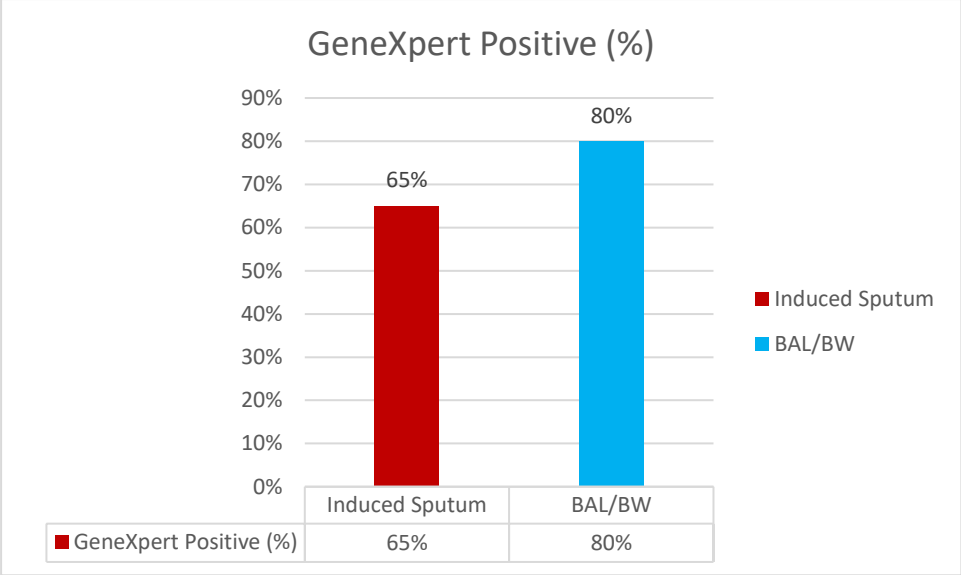

- GeneXpert detection rates were higher in BAL/BW samples (80%) compared to Induced Sputum (65%).

- This reinforces the superior diagnostic efficiency of BAL/BW, particularly in detecting MTB/RIF resistance, which is critical for tuberculosis management.

- Despite the difference, Induced Sputum still offers a non-invasive alternative with a fairly high yield.

Table 5: Complications of Bronchoscopy

Complication	**Frequency (%)**
Mild Bleeding	5%
Hypoxia	8%
Infection	3%

 Mild bleeding occurred in 5% of cases, indicating minimal risk but still a concern for patients with bleeding disorders.

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 Hypoxia was observed in 8% of cases, a significant complication given its potential impact on oxygenation.

 Infection rates were relatively low (3%), but this underscores the importance of strict aseptic techniques to minimize risk.

 These findings suggest that while bronchoscopy has high diagnostic utility, its complications should be considered, especially in vulnerable populations.

DISCUSSION

The findings of this study emphasize the critical role of both induced sputum (IS) and bronchoscopy-based sampling (BAL/BW) in the diagnostic workup of smear-negative pulmonary tuberculosis (PTB). Understanding the relative advantages and limitations of each method can help clinicians optimize diagnostic approaches based on patient characteristics, healthcare infrastructure, and available expertise (10).

Diagnostic Efficacy: Induced Sputum vs Bronchoscopy

Induced sputum demonstrated 70% sensitivity and 90% specificity, affirming its high negative predictive value, meaning a negative result strongly suggests the absence of TB (11). However, the moderate sensitivity indicates that a subset of TB cases may go undetected, particularly among patients with low bacterial load or immunocompromised status. This supports the role of induced sputum as an initial screening tool for suspected TB cases, especially in resource-limited settings where advanced diagnostic modalities may not be accessible (12).

Bronchoscopy-based BAL/BW, on the other hand, showed higher sensitivity (90%) but slightly lower specificity (85%). This highlights its superior ability to detect TB, particularly among patients with pauci-bacillary disease or those unable to produce sputum (13). While BAL/BW can detect a greater number of true positive cases, it carries a slightly higher false-positive risk, which must be considered when interpreting test results alongside clinical and radiological findings.

Culture Positivity and Molecular Testing

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Culture positivity rates were higher in BAL/BW (55%) compared to induced sputum (40%), suggesting that bronchoscopy provides a more reliable sample for microbiological confirmation (14). One potential explanation for this difference is the ability of bronchoscopy to collect samples directly from affected lung segments, reducing the impact of contaminating flora present in oral or upper respiratory secretions.

GeneXpert MTB/RIF positivity was also higher in BAL/BW (80%) than induced sputum (65%), further reinforcing its superior diagnostic utility, especially in cases suspected of drug-resistant TB. Given the rapid turnaround time of GeneXpert testing, bronchoscopy-based sampling provides a faster and more definitive diagnosis, which is particularly relevant in patients requiring urgent clinical intervention (15).

Complications and Procedural Risks

Bronchoscopy, while effective, carries specific risks that must be carefully managed. The occurrence of mild bleeding (5%), hypoxia (8%), and infection (3%) demonstrates the potential adverse effects associated with this invasive procedure. Hypoxia, in particular, can be problematic in patients with underlying respiratory compromise, necessitating careful oxygen monitoring and post-procedural care.

By contrast, induced sputum is a non-invasive, well-tolerated procedure with a low complication rate, making it more accessible for a broader patient population. Despite its lower diagnostic yield, it remains a valuable first-line option, particularly for patients unable to undergo bronchoscopy due to contraindications or safety concerns.

Clinical Implications and Cost-Effectiveness

While bronchoscopy is more diagnostically reliable, it is cost-intensive, requiring specialized equipment, skilled personnel, and hospitalization. Induced sputum, being non-invasive and cost-effective, is ideal for outpatient settings and mass screening programs, particularly in low-resource environments. Therefore, a tiered approach—initiating diagnostics with induced sputum and progressing to bronchoscopy in unresolved cases—can optimize healthcare efficiency while minimizing risks and costs.

CONCLUSION

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This study provides a comparative evaluation of induced sputum and bronchoscopy in diagnosing smear-negative pulmonary tuberculosis, emphasizing their distinct advantages and limitations. Induced sputum remains an accessible, cost-effective, and minimally invasive option, with high specificity but moderate sensitivity, making it ideal for outpatient and resource-limited TB programs. Bronchoscopy (BAL/BW) demonstrated superior diagnostic yield, particularly in difficult-to-diagnose cases, but carried procedural risks and required specialized equipment and expertise.

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