



RESEARCH ARTICLE

Type 2 Diabetes Mellitus and Pulmonary Tuberculosis in Indonesia: Risk, Prognosis, and Implications for Integrated Care

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Abstract

Pulmonary tuberculosis (PTB) and type 2 diabetes mellitus (T2DM) are major and increasingly overlapping public health problems in Indonesia. Evidence suggests that T2DM is associated with a higher risk of active PTB and less favorable treatment-related outcomes, yet Indonesian findings remain fragmented. This structured narrative review synthesized Indonesian studies published between 2020 and 2025 retrieved from Google Scholar and Garuda. Eligible studies examined the association of T2DM with PTB incidence or risk, glycemic control, bacteriological response, treatment duration, mortality, and related modifying factors. Of 442 records identified, 17 studies were included. Most of the included studies were observational and single-center, which limits causal inference and national representativeness. Across the reviewed evidence, T2DM was consistently associated with greater PTB occurrence, with several studies reporting an approximately two- to three-fold higher risk among people with diabetes. PTB incidence within a T2DM cohort was reported as 3.88%. Poor glycemic control, particularly elevated HbA1c, was associated with delayed sputum smear conversion, longer treatment duration, greater clinical severity, and higher mortality risk. Additional modifiers included smoking, poor nutritional status, low education, low income, and close contact with TB cases. In conclusion, in Indonesia, T2DM is strongly associated with increased PTB occurrence and poorer PTB prognosis. Integrated TB-DM screening, closer glycemic monitoring, and stronger continuity of care are needed to improve patient outcomes.

Keywords: Pulmonary tuberculosis; Type 2 diabetes mellitus; Glycemic control; Comorbidity; Treatment outcomes

Abstrak. Tuberkulosis paru (TB paru) dan diabetes melitus tipe 2 (DMT2) merupakan dua masalah kesehatan masyarakat utama di Indonesia yang semakin banyak muncul secara bersamaan. Bukti yang ada menunjukkan bahwa DMT2 berasosiasi dengan risiko TB paru aktif yang lebih tinggi serta luaran pengobatan yang kurang menguntungkan, namun temuan di Indonesia masih terfragmentasi. Tinjauan naratif terstruktur ini mensintesis studi-studi di Indonesia yang dipublikasikan antara tahun 2020 hingga 2025 dan ditelusuri melalui Google Scholar serta Garuda. Studi yang memenuhi syarat menelaah hubungan DMT2 dengan insidensi atau risiko TB paru, kontrol glikemik, respons bakteriologis, durasi pengobatan, mortalitas, dan faktor-faktor pemodifikasi terkait. Dari 442 rekaman yang diidentifikasi, sebanyak 17 studi dimasukkan. Sebagian besar studi yang diikutkan bersifat observasional dan berasal dari satu pusat layanan, sehingga membatasi inferensi kausal dan keterwakilan nasional. Secara keseluruhan, bukti yang ditinjau menunjukkan bahwa DMT2 secara konsisten berasosiasi dengan kejadian TB paru yang lebih tinggi, dengan beberapa studi melaporkan risiko sekitar dua hingga tiga kali lipat lebih besar pada penderita diabetes. Insidensi TB paru dalam satu kohort DMT2 dilaporkan sebesar 3,88%. Kontrol glikemik yang buruk, terutama kadar HbA1c yang tinggi, berasosiasi dengan keterlambatan konversi sputum BTA, durasi pengobatan yang lebih panjang, keparahan klinis yang lebih tinggi, dan risiko kematian yang lebih besar. Faktor pemodifikasi lain meliputi merokok, status gizi yang buruk, pendidikan rendah, pendapatan rendah, dan riwayat kontak erat dengan pasien TB. Sebagai kesimpulan, di Indonesia, DMT2 berasosiasi kuat dengan meningkatnya kejadian TB paru dan prognosis TB paru yang lebih buruk. Skrining terpadu TB-DM, pemantauan glikemik yang lebih ketat, dan kesinambungan layanan yang lebih baik diperlukan untuk meningkatkan luaran pasien.

Kata kunci: Tuberkulosis paru; Diabetes melitus tipe 2; Kontrol glikemik; Komorbiditas; Luaran pengobatan

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INTRODUCTION

Pulmonary tuberculosis (PTB) remains one of the most important infectious diseases globally and continues to impose a major burden on health systems, communities, and national development, particularly in low- and middle-income countries. The World Health Organization (WHO)

states that tuberculosis remains a leading cause of illness and death from a single infectious agent and that progress toward global TB control targets remains insufficient in many high-burden settings. Indonesia continues to rank among the countries with the highest TB burden worldwide, making PTB not only a clinical problem but also a persistent public health, economic, and social challenge. In parallel, type 2 diabetes mellitus (T2DM) has emerged as one of the fastest-growing noncommunicable diseases globally. The 11th edition of the International Diabetes Federation (IDF) Diabetes Atlas reports that 589 million adults were living with diabetes worldwide in 2024, while Indonesia had approximately 20.4 million adults aged 20–79 years with diabetes and one of the largest national diabetes burdens globally. The coexistence of these two conditions has created a complex dual burden in which an expanding metabolic epidemic intersects with a persistent infectious epidemic, thereby challenging conventional disease-control strategies that have historically treated communicable and noncommunicable diseases separately (International Diabetes Federation [IDF], 2025; World Health Organization [WHO], 2024).

The clinical and public health significance of the PTB–T2DM comorbidity lies not merely in the coexistence of two common diseases, but in the fact that each condition can alter the course of the other. Diabetes has increasingly been recognized as an important determinant of active TB risk, delayed response to treatment, and adverse TB outcomes, while active TB may worsen glycemic control through inflammatory stress, altered metabolism, and treatment-related physiological changes. This reciprocal interaction means that PTB and T2DM should no longer be regarded as parallel conditions that happen to occur together in some patients; rather, they constitute a biologically and programmatically linked comorbidity that requires integrated understanding and management. WHO's updated operational guidance on TB and comorbidities explicitly emphasizes comprehensive, people-centered approaches for individuals with both TB and diabetes, including screening, diagnosis, treatment, and co-management. This shift in policy direction reflects a growing consensus that fragmentation between TB and diabetes services may lead to missed diagnoses, delayed treatment, and poorer outcomes in high-burden countries such as Indonesia (WHO, 2025a; WHO, 2025b).

Conceptual clarity is essential when discussing this comorbidity because several epidemiologic terms are often used interchangeably despite referring to different outcomes. In this review, incidence refers specifically to the occurrence or risk of active PTB among people with T2DM. This should be clearly distinguished from the prevalence of diabetes among PTB patients, which describes the burden of metabolic comorbidity within a TB population but does not by itself estimate PTB risk among people with diabetes. Likewise, prognosis refers to clinically relevant outcomes among PTB patients with T2DM, particularly sputum smear or bacteriological conversion during treatment, treatment duration, unfavorable treatment outcomes as classified by WHO, relapse, and mortality. These distinctions are important because the available Indonesian studies report heterogeneous estimates derived from different source populations, study designs, and denominator structures. For example, some hospital-based studies quantify the proportion of T2DM among patients already diagnosed with PTB, whereas other retrospective studies estimate the occurrence of PTB among cohorts of patients with T2DM. Without explicitly separating these constructs, the narrative risks conflating prevalence, incidence, and

prognosis and may overstate the comparability of findings across studies (Franco et al., 2024; Fauziah et al., 2021; Hidayah et al., 2021; Herva et al., 2025; Shewade et al., 2025).

This distinction also helps explain why numerical estimates in the literature vary substantially. Indonesian reports have described T2DM prevalence among PTB patients ranging from approximately 3.7% to 16.7%, whereas other studies have reported PTB incidence among patients with T2DM at around 3.88% in a hospital cohort. Such figures should not be interpreted as contradictory by default; rather, they often reflect differences in case definitions, study setting, population characteristics, inclusion criteria, diagnostic practices, and follow-up structure. More broadly, international evidence suggests that diabetes probably increases the risk of developing TB disease, but the magnitude of effect varies by study design and methodological rigor. The 2024 Cochrane review found that diabetes probably increases TB disease risk, with a pooled risk ratio of 1.60 (95% CI 1.42–1.80) in analyses judged to provide the highest-certainty evidence. At the same time, the review cautioned that glycemic control and access to care may modify the strength of the association, meaning that local interpretation requires contextualization rather than simplistic borrowing of pooled estimates. Therefore, a careful Indonesian synthesis should avoid treating all reported percentages and risk estimates as directly interchangeable (Franco et al., 2024; WHO, 2025a).

The biological plausibility of this association is strong and provides an important conceptual foundation for the present review. Chronic hyperglycemia alters immune function at multiple levels, thereby creating a host environment that is more permissive to *Mycobacterium tuberculosis* infection and progression. Recent immunologic reviews indicate that diabetes is associated with impaired macrophage and neutrophil function, reduced phagocytic activity, delayed antigen presentation, altered cytokine signaling, and dysregulated T-cell responses, all of which are highly relevant to early mycobacterial control and granuloma integrity. These abnormalities may reduce the host's capacity to contain latent infection, facilitate progression to active disease, and increase disease severity once PTB develops. From a clinical perspective, this mechanism helps explain why people with diabetes are more likely to present with smear-positive disease, extensive pulmonary lesions, cavitation, and atypical radiographic features, particularly when glycemic control is poor. WHO's operational handbook similarly notes that people living with diabetes are more likely to be sputum smear-positive and to have more extensive and bilateral pulmonary disease, especially under conditions of poor glycemic control. Thus, the diabetes–TB association is not merely statistical; it is grounded in a coherent immunopathophysiologic framework (Thong et al., 2025; Ye et al., 2024; WHO, 2025b).

The relationship is also bidirectional. Active TB can worsen glycemic regulation through systemic inflammation, stress hormone responses, increased insulin resistance, weight loss, and catabolic imbalance. In some patients, TB may unmask previously undiagnosed diabetes or aggravate pre-existing dysglycemia, thereby complicating both diagnosis and treatment planning. This bidirectionality is clinically important because it means that comorbidity should not be understood solely as “diabetes causing TB.” Rather, once both conditions are present, they may reinforce one another in a vicious cycle that increases symptom severity, complicates metabolic

control, delays microbiological response, and undermines overall recovery. Recent reviews on TB–DM comorbidity have emphasized that this reciprocal relationship should shape how researchers and clinicians conceptualize screening, monitoring, and treatment, especially in health systems where communicable and noncommunicable disease programs have traditionally been organized in separate silos (Ye et al., 2024; WHO, 2025a).

Beyond biologic plausibility, accumulating clinical and epidemiologic evidence supports the importance of T2DM as a determinant of PTB occurrence and outcome. International evidence suggests that diabetes increases the likelihood of developing active TB and may adversely affect treatment outcomes, although the certainty of evidence differs by outcome. The updated systematic review by Shewade et al. (2025) concluded that the available evidence on glycemic control and TB treatment outcomes remains methodologically limited, but it also found that one lower-risk cohort study suggested that stringent glycemic control at baseline was associated with fewer unfavorable end-of-treatment outcomes, including recurrence. The same review additionally reported that insulin use during TB treatment was associated with a lower risk of unfavorable treatment outcomes in one study after adjustment for important confounders. These findings suggest that glycemic control is likely clinically relevant, even though the current evidence base remains imperfect and heterogeneous. In other words, the association between diabetes and PTB prognosis is already plausible and increasingly supported, but the exact magnitude and modifiable pathways still require clearer definition (Shewade et al., 2025).

The Indonesian literature broadly aligns with this international pattern. Several hospital- and facility-based studies have reported that T2DM is associated with increased PTB risk, poor glycemic control, delayed sputum conversion, longer treatment duration, and more severe clinical presentation. For example, local evidence in the revised manuscript indicates that Indonesian studies have documented significant associations between HbA1c levels and sputum smear conversion, poor glycemic control and longer treatment duration, and T2DM status and increased PTB risk. Other studies in Indonesia have also identified modifying factors such as smoking, low nutritional status, socioeconomic disadvantage, and close contact with TB cases, suggesting that the T2DM–PTB relationship operates within a broader constellation of biomedical and social vulnerabilities rather than in isolation. These studies are valuable because they demonstrate the local relevance of TB–DM comorbidity in Indonesia; however, they are often single-center, retrospective, cross-sectional, or limited to selected clinical populations, which constrains their generalizability and causal interpretation (Batubara & Alamsyah Lukito, 2024; Girsang et al., 2023; Rasyid et al., 2024; Suwirda et al., 2025; Widiastuti, 2024; Yanti et al., 2024).

The public health importance of this comorbidity extends beyond epidemiologic risk estimates. In high-burden settings, undetected TB among people living with diabetes may contribute to delayed diagnosis and ongoing transmission, while unrecognized diabetes among PTB patients may reduce treatment success and increase the risk of complications. WHO therefore recommends systematic TB screening for people with diabetes in settings where the background TB prevalence is at least 100 per 100,000 population, and further notes that screening should be prioritized when diabetes is newly diagnosed or glycemic control is poor. WHO also highlights risk stratification factors such as male sex, older age, low

body mass index, and poor glycemic control, all of which may help identify diabetic patients at especially high risk of TB. These recommendations are particularly relevant for Indonesia, where the burden of both TB and diabetes is high and where integrating screening pathways could help close diagnostic gaps and improve continuity of care (WHO, 2025b).

Indonesia has already begun to move in this direction, but implementation gaps remain. A cross-sectional evaluation of TB–DM co-management under the Indonesian National Tuberculosis Control Program found that national TB–DM co-management activities were initiated in 2017 and that, in two Jakarta districts between 2017 and 2019, only 50.8% of new pulmonary TB patients older than 15 years had been tested for diabetes. Among those tested, 20.8% were diagnosed with diabetes, and among detected TB–DM patients, 86.3% completed treatment or were cured. The study also found marked differences across regions and facilities, indicating that screening and co-management practices remain uneven. These findings are important because they show that Indonesia is not starting from zero; policy structures for TB–DM integration exist, but operational performance remains variable and incomplete. Thus, the need is not only to demonstrate that TB–DM comorbidity matters, but also to generate a clearer evidence base that can guide prioritization, screening, and co-management in real-world Indonesian settings (Jiang et al., 2022).

Despite growing recognition of the problem, the Indonesian evidence base remains fragmented in several ways. First, much of the literature focuses on only one dimension of the comorbidity—such as prevalence, HbA1c, bacteriological status, or treatment duration—rather than integrating occurrence-related and prognosis-related outcomes within a single conceptual structure. Second, the methodological designs are often retrospective, cross-sectional, or single-center, which limits causal inference and population representativeness. Third, the terminology used across studies is not always consistent, especially when discussing incidence, prevalence, risk, prognosis, or treatment outcome. Fourth, many local studies report clinically important findings but do not situate them within the larger international evidence base or WHO policy framework. As a result, the literature provides important fragments of knowledge, but not yet a sufficiently coherent synthesis for informing national policy and integrated clinical practice. This gap is especially important in Indonesia, where the burden of TB remains high, diabetes is rising rapidly, and delays in the detection and management of either condition may have consequences for morbidity, mortality, and health-system efficiency (Franco et al., 2024; Jiang et al., 2022; Saktiawati & Probandari, 2025; WHO, 2024; WHO, 2025a).

Against this background, the present review seeks to address a more clearly defined set of questions than those often implied in prior narrative accounts. Specifically, this review aims to synthesize Indonesian evidence on two linked issues: first, whether T2DM increases the occurrence of active PTB; and second, whether T2DM, particularly in the context of poor glycemic control, worsens PTB prognosis, defined here as delayed sputum conversion, prolonged treatment, unfavorable treatment outcomes, relapse, and mortality. By explicitly distinguishing incidence-related from prognosis-related outcomes, situating local findings within current mechanistic and policy frameworks, and emphasizing the implications for bidirectional screening and integrated care, this review seeks to provide a more structured

epidemiologic and clinical foundation for improving TB–DM policy and practice in Indonesia (WHO, 2025a; WHO, 2025b).

METHODS

Study Design

This study was conducted as a structured narrative review of published literature examining the impact of type 2 diabetes mellitus (T2DM) on the incidence and prognosis of pulmonary tuberculosis (PTB) in Indonesia. This design was chosen because the available evidence was methodologically heterogeneous, encompassing cross-sectional studies, case-control studies, retrospective observational studies, descriptive studies, comparative studies, literature reviews, and limited systematic reviews. Accordingly, this manuscript does not present a formal systematic review or meta-analysis; rather, it provides a structured synthesis of the available evidence using transparent search, selection, appraisal, and thematic integration procedures. This approach was considered more appropriate than a meta-analysis because the included studies varied substantially in design, source populations, definitions of exposure and outcome, and reporting formats, thereby limiting the feasibility of quantitative pooling.

The review was guided by two main questions. First, does T2DM increase the occurrence of active PTB among Indonesian populations? Second, among patients with PTB, is T2DM—particularly when accompanied by poor glycemic control—associated with worse clinical prognosis, including delayed sputum smear conversion, prolonged treatment duration, unfavorable treatment outcomes, relapse, or mortality? These questions were formulated to align the review method with the conceptual framework established in the Introduction and to ensure that incidence-related outcomes were clearly distinguished from prognosis-related outcomes throughout the evidence synthesis.

Information Sources and Search Strategy

A structured literature search was conducted using Google Scholar and Garuda (Garba Rujukan Digital) as the primary information sources. These databases were selected because they provide broad coverage of both Indonesian and internationally indexed health literature and allow retrieval of clinical, epidemiologic, and public health studies relevant to PTB–T2DM comorbidity in Indonesian settings. Google Scholar was used to capture peer-reviewed journal articles and broader academic outputs, while Garuda was included to ensure adequate coverage of national publications that may not be consistently indexed in larger international databases.

The search was limited to studies published within the last five years, from January 2020 to December 2025, to prioritize recent evidence reflecting current epidemiologic patterns and contemporary clinical practice. The search was restricted to articles published in English or Bahasa Indonesia. The core search terms were developed from the review question and combined using Boolean operators. The main search string was structured as follows: ("pulmonary tuberculosis" OR "TB paru" OR tuberculosis) AND ("type 2 diabetes mellitus" OR "diabetes mellitus tipe 2" OR T2DM OR diabetes) AND (incidence OR risk OR prognosis OR outcome OR mortality OR "sputum conversion" OR HbA1c OR glycemic control). Equivalent

keyword combinations were adapted for each database according to search-interface requirements. The complete search strategy for each database should be provided in Appendix 1 to ensure reproducibility and auditability.

Eligibility Criteria

Studies were considered eligible if they met all of the following criteria: (1) they examined the relationship between T2DM and PTB incidence, risk, clinical profile, or treatment prognosis; (2) they were conducted in Indonesian settings or included Indonesian patient populations; (3) they used observational, comparative, or review designs relevant to the research question, including cross-sectional, case-control, retrospective cohort, descriptive observational, comparative, literature review, or systematic review designs; and (4) they reported at least one relevant outcome, such as PTB occurrence among patients with T2DM, prevalence of T2DM among PTB patients, HbA1c level, sputum smear conversion, treatment duration, mortality, or other prognosis-related indicators.

Studies were excluded if they were editorials, commentaries, opinion papers, conference abstracts without sufficient methodological detail, duplicate publications, non-Indonesian studies that did not contribute directly to the stated review scope, or studies that discussed PTB or diabetes separately without reporting any analyzable comorbidity-related outcome. Studies were also excluded when the full text was unavailable, the publication year fell outside the review period, or the article lacked sufficient methodological clarity to support meaningful appraisal and extraction.

Study Selection Process

The study-selection process was conducted in several stages. First, all records identified through Google Scholar and Garuda were compiled into a preliminary dataset. Based on the current manuscript, the search yielded 442 records, of which 31 duplicates were removed. The remaining records underwent title and abstract screening to assess topical relevance, publication year, and broad methodological suitability. After this first screening stage, studies that did not address PTB–T2DM comorbidity, fell outside the prespecified time frame, or lacked relevance to the review outcomes were excluded. This process resulted in 28 full-text articles being assessed for eligibility, after which 17 studies were retained for final synthesis.

Data Extraction

Data from the final included studies were extracted using a structured evidence-extraction form developed for this review. To avoid the "textbook-like" narrative criticized by the reviewer, the extraction process should focus on variables actually reported in the included studies rather than hypothetical populations or sample examples. The extracted variables included: first author and year; study setting; study design; population characteristics; sample size; definition of T2DM and PTB where available; main exposure or comparator; outcome domain (incidence/risk, glycemic control, sputum conversion, treatment duration, mortality, or other clinical outcomes); key quantitative results; and the authors' principal conclusions.

For analytic consistency, extracted outcomes were grouped into four predefined domains: (1) PTB incidence or risk among patients with T2DM; (2) glycemic control and bacteriologic or treatment response; (3) adverse

prognosis, including prolonged treatment, treatment failure, relapse, or mortality; and (4) modifying or associated factors, such as nutritional status, smoking, age, socioeconomic status, and history of close contact with TB cases.

Quality Appraisal and Risk-of-Bias Assessment

To strengthen methodological transparency, the quality of included studies should be evaluated using design-appropriate appraisal tools rather than the generic terms “quality control” or “checklists.” In the revised manuscript, observational studies may be appraised using the Joanna Briggs Institute (JBI) critical appraisal tools or the Newcastle–Ottawa Scale (NOS), while included review articles may be assessed with AMSTAR 2, where relevant. The choice of instrument should be stated explicitly and applied consistently according to study design. If more than one tool was used, the manuscript should clarify which tool corresponded to which type of study.

Data Synthesis

Because the included studies were heterogeneous in design, outcome definition, and reporting structure, the findings were synthesized using a qualitative thematic approach rather than meta-analysis. A meta-analysis was not undertaken because the available studies did not provide sufficiently comparable effect measures, uniform diagnostic definitions, or harmonized prognosis outcomes to support valid statistical pooling. Instead, the synthesis was conducted through iterative categorization of findings into conceptually coherent themes derived from the review questions and the extracted variables.

The final synthesis was organized around four analytic themes: (1) the association between T2DM and PTB

incidence or risk; (2) the relationship between glycemic control and PTB prognosis, including sputum smear conversion and treatment duration; (3) mortality and other adverse clinical outcomes in PTB–T2DM comorbidity; and (4) modifying factors that may intensify PTB risk or worsen prognosis, such as poor nutritional status, smoking, older age, low educational attainment, socioeconomic disadvantage, and contact history. Where available, effect estimates, statistical significance, and clinically relevant thresholds—such as HbA1c values—were incorporated into the narrative synthesis. Differences across studies were interpreted in light of study design, sample source, and outcome definition rather than being treated as directly equivalent.

RESULTS OF STUDY

Study Selection

The literature search identified 442 records from Google Scholar and Garuda. After removal of 31 duplicate records, 411 titles and abstracts were screened for relevance. Of these, 383 records were excluded at the title and abstract stage because they fell outside the review period, did not address the PTB–T2DM relationship, did not report outcomes relevant to incidence or prognosis, or lacked sufficient methodological relevance. This process resulted in 28 full-text articles being assessed for eligibility. Following full-text review, 11 articles were excluded because they did not meet the predefined inclusion criteria, leaving 17 studies for final synthesis (Figure 1).

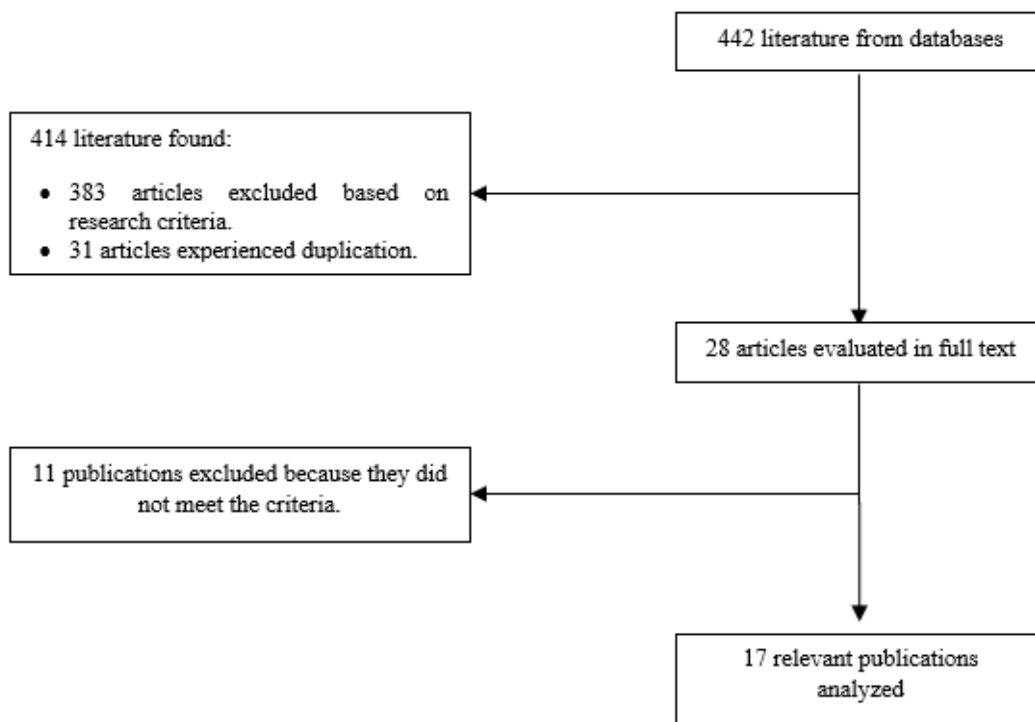


Figure 1. PRISMA-style flow diagram

Table 1. Standardized evidence summary of included studies on T2DM and pulmonary tuberculosis in Indonesia

No.	Study	Design, setting, and sample	Definition of T2DM / PTB	Outcome domain assessed	Main finding / effect estimate	Direction of association	Confounders / adjustment reported	Evidence-quality note*
1	Rasyid et al. (2024)	Descriptive observational study; medical-record data from 2019; setting not clearly specified; sample size NR	T2DM: PTB patients with T2DM comorbidity; diagnostic criteria NR. PTB: pulmonary TB; diagnostic criteria NR	Prognosis: sputum smear (BTA) conversion in relation to HbA1c	Significant association between HbA1c level and sputum smear conversion	Poorer glycemic control was associated with less favorable bacteriologic response	NR	Moderate caution: clinically relevant outcome, but design/reporting details limited
2	Destri (2024)	Systematic literature review of 10 articles	Definitions varied across reviewed studies; no single operational definition reported in the summary	Incidence/risk	Concluded that T2DM increases PTB risk through reduced immune response	Positive association between T2DM and PTB risk	Depends on included studies; not consistently summarized	Review-level evidence; moderate caution due to limited detail in extracted summary
3	Batubara & Alamsyah Lukito (2024)	Cross-sectional analytic study; RSU Haji Medan; total sampling of 67 medical records	T2DM: type 2 diabetes mellitus; diagnostic criteria NR. PTB: pulmonary TB; diagnostic criteria NR	Incidence/risk	Significant relationship between T2DM and increased PTB risk	T2DM associated with higher PTB occurrence	Adjustment for confounders NR; age distribution described (<60 years dominant)	Moderate caution: single-center cross-sectional study with limited adjustment detail
4	Nadapdap et al. (2024)	Descriptive analytic study; RSU Royal Prima Medan; purposive sampling; 2023; sample size not fully clear in summary	T2DM: type 2 diabetes mellitus; PTB: pulmonary TB; criteria NR. HbA1c >5.7% reported as "high"	Risk profile / glycemic status	Among T2DM patients with PTB, 41 patients (82%) had HbA1c >5.7%	Suggests poorer glycemic status among PTB-T2DM patients	NR	High caution: atypical HbA1c cutoff and limited methodological detail
5	Qazzafi & Umar (2023)	Retrospective observational study; Awal Bros Hospital; sample size NR	T2DM with PTB complications; diagnostic criteria NR	Prognosis / clinical severity	Significant relationship between glycemic control and severity of PTB complications	Poorer glycemic control associated with more severe complications	NR	Moderate caution: outcome relevant, but definitions and effect sizes not reported
6	Hadi et al. (2025)	Comparative study; Puskesmas Meninting; 69 patients with TB and DM	Disease definitions NR	Quality of life	DM patients had better quality-of-life scores than TB patients, especially in social and environmental domains	Comparative contextual finding; not a direct PTB-T2DM prognosis estimate	NR	High caution for this review question: indirect relevance to PTB-T2DM prognosis
7	Widiastuti (2024)	Retrospective observational study; RSUP Persahabatan; 82 PTB patients with T2DM	T2DM: defined clinically; details NR. PTB: pulmonary TB; details NR. Poor control emphasized at HbA1c >7%	Prognosis: treatment duration	Poor glycemic control associated with longer PTB treatment duration; HbA1c >7% indicated high risk	Poorer glycemic control associated with worse treatment course	Adjustment details NR	Moderate strength: clinically relevant exposure threshold and outcome, but limited confounder reporting
8	Suwirda et al. (2025)	Case-control study; Aceh Besar; 104 DM patients	T2DM defined clinically; PTB definition NR	Risk modifiers for PTB among DM patients	Risk factors included low education, unhealthy lifestyle, and TB family history	These factors may amplify PTB risk among patients with DM	Specific multivariable adjustment NR	Moderate caution: useful for risk stratification but reporting is limited in summary
9	Yanti et al. (2024a)	Hospital-based cross-sectional study; RS	T2DM defined clinically; PTB definition NR	Incidence/risk	Patients with DM had approximately 2-fold higher	T2DM associated with increased PTB	Confounder control NR	Moderate strength: reports a directional

		Zainoel Abidin; 48 DM patients			risk of PTB	risk		effect estimate, but small sample and unclear adjustment
10	Kaware et al. (2022)	Observational study; Dr. Soetomo General Academic Hospital; 67 patients	Definition details NR	Clinical profile / prevalence context	PTB among DM patients was more common in men aged 51–75 years	Descriptive profile suggests concentration in older male patients	NR	High caution: descriptive contribution only; no direct causal inference
11	Soetrisno et al. (2020)	Descriptive observational study; Dr. Soetomo General Hospital; 53 PTB patients with T2DM	Definitions NR	Clinical profile	Most PTB–T2DM patients were male, >40 years old, with high glucose levels and poor DM control	Describes typical profile of PTB–T2DM comorbidity	NR	High caution: descriptive study; useful for profiling rather than effect estimation
12	Liberty & Liberty (2023)	Literature review of 21 articles	Definitions varied across included studies	Incidence/risk and prognosis	Concluded that T2DM increases PTB risk up to 3-fold and worsens treatment outcomes	T2DM associated with higher PTB risk and worse prognosis	Depends on included studies; not consistently detailed in extracted summary	Review-level evidence; moderate caution due to limited appraisal detail in summary
13	Steffanus et al. (2021)	Case-control study; Atma Jaya Hospital; 121 patients	Definitions NR	Incidence/risk	DM patients had 2.2 times higher risk of PTB than non-DM patients	T2DM associated with increased PTB risk	Adjustment for age/sex/other confounders NR	Moderate strength: useful effect estimate, but limited reporting of covariate adjustment
14	Meilenia et al. (2023)	Cross-sectional analytic observational study; 146 PTB patients (27 with T2DM; 119 without T2DM)	T2DM status distinguished; PTB defined clinically; exact criteria NR	Bacteriologic severity / prognosis proxy	Significant association between T2DM and BTA status ($p = 0.000$); PTB patients with T2DM were more often BTA-positive	T2DM associated with more severe bacteriological presentation	Adjustment details NR	Moderate caution: outcome clinically meaningful, but cross-sectional design limits inference
15	Fauziah et al. (2021)	Retrospective study; RSUP Dr. M. Djamil Padang; 748 T2DM patients	T2DM cohort; PTB occurrence identified retrospectively; exact criteria NR	Incidence	PTB incidence among T2DM patients was 3.88%; most cases were male and aged <60 years	Supports occurrence of PTB within diabetic cohort	NR	Moderate strength: larger sample than most included studies, but still retrospective and single-center
16	Suryoadji et al. (2025)	Systematic review; evidence from 3 studies	Definitions depended on included studies	Mortality prognosis	PTB–T2DM patients had 1.51 times higher mortality risk than PTB patients without T2DM	T2DM associated with higher mortality risk	Depends on included studies; not fully detailed in summary	Moderate-to-high relevance, but based on only 3 studies
17	Girsang et al. (2023)	Case-control analytic study; Putri Ayu Health Center working area; 114 PTB patients	T2DM history reported as one exposure; PTB diagnosed in study population; exact criteria NR	Risk modifiers	Significant associations were found for nutritional status, smoking status, income level, contact history, and diabetes history with TB occurrence	Diabetes acted as one of several factors associated with TB	Multivariable adjustment NR	Moderate caution: informative for contextual risk factors, but effect sizes not reported

Abbreviations: PTB= pulmonary tuberculosis; T2DM= type 2 diabetes mellitus; BTA= acid-fast bacilli smear; HbA1c= glycated hemoglobin; NR= not reported.

Characteristics of Included Studies

The final evidence base comprised 17 studies, the majority of which were primary observational studies conducted in Indonesian clinical settings, supplemented by a small number of review-type articles. Most primary studies used cross-sectional, retrospective observational, case-control, descriptive observational, or comparative designs, while three papers were literature-based reviews, including one systematic review focused specifically on mortality. Most studies were conducted in hospital-based settings, including referral or teaching hospitals in Medan, Padang, Surabaya, Jakarta, and Aceh, whereas only a limited number were conducted in community or primary care settings, such as Puskesmas-based studies. Sample sizes in the primary empirical studies ranged from 48 to 748 participants, indicating substantial variation in study scale and statistical precision. Overall, the evidence base was dominated by single-center studies with clinically relevant but methodologically heterogeneous outcomes, which supports the decision to synthesize the evidence narratively rather than quantitatively. In the Table 1, the included studies standardized by reporting the study design, setting, data-collection period, sample size, PTB and T2DM definitions, prognosis outcomes assessed, direction of association, and a brief note on evidence quality or interpretive caution.

T2DM and the Occurrence of Pulmonary Tuberculosis

Across the included studies, the overall pattern consistently suggested that T2DM is associated with an increased risk of PTB. Several Indonesian primary studies reported elevated occurrence or risk of PTB among patients with T2DM. Yanti et al. reported that patients with T2DM had approximately twice the risk of PTB compared with non-diabetic patients, while Steffanus et al. reported a similar pattern, with a 2.2-fold higher risk among patients with diabetes. Batubara and Alamsyah Lukito also found a significant association between T2DM and PTB in a hospital-based cross-sectional analysis, reinforcing the direction of effect even though more detailed adjusted effect estimates were not consistently reported. In parallel, review-type articles by Destri and Liberty and Liberty concluded that diabetes increases susceptibility to PTB and may elevate risk by up to two to three times, thereby supporting the direction of the primary Indonesian findings. Taken together, the evidence from both primary and review-level sources indicates that T2DM acts as an important comorbidity associated with greater PTB occurrence in Indonesian populations. However, the magnitude of this association should still be interpreted cautiously because many of the included studies reported significance or crude ratios without uniform multivariable adjustment.

The available studies also showed that numerical estimates depend on the denominator and outcome definition used. Fauziah et al., in a retrospective cohort of 748 patients with T2DM, reported a 3.88% incidence of PTB among patients with diabetes. This figure should not be interpreted as inconsistent with studies reporting a twofold or greater risk because it reflects a different epidemiologic measure: the occurrence of PTB within a diabetes cohort rather than a relative comparison between diabetic and non-diabetic populations. Similarly, Kaware et al., 2022. and Soetrismo et al., 2020 described the clinical profile of PTB patients with T2DM, showing that comorbidity was more frequently observed among male patients and older adults, particularly those with poor

glycemic control. These findings suggest that the association between T2DM and PTB occurrence is not only present, but also clinically concentrated in demographic subgroups already known to be vulnerable to poorer health outcomes.

Glycemic Control and Bacteriological or Treatment Response

A second major theme in the reviewed literature was the relationship between poor glycemic control and unfavorable PTB prognosis. Several studies indicated that elevated HbA1c or poor diabetes control was associated with worse bacteriological or clinical response during PTB treatment. Rasyid et al. reported a significant association between HbA1c level and sputum smear conversion, suggesting that poorer glycemic control may delay bacteriological response. Widiastuti similarly found that poor glycemic control, especially in patients with HbA1c >7%, was associated with a longer duration of PTB treatment. Qazzafi and Umar further reported that glycemic control was significantly related to the severity of PTB complications among hospitalized T2DM patients. Collectively, these findings indicate that T2DM is not only associated with PTB occurrence, but that the degree of metabolic control may also shape the clinical trajectory of PTB after diagnosis, especially in relation to bacteriological response and overall treatment duration.

The study by Meilenia et al. adds clinically relevant support to this pattern by showing that PTB patients with T2DM were more likely to have positive sputum smear findings, suggesting a greater bacillary burden or more severe disease presentation. This finding is aligned with the broader interpretation that poor metabolic status may adversely influence host response and disease severity. At the same time, the body of evidence remains uneven in the way prognosis is defined and measured. Some studies focused on sputum smear conversion, others on treatment duration, and others on general clinical severity, meaning that the prognosis domain is supported by converging directionality rather than by a single harmonized outcome measure. For this reason, the upgraded Table 1 should clearly specify which prognosis outcome was assessed in each study and whether the reported direction of association supported a worse, neutral, or unclear outcome among patients with T2DM.

Clarification of the HbA1c Threshold

One important interpretive issue emerged from the extracted results regarding the definition of poor glycemic control. Nadapdap et al. reported that among patients with T2DM and PTB, the largest proportion had HbA1c >5.7%, which the article described as "high." This threshold requires caution in interpretation because HbA1c >5.7% is more commonly recognized as a threshold associated with prediabetes risk rather than a conventional marker of poor control in established T2DM, for which cutoffs such as HbA1c \geq 6.5% for diagnosis or HbA1c >7% for suboptimal control are more commonly used in clinical practice. Accordingly, this finding should be retained in the Results only as reported by the original study, but the wording in the revised manuscript should note that the threshold appears atypical and may reflect either the original study's categorization strategy or a reporting inconsistency that should be verified against the source article. This clarification is important to avoid overstating the comparability of HbA1c-related findings across studies.

Mortality and Other Adverse Prognostic Outcomes

Although relatively few studies directly evaluated hard clinical outcomes such as mortality, the available evidence suggested that PTB patients with T2DM may face a less favorable prognosis than those without diabetes. The strongest explicit mortality-related evidence in the extracted dataset came from the systematic review by Suryoadji et al., which reported that PTB patients with T2DM had a 1.51-fold higher risk of death than PTB patients without diabetes. In addition, the broader literature review by Liberty and Liberty concluded that T2DM not only increases PTB risk but also worsens treatment outcomes, reinforcing the interpretation that PTB–T2DM comorbidity is clinically consequential beyond initial disease occurrence. Although not all included studies reported standardized WHO treatment outcomes, the overall synthesis supports a consistent pattern in which T2DM is associated with slower response, greater clinical severity, and potentially higher mortality risk. These results strengthen the argument that prognosis should be treated as a central outcome domain in PTB–T2DM research, rather than as a secondary descriptive feature.

Modifying Factors and Clinical Profile

Several studies identified additional factors that may intensify PTB risk or complicate prognosis among patients with T2DM. Suwirda et al. reported that low educational level, unhealthy lifestyle, and family history of TB were associated with PTB among diabetic patients. Girsang et al. further identified poor nutritional status, smoking, low income, close contact history, and diabetes history as significant factors associated with TB occurrence. These findings indicate that the PTB–T2DM relationship does not operate in isolation but is embedded within a wider constellation of behavioral, nutritional, and socioeconomic vulnerabilities. Therefore, the association between diabetes and PTB should not be interpreted as purely metabolic; rather, it is likely amplified by risk clustering in socially and clinically vulnerable groups.

The descriptive profile studies also contributed to the clinical characterization of PTB–T2DM comorbidity. Kaware et al. and Soetrisno et al. found that PTB patients with T2DM were predominantly male, generally older than 40 years, and frequently had poor glycemic control. These descriptive findings do not establish causality, but they help identify the patient profile in which PTB–T2DM overlap appears most visible in Indonesian clinical settings. Hadi et al., in a comparative study, reported that patients with diabetes had better quality-of-life scores than patients with PTB in some social and environmental domains; however, this finding should be interpreted narrowly because it compares disease groups rather than directly estimating prognosis among patients with PTB–T2DM comorbidity. As such, it contributes contextual information but should not be weighted as strongly as studies directly addressing PTB risk or treatment outcomes in diabetic populations.

Overall Pattern of Evidence

Taken together, the 17 included studies showed a consistent directional pattern: T2DM is associated with a higher likelihood of PTB occurrence, and among patients with PTB, poor glycemic control is associated with worse clinical indicators such as delayed sputum conversion, longer treatment duration, greater disease severity, and

higher mortality risk. However, the strength of inference remains constrained by the fact that most studies were single-center observational investigations and that many reported only crude associations or statistical significance without adjusted effect sizes, confidence intervals, or detailed confounder control. For this reason, the revised Table 1 should function as a standardized evidence table rather than a simple study list. In addition to the study title, design, and sample, it should include the setting and study period, T2DM and PTB definitions, prognosis outcome assessed, direction of association, available effect size, key confounders, and a brief note on interpretive quality. Presenting the evidence in this format would substantially strengthen the readability, comparability, and credibility of the Results section.

DISCUSSION

This review indicates that type 2 diabetes mellitus (T2DM) is consistently associated with a higher burden of pulmonary tuberculosis (PTB) in Indonesia, both in terms of disease occurrence and a less favorable clinical course. Across the 17 included studies, three interrelated patterns emerged. First, T2DM was repeatedly linked to greater PTB occurrence or higher relative risk of PTB. Second, among patients with established PTB, poorer glycemic control was associated with slower bacteriological response, longer treatment duration, more severe clinical presentation, and a higher risk of adverse outcomes. Third, this relationship was not purely metabolic; it appeared to be amplified by modifying factors such as smoking, poor nutritional status, low educational attainment, low income, older age, and contact history with TB cases. Taken together, these findings support the interpretation that PTB–T2DM comorbidity in Indonesia should be understood as a biologically plausible and clinically consequential interaction that requires integrated management rather than disease-specific siloed care (Franco et al., 2024; Shewade et al., 2025; World Health Organization [WHO], 2025a, 2025b).

A key point that must be stated more precisely is the distinction between prevalence, incidence, and relative risk, because these concepts were not always clearly separated in the earlier draft. In this review, the 3.88% figure reported by Fauziah et al. (2021) should be interpreted as the incidence proportion of PTB within a cohort of patients with T2DM, not as a relative measure comparing diabetic and non-diabetic populations. By contrast, the estimates reported by Yanti et al. (2024) and Steffanus et al. (2021) refer to relative comparisons, indicating that PTB risk was approximately 2.0 to 2.2 times higher among people with diabetes. These findings are directionally consistent with the 2024 Cochrane review, which concluded that diabetes probably increases the risk of developing TB disease and emphasized that the magnitude of association should be interpreted cautiously in light of glycemic control and local contextual factors (Franco et al., 2024). Thus, the Indonesian evidence does not show contradiction; rather, it reflects different epidemiologic measures that all point toward the same overall conclusion: T2DM is an important determinant of PTB occurrence (Fauziah et al., 2021; Franco et al., 2024; Yanti et al., 2024; Steffanus et al., 2021).

The biologic rationale for this pattern is strong and helps unify the epidemiologic findings. Recent immunologic reviews show that chronic hyperglycemia compromises several host-defense mechanisms essential

for controlling *Mycobacterium tuberculosis*, including macrophage phagocytosis, innate-cell recruitment, antigen presentation, and T-cell-mediated immunity. These abnormalities may weaken the host's ability to contain latent infection, facilitate progression to active disease, and increase bacillary burden once PTB develops. This mechanism aligns with the Indonesian studies in this review showing that PTB patients with T2DM were more likely to have positive sputum smears and more severe clinical profiles. Accordingly, the relationship observed in this review should not be interpreted as purely statistical; it is supported by a coherent pathophysiologic model in which hyperglycemia contributes to immune dysregulation and thereby increases both PTB susceptibility and disease severity (Thong et al., 2025; Ye et al., 2024; WHO, 2025a).

The second major synthesis from this review is that poor glycemic control appears to be the principal clinical pathway linking T2DM to worse PTB prognosis. In the included Indonesian studies, higher HbA1c levels were associated with delayed sputum smear conversion, longer treatment duration, and more severe PTB complications. Widiastuti (2024) found that poor glycemic control, especially HbA1c values above 7%, was associated with prolonged treatment, while Rasyid et al. (2024) linked HbA1c to sputum smear conversion, and Qazzafi and Umar (2023) associated glycemic control with complication severity. These findings are broadly consistent with updated international evidence suggesting that poor glycemic control may be associated with worse TB treatment outcomes, although the certainty of that evidence remains limited because of heterogeneity in study design and outcome definition (Shewade et al., 2025). Therefore, the most defensible interpretation is not that hyperglycemia has been definitively proven to cause worse outcomes, but rather that poor glycemic control is consistently associated with less favorable PTB treatment trajectories and should be treated as a clinically actionable risk marker (Qazzafi & Umar, 2023; Rasyid et al., 2024; Shewade et al., 2025; Widiastuti, 2024).

The mortality signal, although supported by fewer studies, is also clinically important. In the included review evidence, Suryoadji et al. (2025) reported that PTB patients with T2DM had a 1.51-fold higher mortality risk than PTB patients without diabetes. This finding is directionally consistent with WHO guidance and recent review literature indicating that TB-DM comorbidity is associated with increased risk of death during treatment and possibly a higher risk of unfavorable end-of-treatment outcomes. Although the current Indonesian evidence remains too limited to estimate a pooled national effect, the presence of a consistent mortality signal suggests that the significance of PTB-T2DM comorbidity extends beyond slower sputum conversion or longer treatment alone. In practical terms, diabetes status—especially when accompanied by poor glycemic control—should be regarded as a prognostic factor that warrants closer follow-up during PTB treatment (Shewade et al., 2025; Suryoadji et al., 2025; WHO, 2025a).

This review also suggests that the PTB-T2DM relationship is shaped by a cluster of modifying factors that may intensify risk or worsen outcomes. In the included studies, poor nutritional status, smoking, low education, low income, unhealthy lifestyle patterns, and contact history with TB cases were repeatedly associated with PTB occurrence among people with diabetes or with the broader PTB population. These factors likely do not operate independently. Instead, they appear to form a layered risk environment in which metabolic vulnerability is compounded by behavioral, nutritional, and socioeconomic

disadvantage. This is important for interpretation because it means that the diabetes-TB association should not be discussed in isolation from the wider social determinants of health. In Indonesian settings, older men with poor glycemic control, nutritional risk, smoking exposure, or known TB contact may represent a particularly vulnerable subgroup for intensified screening and monitoring (Girsang et al., 2023; Kaware et al., 2022; Soetrisno et al., 2020; Suwirda et al., 2025).

From a policy and service-delivery perspective, the findings of this review strongly support more operationally specific bidirectional screening and co-management in Indonesia. WHO recommends systematic TB screening for people living with diabetes in settings where TB prevalence in the general population is at least 100 per 100,000, and diabetes is explicitly recognized as one of the relevant risk factors. Indonesia clearly fits the profile of a high-burden setting where this recommendation is programmatically relevant. On the basis of the reviewed findings, the most appropriate targets for intensified PTB screening would be patients with poorly controlled diabetes, particularly those with elevated HbA1c, older age, male sex, low body mass index or poor nutritional status, smoking history, or recent close contact with a TB case. Operationally, this screening should not be limited to tertiary hospitals. It should be embedded in Puskesmas, internal medicine clinics, diabetes outpatient services, and referral hospitals, with escalation pathways for symptom-positive patients. Monitoring should include TB symptom screening, diagnostic evaluation where indicated, serial HbA1c or glycemic-control assessment, sputum conversion during the intensive phase, treatment adherence, and final treatment outcomes. This moves the policy implication beyond the generic statement that "TB screening should be performed in DM patients" toward a more implementation-ready framework for Indonesia (Jiang et al., 2022; WHO, 2025a, 2025b).

The Indonesian health-system context further supports this interpretation. Evidence from Indonesia shows that TB-DM co-management has already been introduced under the National Tuberculosis Control Program, but implementation remains uneven. In two Jakarta districts, only about half of eligible new pulmonary TB patients had been screened for diabetes, and program performance varied across facilities and regions. These implementation gaps are highly relevant to the present review because they indicate that the challenge is no longer simply proving that PTB-T2DM comorbidity exists. The larger challenge is improving the reach, consistency, and fidelity of integrated screening and co-management. The present synthesis therefore has direct practical relevance: it suggests that risk-stratified TB screening in people with diabetes, combined with closer metabolic monitoring in PTB patients with T2DM, could help reduce missed diagnoses and improve treatment oversight in routine care (Jiang et al., 2022; WHO, 2025a).

Several limitations of this review should be acknowledged explicitly. First, the search was restricted to Google Scholar and Garuda, which increased access to Indonesian literature but may also have introduced selection bias and may have omitted relevant studies indexed elsewhere. Second, the included evidence was highly heterogeneous in design, setting, exposure definition, outcome definition, and reporting completeness; for that reason, a meta-analysis was not appropriate. Third, most included studies were single-center observational studies, often retrospective or cross-sectional, which limits causal inference and national representativeness. Fourth, several studies reported

statistical significance without adjusted effect sizes, confidence intervals, or clear confounder control, making it difficult to compare the strength of associations across studies. Fifth, there is potential publication bias, particularly because some local journal sources vary in editorial rigor and reporting quality. Finally, one extracted finding used an atypical HbA1c threshold of >5.7% as “high” among patients with established T2DM; this should be interpreted with caution because it is lower than thresholds commonly used to define poor glycemic control in diabetes care. These limitations do not negate the overall pattern of findings, but they do mean that the conclusions of this review should be framed as evidence of a consistent association rather than as definitive proof of causality (Franco et al., 2024; Shewade et al., 2025).

Overall, the most coherent interpretation of the evidence is that T2DM is associated with increased PTB occurrence in Indonesia, and that poor glycemic control is associated with less favorable PTB prognosis once disease is established. A useful conceptual model emerging from this review is the following: T2DM contributes to immune dysregulation; immune dysregulation is associated with higher PTB susceptibility and greater disease severity; poor glycemic control is associated with slower treatment response and possibly higher mortality; and social-clinical modifiers such as smoking, malnutrition, age, and low socioeconomic status further amplify these risks. This integrated model is more informative than discussing incidence, prognosis, and risk modifiers separately because it better reflects how the comorbidity operates in clinical and public health settings. Future research in Indonesia should therefore move beyond small single-center observational designs toward multicenter prospective studies with standardized definitions of T2DM, PTB, and treatment outcomes, as well as consistent measurement of HbA1c, nutritional status, smoking exposure, and socioeconomic covariates. Such work would provide a stronger basis for evidence-informed TB–DM policy and for optimizing integrated care pathways in Indonesia (Franco, et al., 2024; Shewade, et al., 2025; Thong, et al., 2025; WHO, 2025a; Ye, et al., 2024).

CONCLUSION

In summary, the available Indonesian evidence indicates that type 2 diabetes mellitus (T2DM) is strongly associated with a higher occurrence of pulmonary tuberculosis (PTB) and a less favorable PTB clinical course. Across the studies reviewed, patients with T2DM consistently showed a greater likelihood of PTB occurrence, while PTB patients with diabetes—particularly those with poorer glycemic control—tended to experience delayed sputum smear conversion, longer treatment duration, greater clinical severity, and a higher risk of adverse outcomes, including mortality in some reports. These findings should be interpreted as evidence of a consistent association rather than definitive proof of causality, because the current evidence base is dominated by observational, retrospective, and single-center studies, with substantial variation in study design, exposure definition, outcome definition, and reporting quality.

The practical implications of this review are clear. In high-burden settings such as Indonesia, TB screening should be more systematically integrated into diabetes care, especially for patients with poor glycemic control, elevated HbA1c, older age, male sex, smoking exposure, poor nutritional status, or recent close contact with a TB

case. Such screening should be implemented not only in referral hospitals but also in Puskesmas, internal medicine clinics, and diabetes outpatient services. In addition, PTB patients with T2DM should receive closer metabolic and treatment monitoring, including glycemic assessment, sputum smear conversion monitoring during the intensive phase, adherence surveillance, and documentation of final treatment outcomes. From a programmatic perspective, these findings support stronger integration of TB–DM services, with particular emphasis on bidirectional screening, risk stratification, and continuity of follow-up across levels of care.

At the same time, the conclusions of this review are bounded by important methodological limitations. The review drew on literature identified primarily from Google Scholar and Garuda, which may have limited database coverage and introduced selection bias. The included studies were heterogeneous, and meta-analysis was not feasible because of inconsistent outcome definitions and incomplete reporting of adjusted effect estimates. Therefore, future research in Indonesia should prioritize multicenter prospective studies with geographically diverse sampling, standardized diagnostic criteria for both T2DM and PTB, and harmonized prognosis outcomes based on WHO TB treatment outcomes. At minimum, future studies should control for key confounders such as age, sex, nutritional status, smoking, socioeconomic status, contact history, and glycemic control indicators such as HbA1c. Stronger evidence of this kind is needed to refine national TB–DM policy, strengthen integrated service delivery, and support more precise prevention and management strategies for patients living with both conditions.

DECLARATION

Ethics approval and consent to participate

Not applicable

Artificial Intelligence-Assisted Technology

Not applicable

Consent for publication

Not applicable.

Availability of data and materials

The data generated and/or analysed during this research is not publicly available but is available from the corresponding author upon reasonable request.

Conflicts of interest Statement

The authors declare that they have no competing interests.

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ADDITIONAL INFORMATION

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