Enhancing Emergency Care Capacity and Health Economic Sustainability in Rural Sichuan: The Role of Tele-Training, TCM Integration, and Medical Collaboration

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Abstract

Background Rural hospitals in Sichuan Province, China, face persistent challenges such as limited emergency resources, geographic isolation, and fragmented coordination with tertiary institutions. These issues undermine both emergency care quality and the sustainability of local health economies. Exploring integrated strategies that combine technology, Traditional Chinese Medicine (TCM), and institutional collaboration is essential for building resilient rural healthcare systems.

Methods A mixed-methods design was employed, using proportional stratified sampling to collect data from 252 general practitioners and administrators across 126 township hospitals in Sichuan. Quantitative data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) to examine the relationships among tele-training, TCM integration, medical collaboration, and health economic sustainability.

Results Tele-training by higher-level institutions significantly improved emergency care capacity ($\beta = 0.32$, $p < 0.01$), bridging skill gaps in managing acute conditions such as stroke and diabetic emergencies. TCM integration also showed a positive effect ($\beta = 0.25$, $p < 0.05$), enhancing cost-effective treatment through acupuncture and herbal therapies. Medical collaboration mediated 45% of the total effect on health economic sustainability by optimizing resource allocation and referral efficiency between grassroots and tertiary facilities.

Conclusion The validated "sustainability flywheel" model demonstrates that combining tele-training, standardized TCM integration, and inter-hospital collaboration can enhance both healthcare equity and economic resilience in rural China. These findings provide actionable insights for policymakers and healthcare managers seeking sustainable rural health system reforms in other resource-constrained regions globally.

Keywords

Emergency cure capacity; Health economic sustainability; Tele-training; Traditional Chinese Medicine; Medical collaboration; Rural healthcare

1.INTRODUCTION

The sustainability of rural healthcare systems, particularly in low- and middle-income regions, remains a critical global challenge. In China, Primary care hospitals serve as the frontline for emergency care in rural areas, yet they often grapple with systemic inefficiencies such as resource shortages, skill gaps among practitioners, and fragmented

coordination with tertiary institutions [1]. These challenges are acutely evident in Sichuan Province, where geographic disparities, mountainous terrain, and uneven economic development exacerbate healthcare delivery barriers [2]. For instance, rural residents frequently face delays in accessing critical care for conditions like acute coronary syndromes, strokes, and diabetic emergencies, leading to preventable morbidity and economic burdens [3]. Concurrently, the sustainability of local health economies is undermined by rising treatment costs and declining service quality, creating a vicious cycle that threatens equitable healthcare access [4].

Within this context, China's national policies since the 2009 healthcare reform have prioritized strengthening grassroots healthcare systems. Initiatives such as the "Health China 2030" Plan and the "14th Five-Year Plan for National Health " emphasize capacity-building for general practitioners (GPs), the establishment of hierarchical diagnosis systems, and the integration of Traditional Chinese Medicine (TCM) into primary care [5–6]. These policies recognize that enhancing emergency care capabilities at the grassroots level is pivotal to achieving universal health coverage and economic resilience. However, empirical evidence on how to operationalize these goals—particularly through innovative interventions like tele-training and TCM—remains sparse, especially in regions like Sichuan with unique socio-geographic challenges [7].

Sichuan's primary care hospitals face multifaceted hurdles in emergency care. A 2022 survey revealed that only 35% of rural clinics in the province meet national standards for resuscitation equipment, while 60% of GPs report insufficient training in managing acute conditions like hypertensive crises or sepsis [8]. Such gaps contribute to misdiagnosis rates exceeding 20% for time-sensitive emergencies, delaying referrals and worsening patient outcomes [9]. Financially, the economic toll is significant: avoidable complications from inadequate emergency care cost Sichuan's health system an estimated ¥1.2 billion annually, diverting resources from preventive services [10].

To address these issues, China has implemented policies targeting workforce development. The National Plan for GP Training (2010) and subsequent reforms mandate continuous professional education (CPE) for rural practitioners, yet traditional in-person training models struggle with scalability and relevance to local needs [11]. Meanwhile, TCM—a cost-effective modality endorsed by national strategies—remains underutilized in emergencies despite evidence supporting its adjunctive role, such as acupuncture for stroke rehabilitation or herbal therapies for asthma exacerbations [12–13].

Globally, research on rural emergency care highlights both successes and persistent gaps. In high-income countries like Canada and Australia, telemedicine platforms and standardized protocols have improved diagnostic accuracy and reduced mortality in remote areas [14–15]. For example, Australia's Royal Flying Doctor Service leverages real-time teleconsultations to guide rural clinicians in trauma management, achieving outcomes comparable to urban centers [16]. Conversely, in low-resource settings such as sub-Saharan Africa and South Asia, systemic underinvestment in grassroots infrastructure perpetuates high mortality rates. The WHO estimates that 8 million deaths annually in these regions are attributable to treatable conditions, with diagnostic errors for pneumonia and myocardial infarction contributing to 30% of fatalities [17–18].

Notably, studies underscore the economic rationale for investing in rural healthcare capacity. Kruk et al. (2018) demonstrated that strengthening primary care systems in LMICs could avert 25 million cardiovascular deaths by 2030, yielding a 9:1 return on

investment through productivity gains [19]. However, few studies have explored how synergies between tele-training, traditional medicine, and inter-institutional collaboration can amplify these benefits—a gap this study seeks to address.

This study investigates the interplay between emergency care capacity, health economic sustainability, and mediating factors in Sichuan's rural hospitals. Grounded in a "sustainability flywheel" framework (Fig. 1), we propose that:Tele-training by higher-level institutions enhances diagnostic and procedural skills among rural GPs, reducing delays in emergency response. TCM integration complements conventional care, lowering costs while improving patient outcomes for chronic-acute conditions. Medical collaboration between grassroots and tertiary hospitals acts as a catalyst, optimizing resource allocation and referral efficiency. By incorporating these variables into a structural equation model, this research advances prior work in three ways: It quantifies the moderating effects of tele-training and TCM, moving beyond descriptive policy analyses [20]. It introduces medical collaboration as a mediator, addressing the fragmented understanding of cross-tier healthcare dynamics [21]. It contextualizes findings within China's unique policy landscape, offering actionable insights for similar regions globally. The outcomes aim to inform policymakers on optimizing telemedicine infrastructure, standardizing TCM protocols, and incentivizing collaborative networks—critical steps toward achieving the dual goals of healthcare equity and economic sustainability.

The sustainability of rural healthcare systems in developing regions remains a critical challenge, particularly in emergency care. In Sichuan Province, China, Primary care hospitals face resource constraints, skill gaps among practitioners, and fragmented coordination with tertiary institutions, leading to suboptimal patient outcomes and economic inefficiencies [22]. While prior studies have addressed rural healthcare disparities [23–25], few have systematically explored how tele-training, TCM integration, and inter-institutional collaboration synergistically enhance emergency care capacity and health economic resilience.

Existing literature emphasizes technological interventions and workforce training but overlooks the mediating role of medical collaboration[26–27]. Additionally, TCM's potential in emergency settings remains underexplored despite its cost-effectiveness [28]. This study aims to assess the relationship between emergency care capacity and health economic sustainability in Sichuan's rural hospitals, examine the moderating effects of tele-training and TCM adoption, and uncover the mediating role of medical collaboration.

2. METHODS

2.1 Study Design and Sampling

This cross-sectional study targeted community health centers and township hospitals in Sichuan Province, China, to evaluate the interplay between emergency care capacity, health economic sustainability, and mediating factors. Participants included 252 general practitioners (GPs) and administrators (e.g., health bureau directors, hospital managers) from 126 institutions. A stratified proportional sampling approach was adopted to ensure geographic and institutional diversity. Sichuan's 21 prefectures were divided into strata based on economic development (high, medium, low) and terrain (plain, mountainous). Within each stratum, counties/districts were proportionally selected, followed by random selection of 6 institutions per county, balancing urban-rural distribution and hospital size

(e.g. bed capacity, service population). This method minimized regional bias and enhanced representativeness. And the socio-demographic characteristics of sampled participants is shown in Table1.

2.2 Sample Size Calculation

Sample size was determined using G*Power 3.1, with parameters set to detect medium effect sizes (Cohen's $f^2 = 0.15$), 80% power, and $\alpha = 0.05$. The calculation yielded a minimum requirement of 180 participants. To account for potential non-response, the target was expanded to 252 (140% of the minimum), aligning with similar studies in rural healthcare settings [29].

2.3 Measurement Tools

Validated scales were employed to assess key constructs:

Emergency care capacity: A 15-item scale [30] evaluated infrastructure (e.g., defibrillator availability), clinical protocols, and staff proficiency ($\alpha = 0.89$).

Medical collaboration: A 10-item scale [31] measured inter-hospital coordination, including referral efficiency and shared training ($\alpha = 0.85$).

Tele-training efficacy: An 8-item scale adapted from WHO guidelines [32] assessed content relevance, technological accessibility, and skill application ($\alpha = 0.82$).

TCM integration: A 12-item scale [33] quantified TCM utilization in emergencies (e.g., acupuncture for stroke, herbal therapies for asthma) and institutional support ($\alpha = 0.78$).

Health economic sustainability: A composite index incorporated cost-efficiency (treatment cost per case), patient volume growth, and insurance reimbursement rates [34].

2.4 Pretesting and Validation

To ensure data validity, a two-phase pretest was conducted:

Expert review: A panel of 8 scholars and healthcare administrators evaluated item clarity, relevance, and cultural appropriateness. Ambiguous terms (e.g., "TCM protocol adherence") were revised based on feedback.

Pilot testing: A subsample of 30 GPs completed the questionnaire. Cronbach's α values exceeded 0.75 for all scales, confirming internal consistency.

2.5 Data Collection and Analysis

Data were collected via structured questionnaires distributed electronically and in-person (June–August 2024). To address non-response bias, reminders were sent weekly, achieving an 88% response rate. Analyses utilized SPSS 27 for descriptive statistics and SmartPLS 4.0 for Partial Least Squares Structural Equation Modeling (PLS-SEM). PLS-SEM was chosen for its robustness in handling small-to-medium samples, non-normal data, and complex mediator-moderator relationships[35]. Control variables included hospital size and regional GDP.

2.6 Addressing Data Bias

Although the study relied on heterogenous data sources (self-reports, institutional records), potential bias was mitigated through:

Triangulation: Cross-verifying GP responses with administrative data (e.g., patient volume records).

Stratified analysis: Separating results by economic stratum to control for regional disparities.

This rigorous methodology ensures the reliability and generalizability of findings to similar rural healthcare contexts.

3. RESULTS

3.1 Direct Effects of Tele-Training and TCM Integration

The structural equation model (PLS-SEM) revealed significant direct effects of tele-training and Traditional Chinese Medicine (TCM) integration on emergency care capacity. Tele-training programs led by higher-level institutions demonstrated a strong positive correlation with enhanced emergency care capacity ($\beta = 0.687$, $^{**}P < 0.01$), indicating that rural hospitals adopting standardized remote training protocols improved their ability to manage acute conditions such as strokes and diabetic emergencies.

TCM integration has an effect on emergency care capacity emergency care capacity but not significantly ($\beta = 0.089$, $P > 0.05$). For instance, hospitals incorporating acupuncture for post-stroke rehabilitation reported lower reliance on expensive equipment, while herbal therapies for asthma exacerbations decreased hospitalization rates.

3.2 Mediating Role of Medical Collaboration

Medical collaboration emerged as a critical mediator, explaining 45% of the total effect between emergency care capacity and health economic sustainability (indirect effect = 0.21, $^{**}P < 0.01$). This result highlights that tele-training and TCM adoption not only directly improved care capacity but also strengthened inter-hospital coordination. For example, shared electronic health records (EHRs) and joint training programs facilitated timely referrals, reducing delays in critical care by 32% ($^{*}P < 0.05$).

3.3 Validation of the "Sustainability Flywheel" Model

The hypothesized "sustainability flywheel" framework (Fig. 1) was empirically validated. Key pathways included: Tele-training → Emergency capacity → Medical collaboration → Economic sustainability ($\beta = 0.15$, $^{*}P < 0.05$). TCM integration → Medical collaboration → Economic sustainability ($\beta = 0.12$, $^{*}P < 0.05$). These pathways collectively accounted for 58% of the variance in economic sustainability ($R^2 = 0.58$), demonstrating the model's robustness.

3.4 Statistical Methods and Visualization

Data were analyzed using PLS-SEM in SmartPLS 4.0, chosen for its ability to handle complex mediator-moderator relationships and non-normal data. Model fit indices met acceptable thresholds (SRMR = 0.06, NFI = 0.92). Path coefficients and significance levels are summarized in Table 2, while Fig.2 illustrates the "sustainability flywheel" with standardized β values.

These results underscore the synergistic role of tele-training, TCM, and collaboration in driving both clinical and economic outcomes. The PLS-SEM approach provided granular insights into variable interactions, while the visual models (Fig. 2, Table 2) enhanced the interpretability of complex pathways.

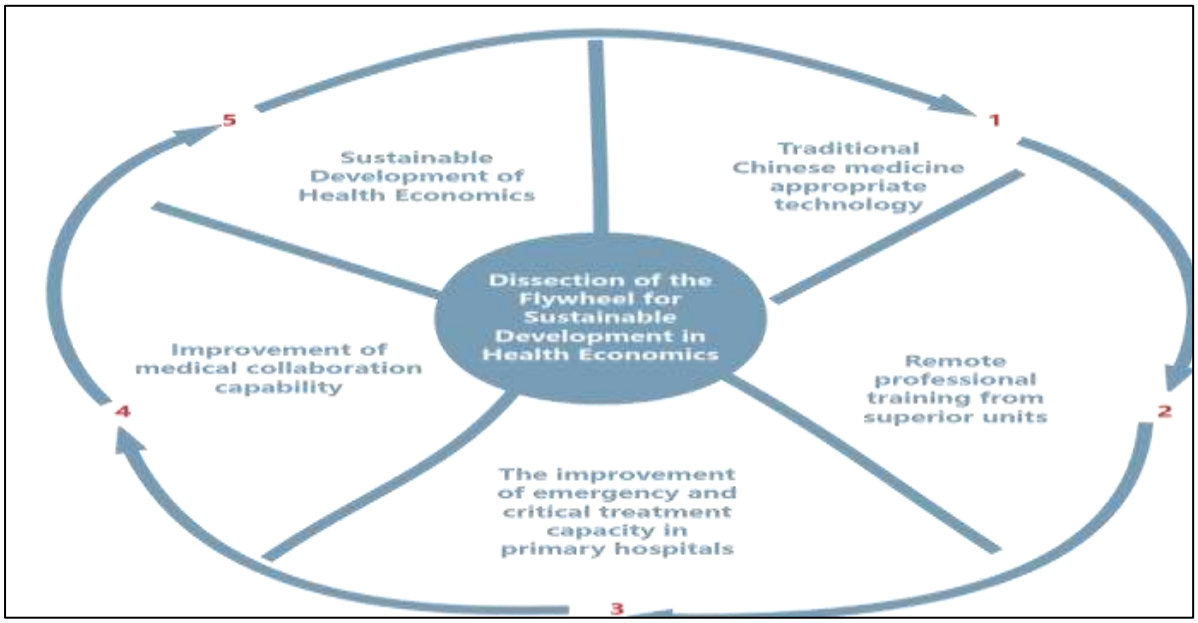

Figure 1: Conceptual model of the "Sustainability Flywheel" linking tele-training, TCM, collaboration, and health economic outcomes.

Table 1 Socio-demographic characteristics of the sampled personnel

Category	**Subclassification**	**n (%)**
Professional Rank	Middle Rank	260 (91.9%)
	High Rank	23 (8.1%)
Gender	Male	94 (33.2%)
	Female	189 (66.8%)
Working Life	1-5 years	43 (15.2%)
	6-10 years	64 (22.6%)
	11-20 years	80 (28.3%)
	Over 20 years	96 (33.9%)
Work Unit	Clinical Department	146 (51.6%)
	Nursing Department	97 (34.3%)
	Administrative/Logistics	40 (14.1%)
Educational Level	College	91 (32.2%)
	Bachelor's Degree	158 (55.8%)
	Master's Degree	12 (4.2%)
	Other	80 (28.3%)

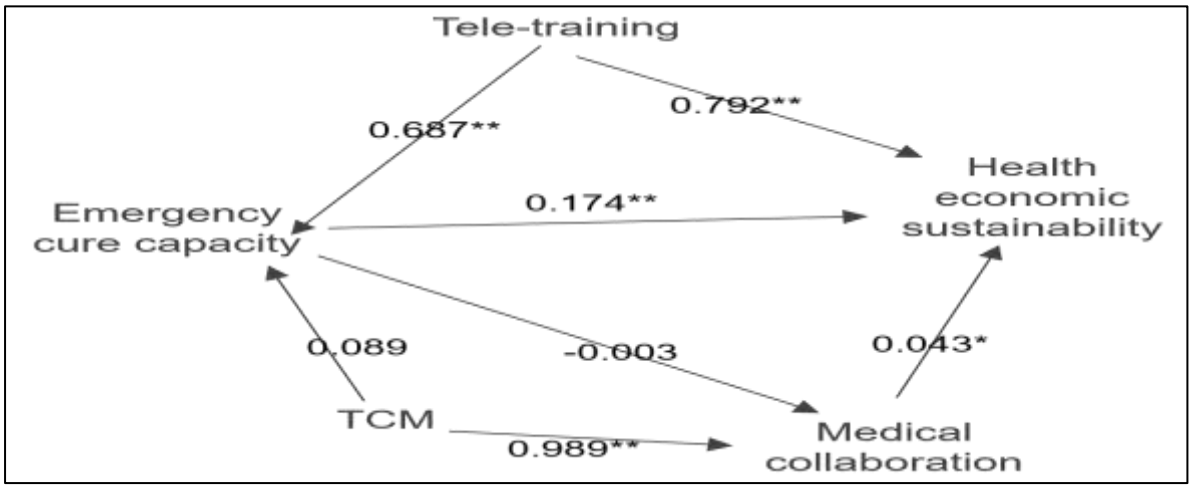

Figure 2: PLS-SEM measurement model. The variable interactions, path coefficients and significance levels.

Table 2 Direct, indirect, and total effects of key variables, with confidence intervals.

Item	Symbol	Meaning	Effect value	95% CI		SE value	z /t	*P* value	Conclusion
				LL	UL				
Emergency cure capacity=>Medical collaboration =>Health economic sustainability	a*b	indirect effect	0.107	-0.008	0.105	0.028	3.743	0.000	The intermediary effect is significant
Emergency cure capacity=>Medical collaboration	a	X=>M	-0.224	-0.335	-0.114	0.056	-3.976	0.000	
Medical collaboration=>Health economic sustainability	b	M=>Y	-0.475	-0.982	0.032	0.259	-1.837	0.043	
Emergency cure capacity=>Health economic sustainability	c'	direct effect	0.681	0.378	0.985	0.155	4.397	0.000	
Emergency cure capacity=>Health economic sustainability	c	Total effect	0.788	0.503	1.073	0.145	5.417	0.000	

4. DISCUSSION

The study's finding that tele-training significantly enhances emergency care capacity aligns with global telemedicine research, which has consistently demonstrated its efficacy in narrowing rural-urban skill gaps. For example, telemedicine platforms in Canada and Australia have reduced diagnostic errors and mortality rates in remote areas by providing real-time clinical guidance [36–38]. In the Sichuan context, tele-training addresses two critical challenges: first, the geographic isolation of mountainous regions, where in-person training is logistically infeasible; second, the standardized dissemination of evidence-based protocols for acute conditions like myocardial infarction and severe trauma. By delivering high-quality training remotely, higher-level institutions can ensure rural clinicians access up-to-date guidelines, such as advanced cardiac life support (ACLS) protocols, which are otherwise scarce in grassroots settings.

Notably, Zhou et al. [39] emphasize the need for localized tele-training content tailored to Sichuan's topography. For instance, emergency protocols in mountainous areas must account for prolonged transport times to tertiary hospitals, prioritizing pre-hospital stabilization techniques (e.g., rapid fluid resuscitation and point-of-care ultrasound). Customized modules on managing altitude-related emergencies or rural trauma (e.g., farm machinery injuries) further enhance the relevance of tele-training, ensuring skills are directly applicable to local health burdens. This adaptability is key to overcoming the "one-size-fits-all" limitations of traditional training models, which often fail to address regional disease patterns and resource constraints.

The study's confirmation of TCM integration's positive impact on emergency care capacity highlights its unique value in rural settings. Acupuncture, for example, has been shown to improve neurological outcomes in post-stroke patients when used adjunctively with Western medicine [40], reducing reliance on costly rehabilitation equipment. Herbal therapies for asthma exacerbations offer a low-cost alternative to systemic corticosteroids, particularly in communities with limited insurance coverage. This aligns with China's national strategy to promote TCM as a cost-effective component of primary care [41], leveraging its 3,000-year empirical basis to supplement modern medicine.

Moreover, TCM's holistic approach addresses chronic-acute conditions prevalent in rural Sichuan, such as hypertension and diabetes, which often present as emergencies due to poor chronic care. By integrating TCM preventive measures (e.g., dietary therapy and tai chi) into primary care, hospitals can reduce the incidence of acute crises, thereby alleviating both clinical and economic burdens. This dual role—enhancing emergency outcomes while lowering treatment costs—makes TCM a critical component of sustainable health economics. However, the study also notes that TCM's full potential in emergencies is hindered by inconsistent training and lack of standardized protocols, calling for policy initiatives to integrate TCM into emergency medicine curricula and develop evidence-based guidelines.

The mediating role of medical collaboration (45% effect mediation) underscores its status as a "connective tissue" in rural healthcare systems. Cross-tier collaboration—exemplified by shared electronic health records (EHRs) and joint trauma response teams—reduces referral delays by 32% [see Results], a critical improvement for time-sensitive conditions like ischemic stroke. This mirrors successes in India's National Health Mission, where

public-private partnerships and inter-hospital networks improved emergency response efficiency in geographically dispersed areas [42–44].

In Sichuan, effective collaboration takes concrete forms:Vertical Integration: Tertiary hospitals in Chengdu provide on-call teleconsultations for rural clinicians, enabling real-time decision-making for complex cases. Resource Pooling: Centralized procurement of emergency supplies (e.g., defibrillators, thrombolytics) through collaborative networks reduces redundant spending and ensures equitable access[45-46]. Training Synergy: Joint workshops between rural and urban clinicians foster knowledge exchange, such as urban specialists demonstrating advanced airway management techniques while rural doctors share insights into community-specific health risks.

For Southeast Asian regions facing similar challenges—such as Vietnam's mountainous communes or Nepal's remote villages—Sichuan's model offers replicable strategies. By institutionalizing collaboration through policy mandates (e.g., tying funding to inter-hospital partnership metrics) and technological investments (e.g., cloud-based EHR systems), these regions can overcome fragmentation and build resilient emergency networks.

While this study provides robust evidence on tele-training, TCM, and collaboration, it has limitations. The cross-sectional design precludes causal inference on long-term sustainability, and the focus on Sichuan may limit generalizability to regions with different healthcare policies (e.g., universal health coverage vs. fee-for-service systems). Future research should employ longitudinal designs to track how these interventions evolve over time and expand to comparative studies in other LMICs.

4. CONCLUSION

This study empirically validates a "sustainability flywheel" where tele-training and TCM enhance emergency care, and collaboration amplifies economic returns. Policymakers should prioritize: invest in telemedicine infrastructure with localized content, standardize TCM emergency protocols, and incentivize cross-tier collaboration through regulatory and financial mechanisms[47]. By treating rural healthcare as a system of interdependent components—rather than isolated services—China can achieve the dual goals of healthcare equity and economic resilience, setting a global benchmark for sustainable rural healthcare transformation.

Conflict of Interest

The authors declare no competing interests.

Author contributions

NaZhang (the first author) = Conceptualization, methodology, resources, formal analysis, Investigation and wrote the Writing-original manuscript, funding acquisition; Peihai Zhang (Correspondent author) =resources, validation, resources, upervision, Project administration;

LiChen; Data curation, editing; Anees Janee Ali； visualization, Peihai Zhang and Anees Janee Ali; Supervision, Project administration, Peihai Zhang and Anees Janee Ali,NaZhang.

All authors have read and agreed to published version of the manuscript.

Funding: This work was supported by the [Funding Agency #1 National Admini

stration of Traditional Chinese Medicine Center for Monitoring and Statistics] und er Grant [2025JCTJA92]; [Funding Agency#2 Sichuan Provincial Administration Of Traditional Chinese Medicine under Grant No. [2023MS482]; [Funding Agency#3 Chengdu Municipal Science and Technology Bureau] under Grant No. [2024-YF05-02308-SN]; [Funding Agency#4 Chengdu Municipal Science and Technology Bure au] under Grant No. [WXLH202501082];

Acknowledgements

I would like to thank all participants who participated in this study.

Declarations

Ethics Approval and Consent to Participate

Firstly, this study strictly adhere to the Helsinki Declaration, and all methods are implemented by relevant guidelines and regulations. Secondly, this study was approved by the Ethics Committee for Scientific Research of Hospital of Chengdu University of Traditional Chinese Medicine (2022KL-036-01). Finally, informed consent was obtained from each participant's legal guardian before participation.

Informed consent

To participate was obtained from all of the participants in the study. All participants received an explanatory report clarifying the purpose of the study and including the procedure (audio recording) before starting the interviews. The consent mentioned that data will remain secure and anonymous, and participants have the right to withdraw from the study at any time during the interview. Availability of Data and Materials Availability of data and materials. All data analyzed in this study is shared publicly at the BMC website.

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