

Tuberculosis Lung Sequelae: A Cross-Sectional Study from a Tertiary Care Hospital in Eastern India

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ABSTRACT

Background: Post-tuberculosis lung disease (PTLD) causes substantial chronic morbidity in high-burden countries, yet its multisystem profile is poorly characterised in eastern India. We describe the clinical, functional, radiological, cardiac and microbiological profile of PTLD and identify factors associated with pulmonary hypertension (PH) and respiratory failure.

Methods: In this cross-sectional study (February 2024–December 2025), 124 symptomatic adults with treated pulmonary tuberculosis underwent clinical assessment, spirometry, chest radiography, HRCT, ECG, 2D echocardiography and sputum microbiology (Gram stain, culture, AFB smear, TrueNat MTB/RIF). Multivariable logistic regression estimated adjusted odds ratios (aOR).

Results: Mean age was 47.85 ± 13.43 years; 58.1% were male and 29.8% underweight. Cough (71.0%) and crackles (79.0%) predominated. Spirometry was abnormal in 90.3%, mostly mixed (44.4%). Fibrotic strands (60.5%) and volume loss (51.6%) led the radiographic findings; HRCT showed bronchiectasis in 58.9%, chiefly traction and cystic. Echocardiographic PH was present in 24.2% and cor pulmonale in 28.2%. Sputum culture was positive in 28.2%, most often *Pseudomonas aeruginosa* (12.1%); *Mycobacterium tuberculosis* was detected in 6.5% (two rifampicin-resistant). Radiographic volume loss independently predicted PH (aOR 2.71, 95% CI 1.08–6.83), and a positive culture was associated with respiratory failure (aOR 11.91, 95% CI 4.15–34.22). Respiratory failure rose with HRCT extent (15.8% to 52.6%; p-trend = 0.006).

Conclusion: PTLD is a multisystem disease with near-universal ventilatory impairment, frequent bronchiectasis, PH and bacterial colonisation, and occasional recurrent tuberculosis. Structured post-treatment assessment is warranted.

Key-words: Post-tuberculosis lung disease, Bronchiectasis, Pulmonary hypertension, Spirometry, HRCT, Sputum microbiology

INTRODUCTION

Tuberculosis (TB) remains the world's leading cause of death from a single infectious agent. In 2024 an estimated 10.7 million people developed TB and 1.23 million died, and India alone accounted for roughly one quarter of global incident cases and deaths ^[1]. Each year, therefore, millions of people complete anti-tubercular

treatment (ATT) and are recorded as “cured” or “treatment completed”, yet a substantial proportion are left with permanent structural and functional damage to the lungs ^[2–4]. Modelling studies suggest that post-TB sequelae contribute almost half of the lifetime disability-adjusted life years attributable to incident TB, a burden that is invisible in programme outcome indicators ^[2]. Survivors of TB also experience an excess all-cause mortality that persists for years after microbiological cure ^[5].

Post-tuberculosis lung disease (PTLD) is now recognised as a heterogeneous entity that includes parenchymal fibrosis and volume loss, cavitation, bronchiectasis, airway stenosis, pleural disease, chronic pulmonary aspergillosis and pulmonary vascular disease ^[3,4,6]. The

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underlying mechanisms involve matrix metalloproteinase-mediated tissue destruction, granulomatous fibrosis and airway remodelling during active disease [4]. Systematic reviews and meta-analyses of spirometric data have shown that obstructive, restrictive and mixed defects are all common after TB and that impairment persists irrespective of treatment success [7–9]. PH is increasingly reported, with a pooled prevalence of 42.4% among hospitalised or symptomatic post-TB patients [10], and post-TB lung damage has been linked to recurrent exacerbations, reduced exercise capacity and death in prospective cohorts [11]. International clinical standards published in 2021 recommend that every patient completing TB treatment be assessed for residual symptoms, lung function, imaging abnormalities and comorbidity, and offered rehabilitation [6,12].

Despite the scale of the problem in India, where previous TB is the leading identified aetiology of bronchiectasis [13], most Indian studies of PTLD have described clinical and radiographic features or spirometry in isolation [14–19]. Few have evaluated HRCT morphology, cardiac involvement by echocardiography, sputum bacteriology and molecular testing for recurrent TB together in the same patients, and very few have examined the factors associated with the most serious complications. Data from eastern India, and from Odisha in particular, are scarce.

The objectives of this study were (i) to describe the clinical features, comorbidities and complications of PTLD in patients attending a tertiary care hospital in southern Odisha; (ii) to characterise the radiological (chest radiograph and HRCT), functional (spirometry) and cardiac (ECG and echocardiography) profile and examine their inter-relationships; (iii) to describe the sputum microbiological profile, including recurrent TB; and (iv) to identify factors independently associated with PH and respiratory failure.

MATERIALS AND METHODS

Study Design and Setting- A hospital-based, observational, cross-sectional study was conducted in the outpatient and inpatient services of the Department of Respiratory Medicine, M.K.C.G. Medical College and Hospital, Berhampur, Odisha, a government tertiary referral and teaching hospital serving southern Odisha,

from 1 February 2024 to 31 December 2025. The study is reported according to the STROBE guidelines [20].

Study population- Adults with a history of treated pulmonary TB who attended with respiratory symptoms were selected by systematic sampling. Participants were enrolled after written informed consent, and those requiring hospital care were admitted as clinically indicated.

Inclusion criteria- (i) Age ≥ 18 years; (ii) a history of microbiologically confirmed pulmonary TB with completion of ATT at least 6 months before enrolment; (iii) current respiratory symptoms (cough, sputum, breathlessness or haemoptysis); and (iv) willingness to provide written informed consent.

Exclusion criteria- (i) Chronic lung disease of a non-tuberculous cause (for example idiopathic pulmonary fibrosis, or chronic obstructive pulmonary disease with an onset unrelated to TB); (ii) malignancy or solid-organ transplantation; and (iii) pregnancy or lactation. People living with HIV on antiretroviral therapy were not excluded.

Sample size calculation- The sample size was estimated with the formula for a single proportion, $n = Z^2P(1 - P)/d^2$, using the expected proportion of the principal outcome from a previous study, a 90% confidence level ($Z = 1.645$) and an absolute precision (d) of 5%. This gave a minimum of 87 participants; allowing for incomplete evaluation and non-response, the target was increased, and 124 participants were enrolled.

Data collection- A structured proforma recorded demographic and clinical details, smoking and alcohol use, previous ATT courses and comorbidities. BMI was classified using WHO Asia-Pacific cut-offs [21]. Spirometry was performed according to ATS/ERS standards and classified as normal, obstructive, restrictive or mixed [22,23]. Chest radiographs were assessed for 12 abnormalities to calculate a CXR score (0–12) and laterality. HRCT findings included bronchiectasis pattern and lobar involvement; extent was graded as mild (1–2 lobes), moderate (3 lobes) or severe (4–5 lobes), with the lingula counted with the middle lobe. ECG and 2D echocardiography were performed to assess cardiac abnormalities and echocardiographic pulmonary



hypertension (PH), graded as mild, moderate or severe^[24]. Echocardiographic abnormalities were summed into a score (0–7). Early-morning sputum underwent Gram staining, bacterial culture and susceptibility testing, Ziehl–Neelsen staining for AFB, and TrueNat MTB/RIF testing. Complications, including cor pulmonale, respiratory failure, haemoptysis, pneumonia and lung abscess, were recorded and summed (0–5).

Statistical Analysis- Data were analysed using SPSS version 26.0 and Python 3 (SciPy), with figures generated using Matplotlib. Continuous variables were compared using Student's t test or Mann–Whitney U test, and Kruskal–Wallis test for more than two groups. Categorical variables were compared using χ^2 or Fisher's exact test, with Wilson 95% confidence intervals (CI). Trends were assessed using the Cochran–Armitage test. Crude ORs and PRs with 95% CI were calculated. Multivariable logistic regression was performed for echocardiographic PH and respiratory failure, with covariates selected a priori and by univariable $p < 0.20$, limited to five per model^[25]. Model fit was assessed using the likelihood-ratio test, Nagelkerke R^2 , Hosmer–Lemeshow test and AUC. Correlations were assessed using Pearson's r and Spearman's ρ ; linear regression was summarised by R^2 . Survival analysis was not applicable due to the cross-sectional design. A two-sided $p < 0.05$ was considered significant.

Ethical Approval- The study protocol was approved by the Institutional Ethics Committee, M.K.C.G. Medical College and Hospital, Berhampur. Written informed consent was obtained from all participants. The study was conducted in accordance with the Declaration of Helsinki (2013) and the ICMR National Ethical Guidelines for Biomedical and Health Research Involving Human Participants (2017). Patient confidentiality and anonymity were maintained throughout.

RESULTS

A total of 124 participants were enrolled and all completed the full evaluation (Fig. 1). The mean age was 47.85 ± 13.43 years (median 47.5, IQR 37.8–60; range 18–80), and 60 (48.4%) were aged 41–60 years. There were 72 (58.1%) males and 52 (41.9%) females. Men were significantly older than women (50.32 ± 12.72 vs 44.44 ± 13.76 years; $p = 0.016$) and were far more likely to smoke (47.2% vs 5.8%; $p < 0.001$) or use alcohol (31.9% vs 3.8%; $p < 0.001$) (Table 1). Housewives (30.6%), farmers (22.6%) and labourers (18.5%) formed the largest occupational groups. The mean BMI was 20.60 ± 2.91 kg/m² and 37 (29.8%) participants were underweight. Fifty-six (45.2%) had at least one comorbidity, most commonly diabetes mellitus (21%) and hypertension (14.5%); 18 (14.5%) had received more than one course of ATT (Table 1).

Table 1: Baseline and clinical characteristics of 124 patients with post-tuberculosis lung sequelae

Variable	n (%)	Variable	n (%)
Demographics		Symptoms	
Age (years), mean $\pm$ SD	47.85 ± 13.43	Cough	88 (71)
Age (years), median (IQR)	47.5 (37.8–60.0)	Expectoration	79 (63.7)
Age 41–60 years	60 (48.4)	Breathlessness	69 (55.6)
Male sex	72 (58.1)	Fever	50 (40.3)
Housewife	38 (30.6)	Haemoptysis	32 (25.8)
Farmer	28 (22.6)	Chest pain	14 (11.3)
Labourer	23 (18.5)	Sputum character (n = 83)	
BMI (kg/m ²), mean $\pm$ SD	20.60 ± 2.91	Mucoid	53 (63.9)
Underweight (BMI <18.5)	37 (29.8)	Mucopurulent	22 (26.5)
Risk factors and comorbidities		Purulent	8 (9.6)
Smoking	37 (29.8)	Physical signs	
Alcohol use	25 (20.2)	Crackles	98 (79)
ATT >1 course	18 (14.5)	Diminished breath sounds	90 (72.6)
Diabetes mellitus	26 (21.0)	Digital clubbing	65 (52.4)
Hypertension	18 (14.5)	Wheeze / rhonchi	37 (29.8)
Coronary artery disease	8 (6.5)	Bronchial breath sounds	12 (9.7)
Chronic kidney disease	8 (6.5)		
HIV infection	3 (2.4)		

Values are n (%) unless stated otherwise. ATT, anti-tubercular treatment; BMI, body mass index; IQR, interquartile range.

Cough (71%), expectoration (63.7%) and breathlessness (55.6%) were the commonest symptoms, followed by fever (40.3%), haemoptysis (25.8%) and chest pain (11.3%). Among the 83 participants with recorded sputum, it was mucoid in 63.9%, mucopurulent in 26.5%

and purulent in 9.6%. Crackles (79%) and diminished breath sounds (72.6%) were the predominant auscultatory signs, and digital clubbing was present in 52.4% (Table 1).

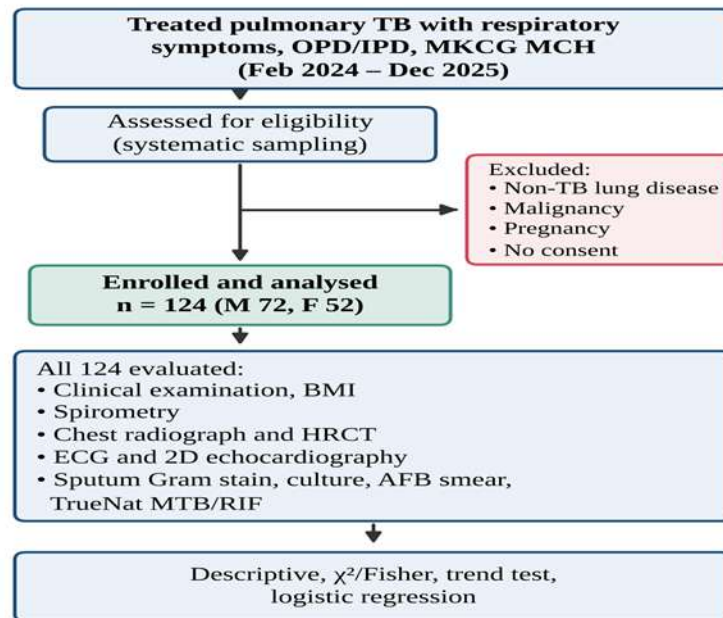


Fig. 1: Study flow diagram (STROBE).

Selection and evaluation of participants; all 124 enrolled patients completed every evaluation.

Spirometry was abnormal in 112 participants (90.3%; 95% CI 83.8–94.4): a mixed defect was the commonest pattern (44.4%), followed by restrictive (25%) and obstructive (21%) patterns. The chest radiograph was abnormal in 106 (85.5%) participants, most often showing fibrotic strands (60.5%), hyperinflation (55.6%), loss of lung volume (51.6%), ring shadows (39.5%), pleural thickening (38.7%) and calcified nodules (37.9%); cavities were seen in 16.1%. Disease was bilateral in 33.9%. HRCT demonstrated bronchiectasis in 73 (58.9%) participants, predominantly traction (25%) and cystic (23.4%) types; cylindrical bronchiectasis was seen once and varicose bronchiectasis not at all. The upper lobes were most often involved (53.2%), and the median number of lobes involved was 2 (IQR 1–3) (Table 2). Among the 105 participants with lobar disease, extent was mild in 59%, moderate in 22.9% and severe in 18.1%.

On ECG, P pulmonale (32.3%) and sinus tachycardia (30.6%) were the most frequent abnormalities, and right ventricular hypertrophy was seen in 14.5%. Echocardiography was abnormal in 53 (42.7%) participants: PH and concentric left ventricular hypertrophy were each present in 30 (24.2%), tricuspid regurgitation in 22.6% and reduced left ventricular ejection fraction in 21.8% (Table 3). PH was mild in 16 (53.3%), moderate in 10 (33.3%) and severe in 4 (13.3%). On sputum Gram staining, Gram-positive cocci in pairs or chains (60.5%) and Gram-negative bacilli (45.2%) predominated, while no organism was seen in 15.3%. Aerobic culture yielded a pathogen in only 35 (28.2%) participants; *P. aeruginosa* was the commonest isolate (12.1%), followed by *Klebsiella* spp. (4.8%), *Escherichia coli* (4%) and *Streptococcus* spp. (4%). AFB smear was positive in 3 (2.4%) participants, whereas TrueNat detected *M. tuberculosis* in 8 (6.5%; 95% CI 3.3–12.2), of whom 2 had rifampicin resistance (Table 3).

**Table 2:** Spirometric and radiological findings (n = 124)

Variable	n (%)	Variable	n (%)
Spirometry		Laterality	
Mixed	55 (44.4)	Bilateral	42 (33.9)
Restrictive	31 (25)	Right	36 (29)
Obstructive	26 (21)	Left	27 (21.8)
Normal	12 (9.7)	HRCT bronchiectasis	
Chest radiograph		Any bronchiectasis	73 (58.9)
Any abnormality	106 (85.5)	Traction	31 (25)
Fibrotic strands	75 (60.5)	Cystic	29 (23.4)
Hyperinflation	69 (55.6)	Mixed	12 (9.7)
Loss of lung volume	64 (51.6)	Cylindrical	1 (0.8)
Ring shadows	49 (39.5)	HRCT lobar involvement	
Pleural thickening	48 (38.7)	Upper lobe	66 (53.2)
Calcified nodules	47 (37.9)	Middle lobe / lingula	33 (26.6)
Tram-track shadows	37 (29.8)	Lower lobe	50 (40.3)
Cardiomegaly	35 (28.2)	Radiological extent	
Reticulation	29 (23.4)	Mild (1–2 lobes)	62 (50)
Cavity	20 (16.1)	Moderate (3 lobes)	24 (19.4)
Infiltration	13 (10.5)	Severe (4–5 lobes)	19 (15.3)
Consolidation	10 (8.1)		

Values are n (%). Radiological extent is shown for all 124 patients; 19 had no lobar involvement. HRCT, high-resolution computed tomography.

Table 3: Cardiac and microbiological findings (n = 124)

Variable	n (%)	Variable	n (%)
Electrocardiogram		Sputum Gram stain	
P pulmonale	40 (32.3)	GPC in pairs/chains	75 (60.5)
Sinus tachycardia	38 (30.6)	Gram-negative bacilli	56 (45.2)
LVH (voltage criteria)	34 (27.4)	GPC in clusters	18 (14.5)
Low-voltage complexes	22 (17.7)	Gram-positive bacilli	17 (13.7)
RVH	18 (14.5)	No organism seen	19 (15.3)
2D echocardiography		Sputum culture	
Any abnormality	53 (42.7)	Pathogen isolated	35 (28.2)
Pulmonary hypertension	30 (24.2)	<i>Pseudomonas aeruginosa</i>	15 (12.1)
Mild / moderate / severe	16 / 10 / 4	<i>Klebsiella</i> spp.	6 (4.8)
Concentric LVH	30 (24.2)	<i>Escherichia coli</i>	5 (4)
Tricuspid regurgitation	28 (22.6)	<i>Streptococcus</i> spp.	5 (4)
Reduced LVEF	27 (21.8)	Others [†]	4 (3.2)
Global LV hypokinesia	23 (18.5)	Mycobacteriology	
Dilated RV	20 (16.1)	AFB smear positive	3 (2.4)
Dilated RA	15 (12.1)	TrueNat: MTB, RIF sensitive	6 (4.8)
		TrueNat: MTB, RIF resistant	2 (1.6)

Values are n (%). [†]*Acinetobacter* spp. (n = 3) and *Staphylococcus aureus* (n = 1). AFB, acid-fast bacilli; GPC, Gram-positive cocci; LVEF, left ventricular ejection fraction; LVH/RVH, left/right ventricular hypertrophy; MTB, *Mycobacterium tuberculosis*; RIF, rifampicin.

Cor pulmonale (28.2%) was the most frequent complication, followed by respiratory failure (25.0%), haemoptysis (23.4%), pneumonia (17.7%) and lung abscess (7.3%); participants had a mean of 1.02 ± 1.02 complications. The prevalence of respiratory failure increased progressively with radiological extent, from 15.8% in participants without lobar involvement to 52.6% in those with severe involvement (p -trend =

0.006), as did pneumonia (5.3% to 31.6%; p -trend = 0.008) and the mean complication count (p = 0.049). Cor pulmonale, haemoptysis, lung abscess and PH showed no significant trend (Table 4). Because this was a cross-sectional study, longitudinal outcomes such as recovery, improvement, deterioration or mortality were not recorded, and time-to-event (Kaplan–Meier) analysis was therefore not applicable.

Table 4: Complications according to radiological extent on HRCT

Complication	Total (n = 124)	None (n = 19)	Mild (n = 62)	Moderate (n = 24)	Severe (n = 19)	p-trend
Cor pulmonale	35 (28.2)	2 (10.5)	21 (33.9)	6 (25)	6 (31.6)	0.400
Respiratory failure	31 (25.0)	3 (15.8)	12 (19.4)	6 (25)	10 (52.6)	0.006
Haemoptysis	29 (23.4)	4 (21.1)	18 (29.0)	6 (25)	1 (5.3)	0.161
Pneumonia	22 (17.7)	1 (5.3)	8 (12.9)	7 (29.2)	6 (31.6)	0.008
Lung abscess	9 (7.3)	0 (0)	6 (9.7)	2 (8.3)	1 (5.3)	0.740
Pulmonary hypertension (echo)	30 (24.2)	1 (5.3)	17 (27.4)	7 (29.2)	5 (26.3)	0.200
Complications per patient, mean $\pm$ SD	1.02 $\pm$ 1.02	0.53 $\pm$ 0.96	1.05 $\pm$ 1.03	1.12 $\pm$ 0.85	1.26 $\pm$ 1.15	0.049 ^k

Values are n (%). Mild, 1–2 lobes; moderate, 3 lobes; severe, 4–5 lobes. p -trend, Cochran–Armitage test; ^k Kruskal–Wallis test.

Of the 112 participants with abnormal spirometry, 94 (83.9%) had an abnormal chest radiograph and 18 had a normal radiograph; all 12 participants with normal spirometry had radiographic abnormalities. This association was not significant (χ^2 = 2.256, p = 0.133; Fisher exact p = 0.211). Spirometric abnormality was likewise unrelated to echocardiographic abnormality (χ^2 = 0.286, p = 0.593).

On univariable analysis, PH was associated with age ≥ 50 years (OR 2.55, 95% CI 1.09–5.95; p = 0.028) and diabetes mellitus (OR 3.05, 95% CI 1.21–7.69; p = 0.015). After adjustment, loss of lung volume on the chest

radiograph was the only independent predictor (aOR 2.71, 95% CI 1.08–6.83; p = 0.034). The model was significant (likelihood-ratio χ^2 = 13.64, p = 0.018) but had modest discrimination (AUC 0.685; Nagelkerke R^2 0.156) and borderline calibration (Hosmer–Lemeshow p = 0.048). Respiratory failure was associated on univariable analysis with male sex, diabetes, involvement of ≥ 3 lobes and a positive sputum culture; in the adjusted model only a positive sputum culture remained significant (aOR 11.91, 95% CI 4.15–34.22; p < 0.001), and the model discriminated well (AUC 0.856; Nagelkerke R^2 0.393; Hosmer–Lemeshow p = 0.543) (Fig. 2).

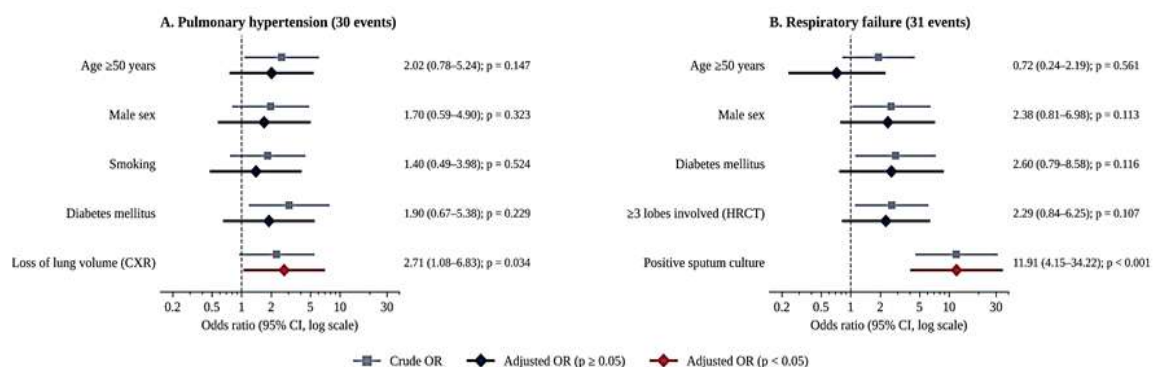


Fig. 2: Factors associated with pulmonary hypertension and respiratory failure.

Crude (grey) and adjusted (diamonds) odds ratios with 95% CI from multivariable logistic regression; red indicates p < 0.05. Model A: Nagelkerke R^2 0.16, AUC 0.68; Model B: Nagelkerke R^2 0.39, AUC 0.86.

The CXR abnormality score correlated weakly but significantly with the number of complications ($r = 0.212$, $R^2 = 0.045$, $p = 0.018$), and age correlated with the echocardiographic abnormality score ($r = 0.253$, $R^2 = 0.064$, $p = 0.005$; Spearman $p = 0.326$, $p < 0.001$). The CXR score correlated moderately with the number of lobes involved on HRCT ($p = 0.44$, $p < 0.001$), whereas symptom count showed little relationship with any imaging or cardiac index.

DISCUSSION

This study highlights five key findings in symptomatic adults with PTLD in southern Odisha: abnormal spirometry in 90%, predominantly mixed defects; HRCT-detected bronchiectasis in nearly 60%, mainly traction and cystic; echocardiographic PH in one-quarter and cor pulmonale in over one-quarter, with radiographic volume loss independently predicting PH; frequent bacterial colonisation, with positive sputum culture associated with respiratory failure; and molecular TB detection in 6.5%, including rifampicin resistance, often missed by smear microscopy. The age and sex distribution of our cohort, with a peak in the fifth decade and male predominance, mirrors that of other Indian series [14–19]. Pandey *et al.* reported 45% of patients aged 41–60 years [18], comparable with 48.4% in our study, whereas Santra *et al.* found a peak at 50–59 years in patients with post-TB obstructive airway disease [17]. The male predominance observed here and in most Indian studies may reflect the higher incidence of TB among men. Smoking and alcohol use, which were strongly concentrated among men in our cohort, may have

further contributed. Under-presentation of women to tertiary care services may also explain this disparity. The fact that housewives were the largest occupational group is noteworthy. Biomass-fuel exposure, a recognised risk factor for TB and chronic airway disease [26], may play a role, although exposure was not formally quantified in this study.

Our symptom profile is similar to that reported by Thoker *et al.* [15] and Gupta *et al.* [16], although cough (71.0%) and expectoration (63.7%) were more frequent than in the series of Naik *et al.* (54.1% and 34.3%) [14], probably because all our participants were symptomatic and some were inpatients. The proportion with underweight BMI (29.8%) is similar to that reported by Thoker *et al.* (33.9%) [15] and underlines the nutritional dimension of PTLD.

The spirometric findings are compared with earlier Indian studies in Table 5. A mixed defect was the commonest pattern in our study, as in the study by Gupta *et al.* [16], whereas others reported a predominance of restriction [18] or obstruction [19]. The proportion with normal spirometry varied widely, from 9% to 40% [16,18,19,27]. These differences are likely to reflect variation in case selection (symptomatic versus all treated patients), the time elapsed since treatment, the reference equations used and the definitions applied. The proportion with abnormal lung function in our study (90.3%) is higher than pooled estimates from unselected post-TB populations [8,9], which is consistent with the selection of symptomatic, hospital-attending patients.

Table 5: Comparison of spirometric patterns with previous Indian studies of post-tuberculosis sequelae

Study (reference)	Year	n	Mixed (%)	Restrictive (%)	Obstructive (%)	Normal (%)
Gupta <i>et al.</i> [16]	2022	—	47.5	30.0	13.5	9.0
Pandey <i>et al.</i> [18]	2020	—	23.0	56.0	3.0	18.0
Chakravarti <i>et al.</i> [19]	2023	—	1.0	6.0	67.0	26.0
Paritala <i>et al.</i> [27]	2024	—	29.8	15.6	14.3	40.3
Present study	2026	124	44.4	25.0	21.0	9.7

Values for previous studies are as reported in the respective publications; “—” indicates sample size not restated here. Differences in case mix, timing after treatment and spirometric definitions limit direct comparison.

Radiographically, fibrotic strands were the commonest abnormality (60.5%), similar to the 65.6% reported by Naik *et al.* [14], and the frequency of cavitation (16.1% vs 15.1%) was almost identical. Our use of HRCT revealed

that traction and cystic bronchiectasis together accounted for more than four-fifths of the bronchiectasis observed. This contrasts with idiopathic and post-infectious bronchiectasis, in which the cylindrical form

predominates, and is consistent with the fibrotic, destructive mechanism of post-TB airway damage^[3,4]. It also supports registry data identifying previous TB as the leading cause of bronchiectasis in India^[13]. The upper-lobe predominance we observed is in keeping with the typical distribution of post-primary TB.

Echocardiographic PH in 24.2% of our participants lies between the 6.3% reported in non-healthcare-seeking post-TB outpatients and the 42.4% reported in hospitalised or symptomatic patients in a recent meta-analysis^[10]. The independent association of PH with radiographic volume loss is biologically plausible: loss of the pulmonary vascular bed, hypoxic vasoconstriction and fibrotic distortion of the vasculature all increase pulmonary vascular resistance^[10,24]. The crude associations of PH with older age and diabetes were attenuated after adjustment, suggesting that they act partly through the extent of parenchymal damage or through left-heart disease. This is supported by the high prevalence of concentric LVH (24.2%) and reduced LVEF (21.8%), which indicates that a proportion of PH in this population may be post-capillary. Earlier Indian studies of PTLD rarely included echocardiography, so our data add to the limited evidence on cardiac involvement in this setting.

Gram-positive cocci and Gram-negative bacilli predominated on Gram staining, but culture yield was low (28.2%), possibly reflecting antibiotic use before referral. *P. aeruginosa* was the leading isolate, as in bronchiectasis cohorts more generally, in which *Pseudomonas* colonisation is associated with a three-fold higher risk of death and more frequent exacerbations and hospital admissions^[28]. The strong association between a positive culture and respiratory failure in our study should be interpreted cautiously because of the cross-sectional design. Sicker, hospitalised patients are more likely both to have respiratory failure and to undergo culture, and infection may be a consequence of severe disease as well as a cause of it. Nevertheless, the association supports routine sputum culture and targeted antimicrobial therapy in patients with post-TB bronchiectasis who present with acute deterioration. Fungal culture results were not available for analysis, although chronic pulmonary aspergillosis is a recognised and frequently missed sequel of TB^[29].

The detection of *M. tuberculosis* by TrueNat in 6.5% of participants, against 2.4% positivity on smear

microscopy, has important programmatic implications. Symptoms of PTLD and of recurrent TB overlap, and residual cavities and bronchiectasis provide a niche for relapse or reinfection. Rapid molecular testing should therefore be performed in every symptomatic patient with previous TB, bearing in mind that nucleic acid amplification tests can occasionally detect non-viable bacilli in previously treated patients and that results need clinical and radiological correlation^[6,12].

Spirometric abnormality was not significantly associated with either radiographic or echocardiographic abnormality. This lack of association should not be interpreted as evidence that the investigations are unrelated. Almost all participants had abnormal spirometry, leaving very few in the comparison group, so the analyses had little statistical power, and all 12 participants with normal spirometry had radiographic abnormalities. The practical message is that the investigations provide complementary rather than interchangeable information: a normal radiograph does not exclude functional impairment, and normal spirometry does not exclude structural disease. Spirometry also cannot measure residual volume, total lung capacity or gas transfer, and plethysmography, diffusing capacity (DL_{CO}) and oscillometry might have revealed further abnormalities.

Our findings support the recommendation that completion of ATT should mark a transition to structured post-TB care rather than discharge from follow-up^[6,12,30]. In a high-burden setting such as ours, a pragmatic pathway at the end of treatment would include assessment of symptoms and nutritional status, spirometry, chest radiography (with HRCT when bronchiectasis or complications are suspected), and screening for PH with ECG and echocardiography in patients with dyspnoea, volume loss or extensive disease. Molecular testing for TB and sputum culture should be performed when symptoms recur. Smoking cessation, glycaemic control, vaccination, airway clearance, pulmonary rehabilitation, long-term oxygen therapy where indicated and nutritional support are interventions that can be delivered within existing programme structures^[6,12]. Integration of post-TB care into India's National Tuberculosis Elimination Programme (NTEP) would make these services widely accessible.

CONCLUSIONS

Post-tuberculosis lung sequelae in symptomatic patients attending a tertiary hospital in eastern India form a multisystem disease characterised by near-universal ventilatory impairment, predominantly mixed; fibrotic and bronchiectatic structural damage dominated by traction and cystic forms; frequent pulmonary hypertension and cor pulmonale; and common bacterial colonisation, particularly with *P. aeruginosa*. Radiographic volume loss independently predicted pulmonary hypertension, culture-positive sputum was strongly associated with respiratory failure, and the extent of disease on HRCT tracked the burden of complications. One in sixteen patients had microbiological evidence of TB, including drug-resistant disease. Comprehensive post-TB assessment comprising spirometry, imaging, echocardiography and sputum microbiology with molecular TB testing, linked to rehabilitation and long-term follow-up, should become a standard component of TB care in India.

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