

The Influencing Factors Of Effective Tuberculosis Prevention and Control among University Students in Heilongjiang Province, China: A Fuzzy-Set Qualitative Comparative Analysis

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Abstract

Background

Tuberculosis (TB) prevention and control in universities represents a critical yet challenging aspect of China's public health strategy. The effectiveness of TB prevention and control in these environments is not dictated by isolated factors; rather, it is shaped by the intricate interplay between individual psychology and the institutional environment. Moving beyond traditional linear analyses, this study employs a configurational approach through fuzzy-set Qualitative Comparative Analysis to reveal the multiple driving paths that contribute to effective TB prevention and control, thereby informing the development of targeted strategies.

Methods

This cross-sectional study focused on students from five universities in Heilongjiang Province, China, during November and December 2024. Data on demographics, psychological and institutional factors, as well as knowledge, attitudes, and practices (KAP) regarding tuberculosis prevention were collected. Descriptive statistics were used to summarize the KAP status, and fuzzy-set Qualitative Comparative Analysis was employed to identify the core antecedent conditions and driving paths influencing the effectiveness of TB prevention and control.

Results

Analysis revealed that both individual psychological factors and institutional environmental factors were pivotal for effective tuberculosis prevention and control. The results of fuzzy-set qualitative comparative analysis identified five distinct driving paths (solution consistency = 0.880), each exhibiting a consistency exceeding 0.8. This indicated the presence of multiple robust combinations of conditions that contributed to high efficacy in TB prevention and control within university settings.

Conclusions

The effectiveness of tuberculosis prevention and control in universities results from the complex interplay of multiple concurrent factors rather than the dominance of any single element. This study identifies two core pathways—individual psychologically-driven and institutionally-oriented—providing a configurational theoretical framework and practical implications for precisely and differentially enhancing tuberculosis prevention and control effectiveness in academic settings.

1. Introduction

Tuberculosis (TB), a chronic infectious disease caused by *Mycobacterium tuberculosis*, remains one of the three major notifiable infectious diseases in China[1]. According to the WHO Global Tuberculosis Report 2025, an estimated 10.7 million new TB cases occurred globally, China's estimated TB incidence ranking declined from the third to the fourth position, accounting for 6.5% of the global total, with an incidence rate of approximately 69.6 cases per 100,000 population. This proportion is lower than that of India (25%), Indonesia (10%), and the Philippines (6.8%). Based on global disease prevalence classification, China has, for the first time, entered the category of countries with intermediate-to-low TB prevalence. Despite commendable progress in TB control in China, a persistent disparity remains—both globally and within China—between the estimated number of new cases and the number of newly diagnosed patients[2]. This gap continues to pose a grave challenge to achieving TB elimination targets, underscoring the necessity for sustained focus on high-risk regions and vulnerable populations.

Schools, due to their dense populations, are settings where undetected tuberculosis infections among students or staff can lead to outbreaks. In China, the student population is substantial, comprising approximately 286 million individuals, or about 20.42% of the total population[3]. Students aged 6 to 31 years have consistently been a key demographic for TB prevention and control, exhibiting the fourth highest incidence rate nationally. Within this age range, high school students (15 to 17 years) and university students (18 to 21 years) are particularly vulnerable due to heightened academic pressure, psychological stress, limited physical activity, and specific dietary requirements, all of which may contribute to reduced immunity[4]. Despite the introduction of multiple policy documents in China aimed at strengthening TB prevention and control in universities, several clustered TB outbreaks have been reported over the past decade[1]. Most existing studies on TB prevention and control in universities have focused on individual students or single institutions, or have examined isolated factors affecting TB control outcomes, thereby lacking a comprehensive understanding of the underlying mechanisms. There is an urgent need for integrated, multi-dimensional research perspectives and a greater emphasis on multi-sectoral collaboration in implementing TB prevention and control measures within academic settings.

As one of China's northernmost provinces bordering Russia, Heilongjiang faces distinct challenges, including a relatively underdeveloped economy, numerous land ports, high population mobility, and limited public awareness of tuberculosis prevention, all of which contribute to its high TB burden[5]. In 2021, the reported incidence of pulmonary TB in Heilongjiang was 50.85 per 100,000, ranking among the highest in the country[6]. The province is home to 78 regular higher education institutions with a total enrollment of 949,000 students, as well as 16 adult higher education institutions with 21,000 students[7]. With an increasing number of international students, the situation regarding TB prevention and control is becoming increasingly severe. Therefore, a comprehensive understanding of the current status of TB-related knowledge, attitudes, and practices (KAP) among university students in Heilongjiang, along with an exploration of the influencing factors and underlying mechanisms affecting the effectiveness of TB prevention and control, is critically important.

In this study, we employed fuzzy-set qualitative comparative analysis (fsQCA) to explore the configuration model of influencing factors and the complex synergistic pathways affecting the effectiveness of tuberculosis prevention and control among universities in Heilongjiang, China. Utilizing questionnaire data that assessed multidimensional factors—including demographic characteristics, mental health indicators, and the institutional and societal TB prevention environment—this research identifies configurational pathways that shape the effectiveness of TB prevention and control. The findings provide valuable insights for optimizing TB prevention effectiveness in universities, clarifying priority areas for campus TB prevention and control, and optimizing the allocation of TB-related resources in China, thereby offering a theoretical foundation and evidence-based reference.

2. Method

2.1 Study design and participants

This study utilized a purposive sampling method to distribute questionnaires through both online and offline channels across five universities located in three regions of Heilongjiang Province. Data collection occurred using the Questionnaire Star platform in conjunction with paper-based surveys targeting the specified population from November to December 2024. A total of 787 online questionnaires and 103 paper questionnaires were collected. Following manual verification, 50 invalid responses that did not meet the inclusion criteria were excluded, resulting in a final valid sample of 840 questionnaires and an effective response rate of 94.38%.

The student questionnaire consisted of three sections. The first section gathered basic demographic information from students. The second section included scales measuring antecedent variables. The third section evaluated outcome variables using a knowledge, attitudes, and practices (KAP) scale to assess the effectiveness of TB prevention and control measures among students at the participating universities. Additionally, A corresponding faculty version was developed to assess institutional TB prevention and control systems. To analyze the pathways influencing the effectiveness of TB prevention and control in higher education institutions in Heilongjiang, faculty responses were paired with those of students from the same school or college. The study protocol received approval from the Ethics Committee of the School of Health Management at Harbin Medical University.

2.2 Measures and instruments

In the preliminary phase of the study, the research team conducted key informant interviews with health administrative staff from Heilongjiang Province, personnel from the Centers for Disease Control and Prevention, staff from university health service offices, and affected students. Utilizing a grounded theory approach, three institutional-level factors affecting the effectiveness of TB prevention and control in universities were identified: the institutional TB prevention and control mechanism, the social environment, and the infectious disease management system. An interview guide was specifically developed for this study. The guide evolved through an iterative constant comparison process. The final institutional-level factors were derived through a three-phase grounded theory coding process, as exemplified in Supplementary File 1. Concurrently, the team performed an integrated analysis of domestic and international literature related to TB prevention and control among university students, focusing on the individual student level. Through this review, core variables influencing TB control outcomes at the student level were identified: self-efficacy, risk perception, optimistic bias, worry about TB, TB-related stigmatization, and media exposure. This study organizes various factors related to TB prevention and control in universities into distinct combinatorial sets, thereby proposing a configuration-based analytical model, as illustrated in Fig. 1. Through this model, the research investigates the interaction and synergy between student-level and institutional-level factors, elucidating their collective impact on the effectiveness of TB prevention and control in higher education settings.

Studies have demonstrated that individuals' adoption of effective infectious disease prevention and control measures is influenced, to a certain extent, by their understanding and attitudes towards the disease[8], which is consistent with the Knowledge-Attitude-Practice (KAP) theory. A high level of KAP among individuals is closely linked to improved outcomes in disease prevention and control. Consequently, this study developed a modified Tuberculosis Knowledge, Attitude, and Practice Questionnaire, drawing from the "College Students' Tuberculosis Prevention and Control Knowledge, Attitude, and Practice Survey Questionnaire"[9] compiled by the China Center for Disease Control and Prevention. This modification also incorporated insights from previous research on students' knowledge, attitudes, and practices regarding tuberculosis [10–11]. The questionnaire was finalized through a collaborative review and revision process conducted by an expert panel, alongside a literature review team. The final version has been designated as the 'Tuberculosis Prevention and Control Knowledge, Attitude, and Practice Questionnaire' for college students in Heilongjiang Province.

The primary scales employed in this study included the General Self-Efficacy Scale[12], the Tuberculosis Risk Perception Scale[13], the Student Tuberculosis Stigmatization Perception Scale[14], and the Media Exposure Scale[15]. These scales were partially adapted and refined to align with the specific context of the study population; consequently, an evaluation of their reliability and validity was necessary. First, internal consistency reliability was assessed using Cronbach's alpha. Generally, a Cronbach's alpha value above 0.8 indicates excellent reliability, a value between 0.6 and 0.8 suggests acceptable reliability, and a value below 0.6 necessitates a revision of the scale structure[16]. Second, confirmatory factor analysis was performed using Amos 22.0 to evaluate model fit. The measurement model was considered to exhibit a good fit when the NFI, CFI, and GFI values all exceeded 0.9, and the RMSEA was below 0.1[17]. The research team's analysis of the reliability and validity data yielded the following results: the General Self-Efficacy Scale had a Cronbach's $\alpha = 0.958$; the Risk Perception Scale showed a Cronbach's $\alpha = 0.90$; the Stigmatization Scale demonstrated a Cronbach's $\alpha = 0.944$; and the Media Exposure Scale exhibited a Cronbach's $\alpha = 0.969$. These results indicate that the internal consistency of all scales exceeded the recommended thresholds in the field, and the confirmatory factor analysis models demonstrated satisfactory fit according to internationally recognized standards.

Worry can interfere with individuals' ability to process health information and engage in rational thinking, thereby influencing their behavioral choices. This study utilized a worry assessment tool [18] to measure the level of worry among university students. The direct measurement method demonstrates stronger correlations when assessing individuals' optimism bias regarding negative life events and exhibits higher predictive validity for emotional responses and behavioral decisions [19]. This study employs this method to evaluate students' optimism bias related to tuberculosis.

2.3 Statistical Analysis

Data analysis employed hierarchical regression in IBM SPSS Statistics 27.0 and fuzzy-set Qualitative Comparative Analysis in fsQCA 3.0. FsQCA is designed to examine multiple driving paths relationships, demonstrating how different configurations of antecedent conditions can lead to the same outcome through distinct pathways. This approach is particularly suitable for analyzing complex real-world cases of tuberculosis prevention and control in university settings. The method enables the standardized transformation of variables to the [0,1] interval, with its distinctive advantage lying in capturing intensity differences among variables, thereby more accurately reflecting complex driving mechanisms in empirical contexts. Consequently, this study employed fsQCA for a comprehensive analysis.

The implementation of the fsQCA methodology comprises four critical stages: data calibration, necessity analysis, truth table construction, and configuration interpretation. Initially, data were collected and underwent calibration to transform continuous variables into fuzzy-set variables ranging from 0 to 1. The calibration process follows an objective calibration framework, wherein theoretical anchors—specifically, full membership, crossover point, and full non-membership—are established based on existing literature and theoretical foundations. Subsequently, data transformation is accomplished through algorithmic procedures. A necessity analysis serves as a prerequisite for configurational analysis, assessing whether individual conditions qualify as necessary elements and thereby identifying core explanatory variables. Scholarly consensus recommends the following thresholds: consistency scores of ≥ 0.8 indicate sufficient conditions, while scores exceeding 0.9 establish necessary conditions. Following the necessity analysis, the calibrated data were transformed into a truth table to examine driving mechanisms between antecedent configurations and the outcome. Each row in this matrix represents a unique combination of antecedent conditions, with k antecedents generating 2^k possible configurations. The truth table standardization procedure yields three solution types: parsimonious, intermediate, and complex. Specifically, the complex solution yields cumbersome and impractical results due to its failure to incorporate logical remainders; the parsimonious solution includes all remainders without theoretical justification, whereas the intermediate solution retains empirically meaningful remainders while maintaining analytical coherence. Accordingly, this study utilized the intermediate solution as the primary analytical framework, employing the parsimonious solution to distinguish between core and peripheral conditions.

3. Results

3.1 Descriptive statistics for variables

The study sample exhibited a female predominance (62.02%, $n=521$) compared to males (37.98%, $n=319$), suggesting a higher willingness among female university students to participate in the survey. The mean age of participants was 19.37 ± 1.59 years, with first-year students comprising the largest subgroup (53.33%, $n=448$). This distribution may reflect greater engagement from incoming students, likely associated with recent health examinations conducted prior to university enrollment. In terms of academic discipline, non-medical students accounted for a significantly larger proportion (65.36%) than medical students (34.64%). Given that medical students generally possess more comprehensive knowledge of tuberculosis TB, this demographic composition may help mitigate bias attributable to professional specialization. Regarding parental education, the largest proportion of parents had completed junior secondary education (approximately 40%), indicating a predominantly low-to-middle educational background among the parental generation. This suggests potential limitations in intergenerational support for TB prevention and control efforts.

Participants exhibited a high level of self-efficacy, as indicated by a mean score of 31.20 ± 5.46 on the self-efficacy scale. Risk perception related to tuberculosis was at a higher level., with a mean score of 24.69 ± 7.08 . Additionally, an optimistic bias was observed, reflected in a mean score of 2.10 ± 1.00 , suggesting that respondents tended to underestimate their personal susceptibility to TB infection. Concerns regarding TB were significant, with a mean score of 3.65 ± 1.01 , as students expressed heightened anxiety about potential impacts on interpersonal relationships, academic progress, and future employment. A substantial level of TB-related stigmatization was reported, with a mean score of 28.01 ± 8.86 . Furthermore, media exposure was low, averaging 2.51 ± 1.21 , which may indicate limited general interest in TB among the student population. The knowledge, attitudes, and practices (KAP) score was moderately high at 28.76 ± 4.04 , suggesting satisfactory TB-related preventive competencies and indicating some effectiveness of current university-led TB health education initiatives. As presented in Table 1, the overall TB prevention and control environment in universities was found to be suboptimal. Scores for institutional TB prevention and control mechanisms, social environment, and infectious disease management systems all fell below average benchmarks. These findings highlight the urgent need for substantial enhancement of TB prevention and control infrastructure within higher education institutions in Heilongjiang Province.

Table 1 Characteristics of a sample of high school students and characteristics of the TB prevention and control environment in a sample of colleges and universities

Variable		Classification	n(%) / M±SD
Individual Level	Gender	Male	319(37.98)
		Female	521(62.02)
	Age	/	19.37±1.59
	Residence	Rural	341(40.59)
		Town	263(31.31)
		City	236(28.10)
	Grade Level	First-year undergraduate students	448(53.33)
		Non-first-year undergraduate students	392(46.67)
	Major	Medical	291(34.64)
		Non-medical	549(65.36)
	Father's Educational Level	Lower secondary education or below	457(54.41)
		Upper secondary education	204(24.29)
		Tertiary education	179(21.31)
	Mother's Educational Level	Lower secondary education or below	486(57.86)
		Upper secondary education	179(21.31)
		Tertiary education	169(20.12)
	Self-efficacy		31.20 ±5.46
	Risk perception		24.67 ±7.08
	Optimistic bias		2.10 ±1.00
	Worry	/	3.65 ±1.01
	Stigmatization		28.01 ±8.86
	Media exposure		2.51 ±1.21
	TB-related Knowledge, Attitudes, and Practices (KAP)		28.76 ± 4.04
Institutional-Level Conditions	University TB prevention and control mechanisms		1.61 ±1.33
	Social environment	/	4.76 ±1.70
	Infectious disease management system		2.83 ±0.75

This study further investigates the implementation of tuberculosis screening, health education, and health management measures in participating universities, as illustrated in Table 2. The findings indicate that a majority of institutions relied solely on chest X-rays (40.95%) for incoming student screening. Notably, over 30% of respondents reported no TB screening at enrollment, which may reflect limited student awareness that examinations such as chest X-rays or tuberculin skin tests (TST) are intended for TB detection. Nonetheless, these reports suggest a substantial gap in systematic TB entry screening across universities in Heilongjiang Province. More than half of the students were unaware whether screening for latent TB infection or active TB was conducted among non-freshmen, indicating both a lack of student engagement with TB prevention and control policies and insufficient dissemination of related information by the institutions. On a positive note, over 80% of students confirmed that their colleges regularly organized TB health education activities, reflecting institutional prioritization of TB-related health promotion. Furthermore, the vast majority (over 95%) reported no documented TB cases within their institutions, suggesting generally effective TB prevention and control outcomes in the surveyed universities.

Table 2 Current status of TB prevention and control in higher education

Variable	Category	n (%)
TB Screening at Enrollment	Chest X-ray only	344 (40.95)
	TST only	25 (2.98)
	Both Chest X-ray and TST	190 (22.62)
	Not screened	281 (33.45)
Screening in Non-freshmen	Active TB screening only	123 (14.64)
	Latent TB infection screening only	21 (2.50)
	Both screenings conducted	189 (22.50)
	Neither screening conducted	53 (6.31)
	Unaware of screening status	454 (54.05)
TB Health Education Frequency	Once per year	340 (40.48)
	Twice per year	124 (14.76)
	Three or more times per year	217 (25.83)
	Never conducted	159 (18.93)
Documented TB Cases in College	Yes	32 (3.81)
	No	808 (96.19)
Screening After Case Detection	Yes	31 (96.88)
	No	1 (3.12)

3.2 Calibration Values

For data calibration, this study employed an objective calibration method to enhance the objectivity and reliability of the evaluation. The anchors were determined using a percentile-based calibration approach. Specifically, the 5th, 50th, and 95th percentiles of both the antecedent variables—including self-efficacy, risk perception, optimistic bias, worry, TB-related stigmatization at the individual level, and institutional-level variables such as TB prevention and control mechanisms, social environment, and infectious disease management systems—and the outcome variable (TB prevention and control effectiveness, measured through students' knowledge, attitudes, and practices toward TB) were utilized to define the three anchor values: full membership, crossover point, and full non-membership. The calibration anchors for all variables are presented in Table 3.

Table 3 calibration values

Antecedents		Calibration values		
		P95	P50	P5
Antecedent Conditions	Self-efficacy	40	30	23
	Risk perception	40	24	13
	Optimistic bias	3	2	1
	Worry	5	4	1.6
	Stigmatization	44	28	17
	Media exposure	5	2	1
	University TB prevention and control mechanisms	3	2	0
	Social environment	7	5	3
	Infectious disease management system	4	3	2
	TB-related Knowledge, Attitudes, and Practices (KAP) among university students	34	29	21

3.3 Comparative Qualitative Analysis of Fuzzy Sets

Necessary condition analysis

The necessity analysis serves as a prerequisite for configurational analysis, which evaluates whether individual condition variables are necessary elements and identifies core factors that possess significant explanatory power for the outcome. A condition is deemed necessary if its consistency score for necessity testing meets or exceeds the threshold of 0.9. The results of the necessity test reveal that all relevant conditions fall below this benchmark, indicating that no single factor qualifies as a necessary condition for enhancing the effectiveness of tuberculosis prevention and control in universities. Instead, the outcome is influenced by the interplay of multiple factors. Therefore, the improvement of TB prevention and control effectiveness in universities in Heilongjiang is a result of the combined effects of various conditions, necessitating further analysis of their driving paths, as illustrated in Table 4.

Table 4 Necessary conditions analysis of FsQCA

Antecedents	Outcomes			
	Effectiveness of tuberculosis prevention and control		~Effectiveness of tuberculosis prevention and control	
	Consistency	Coverage	Consistency	Coverage
Self-efficacy	0.680	0.690	0.694	0.593
~Self-efficacy	0.599	0.699	0.638	0.627
Risk perception	0.651	0.719	0.654	0.608
~Risk perception	0.645	0.689	0.698	0.628
Optimistic bias	0.585	0.610	0.617	0.541
~Optimistic bias	0.560	0.634	0.555	0.530
Worry	0.604	0.704	0.622	0.611
~Worry	0.667	0.677	0.699	0.598
Stigmatization	0.663	0.713	0.662	0.599
~Stigmatization	0.627	0.688	0.682	0.630
Media exposure	0.578	0.780	0.608	0.692
~Media exposure	0.772	0.700	0.807	0.617
University TB prevention and control mechanisms	0.570	0.624	0.598	0.551
~University TB prevention and control mechanisms	0.590	0.635	0.592	0.537
Social environment	0.527	0.643	0.552	0.567
~Social environment	0.645	0.631	0.653	0.537
Infectious disease management system	0.552	0.687	0.600	0.629
~Infectious disease management system	0.702	0.676	0.702	0.569

Sufficiency analysis

Construction of the Truth Table for University TB Prevention and Control Effectiveness

This study examined nine antecedent conditions, which theoretically generate $2^9 = 512$ possible configurations. However, due to the substantial sample size and the necessity to consider counterfactual cases, some theoretically possible combinations were not observed in the data. Following Greckhamer's methodological framework, we established a frequency threshold of 5 cases, a consistency benchmark of 0.9, and a PRI threshold of 0.65. Configurations that did not meet these criteria were excluded from subsequent analyses. A consistency value close to 1 indicates a strong positive causal relationship between a configuration and the outcome, as demonstrated in Table 5.

Table 5 Conditions configurational Analysis of University Tuberculosis Prevention and Control Effectiveness

Self - efficacy	Risk perception	Optimistic bias	Worry	Stigmatization	Media exposure	University TB prevention and control mechanisms	Social environment	Infectious disease management system	raw consist	PRI consist
1	0	0	1	1	1	0	1	1	0.955217	0.667638
1	1	0	1	1	1	1	0	1	0.941565	0.674202
1	1	0	0	1	1	1	0	1	0.940133	0.685482
1	1	0	1	1	1	1	0	0	0.918863	0.662221
1	1	1	1	1	0	1	0	1	0.917034	0.677349
1	1	1	1	1	1	1	0	0	0.915584	0.654021
1	1	1	1	1	0	1	0	0	0.912673	0.692758
0	1	1	1	1	0	1	0	0	0.90448	0.685327
1	1	1	0	1	0	1	0	0	0.898423	0.666559

As shown in Table 6, the overall solution consistency was 0.880, significantly exceeding the reference threshold of 0.7. This indicates that the sufficiency of the configurational conditions in the model is statistically acceptable. All five identified paths exhibited consistency values above 0.8, confirming that these

configural pathways represent sufficient conditions for effective tuberculosis prevention and control. Based on these configurations, two distinct improvement paths were identified: the Individual Emotional Perception Type and the Macro-Institutional Orientation Type.

Individual Emotional Perception Type (C1, C2, C3):

Configuration C1 indicates that even in the presence of low media exposure, an unfavorable social environment, and inadequate infectious disease management, high levels of risk perception, optimistic bias, worry, stigmatization, and robust university prevention and control mechanisms contribute to effective tuberculosis prevention and control. Configuration C2 suggests that under conditions of high self-efficacy, risk perception, optimistic bias, worry, Stigmatization, and strong institutional prevention and control mechanisms, effectiveness remains high despite limited media exposure and a poor social environment. Configuration C3 illustrates that even with deficiencies in the social environment and management systems, high self-efficacy, risk perception, worry, stigmatization, media exposure, and school-based mechanisms can still yield positive outcomes. These findings imply that strong individual emotional perceptions can drive proactive protective behaviors among students, thereby enhancing the effectiveness of TB prevention and control regardless of macro-level conditions.

Macro-Institutional Orientation Type (C4, C5):

Configuration C4 indicates that with high self-efficacy, risk perception, Stigmatization, media exposure, effective school mechanisms, and strong management systems, satisfactory control levels can be maintained despite low optimistic bias and a poor social environment. Configuration C5 suggests that even with low risk perception and optimistic bias among students, as well as imperfect school mechanisms, effective control can be achieved through high self-efficacy, worry, Stigmatization, media exposure, a supportive social environment, and robust institutional management. Notably, C5 demonstrated the highest consistency, representing the most effective configuration. These findings imply that well-established macro-level institutional systems can compensate for shortcomings in individual perceptions and micro-level settings.

Table 6 Configurational Analysis Results of Factors Influencing TB Prevention and Control Effectiveness in Universities

Antecedent Conditions	Configurations				
	Individual Emotional Perception Type			Macro-Institutional Orientation Type	
	C1	C2	C3	C4	C5
Self-efficacy		•	•	•	•
Risk perception	•	•	•	•	⊗
Optimistic bias	•	•		⊗	⊗
Worry	●	●	●		●
Stigmatization	•	•	•	•	•
Media exposure	⊗	⊗	●	●	●
University TB prevention and control mechanisms	•	•	•	•	⊗
Social environment	⊗	⊗	⊗	⊗	•
Infectious disease management system	⊗		⊗	●	●
Consistency	0.893	0.898	0.900	0.936	0.955
Raw coverage	0.189	0.189	0.192	0.122	0.109
Unique coverage	0.019	0.016	0.026	0.012	0.032
Overall solution consistency			0.880		
Overall solution coverage			0.298		

Note: ● indicates the presence of a core condition, • indicates the presence of a peripheral

condition; , blank indicates absence of the condition (irrelevant), ⊗ indicates the absence of a core

condition, ⊗ indicates the absence of a peripheral condition.

Discussion

Building upon the understanding that the effectiveness of tuberculosis prevention and control in schools is shaped by factors at the individual, institutional, and societal levels, this study develops a configurational model to examine how student-level and institutional-level factors interact and jointly influence the

effectiveness of TB prevention and control in universities. The findings reveal that individual psychological factors and institutional environmental factors collectively form the core antecedent conditions affecting TB prevention and control effectiveness. The results indicate that effective TB prevention and control in universities arises from the complex interplay of multiple concurrent factors, which can be summarized into two core pathways: one driven primarily by individual psychological factors, and another dominated by institutional environmental conditions. This analysis provides a configurational theoretical explanation and practical insights for developing targeted, differentiated strategies to enhance TB prevention and control effectiveness in higher education settings.

The study sample consisted predominantly of female, first-year, non-medical students, most of whom came from families with mid-to-low levels of parental education. At the individual psychological and cognitive level, the sample exhibited relatively high self-efficacy and scores for tuberculosis prevention and control knowledge, attitudes, and practices (KAP). However, this was accompanied by moderate risk perception, pronounced optimistic bias (the belief that one's own risk is lower than that of others), high levels of Stigmatization, and low engagement with media for TB-related information. This combination of high confidence, low perceived threat, and low proactive attention reveals a potential decoupling within the Knowledge-Attitude-Practice model. Specifically, possessing knowledge does not necessarily translate into strong protective motivation or sustained behavior, as optimistic bias may significantly weaken an individual's subjective assessment of TB susceptibility, thereby diminishing the perceived urgency to adopt preventive measures[20]. Concurrently, the overall scores for the university TB prevention and control environment were low. Issues such as incomplete coverage of TB screening for new students and insufficient student awareness of these measures expose systemic vulnerabilities in policy design, interdepartmental collaboration, and implementation oversight, even the frequency of tuberculosis health education conducted annually is extremely low. These weaknesses substantially dilute the overall effectiveness of the TB prevention and control system within universities.

Regarding the formative mechanisms influencing the efficacy of tuberculosis prevention and control in universities, the findings indicate that outcomes are shaped by the synergistic interaction of individual cognition, university management mechanisms, and the broader social ecosystem. These pathways can be conceptualized into two archetypes: one primarily driven by students' internal emotional and perceptual frameworks, and the other predominantly influenced by macro-level environmental factors.

The first pathway, driven by individual perceptions, was explored through fsQCA. The results identify individual emotional perception as a crucial dimension influencing prevention and control outcomes, with self-efficacy, risk perception, optimistic bias, worry, and tuberculosis Stigmatization as the primary influencing factors. Although the specific conditional configurations (C1, C2, C3) varied, they all fell under the category of "individual emotional perception type," emphasizing the synergistic role of emotional and cognitive factors in shaping protective behaviors[21]. Worry can induce cognitive bias, prompting individuals to develop negative expectations regarding infection risk, which subsequently enhances protective intentions and behaviors. Risk perception positively influences protective behaviors; a stronger student perception of TB risk correlates with improved TB knowledge and behavioral performance. Self-efficacy promotes positive protective motivation and habit formation by increasing confidence in one's ability to manage personal health. Optimistic bias serves a supplementary role; individuals who perceive their infection risk as higher than that of others are more likely to adopt proactive measures[22]. Consequently, the interplay of dominant worry, heightened risk perception, robust self-efficacy, and optimistic bias can significantly enhance the effectiveness of TB prevention and control in universities. This underscores the necessity for interventions that target the emotional and cognitive levels of students, systematically improving control efficacy by enhancing risk awareness, self-efficacy, and fostering a rationally optimistic attitude.

In contrast, the macro-institutional pathway illustrates that the communicable disease management system serves as a crucial facilitator in enhancing tuberculosis prevention and control outcomes within universities. The improvement of campus-specific TB prevention and control policies, the assurance of adequate funding, and the establishment of robust multi-sectoral collaboration mechanisms are essential for achieving better outcomes, underscoring the foundational significance of governance capacity in public health efficacy. Government departments must delineate the responsibilities and behavioral norms of all stakeholders involved in university TB prevention and control through targeted policies and regulations. Concurrently, coordinated funding from the education, health, and finance sectors is vital to ensure the effective implementation of measures such as screening and disinfection. Furthermore, it is imperative to strengthen a collaborative prevention and control mechanism involving tuberculosis control agencies, hospitals, and universities to ensure an effective response to outbreaks. The university's own TB prevention and control mechanism plays a supplementary role across most pathways. Universities should utilize their authoritative position to conduct TB health education at least once per semester, collaborating with professional agencies and employing diverse formats to ensure effective dissemination, thereby guiding students towards accurate understanding and protective behaviors. Additionally, universities must rigorously enforce policies regarding campus access for infectious individuals and the review process for those returning after recovery to interrupt transmission chains within the campus. The social environment exerted an auxiliary effect only in configuration C5, indicating its relatively limited influence, primarily manifesting under conditions of weak student risk perception, optimistic bias, and a deficient university mechanism. The analysis identifies C5 as the optimal configuration for enhancing prevention and control effectiveness. Future efforts should concentrate on building a positive social support system, increasing societal attention to TB, eliminating stigmatizing perceptions, and fostering an environment conducive to prevention and control.

Media exposure plays a crucial role in enhancing the effectiveness of tuberculosis prevention and control across various pathways within universities. The results of fsQCA indicate that media exposure is a core condition in three high-consistency configurations, highlighting the significant impact of information dissemination efficacy on prevention and control outcomes. As the primary conduit for public access to health information, the scope and depth of media utilization directly influence the dissemination of TB prevention knowledge[23]. Research suggests that deeper engagement with media correlates with a higher likelihood of changes in individual beliefs and behaviors. Given the high frequency and diverse channels of media usage among university students, new media platforms serve as a pivotal hub for improving their knowledge, attitudes, and practices (KAP) regarding TB. Similar studies confirm that, in the context of infectious disease prevention and control, media exposure can shape public protective behaviors by influencing risk perception[24]. It can thus be inferred that media exposure may indirectly enhance students' willingness to engage in protective behaviors by strengthening their perceived susceptibility to TB and the perceived usefulness of preventive measures. Future TB prevention and control initiatives in universities should focus on cultivating a positive 'media ecology': first, by integrating the credibility of authoritative media sources with the penetrative power of social media to guide students toward reliable

information; second, by enhancing media literacy education to improve students' skills in information discrimination; and third, by promoting the establishment of a routine, multi-platform official information dissemination and online information governance mechanism by educational and health departments to mitigate the spread of misinformation and optimize the information environment.

Of particular note, students' perceptions of tuberculosis stigmatization played a supplementary role in all pathways leading to improved the effectiveness of prevention and control. Although typically regarded as a negative factor, stigmatization, when combined with worry and risk perception, constituted an intrinsic psychological mechanism that drives proactive protective behaviors among university students. Within the university setting, fear of discrimination is associated with more high-risk behavior and fewer health-promoting activities, indicating that individuals may not wear their mask, avoid testing, and refuse to comply with social distancing rules in order to disassociate themselves from the stigmatization[25]. Future university strategies should establish a tripartite health promotion system that integrates risk communication, psychological counseling, and behavioral incentives. This can be achieved by enhancing risk cognition through scenario-based simulations, mitigating the impact of stigmatization through education and institutional design, and providing protective measures, such as anonymous screening, to guide stigmatization perception towards the transformation into positive protective behaviors.

Limitations

However, the study has some several limitations. First, the study's focus on higher education institutions in Heilongjiang Province may restrict the generalizability of its configurational findings to other regions with distinct epidemiological, policy, or educational contexts. Future cross-regional comparative research is needed to validate the results. Second, the theory-driven nature of fsQCA constrained the selection of antecedent conditions to those specified by the employed framework. Other influential institutional, behavioral, or environmental factors may thus have been excluded, offering opportunities for future research to explore alternative configurations.

Conclusions

The effectiveness of tuberculosis prevention and control in universities is influenced not by isolated factors, but rather by the interplay of individual emotional elements—such as self-efficacy, risk perception, worry, and stigmatization—and institutional conditions, including prevention and control mechanisms and management systems. Among these elements, worry, tuberculosis-related stigmatization, self-efficacy, and risk perception are crucial in enhancing tuberculosis prevention and control effectiveness within university settings. Conversely, at the institutional level, social environmental factors contribute relatively less to the effectiveness of tuberculosis prevention and control.

Abbreviations

TB
Tuberculosis
fsQCA
Fuzzy-Set Qualitative Comparative Analysis
KAP
knowledge, attitudes, and practices

Declarations

Ethics approval and consent to participate

The survey was conducted on a voluntary and anonymous basis. Respondents were informed about the aims of the study and participation consent was signed by accepting to fulfill the questionnaire. The study protocol adhered to the Declaration of Helsinki and was approved by the Ethics Committee of Harbin Medical University (Approval No. HMUIRB2023021).

Consent for publication

Not applicable.

Availability of data and materials

The data supporting the findings of this study are available from the co-author, Nan Wang, upon reasonable request. Researchers seeking access may be required to provide details regarding their intended use.

Competing interest

The authors declare no competing interests.

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Authors' contributions

JG, NW, and LL conceived and designed the study. JG, NW and XS had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. NW, JG, XD and LL contributed to data collection and investigation. YL and NW performed formal analysis and data curation. WS, LZ, PS and RL carried out validation and visualization. LL, LG, and XD provided critical revisions to the manuscript for important intellectual content. JG, NW and XS drafted the initial manuscript. LL jointly supervised the study and obtained funding. All authors read and approved the final manuscript. JG, NW and XS contributed equally to this work as co-first authors. All authors read and approved the final manuscript.

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Figures

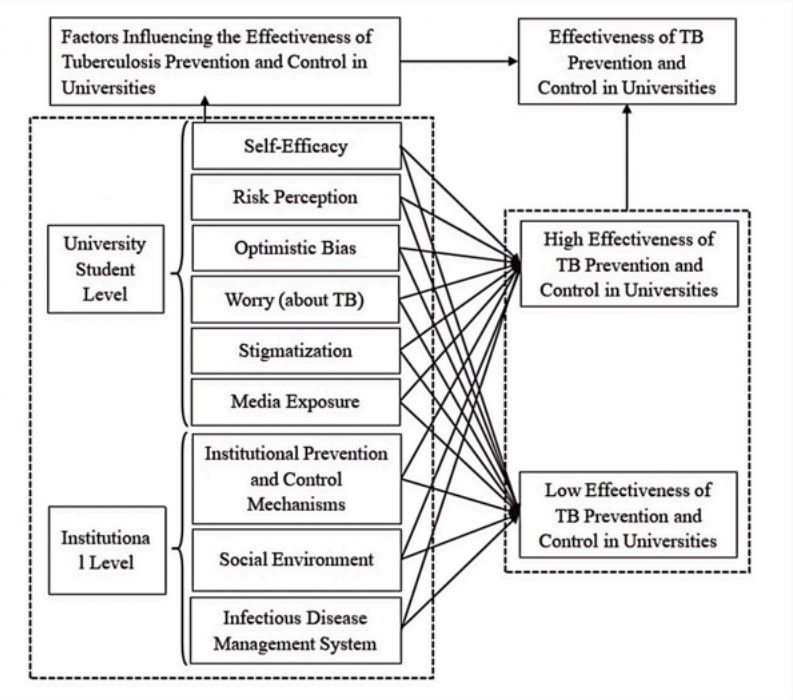


Figure 1

A configurational analytic model of the formation mechanism of TB prevention and control problems in higher education institutions

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