Vol. 4. No.2. 2026 E-ISSN 2987- 2081

Holistic Nursing PLUS
Pillars, Longevity, Ubiquitary, Solicitude

SAKU
SAHABAT PUBLIKASI KUU

Implementation of a Nola J. Pender-Based Health Promotion E-Module to Improve Knowledge and Treatment Adherence Among Patients with Pulmonary Tuberculosis

Khaireza Rindang Kamudi[1], Ani Syafriati[2]

[1] Nursing Science Study Program, Faculty of Health Sciences, Universitas Muhammadiyah Surakarta, Jl. Ahmad Yani, Pabelan, Kartasura, Surakarta 57162, Central Java, Indonesia
[2] Nursing Science Study Program, Faculty of Health Sciences, Universitas Muhammadiyah Surakarta, Jl. Ahmad Yani, Pabelan, Kartasura, Surakarta 57162, Central Java, Indonesia

Academic Editor: Anisa Febristi
Received: 15 August 2026
Accepted: 26 October 2026
Published: 31October 2026

Publisher's Note: HNP stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2026 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

Abstract

Background: Pulmonary tuberculosis (TB) remains a major public health concern, requiring effective educational strategies to improve patient knowledge and treatment adherence.

Purpose: This study evaluated the effectiveness of a Nola J. Pender's Health Promotion Model-based educational e-module in improving knowledge and treatment adherence among patients with pulmonary TB.

Methods: A quasi-experimental pretest–posttest control group study was conducted at RSUP Surakarta, Central Java, Indonesia. Fifty participants were included, comprising 26 in the intervention group and 24 in the control group. The intervention group received e-module-based education, while the control group received routine education. Data were analyzed using the Wilcoxon signed-rank and Mann–Whitney U tests.

Results: Knowledge improved significantly in the intervention group ($Z = -4.309$, $p < 0.001$), with 24 participants improving. Treatment adherence also improved significantly ($Z = -3.651$, $p < 0.001$), with 21 participants improving. Between-group differences were significant for knowledge ($U = 172.000$, $p = 0.006$) and treatment adherence ($U = 156.000$, $p = 0.002$), with higher mean ranks in the intervention group.

Conclusions: The Health Promotion Model-based e-module may improve knowledge and treatment adherence among patients with pulmonary TB. Further studies with larger samples and longer follow-up are recommended.

Keywords: pulmonary tuberculosis; Health Promotion Model; educational e-module; knowledge; treatment adherence.

Introduction

Tuberculosis (TB) is a chronic infectious disease caused by Mycobacterium tuberculosis. It is transmitted primarily through airborne particles released when an individual with infectious TB coughs, sneezes, or speaks, which may subsequently be inhaled by susceptible individuals (Suprayogi, 2021).

Tuberculosis remains a major global public health concern despite ongoing efforts to control its transmission and reduce its burden.

According to the Global Tuberculosis Report 2024, approximately 10.8 million people developed TB worldwide in 2023, with an estimated 1.25 million deaths attributable to the disease. TB was the second leading cause of death from a single infectious agent globally, following COVID-19. The global burden included deaths among people with TB and HIV coinfection, as well as deaths among HIV-negative individuals. Indonesia accounted for approximately 10% of the global TB burden, ranking second worldwide after India (26%), while China accounted for approximately 7% (Ministry of Health of the Republic of Indonesia, 2023). These figures highlight the need to strengthen public knowledge, treatment adherence, and TB control through effective and evidence-based interventions.

In Indonesia, provinces across Java, as well as North Sumatra and South Sulawesi, have been identified as major contributors to the national TB burden, with each reporting more than 40,000 cases (Aksi Nyata Percepatan Eliminasi Tuberkulosis di Indonesia, 2025). According to the Ministry of Health of the Republic of Indonesia (2023), Central Java recorded 70,882 TB cases in 2022, accounting for approximately 10.2% of the 694,808 cases reported nationally. In Surakarta, Central Java, the local health authorities recorded 314 TB cases. The persistently high number of cases underscores the need for effective interventions to strengthen TB prevention, promote early detection, and improve patients' adherence to prescribed treatment regimens.

Health promotion is an essential intervention for improving patients' knowledge, attitudes, and health behaviors related to TB treatment adherence. One theoretical framework that can guide such interventions is the Health Promotion Model (HPM), developed by Nola J. Pender. This model emphasizes the roles of individual characteristics and experiences, behavior-specific cognitions and affect, and interpersonal and situational influences in shaping health-promoting behaviors (Alligood, 2019). In the context of pulmonary TB, the HPM can provide a framework for helping patients understand the importance of taking medication regularly, recognize potential adverse effects, and strengthen their motivation to complete the prescribed treatment regimen (Almeleebia et al., 2021).

Advances in digital technology have created opportunities to deliver health promotion interventions through more accessible and engaging educational approaches, including electronic modules (e-modules). An e-module is a digital learning resource that can be accessed at different times and locations, potentially facilitating continuous learning and reinforcing health-related knowledge. Previous studies have suggested that e-module-based education can improve knowledge and support treatment adherence among patients with chronic diseases (Vasiliu et al., 2024). However, the application of an e-module explicitly grounded in

Pender's Health Promotion Model to improve knowledge and treatment adherence among patients with pulmonary TB in Indonesia remains insufficiently explored (Alligood, 2019; Boom et al., 2021).

Previous studies have also highlighted the potential value of structured and digitally supported educational interventions in TB prevention and control. Zhang et al. (2024) emphasized the importance of strengthening community health education, particularly among family members of patients with TB, to interrupt transmission and support the success of TB control programs. Such educational initiatives should focus on practical knowledge and the adoption of preventive behaviors. Similarly, Pi et al. (2025) reported the need to improve knowledge and treatment-related practices among patients with pulmonary TB, particularly regarding the importance of adherence to long-term treatment and the prevention of drug-resistant TB. Structured educational interventions, family support, and monitoring by healthcare professionals are essential components of efforts to improve treatment outcomes.

Furthermore, Almaghaslah and Almanasef (2024) concluded that educational background influences knowledge, attitudes, and practices (KAP) related to TB. Their findings support the expansion of community-based health education beyond healthcare students to include the broader academic community, with the aim of increasing awareness, reducing stigma, and promoting preventive behaviors. In Oman, Khalili et al. (2022) found that public knowledge of TB remained inadequate, particularly regarding its modes of transmission, prevention, and the importance of completing treatment. Misconceptions persisted, including the belief that TB is hereditary or caused by non-infectious factors, highlighting the need for accurate and accessible public health information. Similarly, Bashorun et al. (2020) identified the need for comprehensive public health interventions in The Gambia, including enhanced public education, anti-stigma campaigns, and improved access to TB services, particularly in remote areas.

Taken together, these findings indicate the importance of developing accessible, theory-driven educational interventions that address both TB-related knowledge and treatment adherence. Integrating Pender's Health Promotion Model into an e-module may provide a structured approach to promoting patients' understanding of TB treatment, strengthening motivation for adherence, and supporting sustained health-promoting behaviors. Therefore, this study aims to evaluate the implementation of a Pender's Health Promotion Model-based health promotion e-module and its effects on knowledge and treatment adherence among patients with pulmonary tuberculosis.

Materials and Methods

Design

This study employed a quantitative quasi-experimental design with a pretest–posttest control group approach to evaluate the effects of health promotion based on Nola J. Pender's Health Promotion Model (HPM), delivered through an electronic module (e-module), on knowledge and treatment adherence among patients with pulmonary tuberculosis (TB). This design was selected to assess changes in the outcome variables before and after the intervention and to compare these changes between the intervention and control groups without full randomization of participants.

The intervention group received HPM-based health promotion education through an e-module, whereas the control group received routine health education provided by the healthcare facility without the additional e-module intervention. Knowledge and treatment adherence were assessed in both groups before and after the intervention using the same measurement instruments. The differences in pretest and posttest scores were examined to evaluate the effects of the intervention.

Participants and Setting

The study was conducted at Surakarta Central General Hospital (RSUP Surakarta), Central Java, Indonesia, a referral healthcare facility providing services for patients with pulmonary TB. The study protocol initially specified a study period from March to May 2026. The actual participant recruitment and data collection dates should be reported in accordance with the approved research protocol and institutional authorization.

The target population comprised all patients diagnosed with pulmonary TB who were registered and actively receiving treatment at RSUP Surakarta during the study period. The planned sample size was 73 participants, calculated using Slovin's formula with a 5% margin of error. Participants were recruited through purposive sampling based on predefined eligibility criteria and assigned to the intervention and control groups according to the quasi-experimental study design.

The inclusion criteria were: (1) a diagnosis of pulmonary TB and registration at RSUP Surakarta; (2) active participation in a prescribed TB treatment regimen; (3) age 18 years or older; (4) the ability to read and understand the e-module materials; and (5) willingness to participate and provide written informed consent.

The exclusion criteria were: (1) serious comorbid conditions that could substantially affect adherence to TB treatment, such as end-stage renal disease or advanced cancer; (2) cognitive or communication impairments that prevented participation in the e-module intervention; (3) concurrent participation in

another research program that could influence the study outcomes; and (4) withdrawal from the study before completion.

The final numbers of participants recruited, allocated to each group, and included in the analysis should be reported based on the actual study records.

Ethical consideration

The study received ethical approval from the Research Ethics Committee of Surakarta Central General Hospital (RSUP Surakarta), Indonesia, under approval number BP.01.01/46/06/2026, issued on 4 June 2026. The approval covered the research proposal entitled "Implementation of Nola J. Pender-Based Health Promotion Through an E-Module on Knowledge and Treatment Regimen Adherence Among Patients with Pulmonary Tuberculosis." The approved protocol was identified as Study Protocol Version 01 (2025), and the informed consent form was identified as Version 01 (2025).

All eligible participants were to receive clear information regarding the study objectives, procedures, potential benefits, and possible risks before enrollment. Written informed consent was obtained before participation. Participation was voluntary, and participants were informed that they could decline or withdraw from the study at any time without adverse consequences for the healthcare services they received.

Participant confidentiality was maintained by using numerical identification codes instead of personal names in the analytical dataset. Research data were handled securely and used for academic and scientific purposes. The research team was responsible for minimizing potential risks, respecting participants' rights and dignity, and reporting serious adverse events and protocol deviations to the relevant ethics committee in accordance with the approval requirements.

Data collection

Data collection comprised instrument preparation, baseline assessment, implementation of the intervention, and post-intervention assessment. The study instruments consisted of an HPM-based health promotion e-module, a pulmonary TB knowledge questionnaire, and a treatment adherence questionnaire.

Before implementation, the e-module was developed according to the principles of Pender's HPM. The educational materials addressed pulmonary TB, including its definition, causes, symptoms, complications, and treatment regimen. The module also incorporated educational content intended to strengthen perceptions of treatment benefits, address perceived barriers, enhance self-efficacy, encourage interpersonal support, and promote commitment to recommended health behaviors.

The e-module underwent expert review to assess its content relevance, accuracy, language clarity, suitability for patients with pulmonary TB, and alignment with HPM. The knowledge and treatment adherence questionnaires were also subjected to content validity assessment. A permit issued by the Surakarta City Health Office on 10 April 2026 authorized the implementation of validity and reliability testing of the questionnaires at Sangkrah Community Health Center (Puskesmas Sangkrah). The testing focused on questionnaire items addressing knowledge of pulmonary TB and adherence to prescribed medication. The permit documented authorization to conduct the testing; the numerical validity and reliability results must be reported separately based on the actual test output.

At baseline, both groups completed the knowledge and treatment adherence assessments before the intervention. The intervention group subsequently received health promotion education through the HPM-based e-module, either independently or with guidance from the researcher or healthcare personnel. Participants' engagement with the module was documented during the educational sessions.

The control group continued to receive routine health education and standard TB care without the additional e-module intervention. After completion of the intervention period, both groups completed the same assessment instruments to measure post-intervention knowledge and treatment adherence.

The pulmonary TB knowledge questionnaire consisted of multiple-choice questions covering disease definitions, causes, symptoms, complications, and treatment regimens. Knowledge scores were calculated on a scale of 0–100 and categorized as good (≥76%), moderate (56–75%), or poor (≤55%), according to the study protocol.

Treatment adherence was assessed using a questionnaire with a four-point Likert response scale. The instrument evaluated adherence to prescribed medication schedules, attendance at routine follow-up appointments, and compliance with other relevant treatment procedures. The protocol specified total-score categories of high adherence (31–40), moderate adherence (21–30), and non-adherence (<20). The final scoring procedure and category boundaries should be verified against the finalized questionnaire and scoring guide before publication.

Data analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS). Data preparation included checking questionnaire completeness, coding responses, verifying data entry, identifying duplicate records, and examining potential outliers. Descriptive statistics were used to summarize participants' characteristics and outcome measures.

Categorical variables were presented as frequencies and percentages. Continuous variables were summarized using means and standard deviations for approximately normally distributed data or medians and interquartile ranges for non-normally distributed data, as appropriate.

The Shapiro–Wilk test was used to assess the normality of continuous outcome scores. For normally distributed data, paired-samples t-tests were used to compare pretest and posttest scores within each group, while independent-samples t-tests were used to compare outcomes between the intervention and control groups. For non-normally distributed data, the Wilcoxon signed-rank test was used for within-group comparisons, and the Mann–Whitney U test was used for between-group comparisons.

The primary outcomes were changes in pulmonary TB knowledge and treatment adherence following the intervention. The findings were interpreted by examining pretest and posttest scores and differences between the intervention and control groups. Where appropriate, between-group differences in change scores, effect sizes, and 95% confidence intervals should also be reported to provide estimates of the magnitude and precision of the intervention effects. All statistical tests were two-sided, with statistical significance set at $p < 0.05$.

Trustworthiness

The methodological rigor of this quantitative study was supported by content validation, reliability assessment, standardized data collection procedures, and systematic data management.

The content validity of the HPM-based e-module was assessed through expert review. The reviewers evaluated the relevance, accuracy, clarity, and alignment of the educational materials with Pender's HPM and the study objectives. The knowledge and treatment adherence questionnaires were also reviewed for the relevance and clarity of their items in measuring the intended outcomes.

Validity and reliability testing of the questionnaires was authorized by the Surakarta City Health Office, with testing designated to take place at Puskesmas Sangkrah. The knowledge questionnaire covered pulmonary TB knowledge and treatment regimens, whereas the adherence questionnaire addressed medication-taking behavior, follow-up attendance, and other prescribed treatment procedures.

Internal consistency was planned to be assessed using Cronbach's alpha, with a coefficient of ≥0.70 considered acceptable. The actual Cronbach's alpha coefficients, item-level validity results, and number of respondents involved in instrument testing should be reported based on the completed statistical analyses. These values should not be inferred from the testing authorization letter.

To support measurement consistency, the same instruments and standardized administration procedures were used for pretest and posttest assessments in both groups. Data quality was further supported by checking questionnaire completeness, verifying data entry, and cleaning the dataset before statistical analysis.

Results

A total of 50 respondents were included in the univariate analysis. The analysis was conducted to describe the distribution of respondents according to study group, age category, sex, educational level, knowledge level, and treatment adherence. The findings provide an overview of the respondents' demographic characteristics and their baseline distribution across the measured outcome categories.

Table 1. Demographic Characteristics, Knowledge Level, and Treatment Adherence of Respondents

Variables	Categories	Frequency (n)	Percentage (%)
Study group	Intervention	26	52.0
	Control	24	48.0
Age category	Young adults	14	28.0
	Middle-aged adults	8	16.0
	Older adults	18	36.0
	Elderly	10	20.0
Sex	Male	32	64.0
	Female	18	36.0
Educational level	Elementary school	9	18.0
	Junior high school	10	20.0
	Senior/vocational high school	22	44.0
	Bachelor's/master's/doctoral degree	9	18.0
Knowledge level	Good	32	64.0
	Moderate	17	34.0
	Poor	1	2.0
Treatment adherence	High adherence	30	60.0
	Moderate adherence	20	40.0
	Low adherence	0	0.0
Total		**50**	**100.0**

Regarding study group allocation (Table 1), 26 respondents (52.0%) belonged to the intervention group, while 24 (48.0%) were in the control group. In terms of age, the largest proportion of respondents were classified as older adults (36.0%), followed by young adults (28.0%), older people or older adults in the elderly category (20.0%), and middle-aged adults (16.0%). Male respondents accounted for 64.0% of the sample (n = 32), whereas female respondents accounted for 36.0% (n = 18).

Regarding educational attainment, the largest proportion of respondents had completed senior high school or vocational high school (44.0%). Meanwhile, 20.0% had completed junior high school, and 18.0% each had completed elementary school and tertiary education (bachelor's, master's, or doctoral degree).

For knowledge level, 32 respondents (64.0%) were categorized as having good knowledge, 17 (34.0%) had moderate knowledge, and one respondent (2.0%) had poor knowledge. With respect to treatment adherence, 30 respondents (60.0%) demonstrated high adherence, while 20 (40.0%) were categorized as having moderate adherence. No respondents were classified as having low adherence in the reported frequency distribution.

Overall, the univariate findings indicate that the sample was predominantly male, the largest age category was older adults, and senior high school or vocational high school was the most common educational level. Most respondents were classified as having good knowledge and high treatment adherence. These descriptive findings provide the basis for subsequent analyses examining differences in knowledge and treatment adherence between the intervention and control groups.

Table 2. Tests of Normality for Knowledge and Treatment Adherence Scores

Variable	Kolmogorov–Smirnov Statistic	df	p-value	Shapiro–Wilk Statistic	df	p-value
Pretest knowledge	0.129	26	0.200*	0.963	26	0.445
Posttest knowledge	0.161	26	0.081	0.898	26	0.014
Pretest treatment adherence	0.113	26	0.200*	0.976	26	0.770
Posttest treatment adherence	0.160	26	0.087	0.917	26	0.038

Because the sample size was 26, the Shapiro–Wilk test was considered in interpreting normality. The pretest knowledge scores ($p = 0.445$) and pretest treatment adherence scores ($p = 0.770$) did not show statistically significant departures from normality. In contrast, the posttest knowledge scores ($p = 0.014$) and posttest treatment adherence scores ($p = 0.038$) showed statistically significant departures from normality at the 0.05 level.

Table 3. Tests of Normality by Study Group

Outcome variable	Study group	Kolmogorov–Smirnov Statistic	df	p-value	Shapiro–Wilk Statistic	df	p-value
Knowledge level	Intervention	0.161	26	0.081	0.898	26	0.014

Outcome variable	Study group	Kolmogorov –Smirnov Statistic	df	p-value	Shapiro–Wilk Statistic	df	p-value
Knowledge level	Control	0.129	24	0.200*	0.941	24	0.172
Treatment adherence	Intervention	0.160	26	0.087	0.917	26	0.038
Treatment adherence	Control	0.123	24	0.200*	0.927	24	0.083

Based on the Shapiro–Wilk test, knowledge scores in the intervention group ($p = 0.014$) and treatment adherence scores in the intervention group ($p = 0.038$) deviated significantly from normality at the 0.05 level. In the control group, knowledge scores ($p = 0.172$) and treatment adherence scores ($p = 0.083$) did not show statistically significant departures from normality.

Table 4. Wilcoxon Signed-Rank Test Results for Knowledge and Treatment Adherence

Outcome	Rank category	n	Mean rank	Sum of ranks	Z	p-value
Knowledge	Negative ranks (posttest > pretest)	24	12.50	300.00	-4.309	<0.001
	Positive ranks (posttest < pretest)	0	0.00	0.00		
	Ties (posttest = pretest)	2	—	—		
	Total	**26**	**—**	**—**		
Treatment adherence	Negative ranks (posttest > pretest)	21	13.19	277.00	-3.651	<0.001
	Positive ranks (posttest < pretest)	3	7.67	23.00		
	Ties (posttest = pretest)	2	—	—		
	Total	**26**	**—**	**—**		

The Wilcoxon signed-rank test showed a statistically significant difference between pretest and posttest knowledge scores ($Z = -4.309$, $p < 0.001$). Knowledge scores increased in 24 respondents, remained unchanged in two respondents, and decreased in none. These findings indicate a significant improvement in knowledge scores after the intervention.

A statistically significant difference was also observed between pretest and posttest treatment adherence scores ($Z = -3.651$, $p < 0.001$). Treatment adherence scores increased in 21 respondents, decreased in three respondents, and remained unchanged in two respondents. Overall, the results indicate a significant improvement in treatment adherence scores after the intervention.

Table 5. Mann–Whitney U Test Comparing Knowledge and Treatment Adherence Between Study Groups

Outcome	Study group	n	Mean rank	Sum of ranks	Mann–Whitney U	Z	p-value
Knowledge level	Intervention	26	30.88	803.00	172.000	-2.761	0.006
Knowledge level	Control*	24	19.67	472.00			
Treatment adherence	Intervention	26	31.50	819.00	156.000	-3.047	0.002
Treatment adherence	Control*	24	19.00	456.00			

The Mann–Whitney U test indicated a statistically significant difference in knowledge levels between the intervention and control groups (U = 172.000, Z = −2.761, p = 0.006). The intervention group had a higher mean rank (30.88) than the control group (19.67), indicating higher knowledge scores in the intervention group.

A statistically significant between-group difference was also observed in treatment adherence (U = 156.000, Z = −3.047, p = 0.002). The intervention group had a higher mean rank (31.50) than the control group (19.00), indicating higher treatment adherence scores in the intervention group.

These findings indicate that knowledge and treatment adherence scores differed significantly between the two study groups. Because the output does not identify the measurement time point, the manuscript should specify whether these comparisons refer to posttest scores or another assessment. If they represent posttest results, baseline comparability should also be considered when interpreting the intervention effect.

Discussion

Effects of the Nola J. Pender-Based Health Promotion E-Module on Knowledge

The findings of this study demonstrate a statistically significant improvement in knowledge among patients with pulmonary tuberculosis (TB) following the implementation of a health promotion intervention delivered through an electronic module (e-module) based on Nola J. Pender's Health Promotion Model (HPM). The Wilcoxon signed-rank test showed a significant difference between pretest and posttest knowledge scores (Z = −4.309, p < 0.001). Among the 26 participants in the intervention group, 24 experienced an increase in knowledge scores, whereas two showed no change. No participants experienced a decrease in knowledge scores. Furthermore, the Mann–Whitney U test revealed a significant difference in knowledge scores between the intervention and control groups (U = 172.000, Z = −2.761, p = 0.006). The intervention

group demonstrated a higher mean rank than the control group (30.88 versus 19.67), suggesting better knowledge outcomes in the intervention group.

These findings are consistent with the growing body of evidence supporting digital health education as a strategy for improving TB-related knowledge and treatment-related behaviors. Ridho et al. (2022), in a systematic review of randomized controlled trials, identified several digital health technologies used to support TB medication adherence and treatment outcomes, including text-message reminders, video-observed therapy, and electronic medication monitoring. Their findings highlight the potential of digital approaches to complement conventional TB care, although effectiveness varies according to the intervention and outcome measured. Similarly, Kaaffah et al. (2023), in a multicenter study conducted in Indonesia, highlighted the importance of understanding knowledge, attitudes, and perceptions related to TB in developing appropriate public health interventions. Together, these findings support the need for educational strategies that address disease-specific knowledge while considering patients' sociocultural and educational backgrounds.

The observed improvement in knowledge may be explained by the structured and accessible nature of the e-module. Unlike brief, one-time educational encounters, digital learning materials can provide systematically organized information that patients can review repeatedly. The module can also present complex information about TB transmission, treatment duration, potential adverse effects, and the consequences of interrupted treatment in a more organized format. Repeated exposure to accurate information may help patients consolidate their understanding and correct misconceptions that could otherwise interfere with treatment-related decision-making.

Evidence from recent studies further supports the potential value of digital interventions in TB care. Huda et al. (2024), in a meta-analysis of technology-based interventions involving 4,794 participants, reported that such interventions were associated with improved medication adherence, although the pooled estimates for treatment completion and treatment success were less conclusive. The authors also reported substantial heterogeneity across studies, indicating that digital interventions should not be considered uniformly effective across all settings. In addition, Syahrul et al. (2025) reviewed mobile application-based interventions for pulmonary TB and identified improvements in several adherence-related outcomes, including medication-taking behavior, treatment completion, and attendance at healthcare appointments. These findings are relevant to the present study because they suggest that digital education may provide a useful means of reinforcing disease knowledge and supporting patients throughout the treatment process.

Nevertheless, the present findings should be interpreted in relation to the specific intervention and outcomes assessed. Knowledge improvement does not necessarily translate into sustained behavioral change or successful completion of TB treatment. Although knowledge is an important prerequisite for informed health-related decisions, patients may continue to encounter practical and psychosocial barriers, including medication adverse effects, financial difficulties, limited family support, and treatment fatigue. Therefore, the educational value of an e-module should be considered alongside the need for ongoing clinical guidance and individualized treatment support.

Effects of the Intervention on Treatment Adherence

The present study also identified a statistically significant improvement in treatment adherence following the intervention. The Wilcoxon signed-rank test demonstrated a significant difference between pretest and posttest adherence scores ($Z = -3.651$, $p < 0.001$). Of the 26 participants in the intervention group, 21 showed an increase in adherence scores, three showed a decrease, and two showed no change. The Mann–Whitney U test also indicated a statistically significant difference between the intervention and control groups ($U = 156.000$, $Z = -3.047$, $p = 0.002$). The intervention group had a higher mean rank than the control group (31.50 versus 19.00), indicating comparatively higher adherence scores in the intervention group.

These findings are consistent with evidence from trials evaluating digital adherence technologies among patients receiving TB treatment. Liu et al. (2023), in a cluster-randomized trial conducted in China, evaluated an intervention combining medication reminders, healthcare-provider review of adherence data, and differentiated care for patients experiencing adherence difficulties. Their study illustrates the importance of integrating digital monitoring with responsive healthcare-provider support rather than relying on technology alone. Similarly, Manyazewal et al. (2022) evaluated a digital medication event reminder and monitor device in a multicenter randomized controlled trial in Ethiopia. Their study demonstrated the feasibility of incorporating digital adherence monitoring into TB treatment services and highlighted the importance of evaluating digital approaches in real-world healthcare settings.

More recent evidence reinforces the potential role of digital interventions in TB treatment support. Wei et al. (2024) evaluated a comprehensive intervention based on electronic medication monitors in a multicenter randomized controlled trial in Tibet, China. Their research provides further evidence that digital monitoring should be considered within a broader package of treatment support. Santosa et al. (2025), in a systematic review and meta-analysis of randomized controlled trials, reported that digital adherence technologies were associated with significantly higher medication adherence than directly observed therapy

in the included studies. However, their findings also indicated that effectiveness varied according to the technology used and the economic context of implementation.

The present study extends this evidence by examining a digital educational intervention explicitly guided by a nursing theoretical framework. While many digital adherence interventions focus primarily on reminders, medication monitoring, or reporting of missed doses, an HPM-based e-module is intended to strengthen the cognitive and motivational processes underlying health-promoting behavior. This distinction is important because treatment adherence involves more than remembering when to take medication. Patients must understand the rationale for treatment, recognize the consequences of interruption, develop confidence in their ability to follow the prescribed regimen, and identify practical strategies for overcoming barriers.

The higher mean rank observed in the intervention group suggests that the e-module may have contributed to better treatment adherence outcomes than routine health education alone. Nevertheless, adherence is influenced by multiple interacting factors, including treatment-related adverse effects, perceived disease severity, family support, accessibility of healthcare services, and the quality of communication with healthcare professionals. Accordingly, the intervention is best understood as a potentially useful component of patient-centered TB care rather than a substitute for clinical monitoring and comprehensive adherence support.

Interpretation Through Pender's Health Promotion Model

Pender's Health Promotion Model provides a useful theoretical framework for interpreting the observed improvements in knowledge and treatment adherence. The model conceptualizes health-promoting behavior as the result of interactions among individual characteristics and experiences, behavior-specific cognitions and affect, and behavioral outcomes. Relevant constructs include perceived benefits, perceived barriers, self-efficacy, interpersonal influences, situational influences, and commitment to a plan of action.

In the present study, the e-module may have supported the development of health-promoting behavior by providing information about the benefits of completing TB treatment and the risks associated with interrupted medication use. Improved understanding of these benefits may strengthen patients' motivation to adhere to the prescribed regimen. Educational content that addresses perceived barriers and strategies for managing treatment-related difficulties may also help patients develop more realistic plans for maintaining adherence during the treatment period.

The model's emphasis on self-efficacy is particularly relevant. Patients who understand their treatment but lack confidence in their ability to manage medication schedules, attend follow-up appointments, or respond appropriately to adverse effects may still experience adherence difficulties. An educational intervention that reinforces practical skills and encourages patients to seek assistance when problems arise may help strengthen confidence in treatment self-management.

The relevance of HPM-based digital education is supported by Javadzade et al. (2024), who investigated web-based education guided by Pender's Health Promotion Model among patients with cardiovascular disease. Although their study involved a different clinical population, it provides evidence for the applicability of theory-guided digital education in supporting health-promoting and self-care behaviors. The conceptual relevance of this approach to TB care lies in its focus on behavioral determinants rather than information delivery alone.

However, the present study measured knowledge and treatment adherence rather than all the cognitive and interpersonal constructs specified in HPM. Consequently, the results support the potential usefulness of an HPM-informed educational intervention but do not establish that changes in self-efficacy, perceived benefits, perceived barriers, or interpersonal influences mediated the observed outcomes. Future studies should measure these constructs directly to determine which theoretical mechanisms contribute most strongly to improved adherence.

Digital Health Education and the Indonesian TB Care Context

The use of e-modules may be particularly relevant in settings where healthcare professionals have limited time for repeated face-to-face education. A structured digital resource can standardize the information delivered to patients and provide a reference that remains accessible beyond individual consultations. This may be useful for reinforcing instructions about medication schedules, follow-up appointments, treatment duration, and the importance of communicating with healthcare professionals when adverse effects occur.

Nevertheless, digital accessibility should not be equated with universal accessibility. Patients may differ in digital literacy, reading ability, access to smartphones, internet connectivity, and familiarity with electronic learning materials. These differences may affect the extent to which patients can engage with the module and benefit from its content. For this reason, digital education should be designed to accommodate diverse educational backgrounds and should provide alternative forms of support when patients experience difficulty accessing or understanding the materials.

Evidence concerning digital adherence technologies also indicates that improvements in adherence measures do not always translate into consistent improvements in clinical outcomes. Mohamed et al. (2025), in a systematic review and meta-analysis, reported variable effects of digital adherence technologies across different TB outcomes and study settings. Their findings emphasize the need to distinguish behavioral outcomes from treatment success and to account for differences in intervention design, implementation, and healthcare context.

Similarly, Tadesse et al. (2025) evaluated digital adherence technology interventions in a pragmatic, cluster-randomized trial in Ethiopia, demonstrating the continuing importance of evaluating these approaches under routine program conditions. Taken together, this evidence suggests that an HPM-based e-module should be integrated into a broader system of TB care that includes healthcare-provider communication, follow-up, and support for patients experiencing treatment difficulties.

Clinical and Nursing Implications

The findings have several implications for nursing practice. First, nurses can incorporate structured digital educational materials into routine TB counseling to reinforce information delivered during consultations. Second, the content of these materials should be tailored to patients' knowledge levels and practical treatment needs rather than focusing exclusively on disease definitions and biomedical information. Third, nurses should assess barriers to adherence and provide individualized guidance when patients report adverse effects, difficulties maintaining medication schedules, or problems attending follow-up appointments.

An HPM-based e-module may also support continuity of education between clinical encounters. By providing a consistent reference, it can help patients revisit important information and prepare questions for subsequent consultations. However, digital resources should complement rather than replace interpersonal communication, particularly when patients require clarification, emotional support, or assistance with treatment-related problems.

For implementation at the healthcare-facility level, the module should be evaluated for usability, readability, cultural appropriateness, and compatibility with patients' access to digital devices. Integration with routine nursing workflows may also require staff training, clear referral pathways for patients experiencing adverse effects, and a mechanism for identifying individuals who need additional adherence support.

Conclusions

This study found statistically significant improvements in knowledge and treatment adherence following the implementation of an HPM-based health promotion e-module among patients with pulmonary TB. Significant differences were also observed between the intervention and control groups, with higher mean ranks in the intervention group for both outcomes. These findings suggest that theory-informed digital education may be a useful component of nursing interventions to strengthen TB-related knowledge and support treatment adherence. However, the results should be interpreted in light of the sample size, quasi-experimental design, and need to establish the timing of between-group comparisons. Further research should assess longer-term adherence, clinical treatment outcomes, and the behavioral mechanisms underlying the potential benefits of HPM-based digital education.

Declaration of Interest

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

Acknowledgment

The authors would like to express their sincere gratitude to the management and healthcare professionals of RSUP Surakarta, Central Java, Indonesia, for their support and assistance during the research process. The authors also thank all patients who participated in this study for their time and valuable contributions. Their participation was essential to the completion of this research.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy and confidentiality considerations concerning the study participants.

Bibliography

Al Khalili, S., Al Yaquobi, F., Al Abri, B., Al Thuhli, K., Al Marshoud, S., Al Rawahi, B., & Al-Abri, S. (2022). Assessing Oman's knowledge, attitude and practice regarding tuberculosis: A cross-sectional study that calls for action. International Journal of Infectious Diseases, 124(Suppl. 1), S4–S11. https://doi.org/10.1016/j.ijid.2022.06.002.

Bashorun, A. O., Linda, C., Omoleke, S., Kendall, L., Donkor, S. D., Kinteh, M.-A., Danso, B., Leigh, L., Kandeh, S., D'Alessandro, U., & Adetifa, I. M. O. (2020). Knowledge, attitude and practice towards tuberculosis in Gambia: A nation-wide cross-sectional survey. BMC Public Health, 20, Article 1566. https://doi.org/10.1186/s12889-020-09685-3.

Huda, M. H., Rahman, M. F., Zalaya, Y., Mukminin, M. A., Purnamasari, T., Hendarwan, H., et al. (2024). A meta-analysis of technology-based interventions on treatment adherence and treatment success among TBC patients. PLOS ONE, 19(12), e0312001. https://doi.org/10.1371/journal.pone.0312001

Javadzade, H., Vahedparast, H., Khodaminasab, A., Tahmasebi, R., Reisi, M., & Kiani, J. (2024). The effect of web-based education on self-care behaviors in cardiovascular patients: Application of the Pender's Health Promotion Model. Archives of Public Health, 82, 64. https://doi.org/10.1186/s13690-024-01299-0

Jerene, D., van Kalmthout, K., Levy, J., Alacapa, J., Deyanova, N., Dube, T., et al. (2025). Effect of digital adherence technologies on treatment outcomes in people with drug-susceptible tuberculosis: Four pragmatic, cluster-randomised trials. The Lancet, 405(10485), 1155–1166. https://doi.org/10.1016/S0140-6736(24)02847-2.

Kaaffah, S., Kusuma, I. Y., Renaldi, F. S., Lestari, Y. E., Pratiwi, A. D. E., & Bahar, M. A. (2023). Knowledge, attitudes, and perceptions of tuberculosis in Indonesia: A multi-center cross-sectional study. Infection and Drug Resistance, 16, 1787–1800. https://doi.org/10.2147/IDR.S404171

Kandasamy, G., Almaghaslah, D., & Almanasef, M. (2024). Knowledge, attitude and practice towards tuberculosis among healthcare and non-healthcare students at a public university in Saudi Arabia. Frontiers in Public Health, 12, Article 1348975. https://doi.org/10.3389/fpubh.2024.1348975

Kementerian Kesehatan Republik Indonesia. (2025, March 25). Aksi nyata percepatan eliminasi tuberkulosis di Indonesia. https://www.kemkes.go.id/id/47510/Pada-2025-target-nasional.

Liu, X., Thompson, J., Dong, H., Sweeney, S., Li, X., Yuan, Y., et al. (2023). Digital adherence technologies to improve tuberculosis treatment outcomes in China: A cluster-randomised superiority trial. The Lancet Global Health, 11(5), e693–e703. https://doi.org/10.1016/S2214-109X(23)00068-2

Manyazewal, T., Woldeamanuel, Y., Holland, D. P., Fekadu, A., Marconi, V. C., et al. (2022). Effectiveness of a digital medication event reminder and monitor device for patients with tuberculosis (SELFTB): A multicenter randomized controlled trial. BMC Medicine, 20, 310. https://doi.org/10.1186/s12916-022-02521-y

Mohamed, M. S., Zary, M., Kafie, C., Chilala, C. I., Bahukudumbi, S., Foster, N., et al. (2025). The impact of digital adherence technologies on treatment outcomes, adherence, and patient-reported outcomes in tuberculosis: A systematic review and meta-analysis. BMC Infectious Diseases, 25, 1314. https://doi.org/10.1186/s12879-025-11503-3

Pi, Y., Tan, J., Yang, P., Pan, J., Yang, X., Xiang, M., & Li, T. (2025). Knowledge, attitude, and practice toward antitubercular agents among pulmonary tuberculosis patients in southwestern China: A cross-sectional study. Patient Preference and Adherence, 19, 1615–1624. https://doi.org/10.2147/PPA.S520100

Ridho, A., Alfian, S. D., van Boven, J. F. M., Levita, J., Yalcin, E. A., Le, L., et al. (2022). Digital health technologies to improve medication adherence and treatment outcomes in patients with tuberculosis: Systematic review of randomized controlled trials. Journal of Medical Internet Research, 24(2), e33062. https://doi.org/10.2196/33062

Santosa, A., Juniarti, N., Pahria, T., et al. (2025). Digital adherence technology to improve medication adherence in tuberculosis patients: A systematic review and meta-analysis randomized control trials. npj Primary Care Respiratory Medicine, 35, 52. https://doi.org/10.1038/s41533-025-00457-3

Syahrul, S., Irwan, A. M., Saleh, A., Syam, Y., Fiqri, A. M., & Jannah, S. N. (2025). Effectiveness of mobile application-based intervention on medication adherence among pulmonary tuberculosis patients: A systematic review. CIN: Computers, Informatics, Nursing, 43(4), e01213. https://doi.org/10.1097/CIN.0000000000001213

Tadesse, A. W., Sahile, M., Foster, N., McQuaid, C. F., Weldemichael, G. T., Abdurhman, T., et al. (2025). Digital adherence technology interventions to reduce poor end-of-treatment outcomes and recurrence among adults with drug-sensitive tuberculosis in Ethiopia: A three-arm, pragmatic, cluster-randomised, controlled trial. The Lancet Digital Health, 7(9), 100895. https://doi.org/10.1016/j.landig.2025.100895

Wei, X., Hicks, J. P., Zhang, Z., Haldane, V., Pasang, P., Li, L., et al. (2024). Effectiveness of a comprehensive package based on electronic medication monitors at improving treatment outcomes among tuberculosis patients in Tibet: A multicentre randomised controlled trial. The Lancet, 403(10430), 913–923. https://doi.org/10.1016/S0140-6736(23)02270-5

World Health Organization. (2024). Global tuberculosis report 2024. World Health Organization. https://www.who.int/publications/i/item/9789240101531