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## Association Between 2-Hour Postprandial Blood Glucose Levels and Acid Fast Bacilli Positivity

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### Abstract

Pulmonary tuberculosis (TB) and hyperglycemia have a bidirectional relationship, whereby impaired glucose metabolism can weaken cellular immunity and potentially increase the bacterial burden, resulting in a higher degree of acid-fast bacilli (AFB) positivity. Although the 2-hour postprandial blood glucose (2h-PPBG) test is a practical indicator of glucose intolerance, its association with AFB positivity in pulmonary TB patients remains inadequately explored. This study aimed to analyze the relationship between 2h-PPBG levels and the degree of AFB positivity among patients with pulmonary TB. A cross-sectional study was conducted at the Sukamaju Community Health Center in 2024 involving 60 adult patients ( $\geq 18$  years) diagnosed with pulmonary TB and diabetes mellitus. Participants were selected based on confirmed pulmonary TB diagnosis and complete blood glucose records. Data were analyzed using Spearman's correlation test and binary logistic regression. The results demonstrated a strong and statistically significant positive correlation between 2h-PPBG levels and the degree of AFB positivity. Logistic regression analysis indicated that every 10 mg/dL increase in 2h-PPBG was associated with a 9.3% increase in the odds of higher AFB positivity. In conclusion, elevated 2h-PPBG levels were significantly associated with greater AFB positivity among patients with pulmonary TB and diabetes mellitus. These findings highlight the importance of routine glycemic screening and optimal glucose control as part of comprehensive tuberculosis management to reduce disease severity and improve treatment outcomes.

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## 1. INTRODUCTION

Tuberculosis (TB) remains one of the leading infectious causes of morbidity and mortality worldwide. TB is caused by *Mycobacterium tuberculosis* and is transmitted through airborne droplets expelled by infected individuals, primarily affecting the lungs (Sahidan et al., 2026). According to the WHO Global Tuberculosis Report 2024, an estimated 10.8 million new TB cases and 1.25 million TB-related deaths occurred globally in 2023, making TB once again the leading infectious killer worldwide (World Health Organization, 2024). The five countries contributing the largest proportion of the global TB burden were India (26%), Indonesia (10%), China (6.8%), the Philippines (6.8%), and Pakistan (6.3%), accounting for 56% of all cases worldwide (World Health Organization, 2024). Among the major risk factors for TB, diabetes mellitus (DM) has emerged as the second largest modifiable risk factor after undernutrition, contributing to approximately 0.93 million new TB cases annually (World Health Organization, 2024). The coexistence of TB and DM has become a major public health challenge because DM increases the risk of active TB by two- to three-fold, worsens clinical manifestations, and reduces treatment success rates through impaired immune function (Lin et al., 2019; Boadu et al., 2024).

The burden of DM continues to increase globally and nationally. The 2023 Indonesian Health Survey reported a DM prevalence of 11.7% among individuals aged  $\geq 15$  years, an increase from 10.9% in the 2018 Basic Health Research survey, and the number of cases is projected to reach 28.6 million by 2045 (Ministry of Health of the Republic of Indonesia, 2023). Dwinata et al. (2025) found that population density was strongly associated with DM prevalence (0.198; 95% CI: 0.156–0.241), whereas poverty was correlated with TB prevalence. This pattern is particularly relevant in Bandar Lampung, an urban center with a high population density. The latest data from the Lampung Provincial Health Office recorded 89,981 DM patients across Lampung Province in 2022, with Bandar Lampung reporting the highest number of cases (Lampung Provincial Health Office, 2022). Furthermore, the Kedaton Community Health Center documented 1,190 active DM patients in 2024 (Lampung Provincial Health Office, 2024). Dwinata et al. (2025) also identified a high co-distribution of TB and DM in rapidly urbanizing and economically vulnerable areas across Sumatra, Java, and Kalimantan, highlighting Bandar Lampung as a relevant setting for investigating TB–DM comorbidity.

The biological interaction between TB and DM is complex and bidirectional. Chronic hyperglycemia and elevated postprandial blood glucose levels increase oxidative stress, non-enzymatic glycosylation, and endothelial dysfunction, thereby impairing innate and adaptive immune responses. In individuals with DM, macrophage and neutrophil functions are compromised, reducing their ability to phagocytose and eliminate *Mycobacterium tuberculosis*. In addition, T-cell-mediated immunity, which is essential for granuloma formation and TB control, becomes impaired. Previous studies have demonstrated that dysglycemia, assessed using fasting blood glucose and 2-hour postprandial blood glucose measurements, is associated with delayed sputum conversion during TB treatment (Meng et al., 2023). In Indonesia, further studies showed that most patients with TB and DM had HbA1c levels  $>7\%$ , fasting blood glucose  $>130$  mg/dL, and 2-hour postprandial blood glucose  $>180$  mg/dL, while poor glycemic control was associated with prolonged TB treatment duration. These findings suggest that postprandial hyperglycemia may influence mycobacterial burden and disease progression, making 2-hour postprandial blood glucose an important clinical indicator in patients with TB and DM.

Despite increasing evidence linking glycemic control to TB outcomes, most studies have focused on HbA1c and fasting blood glucose as the primary indicators of glycemic status. A comprehensive review by Ye et al. (2024) reported that most studies used HbA1c

$\geq 7\%$  or fasting blood glucose  $> 130$  mg/dL as measures of glycemic control, whereas only a few incorporated 2-hour postprandial glucose measurements. Similarly, Zahid et al. (2025) found that none of the studies published between 1975 and 2024 specifically evaluated 2-hour postprandial glucose as a sole predictor of acid-fast bacilli (AFB) positivity. Moreover, a recent systematic review and meta-analysis concluded that good glycemic control improves treatment outcomes and reduces sputum positivity among TB–DM patients; however, most studies categorized dysglycemia as a binary variable and relied on HbA1c or DM status rather than directly examining postprandial glucose levels (Yorke et al., 2021; Lee et al., 2025). Consequently, the specific relationship between 2-hour postprandial blood glucose levels and the degree of AFB positivity remains poorly understood.

Although postprandial hyperglycemia is clinically relevant and may better reflect acute glycemic fluctuations affecting immune competence, evidence regarding its association with TB bacterial burden remains limited, particularly in middle-income countries with a high TB burden such as Indonesia. Most available studies originate from East Asia and Sub-Saharan Africa, leaving a substantial knowledge gap in the Indonesian context despite Indonesia having the second highest TB burden globally (World Health Organization, 2024). Therefore, this study aimed to analyze the relationship between 2-hour postprandial blood glucose levels and the degree of acid-fast bacilli positivity among patients with pulmonary tuberculosis and diabetes mellitus and to determine whether postprandial hyperglycemia independently contributes to increased mycobacterial burden after accounting for relevant clinical factors.

## 2. METHOD

This study used an observational analytical design with a cross-sectional approach in DM patients with pulmonary TB undergoing treatment at the Sukamaju Community Health Center during March 2024–December 2024. This design was chosen because it is suitable for describing the relationship between 2-hour postprandial blood glucose levels and AFB status at a single time point during the initial TB treatment period (Yorke et al., 2021).

This design was chosen because it suited the initial exploratory objective of identifying the magnitude of the association between postprandial blood glucose levels and acid-fast bacillus positivity, which serves as a foundational step before a larger, longitudinal study. A similar approach was used by Jayashankar et al. (2021) in a hospital-based cross-sectional study examining the correlation of glycemic parameters with acid-fast bacillus positivity. This design is consistent with similar exploratory investigations in the TB-DM literature (Wu et al. 2022). We acknowledge that cross-sectional studies are inherently limited in establishing temporal or causal relationships, as glucose and smear status are measured simultaneously. This limitation is explicitly stated in the Discussion. Future longitudinal or cohort studies are recommended to confirm the directionality of the observed association, as advocated by El Nahas et al. (2023) who reviewed prospective cohort evidence as the requisite design for establishing causality in TB-DM interactions.

The target population was all DM TB patients registered in the TB program registry at the facility. Inclusion criteria were age  $\geq 18$  years, a documented DM diagnosis, a bacteriologically confirmed pulmonary TB diagnosis, and a 2-hour postprandial blood glucose test result and initial AFB score. The sample size was 60 patients with 2-hour postprandial blood glucose levels (mg/dL) and acid-fast bacillus scores ranging from 0–3 (negative to 3+). Sputum acid-fast bacilli examination was performed on three sputum specimens collected in the morning at any time in the morning in accordance with the WHO protocol, acid-fast bacilli counting was performed by two trained medical laboratory

technologists independently (blinded) using the International Union Against Tuberculosis and Lung Disease (IUATLD) scale, internal quality control was performed by examining 10% of samples at random by the laboratory supervisor, blinded to initial results. The glucometer used for blood glucose measurement was calibrated daily against laboratory - certified glucose standard controls (World Health Organization, 2024; Chiang et al., 2020).

Regarding the exclusion of human Immunodeficiency virus (HIV) patients, this decision was made to control for the confounding effects of HIV-associated immunosuppression on the bacterial burden of tuberculosis, given evidence that HIV independently reduces bacterial load in sputum via immunopathological mechanisms distinct from hyperglycaemia (Chidambaram et al. 2021). However, we acknowledge that this limits generalisation to populations with TB-HIV co-infection. This is now stated as a major limitation, and we recommend that future studies include HIV co-infection with stratified analysis. Exclusion criteria were patients with only extrapulmonary TB, HIV, or incomplete 2-hour postprandial blood glucose/Acid-Fast Bacillus data. Consecutive sampling was used for all cases meeting the criteria (Bhargava et al., 2023; Field, 2020).

The independent variable included 2-hour postprandial blood glucose levels, either as a continuous variable or as clinical categories: <140 mg/dL, 140–199 mg/dL, and ≥200 mg/dL, considering the 2-hour postprandial blood glucose threshold of >180 mg/dL commonly used in TB and DM studies. The dependent variable included TB positivity, assessed by an AFB smear score of 0–3+, with AFB negative (score 0) and AFB positive (score 1–3) defined as AFB positive. Covariates consisted of age, sex, BMI, smoking, previous history of TB, DM duration, following variables commonly analyzed in TB sputum conversion studies. This study was approved by the Health Research Ethics Committee of the Tanjungkarang Health Polytechnic under registration number 547/KEPK-TJK/XII/2024.

### 3. RESULTS AND DISCUSSION

The results of this research include univariate, bivariate and multivariate results. Univariate analysis was conducted to describe the characteristics of each research variable, namely 2-hour postprandial blood glucose levels and (AFB) positivity scores.

**Table 1.** Characteristics of Study Subjects.

<b>Characeristics</b>	<b>n</b>	<b>%</b>
Age (years)		
18–40 years	8	13.3
41–60 years	38	63.3
> 60 years	14	23.4
Gender		
Male	38	63.3
Female	22	36.7
Duration of Diabetes Suffering (years)		
< 5 years	32	53.3
≥ 5 years	28	46.7
Smoking status		
Current smoker	22	36.7
Former smoker	11	18.3
Non smoker	27	45.0
Previous history of tuberculosis		
Yes	9	15.0
No	51	85.0

Characeristics	n	%
Body mass index (kg/m <sup>2</sup> )		
Underweight (< 18.5)	22	36.7
Normal (18.5–24.9)	33	55.0
Overweight (≥ 25)	5	8.3

The characteristics of study subjects are shown in Table 1. The largest age group was 41–60 years (63.3%), and men predominated (63.3%). The majority of subjects (53.3%) had diabetes for <5 years. The prevalence of active smokers is 36.7. Underweight (BMI <18.5) was experienced by 36.7% of subjects.

**Table 2.** Distribution of 2-Hour postprandial blood glucose levels.

2-Hour Postprandial Glucose Category	Reference value (mg/dL)	n	%
Normal	< 14	0	0.0
Prediabetes	140 – 199	55	91.7
Diabetes Mellitus	≥ 200	5	8.3
Total		60	100.0

Table 2 describes that none of the respondents had 2 hours postprandial glucose levels in the normal category (<140 mg/dL). The majority of respondents (91.7%; n=55) were classified as prediabetic (140–199 mg/dL), while 8.3% (n=5) were classified as diabetic (≥200 mg/dL). The mean 2 hours postprandial glucose level was 178.28 ± 13.48 mg/dL with a median of 177 mg/dL. The Shapiro-Wilk normality test showed that the distribution of 2 hours postprandial glucose data was normal (W=0.967; p=0.103).

**Table 3.** Distribution of acid-fast bacillus positivity scores.

Score of acid-fast bacilli	Interpretation	n	%
0	Negatif (No acid-fast bacilli found)	21	35.0
+1	Positif 1+ (10–99 acid-fast bacilli/100 visual fields)	15	25.0
+2	Positif 2+ (1–10 acid-fast bacilli/100 visual fields)	15	25.0
+3	Positif 3+ (> 10 acid-fast bacilli/100 visual fields)	9	15.0
Total		60	100.0

Table 3 shows that 39 respondents (65.0%) had positive acid-fast bacilli smear results (scores 1–3), and 21 respondents (35.0%) had negative acid-fast bacilli smear results (score 0). The highest acid-fast bacilli scores were 1 and 2, each with 25.0%. The mean acid-fast bacilli score was 1.20 ± 1.09, with a median of 1. The Shapiro-Wilk normality test yielded W = 0.845 with p < 0.001, indicating a non-normal distribution of AFB scores (right-skewed/positively skewed). Therefore, a non-parametric statistical test was appropriate for further analysis.

**Table 4.** Cross tabulation of 2-hour postprandial glucose categories with acid-fast bacilli

Category of 2-hour postprandial glucose	Acid-fast bacilli Negative	Acid-fast bacilli Positive	Total
Prediabetes (140–199 mg/dL)	20 (36.4%)	35 (63.6%)	55
Diabetes Mellitus (≥200 mg/dL)	1 (20.0%)	4 (80.0%)	5
Total	21 (35.0%)	39 (65.0%)	60

Bivariate analysis aimed to examine the relationship between 2-hour postprandial blood glucose levels and acid-fast bacilli positivity. Because the distribution of acid-fast bacilli scores was non-normal, the Spearman correlation test was used. The results of the crosstabulation and statistical tests are presented in Tables 3 and 4.

**Table 5.** Bivariate statistical test result

Statistical test	Variable	Test value	p-value
Spearman correlation	2 hours postprandial with acid-fast bacilli	$\rho = 0.660$	< 0.001

The Spearman correlation test showed a strong and highly significant correlation ( $\rho=0.660$ ;  $p<0.001$ ). The positive direction of the correlation indicates that the higher the 2-hour postprandial glucose level, the higher the acid-fast bacillus positivity. A correlation strength of 0.660 is categorized as a strong correlation according to the Guilford criteria.

**Table 6.** Binary Logistic Regression: Predictors of Acid-Fast Bacilli (AFB) Positivity.

Predictor	$\beta$	SE	Wald $X^2$	Odds Ratio	95 % CI	p-value
2-hour postprandial glucose (mg/dL)	0.089	0.031	8.24	1.093	1.029 -1.162	0.004
Constant (Intercept)	-16.24	5.82	7.80	-	-	0.005

Binary logistic regression (Table 6): For every 1 mg/dL increase in 2-hour postprandial glucose, the odds of AFB positivity increased by 9.3% (OR = 1.093; 95% CI: 1.029–1.162;  $p = 0.004$ ). Per 10 mg/dL increment, the odds increase approximately 2.42-fold (OR<sup>10</sup>  $\approx$  2.42). McFadden pseudo-R<sup>2</sup> = 0.155 indicates the predictor explains ~15.5% of AFB positivity variability.

The results of binary logistic regression (OR=1.093; 95% CI: 1.029–1.162;  $p=0.004$ ) showed that 2-hour postprandial glucose levels were a significant independent predictor of positive acid-fast bacilli. The OR value of 1.093 means that every 1 mg/dL increase in 2-hour postprandial glucose levels increases the odds of positive acid-fast bacilli by 9.3%. Calculated per 10 mg/dL increase in glucose, the odds of positive acid-fast bacilli increase by approximately 142% [OR<sup>10</sup>=(1.093)<sup>10</sup> $\approx$ 2.42]. This magnitude of effect is clinically relevant considering that the 2-hour postprandial glucose range in this sample ranged from 148–220 mg/dL (Field, 2020).

The positive association between postprandial hyperglycemia and acid-fast bacilli sputum smear positivity observed in our study is corroborated by multiple lines of evidence. A meta-analysis of 12 studies (n=2,320) by Zahid et al. (2025) reported that patients with uncontrolled DM (HbA1c  $\geq$ 7%) had a 2.97-fold higher risk of sputum smear positivity at 3 months compared to those with controlled glycemia (RR 2.97, 95% CI 1.10–8.07,  $p=0.03$ ). Similarly, Meng et al. (2023) in a large cohort (n=3,393) found significantly higher fasting plasma glucose and HbA1c in sputum-positive TB-DM patients, with poor glycemic control independently predicting smear positivity.

Ssekamate et al. (2023) confirmed that poor glycemic control, which can be measured through several parameters, including postprandial glucose, increases the risk of active TB infection in DM patients through various immunological pathways. Therefore, the 2-hour postprandial blood glucose measurement used in this article as an independent variable is clinically relevant and supported by current literature.

However, contrasting findings also merit discussion. In a cross-sectional study at a tertiary center in New Jersey, Kreisel et al. (2019) reported that initial smear grade did not significantly differ between DM-positive and DM-negative TB patients ( $p=0.995$ ), suggesting that the magnitude of the hyperglycemia smear positivity relationship may be context-dependent and influenced by host factors, diabetes duration, and glycemic control trajectory. Furthermore, the complexity of this relationship is underscored by evidence that any degree of hyperglycemia, not limited to overt, poorly controlled DM, may influence TB

susceptibility and bacterial burden (Byers et al, 2024). These discrepancies may reflect differences in patient populations, glycemic measurement tools, specimen collection protocols, and the specific glycemic parameter assessed, which should be considered when interpreting our findings.

#### 4. CONCLUSION

All patients exhibited elevated 2-hour postprandial blood glucose levels above the normal range. A strong and significant positive relationship was observed between 2-hour postprandial blood glucose levels and the degree of acid-fast bacillus positivity, indicating that higher postprandial glucose levels were associated with greater mycobacterial burden. Furthermore, 2-hour postprandial blood glucose was identified as a significant predictor of acid-fast bacillus positivity. These findings suggest that poor postprandial glycemic control may contribute to increased disease severity in patients with pulmonary tuberculosis and diabetes mellitus, highlighting the importance of routine glycemic monitoring and optimal glucose management as part of comprehensive tuberculosis care.

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