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Impact of Type 2 Diabetes on Lung Damage and Outcomes in treatment-naïve pulmonary tuberculosis

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Objective: To assess the impact of type 2 diabetes mellitus (T2DM) on risk and severity of structural lung disease (SLD) in treatment-naïve pulmonary tuberculosis (TB) patients, identify early predictors, and develop a prediction model for timely clinical intervention.

Methods: We retrospectively studied 296 newly diagnosed pulmonary TB patients (201 males and 95 females; mean age 53.8 ± 18.0 years) between December 2021 and December 2024. Patients were categorized into SLD and non-SLD groups based on chest CT findings assessed using integrated visual CT scoring and quantitative image analysis. Baseline demographics, symptoms, and laboratory parameters were compared between groups. Multivariate logistic regression identified independent predictors of SLD; receiver operating characteristic (ROC) analysis evaluated the diagnostic performance of the clinical prediction model.

Results: SLD patients were older, predominantly male, and had higher T2DM prevalence ($P<0.05$). A combined five-parameter model incorporating sex, T2DM, C-reactive protein (CRP), fasting plasma glucose, and erythrocyte sedimentation rate (ESR) demonstrated excellent diagnostic performance with an AUC of 0.881 (95% CI: 0.855–0.927), sensitivity of 91.2%, and specificity of 72.5%. Internal Bootstrap validation (1000 iterations) confirmed model robustness with optimal calibration (Brier score: 0.1352). Among SLD patients, T2DM was independently associated with higher BMI, increased symptom burden, elevated inflammatory markers, and

more severe CT abnormalities (P<0.05). Critically, new-onset SLD during 6-month therapy occurred in 63.0% of T2DM patients versus 21.4% without T2DM (P<0.001).

Conclusion: T2DM significantly increases structural lung disease risk, severity, and progression in treatment-naïve TB patients. A clinical prediction model incorporating sex, T2DM, C-reactive protein, fasting plasma glucose, and erythrocyte sedimentation rate demonstrates good diagnostic performance (AUC 0.881) for early SLD identification. T2DM was independently associated with higher inflammatory markers and more severe radiological abnormalities. These findings highlight the importance of intensive monitoring, optimal glycemic control, and early diabetes screening to prevent SLD progression and improve TB treatment outcomes in this high-risk population.

Introduction：

Tuberculosis (TB) remains a major global public health challenge and continues to be one of the leading infectious causes of mortality worldwide. According to the latest World Health Organization (WHO) data, there were an estimated 10.6 million new TB cases and 1.6 million TB-related deaths in 2021, with Southeast Asia and Africa together accounting for 68% of the global burden.[1]. Pulmonary TB can cause structural damage to lung parenchyma early in the course of anti-tuberculosis treatment, leading to impaired lung function and irreversible lesions. In multidrug-resistant TB (MDR-TB), the extent of lung destruction is often greater,

leaving permanent structural lung disease (SLD) [2] .SLD encompasses bronchiectasis, pulmonary fibrosis, and chronic obstructive pulmonary disease, all of which are characterized by persistent structural alterations in the lung parenchyma and airway architecture. These pathological changes result in chronic respiratory impairment, manifesting as dyspnea, reduced exercise tolerance, recurrent respiratory infections, sustained hypoxemia, and chronic productive cough; in severe cases, respiratory failure may occur [3]. In addition, both TB and the sequelae of SLD can increase the risk of cardiovascular events, including ischemic heart disease [4].

In recent decades, alongside rising global living standards, the prevalence of type 2 diabetes mellitus (T2DM) has increased steadily. The International Diabetes Federation (IDF) 2021 report estimates that 537 million people worldwide are living with T2DM [5]. T2DM not only heightens susceptibility to TB infection but also adversely affects treatment outcomes and long-term prognosis[6,7] . Patients with concomitant TB and T2DM often require prolonged treatment, face higher recurrence rates, and are at increased risk for complications, thereby imposing greater socio-economic and healthcare burdens. Emerging evidence suggests that the coexistence of T2DM and TB may accelerate the development and progression of SLD. Such patients are more likely to sustain irreversible structural damage, including bronchiectasis, pulmonary fibrosis, and cavity formation, which significantly impairs quality of life and prognosis[8,9] .

However, a critical knowledge gap exists in our understanding of T2DM's role in early SLD development among treatment-naïve TB patients. Current research remains limited, with most studies focusing on advanced disease stages when irreversible lesions have already formed, rather than addressing the crucial early phase when intervention might be most effective. Importantly, no previous investigations have integrated both radiologist-based visual severity scoring and quantitative chest computed tomography (CT) metrics to establish early predictive models for SLD risk stratification in T2DM-TB patients. This methodological limitation has resulted in the absence of validated tools for identifying high-risk patients before substantial lung destruction occurs. In clinical practice, SLD in T2DM-TB patients is often recognized only after extensive structural damage has developed, fundamentally missing the optimal therapeutic window for lung-protective interventions.

To address this significant research gap, we retrospectively analyzed clinical data from treatment-naïve pulmonary TB patients with and without T2DM, employing an innovative approach that combines radiologist-assessed visual severity scoring with quantitative CT analysis. Our primary objective was to develop and validate an early prediction model that enables timely risk stratification and targeted intervention strategies before irreversible lung damage occurs. This study aims to provide the first comprehensive evidence supporting early diagnosis and personalized management

approaches for preventing SLD progression in this vulnerable population.

Materials and Methods

Study population:

We retrospectively reviewed the records of 362 newly diagnosed treatment-naïve pulmonary tuberculosis (PTB) patients admitted to the First Affiliated Hospital of Wannan Medical College (Yijishan Hospital, Wuhu, China) between December 2021 and December 2024. Demographic characteristics, clinical features, and quantitative chest computed tomography (CT) parameters were extracted.

Inclusion criteria:

PTB diagnosis based on the Chinese National Health Commission “Tuberculosis Classification Standard” (WS196-2017), “Tuberculosis Diagnosis Standard” (WS288-2017), and the National Tuberculosis Control Association (NTCA) guidelines on respiratory isolation to reduce community transmission[10,11] ;

Type 2 diabetes mellitus (T2DM) diagnosis according to Standards of Medical Care in Diabetes—2022: fasting plasma glucose ≥7.0 mmol/L, random plasma glucose ≥11.1 mmol/L, or HbA1c >6.5%[12] ;Structural lung disease (SLD) confirmed by CT,

defined as one or more of the following: secondary bronchiectasis, honeycombing, multiple bullae, fibrocavitary tuberculosis, or tuberculous lung destruction[13]. Exclusion criteria:(1) loss to follow-up;(2) incomplete clinical or imaging data;(3) coexistent malignancy, AIDS, or other cachectic diseases.After applying these criteria, 296 patients were eligible for inclusion, as shown in Figure 1.

1.2 Clinical Data Collection

Baseline data included age, sex, body mass index (BMI), history of hypertension, and history of T2DM. Laboratory tests comprised complete blood count, biochemical profile, erythrocyte sedimentation rate (ESR), and inflammatory markers.

1.3 Visual Scoring of CT Images

Pulmonary tuberculosis (PTB) severity was assessed using a CT-based visual scoring system. All images were independently evaluated in a double-blind fashion by two experienced radiologists (with 10 and 15 years of experience) who were blinded to the clinical and laboratory data. To evaluate inter-observer reliability, the intraclass correlation coefficient (ICC) was calculated for the total severity scores, and the weighted Kappa coefficient was used for the scores of individual radiological features. Agreement was interpreted as poor (<0.40), fair (0.40–0.59), good (0.60–0.74), or excellent (0.75–1.00). Any disagreements between the two readers were resolved by consensus.

Five radiological features were assessed: (1) micronodules and “tree-in-bud” sign; (2)

ground-glass opacity; (3) acinar nodules with lobular consolidation; (4) segmental/lobar consolidation; and (5) cavities [14]. Each feature was scored based on its extent in each of the five lung lobes using a 6-point scale: 0 (none), 1 (<5%), 2 (5%–25%), 3 (25%–50%), 4 (50%–75%), or 5 (>75%). Scores for all lobes were summed for each feature, and the final total severity score was calculated as the sum of all feature scores (maximum possible score: 125). A schematic representation of the scoring method is shown in Figure 2 (A–E).

1.4 Quantitative CT Analysis

Thin-section chest CT scans (slice thickness 1.5 mm) were exported in DICOM format to 3D Slicer software (version 5.8.1) for quantitative analysis. Using a threshold-based segmentation method, the lung analysis module automatically identified ground-glass opacity (GGO) and solid opacity according to predefined attenuation thresholds, as previously described[15-16] .

For each scan, total lung volume (TLV) was calculated from the segmented bilateral lung fields. Voxels with attenuation values between −700 and −300 HU were classified as GGO to derive the ground-glass opacity volume (GGOV), and voxels between −300 and 0 HU were classified as solid opacity to derive the solid opacity volume (SOV). Total lesion volume (LeV) was calculated as GGOV plus SOV. Voxels with attenuation values < −950 HU were classified as emphysematous areas to calculate emphysema volume (LAA). Percentages for each parameter (GGOV%, SOV%, LeV%, LAA%) were obtained by dividing the respective volume by TLV. A

schematic illustration of the quantitative CT analysis workflow is provided in Figure 2(F–H).

1.5 Statistical Analysis

Sample size was justified by the events-per-variable rule (EPV = 25, exceeding the recommended 10–15 threshold). Statistical analyses were performed using SPSS (version 26.0; IBM Corp., Armonk, NY, USA) and R software (version 4.2.2; R Foundation for Statistical Computing, Vienna, Austria). Continuous variables were expressed as mean ± SD or median (IQR) and compared using the independent-samples t-test or Mann–Whitney U test, as appropriate. Categorical variables were presented as n (%) and compared using the χ^2 test or Fisher's exact test.Variables with $P < 0.05$ in univariate analysis were entered into multivariate logistic regression to identify independent risk factors. Receiver operating characteristic (ROC) curve analysis was performed using MedCalc (version 11.4; MedCalc Software Ltd., Ostend, Belgium) to assess discriminative performance, including the area under the curve (AUC), sensitivity, and specificity. Internal validation was conducted using Bootstrap resampling (1,000 iterations). Model calibration was evaluated using calibration curves and the Brier score. All statistical tests were two-sided, and $P < 0.05$ was considered statistically significant.

Results

1.1 Clinical Characteristics and indicator comparison between structural and non-Structural lung disease in patients with pulmonary tuberculosis.

A total of 296 patients with newly diagnosed treatment-naïve pulmonary tuberculosis (PTB) were enrolled in the present study, comprising 125 patients (42.2%) in the SLD group and 171 patients (57.8%) in the non-SLD group. As shown in Table 1, hemoptysis was significantly more prevalent in the SLD group than in the non-SLD group ($P = 0.002$). Significant intergroup differences were also observed in age ($P = 0.026$), sex distribution ($P = 0.001$), and the prevalence of comorbid type 2 diabetes mellitus (T2DM; $P = 0.006$). No statistically significant differences were detected between the two groups in terms of body mass index (BMI), education level, other respiratory symptoms (including cough, sputum production, and chest pain), or the presence of hypertension (all $P \geq 0.05$).With respect to laboratory parameters, the SLD group exhibited significantly different values compared with the non-SLD group for red blood cell count ($P < 0.05$), hemoglobin concentration ($P = 0.047$), C-reactive protein (CRP; $P < 0.001$), albumin ($P < 0.05$), cystatin ($P = 0.036$), triglycerides ($P = 0.027$), fasting glucose ($P < 0.001$), low-density lipoprotein (LDL; $P = 0.036$), and erythrocyte sedimentation rate (ESR; $P < 0.001$).All baseline characteristics and laboratory parameters are summarized in Table 1.

1.2 Multivariate logistic regression analysis

Variables with $P < 0.05$ in the univariate analysis — including sex, hemoptysis, age,

type 2 diabetes mellitus (T2DM), red blood cell count, haemoglobin, C-reactive protein (CRP), albumin, cystatin, triglycerides, fasting glucose, low-density lipoprotein (LDL), and erythrocyte sedimentation rate (ESR) — were entered into a multivariate logistic regression model. The results indicated that sex, T2DM, CRP, fasting glucose, and ESR were independent risk factors for Structural lung disease (SLD) (all $P < 0.05$).Details of the multivariate logistic regression analysis are presented in Table 2.

1.3 ROC curve analysis

Receiver operating characteristic (ROC) curve analysis of the five independent predictors revealed that the combined model achieved an area under the curve (AUC) of 0.889, with a sensitivity of 91.2% and a specificity of 72.5%. The AUC values for the individual predictors were as follows: sex, 0.592; type 2 diabetes mellitus (T2DM), 0.578; C-reactive protein (CRP), 0.772; fasting glucose, 0.796; and erythrocyte sedimentation rate (ESR), 0.752. The combined model nomogram underwent internal validation using Bootstrap resampling with 1000 iterations. The internal validation yielded an AUC of 0.881 (95% CI: 0.855, 0.927), confirming robust discriminative performance. The calibration curve demonstrated good agreement between predicted probabilities and actual incidence rates (Brier score = 0.1352), indicating excellent model calibration. These results are illustrated in Figure 2(I, J, K).

2.1Clinical characteristics, laboratory parameter comparisons, and imaging

assessments of structural lung disease in pulmonary tuberculosis patients with and without type 2 diabetes mellitus.

Among the 125 patients in the SLD group, 59 (47.2%) had comorbid type 2 diabetes mellitus (T2DM), while 66 (52.8%) did not. Compared with the non-T2DM group, patients with T2DM presented with significantly lower frequencies of cough ($P<0.001$), sputum production ($P=0.008$), and fever ($P=0.012$), but had higher body mass index (BMI) values ($P=0.002$). No statistically significant differences were observed in age, sex, hemoptysis, or chest pain (all $P\geq0.05$). Laboratory analyses revealed that, compared with non-T2DM patients, those with T2DM exhibited significant differences in several parameters, including red blood cell count ($P=0.01$), hemoglobin ($P=0.047$), C-reactive protein (CRP; $P<0.001$), albumin (ALB; $P<0.001$), triglycerides (TG; $P=0.027$), fasting blood glucose (FBG; $P<0.001$), low-density lipoprotein (LDL; $P=0.036$), erythrocyte sedimentation rate (ESR; $P<0.001$), and procalcitonin ($P<0.001$)..Regarding visual CT scoring, the T2DM group demonstrated significantly higher total lung severity scores ($P=0.006$), consolidation scores ($P=0.001$), and cavity scores ($P<0.001$) than the non-T2DM group, whereas scores for micronodules/tree-in-bud, acinar nodules/lobular consolidation, and ground-glass opacity did not significantly differ between the groups (all $P\geq0.05$).Quantitative CT analysis further indicated that patients with T2DM had significantly greater total lung volume (TLV), low-attenuation area (LAA; mL), LAA percentage, solid opacity volume (SOV), SOV percentage, and lesion volume (LeV) compared with their non-

T2DM counterparts (all P<0.05). No significant between-group differences were noted for ground-glass opacity volume (GGO), GGO percentage, or LeV percentage (all P≥0.05).All comparisons are summarised in Tables 3.

3.1 Incidence of new-onset SLD during follow-up

Of the 171 patients without SLD at baseline, 54 had type 2 diabetes mellitus (T2DM) and 117 did not. After six months of standard anti-tuberculosis therapy, new-onset SLD was detected in 34 patients (63.0%) in the T2DM group and 25 patients (21.4%) in the non-T2DM group (P < 0.001).These findings are illustrated in Figure 2(L).

Discussion

In this retrospective study of 296 patients with treatment-naïve secondary pulmonary tuberculosis (PTB), the incidence of SLD was 42.2%. Multivariate logistic regression identified sex, T2DM, CRP, fasting glucose, and ESR as independent risk factors. The combined diagnostic model demonstrated excellent discriminative performance (AUC = 0.889, sensitivity 91.2%, specificity 72.5%), substantially outperforming any single marker. Bootstrap internal validation with 1000 iterations confirmed the model's robustness (AUC = 0.881, 95% CI: 0.855–0.927), and the calibration curve showed good agreement between predicted probabilities and observed outcomes (Brier score = 0.1352). These findings underscore the value of integrated clinical and laboratory assessment in identifying patients at high risk for structural lung damage [9,17] .

Clinically, SLD patients demonstrated a significantly higher incidence of hemoptysis compared to non-SLD patients, which is attributable to bronchiectasis and post-inflammatory pulmonary fibrosis. Laboratory parameters revealed that SLD patients had lower red blood cell and hemoglobin levels, elevated inflammatory markers (CRP and ESR), reduced serum albumin, and higher fasting glucose levels compared to non-SLD patients. These findings suggest that SLD is associated with chronic inflammation, malnutrition, and impaired glucose metabolism. The elevated inflammatory markers (CRP and ESR) indicate ongoing inflammatory activity that may facilitate fibrotic progression, while hyperglycemia is associated with impaired immune function and increased susceptibility to pulmonary injury[18].

Subgroup analysis further demonstrated that structural lung disease (SLD) patients with comorbid type 2 diabetes mellitus (T2DM) exhibited significantly higher levels of inflammatory markers (including C-reactive protein, erythrocyte sedimentation rate, and procalcitonin) and more pronounced metabolic abnormalities (such as elevated triglycerides). Notably, although the difference in total protein levels between the two groups did not reach statistical significance, albumin levels were significantly lower in the T2DM group, suggesting that T2DM exacerbates systemic inflammation and nutritional depletion. Imaging analysis revealed that in visual assessments, the T2DM group had higher total severity, consolidation, and cavity scores, indicating more extensive lung parenchymal destruction. Quantitative CT

analysis confirmed increases in total lesion volume, low-attenuation area percentage (LAA%), solid opacity percentage (SOV%), and their respective volumes, reflecting more severe emphysematous-like changes and consolidation [19,20]. During the follow-up period, the incidence of new-onset SLD was significantly higher in T2DM patients (63.0% vs. 21.4%), confirming the role of T2DM in accelerating the deterioration of post-tuberculosis structural lung injury and predicting a poor prognosis.

A notable strength of this study is the combined application of visual scoring and quantitative CT analysis for comprehensive evaluation of SLD. Visual scoring provides an intuitive overview of lesion distribution and morphology, whereas quantitative CT offers objective, reproducible metrics that enable detailed assessment and longitudinal monitoring. This dual-modality approach facilitates early recognition of high-risk patients, supports personalized therapeutic strategies, and allows dynamic evaluation of treatment response—particularly valuable for PTB patients with T2DM [21,22]. Furthermore, the predictive model's favorable internal validation results, with robust discriminative ability and good calibration, support its potential clinical utility for risk stratification in similar patient populations.

From a management perspective, treatment-naïve secondary PTB patients with T2DM require not only standard anti-tuberculosis therapy but also strict glycemic control, regular monitoring of fasting glucose, and optimization of antidiabetic regimens. For those at high risk of SLD—as identified by the validated predictive model—

integrated monitoring combining inflammatory markers (CRP, ESR) and imaging parameters should be incorporated into routine follow-up to reduce the likelihood of irreversible structural damage, mitigate complications such as hemoptysis and respiratory insufficiency, and improve long-term functional outcomes. This approach aligns with the WHO 2023 guidelines, which emphasize the importance of glycemic management in reducing adverse outcomes among TB–T2DM patients [23].

The present study has several limitations. First, the single-center, retrospective design limits generalizability and introduces potential selection bias. Unmeasured confounding factors—including nutritional status, socioeconomic conditions, smoking history, symptom duration before diagnosis, and treatment adherence—may have influenced both SLD development and the observed associations with T2DM. Our relatively small sample size (n=296) may also have limited statistical power for subgroup analyses [24]. Second, exclusion of retreatment and drug-resistant TB cases may underestimate the true burden of SLD in clinical practice[18]. Third, the absence of serial pulmonary function testing precludes direct assessment of the relationship between radiological structural changes and functional outcomes such as airflow obstruction, exercise capacity, and quality of life.

Fourth, while Bootstrap internal validation demonstrated good model performance, the lack of external validation in an independent cohort remains a critical limitation. Internal validation alone cannot fully address concerns regarding overfitting or assess

performance across different populations, healthcare settings, or geographic regions. These limitations highlight the need for multicenter, prospective studies with larger cohorts, serial functional assessments, extended follow-up, and—most importantly—external validation in diverse patient populations to confirm our findings and establish the model's generalizability.

In conclusion, T2DM substantially increases the risk and severity of SLD in treatment-naïve pulmonary TB patients. A simple five-parameter clinical model based on sex, T2DM status, C-reactive protein, fasting plasma glucose, and erythrocyte sedimentation rate shows good discrimination for early SLD detection (AUC 0.881) [25-26]. Combined with CT assessment, this model may facilitate risk stratification and guide individualized treatment decisions. However, the retrospective single-center design limits generalizability. External validation in prospective cohorts is warranted before clinical adoption. Future investigations incorporating quantitative CT features may enhance model performance.

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Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics Statement

This retrospective study was approved by the Ethics Committee of The First Affiliated Hospital of Wannan Medical College, Yijishan Hospital (Approval No. 2023-5). As the study involved only the analysis of existing clinical data—including computed tomography images and laboratory test results—without direct patient contact, the requirement for written informed consent was waived by the ethics committee. All data were anonymized prior to analysis to ensure patient confidentiality. The study was conducted in accordance with the ethical standards of the institutional and/or national research committee, and with the 1964 Declaration of Helsinki and its later amendments.

Availability of Data and Materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

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Table 1.Clinical Characteristics and indicator comparison between structural and non-Structural lung disease in patients with pulmonary tuberculosis

	Total(n=296)	Structural Lung Disease Group（n=125)	Non-structural Lung Disease Group(n=171)	Statistic	P value
General information					
Gender (Male/Female)	296(210/86)	125(102/23)	171(108/63)	11.915	0.001
Age, years	53.8±18.0	56.5±16.6	51.8±18.8	2.36	0.026
Education levels（%）				6.958	0.073
1-6 years	80(27.0)	27(21.6)	53(31.0)		
7-9 years	119(40.2)	56(44.8)	63(36.8)		
10-12 years	52(17.6)	27(21.6)	25(14.6)		
>12 years	45(15.2)	15(12.0)	30(17.5)		
BMI（kg/m2）	20.0±3.1	19.6±3.0	20.3±3.1	-1.70	0.09
Symptoms and signs（%）					
Cough	245(82.8)	102(81.6)	143(83.6)	0.208	0.649
Hemoptysis	62(20.9）	37(29.6）	25(14.6）	9.786	0.002
Expectoration	233(78.7)	103(82.4)	130(76.0)	1.753	0.186
Chest pain	40(13.5）	16(12.8)	24(14.0)	0.094	0.759
Fever	115(38.9）	55(44.0）	60(35.1）	2.414	0.12
Underlying diseases（%）					
Type 2 diabetes mellitus	113(38.2）	59(47.2）	54(31.6）	7.466	0.006
Hypertension	44(14.9）	17(13.6)	27((15.9)	0.296	0.587
Complications（%）					
Heart failure	12(4.1）	3(2.4)	9(5.3)	1.546	0.214
Respiratory failure	15(5.1）	4(3.2)	11(6.5)	1.597	0.206
Electrolyte imbalance	67(22.7）	31(24.8)	36(21.2)	0.539	0.463
Parameters					

WBC (10^9/L)	7.5±3.3	7.6±3.3	7.4±3.1	0.51	0.61
NEU (10^9/L)	5.6±5.0	5.4±2.8	5.7±6.2	-0.497	0.619
LYM (10^9/L)	1.2(0.9,1.7)	1.1(0.8,1.6)	1.3(1.0,1,8)	-1.829	0.067
MON (10^9/L)	0.5(0.4,0.7)	0.5(0.4,0.8)	0.5(0.4,0.7)	-1.104	0.269
RBC(10^12/L)	3.9(3.5,4.4)	3.9(3.4,4.2)	4.0(3.6,4.5)	-2.566	0.01
HGB (g/L)	117.5(103.0,131.0)	115(101,128)	119(104,133)	-1.985	0.047
PLT (10^9/L)	242.3±113.7	227.5±104.8	253.1±118.9	-1.79	0.074
CRP (mg/L)	17.4(13.7,21.5)	20.8(16.3,29.4)	15.5(12.5,18.2)	-8.015	＜0.001
TP (g/L)	45.2(37.5,64.3)	47.2(40.1,61.6)	43.4(35.6,65.1)	-0.68	0.496
ALB (g/L)	39.0(33.9,43.0)	35.1(29.7,40.1)	39.0(33.5,43.1)	-3.63	＜0.001
TBIL (μmol/L)	8.9(6.9,13.4)	9.3(7.4,15.7)	8.7(6.7,12.7)	-1.517	0.129
DBIL (μmol/L)	3.0(2.1,4.3)	3.4(2.2,4.2)	2.9(2.1,4.3)	-1.495	0.135
ALT (U/L)	13.5(9.0,21.0)	12.0(9.0,21.0)	14.0(9.0,20.0)	-0.781	0.435
AST (U/L)	19.0(14.0,37.0)	22.0(14.0,38.0)	18.0(14.0,35.0)	-1.031	0.303
Bun(μmol/L)	4.9(3.9,6.3)	5.0(3.9,6.3)	4.9(3.9,6.3)	-0.032	0.975
Cr (μmol/L)	62.5±23.2	59.9±23.2	64.4±23.0	-1.678	0.094
CysC (mg/dL)	0.9(0.8,13)	0.89(0.82,1.21)	0.90(0.73,1.10)	-2.098	0.036
UA (μmol/L)	289.9±148.8	284.0±156.0	294.0±144	-0.657	0.511
TG (μmol/L)	1.8±0.85	1.9±1.0	1.7±0.7	2.223	0.027
CHOL(mmol/L)	3.8±0.9	3.7±0.9	3.9±0.9	-1.847	0.066
FBG((mmol/L)	6.1(5.4,7.7)	6.8(6.0,11.8)	5.6(5.0,6.5)	-7.993	＜0.001
LDL(mmol/L）	2.4±0.8	2.3±0.8	2.5±0.9	-2.014	0.036
ESR （mm/h)	39.4±24.1	51.9±25.3	30.4±18.7	8.032	＜0.001
PCT (ng/mL)	0.6(0.03,0.3)	0.23(0.05,0.7)	0.05(0.031,0.1)	0.423	0.672

Table 2. Independent risk factors for structural lung disease identified by multivariate logistic regression

Parameter	β value	Standard error (SE)	Waldχ2	P value	OR（95%CI)
Gender	0.904	0.386	5.49	0.019	2.469(1.159,5.258)
Hemoptysis	0.466	0.398	1.37	0.242	1.593(0.730,3.476)
Type 2 diabetes mellitus	1.47	0.469	9.828	0.02	4.35(1.74, 10.87)
Age	0.014	0.1	2.068	0.15	1.014(0.995,1.034)
RBC(10^12/L)	-0.298	0.432	0.475	0.491	0.743(0.318,1.732)
HGB (g/L)	0.005	0.015	0.125	0.724	1.005(0.977,1.034)
CRP (mg/L)	0.165	0.035	22.8	＜0.001	1.179(1.102,1.262)
CysC (mg/dL)	-0.585	0.337	3.007	0.083	0.557(0.288,1.079)
TG (μmol/L)	0.15	0.226	0.44	0.507	1.162(0.746,1.811)
FBG(mmol/L）	0.376	0.109	11.936	0.001	1.457(1.177,1.804)
LDL(mmol/L）	-0.175	0.191	0.839	0.36	0.840(0.578,1.220)
ESR （mm/h)	0.036	0.008	20.451	＜0.001	1.037(1.021,1.054)

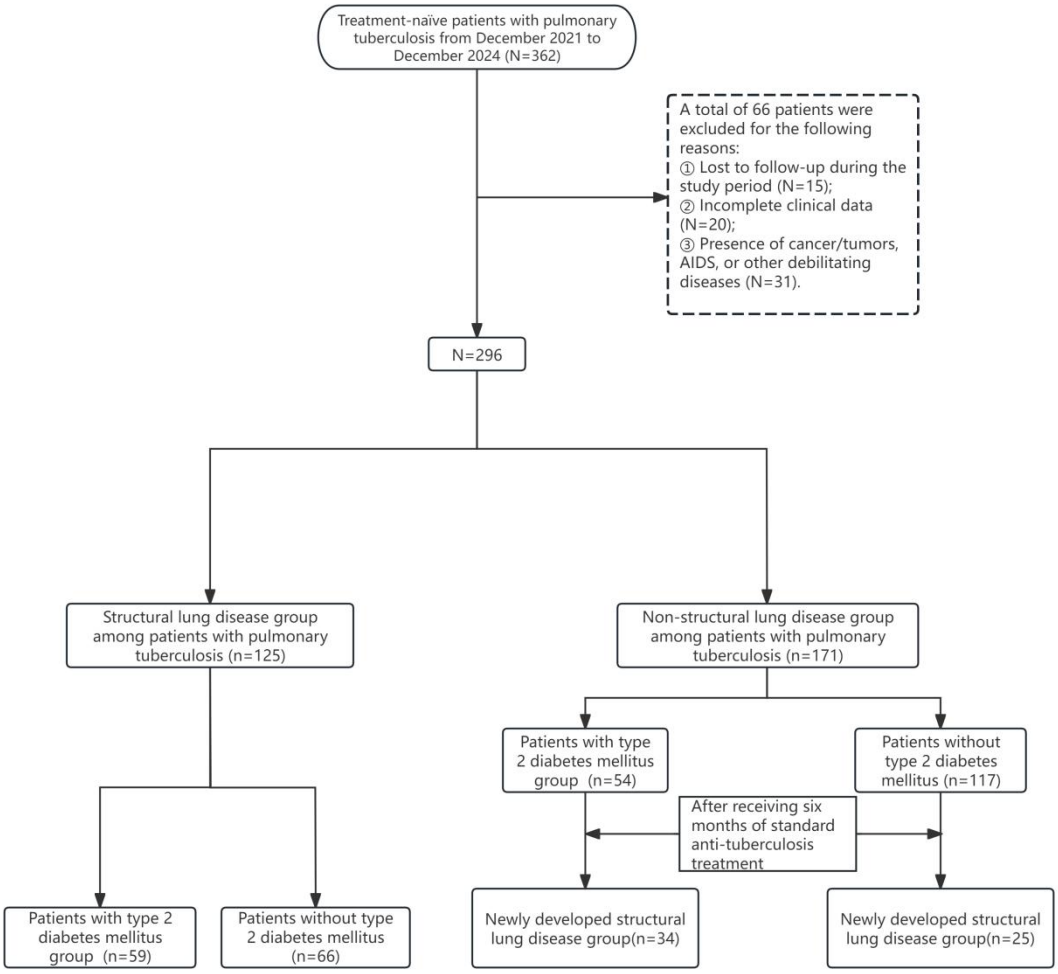
Table 3. Clinical characteristics, laboratory parameter comparisons, and imaging assessments of structural lung disease in pulmonary tuberculosis patients with and without type 2 diabetes mellitus

	Total (n=125)	Type 2 diabetes mellitus Group(n=59)	Non-type 2 diabetes mellitus Group (n=66)	Statistic	P value
General information					
Gender (Male/Female)	125(102/23)	59(51/8)	66(51/15)	1.744	0.187
Age, years	56.5±16.6	58.4±14.1	54.79±18.49	1.229	0.221
Education levels(%)				2.316	0.073
1-6 years	27(21.6)	11(18.6)	16(24.2)		
7-9 years	56(44.8)	29(49.2)	27(40.9)		
10-12 years	27(24.2)	11(18.6)	16(24.2)		
>12 years	15(12.0)	5(8.5)	10(15.2)		
BMI（kg/m2）	19.64±3.04	20.53±3.11	18.85±2.78	3.200	0.002
Symptoms and signs (%)					
Cough	102(81.6)	39(66.1)	63(95.5)	17.876	<0.001
Hemoptysis	37(29.6)	20(33.9)	17(25.8)	0.991	0.32
Expectoration	103(82.4)	43(72.9)	60(52.8)	6.981	0.008
Chest pain	1612.8)	9(15.3)	7(10.6)	0.603	0.437
Fever	55(44.0)	19(32.2)	36(54.5)	6.311	0.012
Underlying diseases (%)					
Hypertension	17(13.6)	11(18.6)	6((9.1)	2.42	0.12

Complications（%）					
Heart failure	3(2.4）	3(5.1)	0(0)	3.438	0.204
Respiratory failure	4(3.2）	1(1.7)	3(4.5)	0.817	0.693
Electrolyte imbalance	31(24.8）	11(18.6)	20(30.3)	2.271	0.132
Parameters					
WBC (10^9/L)	7.5±3.3	7.6±3.3	7.4±3.1	0.51	0.61
NEU (10^9/L)	5.4±2.8	5.4±2.8	5.7±6.2	-0.497	0.619
LYM (10^9/L)	1.1(0.8,1.6)	1.1(0.8,1.6)	1.3(1.0,1,8)	-1.829	0.067
MON (10^9/L)	0.5(0.4,0.8)	0.5(0.4,0.8)	0.5(0.4,0.7)	-1.104	0.269
RBC(10^12/L)	3.9(3.4,4.2)	3.9(3.4,4.2)	4.0(3.6,4.5)	-2.566	0.01
HGB (g/L)	115(101,129)	115(101,128)	119(104,133)	-1.985	0.047
PLT (10^9/L)	227.5±104.8	227.5±104.8	253.1±118.9	-1.79	0.074
CRP (mg/L)	21.2(16.6,29.5)	20.8(16.3,29.4)	15.5(12.5,18.2)	-8.015	＜0.001
TP (g/L)	47.10(40.0,62.0)	47.2(40.1,61.6)	43.4(35.6,65.1)	-0.681	0.496
ALB (g/L)	38.3(33.9,42.5)	35.1(29.7,40.1)	39.0(33.5,43.1)	-3.633	＜0.001
TBIL (μmol/L)	9.3(7.4,15.8)	9.3(7.4,15.7)	8.7(6.7,12.7)	-1.517	0.129
DBIL (μmol/L)	3.4(2.2,4.2)	3.4(2.2,4.2)	2.9(2.1,4.3)	-1.495	0.135
ALT (U/L)	12.0(9.0,21.0)	12.0(9.0,21.0)	14.0(9.0,20.0)	-0.781	0.435
AST (U/L)	22.0(14.0,38.0)	22.0(14.0,38.0)	18.0(14.0,35.0)	-1.031	0.303
Bun(μmol/L)	5.0(3.9,6.3)	5.0(3.9,6.3)	4.9(3.9,6.3)	-0.032	0.975
Cr (μmol/L)	60.0±23.4	59.9±23.2	64.4±23.0	-1.678	0.094
CysC (mg/dL)	0.95(0.81,1.19)	0.95(0.79,1.19)	0.95(0.83,1.17)	-0.089	0.929
UA (μmol/L)	284.0±156.0	284.0±156.0	294.0±144	-0.657	0.511
TG (μmol/L)	1.9±1.0	1.9±1.0	1.7±0.7	2.223	0.027
CHOL(mmol/L)	3.7±0.9	3.7±0.9	3.9±0.9	-1.847	0.066
FBG((mmol/L)	7.1(5.9,11.8)	6.8(6.0,11.8)	5.6(5.0,6.5)	-7.993	＜0.001
LDL(mmol/L）	2.3±0.8	2.3±0.8	2.5±0.9	-2.014	0.036
ESR(mm/h)	51.7±25.2	51.9±25.3	30.4±18.7	8.032	＜0.001
PCT(ng/mL)	0.22(0.05,0.70)	0.57(0.13,0.91)	0.06(0.03,0.33)	-4.543	＜0.001
Total lung severity score	15(11,18)	16(15,18)	14(7,18)	-2.769	0.006
Micronodule and "tree-in-bud"score	3(2,4)	3(2,4)	3(2.5,4)	-0.026	0.979
Acinar nodule and lobular consolidation score	3(2,4)	3(2,4)	3(2,4)	-0.253	0.800
Segmental or lobar consolidation score	4(2,6)	5(4,6)	3.5(2,5)	-3.432	0.001
Ground-glass opacity score	2(0,2)	2(0,2)	2(0,2)	-0.386	0.700
Cavity score	3(0,4)	4(3,4)	2(0,3)	-6.136	＜0.001
TLV(mL)	3996.1(3374.5,4822.1)	4475.4(3619.6,5038.8)	3866.7(3183.0,4516.1)	-2.389	0.017
LAA(mL)	655.9(400.5,907.1)	818.1(510.2,1161.9)	528.5(381.0,776.6)	-3.798	＜0.001

LAA%	15.8(11.6,21.3)	17.9(14.8,22.7)	13.9(10.2,17.5)	-3.843	＜0.001
GGO(mL)	568.4(495.5,650.5)	572.1(506.1,660.5)	560.8(483.5,640.9)	-1.207	0.228
GGO%	13.7(10.8,17.0)	14.1(10.8,17.6)	13.6(11.2,17.0)	-0.173	0.863
SOV(mL)	147.1(100.0,196.3)	182.3(117.0,293.3)	130.4(98.4,160.3)	-4.055	＜0.001
SOV%	3.5(2.8,5.1)	3.8(3.0,6.6)	3.4(2.6,4.2)	-2.552	0.011
Lev(mL)	746.3(633.9,834.0)	767.1(709.0,929.0)	670.7(613.2,779.9)	-3.768	＜0.001
Lev%	17.7(14.4,21.7)	18.7(15.7,21.7)	16.9(14.0,21.6)	-1.454	0.146

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540 Figure 1

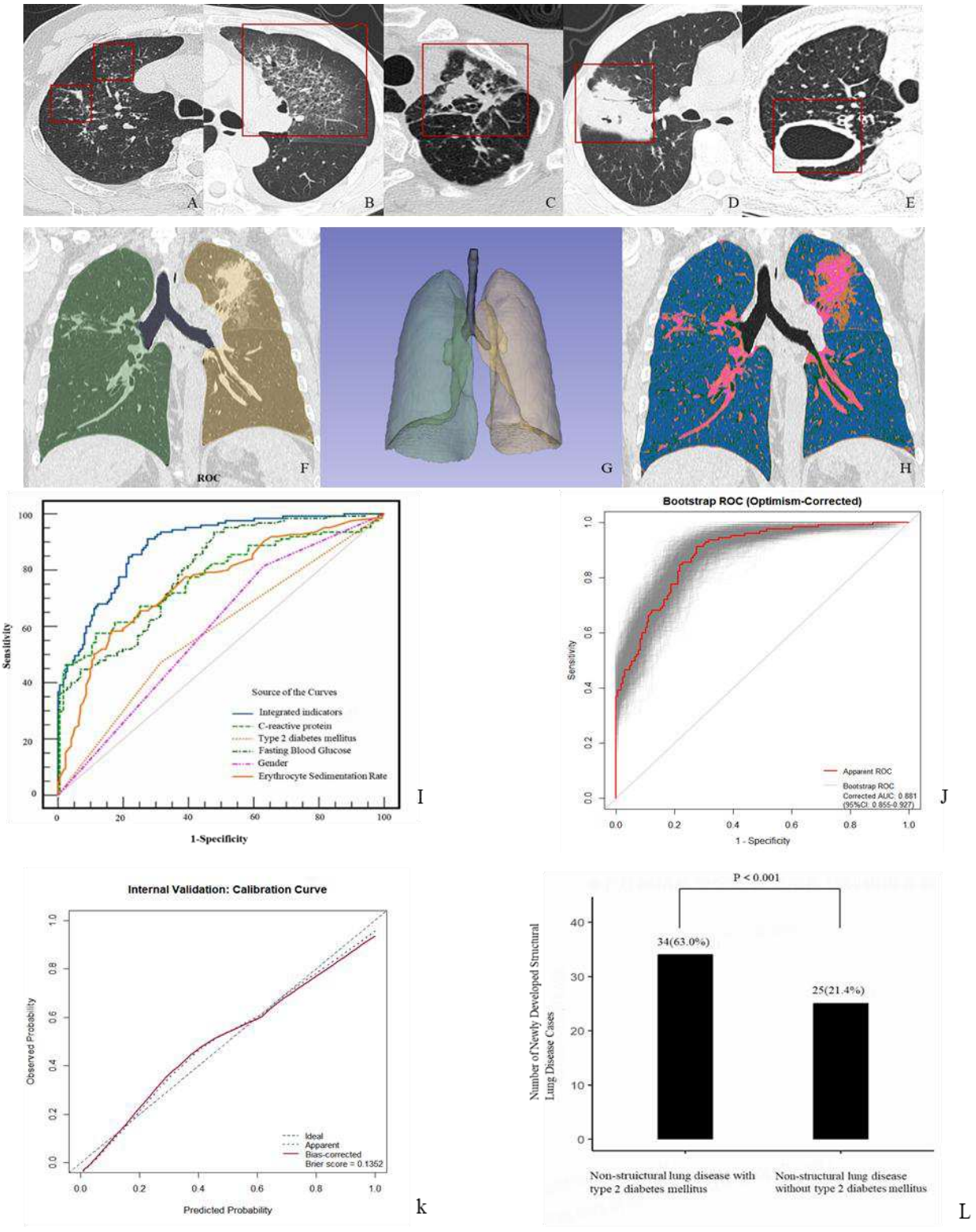

A
B
C
D
E
ROC
F
G
H
Sensitivity
1-Specificity
Source of the Curves
Integrated indicators
C-reactive protein
Type 2 diabetes mellitus
Fasting Blood Glucose
Gender
Erythrocyte Sedimentation Rate
I
Bootstrap ROC (Optimism-Corrected)
Sensitivity
1 - Specificity
Apparent ROC
Bootstrap ROC
Corrected AUC: 0.881
(95%CI: 0.855-0.927)
J
Internal Validation: Calibration Curve
Observed Probability
Predicted Probability
Ideal
Apparent
Bias-corrected
Brier score = 0.1352
k
P < 0.001
34(63.0%)
25(21.4%)
Number of Newly Developed Structural Lung Disease Cases
Non-struictural lung disease with type 2 diabetes mellitus
Non-structural lung disease without type 2 diabetes mellitus
L

Figure 2

Figure Legends

Figure 1. Flowchart of patient grouping to assess the association between type 2 diabetes mellitus and structural lung disease in treatment-naïve pulmonary tuberculosis patients, December 2021–December 2024.

Figure 2. Comparison of visual scoring, quantitative chest CT analysis, diagnostic model performance with bootstrap internal validation, and incidence of structural lung disease in pulmonary tuberculosis patients with and without type 2 diabetes mellitus

A–E: Five representative CT features indicating disease severity: micronodules and "tree-in-bud" sign (A), ground-glass opacity (B), acinar nodules with lobular consolidation (C), segmental/lobar consolidation (D), and cavities (E).

F–H: Quantitative chest CT analysis in a 54-year-old man with treatment-naïve tuberculosis (TB): coronal CT image (F), lung segmentation and 3D reconstruction using the "Lung CT Segmenter" module in 3D Slicer (G), and lesion quantification with the "Lung CT Analyzer" showing ground-glass opacity volume (GGOV, orange), solid opacity volume (SOV, red), total lesion volume (LeV), and low attenuation area percentage (LAA%, green) (H).

I: Receiver operating characteristic (ROC) curves for gender, type 2 diabetes mellitus (T2DM), C-reactive protein (CRP), fasting blood glucose (FBG), and erythrocyte

sedimentation rate (ESR) in identifying structural lung disease (SLD).

J: Internal validation was performed using Bootstrap resampling with 1000 iterations, yielding an area under the ROC curve of 0.881 (95% CI: 0.855–0.927).

K: The calibration curve showed good agreement between predicted and observed probabilities. The Brier score of 0.1352 indicated favorable calibration performance.

L:Incidence of newly developed structural lung disease (SLD) after 6 months of standard anti-tuberculosis (TB) therapy in patients without baseline SLD: 63.0% in those with type 2 diabetes mellitus (T2DM) versus 21.4% in those without T2DM ($P < 0.001$).