ORIGINAL ARTICLE

Cross-sectional study of tuberculosis infection among household contacts of patients with pulmonary tuberculosis

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ABSTRACT

Background: Tuberculosis (TB) remains a major public health concern, particularly among household contacts of pulmonary TB patients, where transmission risk is high. This study assessed the prevalence of positive TB screening tests and identified key demographic, behavioral, and environmental risk factors associated with infection.

Material and Methods: The cross-sectional analytical study was done at the Department of Medicine, Mardan Medical Complex, Mardan, from 1st October 2023 to 30th March 2024 including 286 household contacts of confirmed pulmonary TB cases. Participants underwent Tuberculin Skin Test (TST), Interferon Gamma Release Assay (IGRA), chest X-ray, sputum smear microscopy, and GeneXpert MTB/RIF testing. Logistic regression was performed to identify independent predictors of TB infection, adjusting for potential confounders.

Results: Positivity rates were 31.5% for TST, 29.7% for IGRA, 17.5% for chest X-ray suggestive of TB, 10.5% for sputum smear microscopy, and 9.8% for GeneXpert. Independent predictors included older age (≥35 years), absence of BCG vaccination, HIV positivity, current smoking, close sleeping proximity to the index patient, and poor household ventilation (all $p < 0.05$). Diabetes showed borderline significance, while sex and former smoking were not significant.

Conclusion: TB infection among household contacts is influenced by a combination of biological, behavioral, and environmental factors. Targeted interventions, including vaccination, smoking cessation, HIV care, and improvements in household ventilation, could substantially reduce transmission risk.

Keywords: Tuberculosis, Household contacts, BCG vaccination, HIV, Smoking, Ventilation.

BACKGROUND

Tuberculosis (TB) continues to be one of the most serious global health challenges, ranking among the top 13 causes of death worldwide.[1] It is currently the second leading cause of mortality from a single infectious agent, coming only after COVID-19.[2] In 2019, almost 10 million people developed the disease and about 1.2 million died from it, despite the availability of effective treatment.[3] Despite global control efforts, more than 30% of new TB cases remain either undiagnosed or unreported annually, contributing significantly to the ongoing burden. TB disproportionately affects low- and middle-income countries, where poverty, malnutrition, and limited access to healthcare facilitate disease transmission.[4] The disease is caused by Mycobacterium tuberculosis and most often presents as pulmonary tuberculosis (PTB). Pulmonary TB affects the lungs and is the main driver of transmission, spreading when infectious droplets are released through coughing, sneezing, or even speaking. People living with untreated smear-positive TB patients are especially at risk of contracting the disease.[5, 6]

At the regional level, Africa bears a substantial portion of the global TB burden, contributing approximately one-quarter of all reported cases in 2019.[7] The region has relied heavily on passive case detection, whereby patients seek care once symptoms become severe. While this approach identifies some cases, it frequently results in delayed diagnosis and sustained community transmission. Data from African contact tracing studies indicate that household contacts (HHC) of TB patients represent a critical high-risk group, with bacteriologically confirmed TB reported in 1.2%, latent TB infection in over half of contacts, and multidrug-resistant (MDR) or extensively drug-resistant (XDR) TB detected in 3.4% of cases.[8, 9] These findings highlight the potential of systematic contact

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investigation to uncover hidden cases and prevent further spread.

Pakistan, classified among the high TB burden countries, continues to face major challenges in TB control. The country reports nearly 570,000 new TB cases annually, yet a significant proportion remain undiagnosed or untreated.[10] Household contacts of PTB patients represent a particularly vulnerable group due to their prolonged exposure, yet preventive treatment and structured contact tracing in Pakistan remain under-implemented, falling short of the End TB Strategy targets set for 2020. The WHO strongly advocates for active case detection and comprehensive contact investigation, which include clinical screening, chest radiography, sputum microbiological testing, and latent TB evaluation. These interventions are crucial for early identification of both active and latent TB, enabling timely treatment, breaking chains of transmission, and reducing morbidity and mortality.[11]

Despite international recommendations, limited implementation of systematic contact tracing and preventive therapy persists in low-resource settings such as Pakistan. Socio-demographic factors, clinical characteristics of the index patient, and environmental conditions within households all play critical roles in shaping transmission risk, yet remain underexplored in local contexts. This study, therefore, aims to identify socio-demographic, clinical, and environmental factors associated with TB infection among household contacts of pulmonary TB patients. Findings from this work are expected to provide evidence-based insights that can guide targeted preventive interventions, strengthen active case detection, and support Pakistan's contribution to achieving the global End TB goals.

MATERIAL AND METHODS

This cross-sectional analytical study took place at the Department of Medicine, Mardan Medical Complex, Mardan, from 1st October 2023 to 30th March 2024, having received approval from the Institutional Review Board (IRB) under reference number 815/BKMC dated 4th September 2023. To establish our study parameters, an extensive review of existing literature was performed. From this analysis, we determined a sample size of 286 participants utilizing the World Health Organization (WHO) sample size calculator. This determination was based on a 5% margin of error, a 95% confidence level, and 20-30% prevalence of tuberculosis infection among household contacts based on previous studies.[12] A non-probability consecutive method of sampling was used for the sampling process. The study population comprised household contacts of index cases diagnosed with sputum smear-positive pulmonary TB. A household contact was defined as any individual residing in the same household as the index patient for at least three months prior to the diagnosis.

Inclusion criteria is;

- Individuals of any age living in the same household as the index TB case.
- Willingness to participate and provide informed consent (for minors, parental/guardian consent was obtained).

Exclusion criteria is;

- Contacts currently on anti-TB treatment.
- Individuals with incomplete demographic or clinical data.

Ethical permission was secured from the Institutional Review Board/Ethics Committee. Informed permission in writing was acquired from all subjects. Confidentiality was upheld, and participants who tested positive for TB were promptly referred for treatment in accordance with national TB control protocols.

Data were gathered through a systematic methodology that included interviews, clinical assessments, and laboratory analyses. A validated questionnaire was distributed to each participant to collect socio-demographic data, encompassing age, gender, educational attainment, occupation, and residence status. The clinical history was recorded, emphasising prior tuberculosis exposure, the existence of cough or other tuberculosis symptoms, BCG vaccination status (confirmed via scar examination), smoking history, HIV status, and comorbidities including diabetes. The questionnaire was administered via in-person interviews performed in the local language by qualified field investigators.

Subsequent to the interview, each participant was subjected to a series of diagnostic screening tests to identify TB infection. The Tuberculin Skin Test (TST) was conducted via intradermal injection of 0.1 mL of pure protein derivative (PPD) into the forearm, with findings assessed 48–72 hours later; an induration of ≥10 mm was deemed positive. An Interferon-Gamma Release Assay (IGRA) was conducted following the manufacturer's instructions, with results exceeding the specified threshold interpreted as positive. Participants underwent a chest X-ray, which was evaluated by a

certified radiologist for anomalies indicative of tuberculosis.

Sputum samples were obtained for microscopy and GeneXpert MTB/RIF testing from people exhibiting respiratory symptoms or abnormal chest X-ray results. Sputum smear microscopy was conducted utilising Ziehl–Neelsen staining to identify acid-fast bacilli, whereas the GeneXpert assay identified Mycobacterium tuberculosis DNA and evaluated rifampicin resistance. The integration of questionnaire data, clinical assessment, and laboratory findings facilitated thorough screening and precise categorisation of TB infection status among participants.

Data were entered into SPSS version 26.00 for analysis. Descriptive statistics were used to summarize demographic, behavioral, and clinical characteristics. Bivariate logistic regression was performed to assess crude associations between variables and TB infection. Variables with $p < 0.20$ were entered into a multivariable logistic regression model to determine adjusted odds ratios (AORs) with 95% confidence intervals (CIs). A p-value < 0.05 was considered statistically significant.

RESULTS

The study examined 286 household contacts of pulmonary tuberculosis patients, with a mean age of 32.0 ± 16.2 years. The majority were aged 25-34 (24.5%), followed by 15-24 (21.0%) and under 15 (14.0%). Most participants were urban (62.9%) and male (55.9%). Educational attainment varied: 31.5% secondary, 28.0% primary, 23.1% higher, and 17.5% no formal schooling. The majority (69.9%) were never smokers, and 76.9% had BCG scars. Only 2.8% were HIV-positive, and 2.8% were untested. Children (31.5%), spouses (24.5%), and other relatives (23.1%) dominated household interaction. Economically, 42.0% were low-income, 38.5% middle-income, and 19.6% high-income. Diabetes affected 11.9% of subjects. The occupations were 35.0% jobless or doing domestic work, 28.0% manual, 21.0% nonmanual, and 16.1% students.

The majority (93.7%) of the 286 household contacts had never had tuberculosis, whereas 6.3% had. Most participants (76.9%) had undergone BCG, and HIV positive was 2.8%, with same numbers untested. 11.9% of contacts had diabetes. Among lifestyle characteristics, 69.9% were never smokers, 10.5% were former smokers, 19.6% were current smokers, and 15.7% consumed alcohol. Nutritional status examination showed that 54.2% had a normal BMI, 22.7% were underweight, 15.7% overweight, and 7.3% obese.

Household contacts examined had 31.5% positive Tuberculin Skin Test (TST) and 29.7% positive Interferon Gamma Release Assay (IGRA). 17.5% had tuberculosis-related chest X-rays. In 10.5% of contacts, sputum smear microscopy found acid-fast bacilli, and 9.8% had Mycobacterium tuberculosis.

The regression analysis revealed multiple significant predictors of tuberculosis infection in home contacts of pulmonary TB patients. Older age groups, especially 35-44 (AOR = 1.95, p = 0.043), 45-54 (AOR = 2.10, p = 0.035), and ≥55 (AOR = 2.25, p = 0.037), showed greater infection risks than children under 15. Lack of BCG vaccination significantly raised risk (AOR = 2.80, $p < 0.001$), as did HIV positivity (AOR = 3.45, p = 0.031). Current smokers showed higher risk (AOR = 2.05, p = 0.020), while close sleeping proximity to the TB patient (AOR = 3.10, $p < 0.001$) and inadequate household ventilation (AOR = 2.45, $p < 0.001$) were significant environmental risk factors. Diabetes was a borderline predictor (AOR = 1.95, p = 0.065), while sex and past smoking were not. In conclusion, older age, lack of BCG vaccination, HIV infection, smoking, close closeness, and poor ventilation significantly enhance household TB transmission risk.

Table-I: Demographic characteristics of household contacts (n = 286)

Variable	Category	Frequency	%
Age (years)	Mean ± SD	32.0 ± 16.2	—
Age group	<15	40	14.0%
	15–24	60	21.0%
	25–34	70	24.5%
	35–44	50	17.5%
	45–54	35	12.2%
	≥55	31	10.8%
Sex	Male	160	55.9%
	Female	126	44.1%

Residence	Urban	180	62.9%
	Rural	106	37.1%
Education	No formal education	50	17.5%
	Primary	80	28.0%
	Secondary	90	31.5%
	Higher (college/university)	66	23.1%
Smoking status	Never smoker	200	69.9%
	Former smoker	30	10.5%
	Current smoker	56	19.6%
BCG scar	Present	220	76.9%
	Absent	66	23.1%
HIV status	Negative	270	94.4%
	Positive	8	2.8%
	Unknown / not tested	8	2.8%
Type of household contact	Spouse	70	24.5%
	Child	90	31.5%
	Parent	20	7.0%
	Sibling	40	14.0%
	Other (relative/other)	66	23.1%
Socioeconomic status	Low	120	42.0%
	Middle	110	38.5%
	High	56	19.6%
Diabetes	Yes	34	11.9%
	No	252	88.1%
Occupation	Unemployed / Household	100	35.0%
	Employed — manual	80	28.0%
	Employed — nonmanual	60	21.0%
	Student	46	16.1%

Table-II: Clinical characteristics and risk factors among household contacts (n = 286)

Variable	Category	n	%
History of previous TB	Yes	18	6.3%
	No	268	93.7%
BCG vaccination	Yes	220	76.9%
	No	66	23.1%
HIV status	Positive	8	2.8%
	Negative	270	94.4%
	Unknown	8	2.8%
Diabetes mellitus	Yes	34	11.9%
	No	252	88.1%
Smoking	Never	200	69.9%
	Former	30	10.5%
	Current	56	19.6%
Alcohol consumption	Yes	45	15.7%
	No	241	84.3%
Nutritional status (BMI)	Underweight (<18.5)	65	22.7%
	Normal (18.5–24.9)	155	54.2%
	Overweight (25–29.9)	45	15.7%
	Obese (≥30)	21	7.3%

\Table-III: Tuberculosis screening results among household contacts (n = 286)

Screening Test	Positive	%	Negative	%
Tuberculin Skin Test (TST)	90	31.5%	196	68.5%
Interferon Gamma Release Assay (IGRA)	85	29.7%	201	70.3%
Chest X-ray suggestive of TB	50	17.5%	236	82.5%
Sputum smear microscopy positive	30	10.5%	256	89.5%
GeneXpert MTB/RIF positive	28	9.8%	258	90.2%

Table-IV: Multivariable logistic regression analysis of factors associated with tuberculosis infection among household contacts (n = 286)

Variable	Category	Adjusted OR	95% CI	p-value
Age group	<15	1.00	Reference	—
	15–24	1.35	0.72–2.54	0.34
	25–34	1.68	0.89–3.16	0.11
	35–44	1.95	1.02–3.74	**0.043**
	45–54	2.10	1.05–4.20	**0.035**
	≥55	2.25	1.05–4.83	**0.037**
Sex	Female	1.00	Reference	—
	Male	1.42	0.87–2.33	0.16
BCG vaccination	Yes	1.00	Reference	—
	No	2.80	1.58–4.95	**<0.001**
HIV status	Negative	1.00	Reference	—
	Positive	3.45	1.12–10.64	**0.031**
Diabetes	No	1.00	Reference	—
	Yes	1.95	0.96–3.95	0.065
Smoking	Never	1.00	Reference	—
	Former	1.50	0.65–3.45	0.34
	Current	2.05	1.12–3.76	**0.020**
Close sleeping proximity (same room)	No	1.00	Reference	—
	Yes	3.10	1.85–5.18	**<0.001**
Ventilation in household	Adequate	1.00	Reference	—
	Poor	2.45	1.48–4.04	**<0.001**

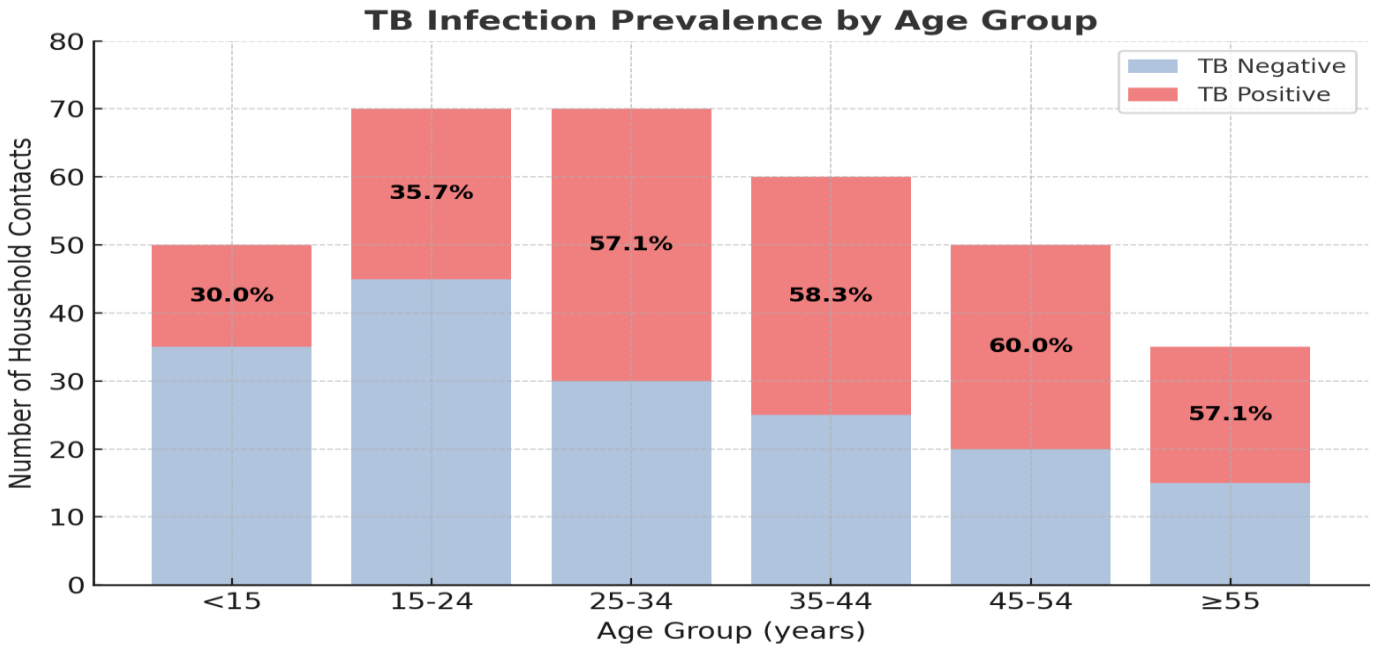

Figure-I: Stacked bar chart showing TB infection prevalence by age group among household contacts.

DISCUSSION

This study investigated tuberculosis (TB) infection among household contacts (HHCs) of pulmonary TB patients, revealing that 31.5% were positive on tuberculin skin test (TST), 29.7% on interferon gamma release assay (IGRA), and 9.8% on GeneXpert MTB/RIF. Several socio-demographic, clinical, and environmental predictors were identified, including older age, lack of BCG vaccination, HIV positivity, smoking, close sleeping proximity, and inadequate household ventilation. These findings highlight the importance of contact investigation as a key strategy to interrupt transmission within households.

Our prevalence of latent TB infection (LTBI), reflected by TST and IGRA positivity, aligns with global systematic reviews. Fox *et al.*[13] reported a pooled LTBI prevalence of 51.5% and active TB prevalence of 3.1% among HHCs in low- and middle-income countries,

while bacteriologically confirmed TB was detected in 1.2% of contacts. Similarly, Krishnamoorthy *et al*.[14] found that nearly half of household contacts in India had LTBI, supporting our findings of substantial hidden infection reservoirs.

Age emerged as a significant predictor, with those 25-34 years showing higher risk of infection. This is consistent with Lu *et al*.[15] in Japan, who demonstrated that older adults had significantly higher infection rates due to cumulative exposure and age-related immune decline. However, our results contrast with some African studies where children <15 years were disproportionately affected due to closer daily interaction with infectious adults.[16]

BCG vaccination was protective in our cohort, with unvaccinated individuals almost three times more likely to acquire infection. This corroborates findings from a systematic review that confirmed partial but sustained protection of BCG against TB infection in high-risk populations.[17] Despite this, other studies argue that the protective effect of BCG wanes with age, suggesting that our findings may be influenced by relatively younger participants.[18]

HIV infection significantly increased the risk of TB, consistent with Velen *et al*.[19] study who reported higher rates of LTBI and active TB among HIV-positive contacts in high-burden African settings.

Interestingly, diabetes in our cohort showed only borderline association with TB, whereas other studies such as Yang *et al*.[16] in Korea have established diabetes as a strong risk factor for both LTBI and progression to active TB. This discrepancy may be due to the relatively younger age and smaller diabetic subgroup in our study population.

Lifestyle and environmental risk factors also contributed to infection. Current smoking was associated with over twice the risk, supporting previous evidence that smoking impairs mucosal immunity and doubles TB risk. Inadequate ventilation and close sleeping proximity to the index case were among the strongest predictors, echoing Praveen *et al*.,[20] who demonstrated that poorly ventilated households had significantly higher transmission rates.

The clinical implications of these findings are significant. High LTBI prevalence underscores the need for routine screening of HHCs using TST/IGRA, chest radiography, and microbiological testing, particularly in high-burden countries like Pakistan. Preventive therapy remains underutilized despite WHO's recommendation for systematic screening and treatment of contacts. Strengthening household-level interventions, including ventilation improvements, smoking cessation, and targeted prophylaxis for high-risk groups (unvaccinated, HIV-positive, elderly), is essential to reduce transmission.

LIMITATION OF THE STUDY:

The main limitation of this study is its single-center design with a relatively small sample size, which may restrict the generalizability of findings to broader populations. Additionally, potential confounding factors such as nutritional status, co-morbid conditions, and concurrent medications were not fully explored. A larger multicenter study would provide stronger evidence and more representative outcomes.

CONCLUSION

This study emphasizes that tuberculosis infection among household contacts is highly affected by age, absence of BCG vaccination, HIV positivity, active smoking, inadequate household ventilation, and close sleeping proximity to TB patients. Targeted interventions aimed at enhancing vaccine coverage, improving living circumstances, promoting smoking cessation, and facilitating early HIV care are crucial for mitigating TB transmission in high-risk households.

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CONFLICT OF INTEREST

None

GRANT SUPPORT & FINANCIAL DISCLOSURE

Declared none

AUTHOR CONTRIBUTION

Muhammad Sohrab Khan: Substantial contribution to study design, data collection, manuscript drafting, final approval, accountable for all aspects of publication.

Fazli Rabbi: Acquisition of data, analysis and interpretation of data, final approval, accountable for all aspects of publication.

Intikhab Alam Khan: Data interpretation, result writing, final approval, accountable for all aspects of publication

Uzair Ali Khan: Critical review, final approval, accountable for all aspects of publication.

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