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Research Article

Cost-effectiveness analysis of TB-R (Tuberculosis Reminder) application implementation for pulmonary tuberculosis patient management in hospitals across underdeveloped regions of Indonesia

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ABSTRACT

Pulmonary tuberculosis (TB) remains a major health problem in Indonesia. Patient adherence to long-term therapy is a challenge, impacting the effectiveness and cost of healthcare. Technological innovations such as the Tuberculosis Reminder (TB-R) application have the potential to support more effective and efficient treatment. This study evaluates the cost-effectiveness of implementing the TB-R application on the management of pulmonary TB patients in Indonesia. This study was conducted at a hospital in a disadvantaged district of Indonesia (Pandeglang). A quasi-experimental study was conducted in a hospital in a disadvantaged area, with 66 pulmonary TB patients divided into an intervention group (using the TB-R application) and a control group (without the TB-R application). Data were collected through medical records, AFB smear examinations, radiology, and treatment cost summaries. Cost-effectiveness analysis was calculated using the Incremental Cost-Effectiveness Ratio (ICER), and sensitivity analysis was performed. Therapeutic effectiveness, defined as treatment success based on negative conversion of Acid-Fast Bacillus (AFB) smear and improvement in chest radiology findings at the end of the intervention period, was higher in the TB-R group (63.6%) compared with the control group (30.3%). The total treatment cost per patient was also lower (IDR 698,182 vs. IDR 741,818). The ICER value of -IDR 130,909 indicates that the TB-R group was dominant (more effective and less expensive) than the control group. Sensitivity analysis showed that the parameters influencing the ICER value were the results of the Acid-Fast Bacillus (AFB) and radiology examinations. TB-R has been proven to be a cost-effective intervention in the treatment of pulmonary TB, with higher clinical effectiveness and cost-efficiency.

Keywords:
Cost-effectiveness; Digital application; Pulmonary tuberculosis

1. INTRODUCTION

Pulmonary tuberculosis (TB) remains a serious global public health problem, with Indonesia ranking second globally in terms of TB caseload after India. By 2023, there are an estimated 1,060,000 TB cases in Indonesia, with a death rate of 134,000 per year[1]. The bacteria Mycobacterium tuberculosis cause this disease and attack the lungs, which, if not treated properly, can cause serious complications, further transmission, and even death[2,3]. In addition to significant clinical and social impacts, pulmonary TB also poses a substantial economic burden for patients, their families, and the health system[4]. The costs of treatment, diagnosis, transportation, loss of productivity due to illness, and the potential development of drug resistance (MDR-TB),

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which requires more complex and expensive treatment regimens, cumulatively contribute to a very large cost burden[5,6]. Patient adherence to long-term treatment regimens is key to mitigating this burden, but it is often challenging. Pulmonary TB treatment requires strict adherence for at least six months. Non-adherence can lead to treatment failure, relapse, and the development of drug resistance (MDR-TB), which is much more difficult and expensive to treat[7,8].

With the advancement of digital technology, mobile apps have shown great potential in supporting chronic disease management, particularly in improving patient adherence. These apps offer reminders and health education features, which can bridge the communication gap between patients and healthcare providers. Previous studies in various health areas, such as diabetes and hypertension, have shown that app-based interventions can significantly improve medication adherence and clinical outcomes[9–12]. In the TB context, several technology-based initiatives have begun to be explored to strengthen program compliance and efficiency[13].

The TB-R (Tuberculosis Reminder) app is a digital innovation designed to help TB patients manage their treatment more effectively. The app features daily medication reminders, educational information about TB, and the importance of adherence[14]. The aim is to address common barriers to adherence, such as forgetting to take medication or a lack of understanding about the disease, thereby hopefully increasing the success rate of treatment and reducing the incidence of MDR-TB.

Although the TB-R application is promising in increasing compliance among pulmonary TB patients[14], There has been no comprehensive evaluation of the cost-effectiveness of its implementation in Indonesia. Given limited health resources and the high burden of TB, economic evaluation is crucial to ensure that investments in health technology provide the best value. This study aims to determine the cost-effectiveness of implementing the TB-R application for managing pulmonary TB patients in Indonesia. The results of this study are expected to provide a strong evidence base for policymakers to make informed decisions regarding integrating the TB-R application into the national TB control program.

2. MATERIALS AND METHODS

2.1. Research design

A Cost-Effectiveness Analysis (CEA) study was conducted using a quasi-experimental method to assess the cost-effectiveness of using the TB-R application at Berkah Pandeglang Regional General Hospital. This study used payer and healthcare perspectives, collecting data from March to May 2025. Patients in the intervention group used the TB-R application continuously for 2 months (8 weeks), and clinical outcomes were assessed at baseline and at the end of the follow-up period using AFB smear results and chest radiology findings. Inclusion criteria for patients in this study were pulmonary tuberculosis patients in the advanced treatment phase who had complete medical records and treatment cost data. The total number of patients in the intervention and control groups was 66.

A formal sample size calculation was not performed because this study applied a quasi-experimental approach using total sampling. All eligible pulmonary TB patients who met the inclusion criteria and had complete medical and cost records during the study period were included. Group allocation was non-randomized; patients who agreed and were able to use the TB-R application (including smartphone availability) were assigned to the intervention group, while those who did not use the application were assigned to the control group.

2.2. Use of TB-R application (intervention)

The TB-R application is an Android-based mobile application designed to support pulmonary TB treatment adherence through medication reminders and tuberculosis-related education, allowing patients to download and use it flexibly on their smartphones. Its main features include a user profile, OAT reminders, and educational materials. The use of OAT reminders is considered effective because it can improve patient compliance and is expected to accelerate the healing process. The TB-R application works by sending automatic daily reminders for the appropriate OAT intake times[14] The intervention, which used the TB-R application, was intended to improve medication adherence, a crucial factor in successful TB treatment. Therefore, increased effectiveness was interpreted as an increase in the number of patients cured in the intervention group compared to the control group.

The TB-R application is provided free of charge to patients. During the study period, the application was managed and maintained by the research team in collaboration with hospital staff. The reminder system operates through automated one-way notifications delivered to the patient’s smartphone based on a predefined medication schedule. The application does not provide direct two-way communication with healthcare providers; however, patients may use the information provided in the application to support communication during routine clinic visits.

2.3. Outcome measurement

Tools to measure patient adherence using the Medication Adherence Report Scale-5 (MARS-5) as the output in this study, an internationally validated instrument for assessing medication adherence. The MARS-5 questionnaire was used for academic research purposes with appropriate citation of the original validated source, and no modifications were made to the original instrument.

The MARS-5 questionnaire consists of five items describing patient medication habits, such as forgetting to take medication, changing doses without instructions, or discontinuing medication independently. Each item is on a Likert scale of 1–5, with a score of 1 indicating very frequent non-adherence and a score of 5 indicating never non-adherence. The total score ranges from 5–25, with higher scores reflecting better adherence. In this study, patients with a score of ≥ 20 were categorised as adherent, while those with < 20 were classified as non-adherent[15]. Compliance measurements were carried out on both groups, namely the intervention group (TB-R application users) and the control group (non-TB-R application users).

The primary outcome measure in this study was treatment success (binary outcome: success vs. non-success), defined according to the Indonesian Ministry of Health criteria as cure or treatment completion with bacteriological conversion and chest radiology. Treatment success was coded as 1 (success) if AFB smear conversion was negative at follow-up and radiological findings showed clinical improvement, and coded as 0 (non-success) otherwise. Treatment success was defined as a composite endpoint, requiring both bacteriological conversion (AFB negative) and radiological improvement at follow-up.

2.4. Treatment costs and cost of the application implementation

The cost analysis in this study uses a payer and healthcare perspective, focusing on direct medical costs. Under the payer perspective, costs reflected the reimbursed expenditures covered by the national health insurance scheme for outpatient visits, diagnostic tests, radiology examinations, and anti-tuberculosis drugs. Under the healthcare perspective, costs reflected the hospital's direct medical service costs recorded in the hospital financial system for the same components. In this study, both perspectives included the same types of direct medical resources; however, the unit values differed depending on reimbursement tariffs (payer) and internal hospital cost records (healthcare).

Direct medical costs were calculated based on actual resource utilization extracted from patient billing and hospital cost records, including outpatient visit costs, laboratory tests (AFB smear), radiology examinations (chest X-ray), and anti-tuberculosis drug (OAT) costs. All costs were calculated per patient by summing each component throughout the treatment period. Cost data was obtained from the financing installation and the pulmonary clinic at Berkah Pandeglang Regional Hospital. Cost components included: (1) outpatient visit costs, (2) laboratory examination costs (including AFB smear tests), (3) radiology costs (chest X-ray), and (4) anti-tuberculosis drug costs (OAT). Costs were reported in Indonesian Rupiah (IDR) and presented as mean cost per patient for both groups.

The cost of implementing the TB-R application was not included as a separate cost component because this study was conducted primarily from the payer perspective, which captures reimbursed direct medical expenditures only. During the study period, there was no established reimbursement policy or standardized tariff for digital health technology interventions (including software development, maintenance, technical support, and training). Therefore, these intervention costs could not be identified or valued using the payer reimbursement records. The difference in direct medical costs to patients was due to the frequency of hospital visits. All fees are presented in Indonesian Rupiah (IDR).

2.5. Incremental cost-effectiveness ratio (ICER)

This study uses ICER calculations to determine the additional costs incurred to obtain additional effectiveness from using the TB-R application compared to not using the application(16–18). The ICER value is then interpreted to determine whether the intervention with the TB-R application is more cost-effective, more effective, or falls into the dominant category (both more effective and cheaper) compared to the control group. The ICER was calculated using the following formula:

$$\text{ICER} = \frac{\text{C\_intervention} - \text{C\_control}}{\text{C\_intervention} - \text{C\_control}}$$

where C represents the mean total direct medical cost per patient and E represents the proportion of patients achieving treatment success.

2.6. Sensitivity analysis

A univariate (one-way) sensitivity analysis was conducted to investigate the impact of input parameter variations on the ICER. Each parameter was varied by ±25% of its baseline value or within a clinically/economically reasonable range, while other parameters were held constant (Table 1). The base-case values used in the sensitivity analysis were derived

Table 1. List of input parameters used, base values, and ±25% variation

Input Parameters	Core Values	Variation (±25%)
X-ray results	81.82%	102.3%-61.4%
Treatment cost per patient	IDR 698,182	IDR 523,636.5 – 872,727.5
BTA examination results	72.73%	54.5%-90.9%

from the main cost-effectiveness model inputs applied in the ICER calculation (mean cost per patient and treatment success probability). These baseline parameters represent the comparative model between the intervention and control groups rather than group-specific values.

Input parameters used in the sensitivity analysis were selected based on their clinical and economic relevance to the ICER results and the availability of valid data. The parameters tested included: reatment success rate (results of X-ray and AFB examination), and treatment costs per case. The results of the sensitivity analysis will be presented in the form of a tornado diagram[19,20].

2.7. Data analysis

Data analysis was conducted to assess the effect of TB-R application usage on the cost-effectiveness of pulmonary tuberculosis patient treatment. Statistical tests were selected based on the type and distribution of the data. Normally distributed numerical data were analysed using parametric tests, while non-normally distributed or categorical data were analysed using non-parametric tests. The statistical significance threshold was set at $p < 0.05$.

Comparison of average treatment costs between the intervention and control groups was analysed using Welch's two-sample t-test was applied because the cost data showed unequal variances between groups and cost distributions are commonly heteroscedastic in healthcare economic evaluations. The relationship between TB-R app use and patient recovery rates was analysed using Pearson's Chi-Square test. When the expected frequency in the contingency table was less than five, Fisher's Exact test was used as an alternative. The results of Fisher's Exact test are not only reported based on the p-value but also interpreted through the Odds Ratio (OR), Confidence Interval (CI 95%), and χ^2 values to provide a more comprehensive picture of the strength and direction of the relationship between variables.

Exploratory regression analysis was initially planned; however, due to the limited sample size, the final analysis focused on bivariate comparisons of costs and outcomes between groups and sensitivity analysis. The relationship between medication adherence and treatment costs was analysed using Spearman's rank correlation because adherence data were ordinal and not normally distributed. All analyses were performed using R-Studio statistical software.

3. RESULTS

3.1. Characteristics of pulmonary TB patients

The age distribution of patients between the TB-R app user group and the control group showed no statistically significant difference. However, the intervention group was dominated by elderly patients (>60 years). Similar differences were also seen in gender and employment status, where the proportions between the two groups were relatively balanced and no significant differences ($p > 0.05$). However, an important difference was found in medication adherence ($p = 0.012$). The TB-R user group showed a significantly higher adherence rate than the control group (Table 2).

Treatment adherence was 86.4%, which is quite high. This high level of adherence in this group can be attributed to the technological support of the TB-R app, which provides medication reminders, scheduled check-ups, and self-education.

3.2. Cost analysis

Direct costs in this study included patient visits, supporting examinations, and medication. In the context of this study, the average direct medical cost per outpatient visit, based on hospital accounting and billing records, was IDR 180,000, which included service fees, basic examinations, and some standard medication for pulmonary TB. The total cost for each patient was calculated by multiplying this per-visit rate by the number of patient visits during the treatment period. Therefore, the difference in total costs between groups was primarily influenced by the frequency of patient visits. As shown in Table 3, the average total cost for the TB-R group was IDR 23,040,000 (IDR 698,182/patient), while for the control group it was IDR 24,480,000 (IDR 741,818/patient). This difference indicates that the implementation of TB-R reduced the economic burden by almost 5,9%. The control group required more frequent follow-up visits mainly due to lower adherence and delayed clinical improvement, resulting in repeated laboratory and radiology monitoring.

Table 2. Characteristics of Pulmonary TB Patients

No	Characteristics	TB-R	No TB-R	Total	Statistical test	P value
1	**Age (Years)**					
	Mean ± SD	50.32 ± 16.52	44.15 ± 15.64	47.23 ± 16.28	Independent t-test	0.270
	Median (IQR)	55.50	45.00	45.00		
	18-28	7 (21.2%)	7 (21.2%)	14 (21.2 %)		
	29-39	4 (12.1%)	8 (24.2%)	12 (18.2 %)		
	40-50	5 (15.2%)	4 (12.2%)	9 (13.6 %)		
	51-60	5 (15.2%)	8 (24.2%)	13 (19.7 %)		
	>60	12 (36.4%)	6 (18.2%)	18 (27.3 %)		
2	**Sex**					
	Female	10 (30.3%)	15 (45.5%)	25 (37.9)	Independent t-test	0.208
	Male	23 (69.7%)	18 (54.5%)	41 (62.1)		
3	**Employment Status**					
	Work	27 (81.8%)	27 (81.8%)	54 (81.8%)	Independent t-test	0.827
	Doesn't work	6 (18.2%)	6 (18.2%)	12 (18.2%)		
4	**Medication Adherence**					
	Adherent	32 (97%)	25 (75.8%)	57 (86.4%)	Independent t-test	0.012
	Non-adherent	1 (3%)	8 (24.2%)	9 (13.6%)		
Total Patients		33 (100%)	33 (100%)	66 (100%)		

During standard TB treatment, patients generally attend routine follow-up visits (typically monthly) for clinical monitoring, drug refills, and supporting examinations. The TB-R application may reduce additional unscheduled visits by improving adherence through daily reminders and educational support, thereby minimizing treatment interruptions and the need for repeated clinical reassessment. Specific TB-R features that may contribute to reducing unnecessary hospital visits include automated daily medication reminders, educational modules regarding treatment importance, and notification prompts encouraging patients to follow scheduled visits rather than making unscheduled visits due to missed doses.

3.3. Treatment effectiveness analysis

Based on Table 4, the effectiveness of therapy in this study was defined as the successful conversion of AFB and radiological status to negative. The TB-R group (using TB-R) showed an effectiveness of 63.6%, it higher than the control group (30.3%). Differences in the effectiveness proportion between groups were tested using the Pearson Chi-Square test, with Fisher's Exact test as an alternative if the expected frequency was <5. Overall treatment success (composite endpoint of AFB conversion and radiological improvement) was significantly higher in the TB-R group (63.6%) compared with the control group (30.3%) ($\chi^2 = 7.32$; $p = 0.0068$). However, when analysed separately, AFB conversion alone showed a borderline difference (Fisher’s exact test $p = 0.077$), while radiological improvement did not reach statistical significance ($p > 0.05$). The Odds Ratio (OR) of 4.025 (95% CI: 1.41–11.50) indicated that patients in the TB-R group were 4 times more likely to achieve therapy success than the control group.

Table 3. Cost Analysis

Cost Analysis	TB-R	No TB-R	Statistical test	P-Value
Total cost	IDR 23,040,000	IDR 24,480,000	Independent t-test	0.010
Average Cost	IDR 698,182	IDR 741,818		

Table 4. Effectiveness of TB-R Application Therapy

Group	Effective	Percentage (%)	Ineffective	Percentage (%)	Total	Persentase (%)
TB-R	21	63.6	12	36.4	33	100
No TB-R	10	30.3	23	69.7	33	100
Statistical test	Fisher's exact test					
p-Value	0.008					

The Fisher's exact test showed p = 0.077 (nearly significant), indicating a tendency for the control group to have a lower chance of AFB conversion than the intervention group (Figure 1a). Analysis of radiological examinations did not find a statistically significant difference (p > 0.05) in the proportion of radiological conversions between the two groups. However, a trend of lower positive radiological values in the intervention group compared to the control group (OR = 0.39) was still observed (Figure 1b).

3.4. Cost-effectiveness analysis

The cost-effectiveness analysis in this study used the Incremental Cost-Effectiveness Ratio (ICER) to compare the costs and effectiveness between the TB-R group (using the TB-R application) and the Control group (without TB-R). The cost-effectiveness analysis demonstrated that the TB-R intervention was dominant, as it resulted in lower costs and higher treatment success compared with the control group. This reduction in cost per successful treatment strengthens TB-R's position as a health technology that supports cost efficiency in TB control programs (Table 5). With its limited TB program budget and high disease burden, interventions with low cost-effectiveness ratios are crucial for adoption in the Indonesian context. The efficiency demonstrated by the low ICER value also provides a strong argument for a value-based healthcare approach.

3.5. Sensitivity analysis

Sensitivity analysis showed that the TB-R application remained cost-effective across various parameter change scenarios. The obtained Incremental Cost-Effectiveness Ratio (ICER) values indicated that the application was highly effective at a lower cost, thus declaring this intervention cost-efficient (Figure 2a).

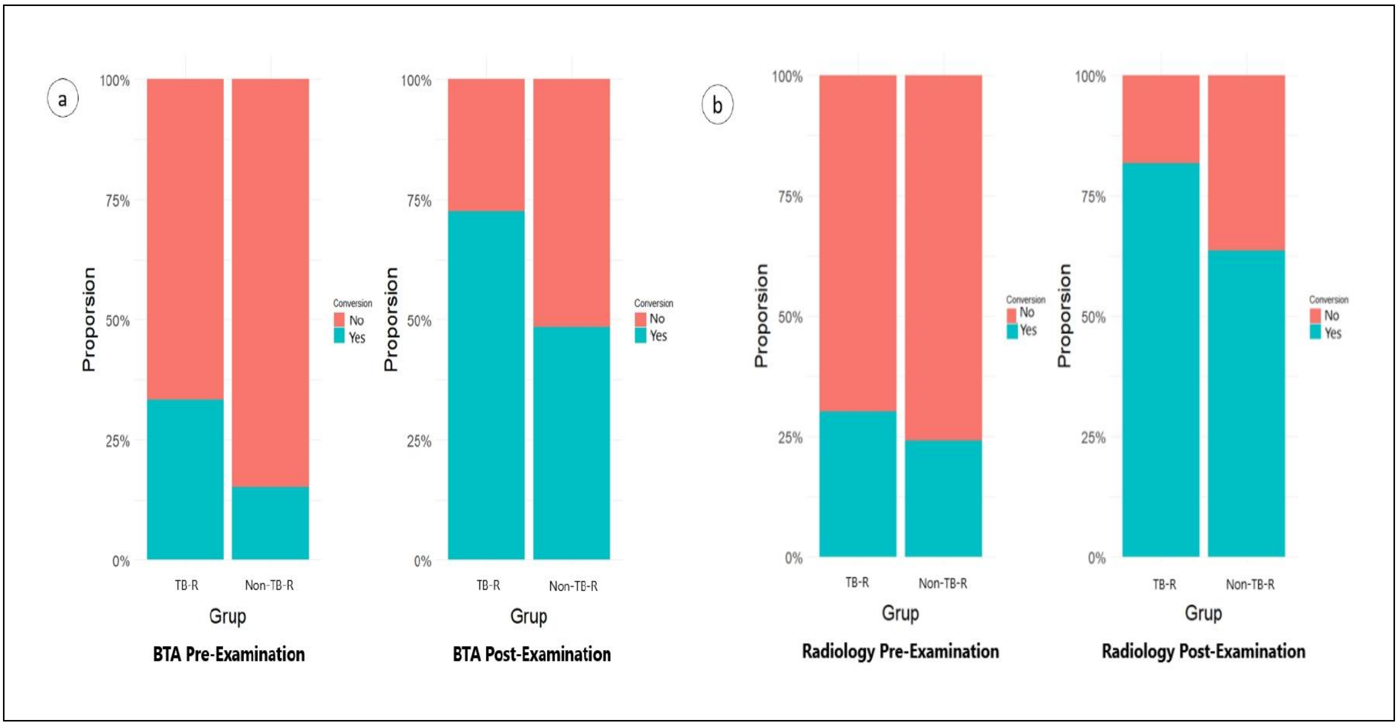

Figure 1. (a) Result of the Analysis of the Relationship between Intervention and BTA. (b) Result of the Analysis of the Relationship between Intervention and Radiological Examination Results.

Table 5. ICER calculation

Group	Average cost per patient (IDR)	Effectiveness	Cost difference (IDR)	Difference in effectiveness	ICER (IDR)
TB-R	698,182	0,636	-43,631	0.333	-130,909
No TB-R	741,818	0.303			

Welch's t-test results showed a significant difference in average costs between patients with negative and positive radiological results ($p < 0.001$) (Figure 2b). Fisher's exact test analysis showed that the intervention group had almost 4 times higher odds of achieving cost-effectiveness than the control group (OR = 3.93; $p = 0.013$) (Figure 2c). The results of the Spearman correlation analysis showed no statistically significant relationship between changes in adherence (Δ Adherence) and total treatment costs (rho = –0.144; $p = 0.249$) (Figure 2d).

4. DISCUSSION

Regarding patient characteristics, WHO data (2022) shows that the elderly and male age groups dominate the number of global TB cases, which is often associated with high workloads, exposure to unhealthy environments, and unequal access to health services[21]. Men are more vulnerable due to higher levels of mobility, exposure to heavy work, smoking, and less supportive health behaviors. Our study confirmed this tendency, as the TB-R group was dominated by elderly patients (>60 years). Moreover, the use of the TB-R application significantly increased medication adherence, supporting findings from Mohammed et al. (2021) in Ethiopia[22].

In terms of cost analysis, the reduced average cost in the TB-R group aligns with Cooper et al. (2016), who reported that digital interventions can reduce patient costs by up to 48%[23]. This is particularly relevant in Indonesia, where most TB patients belong to lower-middle economic groups and financial barriers often lead to treatment dropout.

Effectiveness analysis showed that TB-R improved treatment outcomes, with users being four times more likely to achieve therapy success than the control group. This is consistent with the Health Belief Model (HBM), which highlights the role of perceived benefits in motivating adherence[24]. The findings also align with global studies and meta-analyses confirming that digital adherence technologies (DATs) such as VOT, SMS reminders, and mobile applications enhance TB treatment completion[4,25–30].

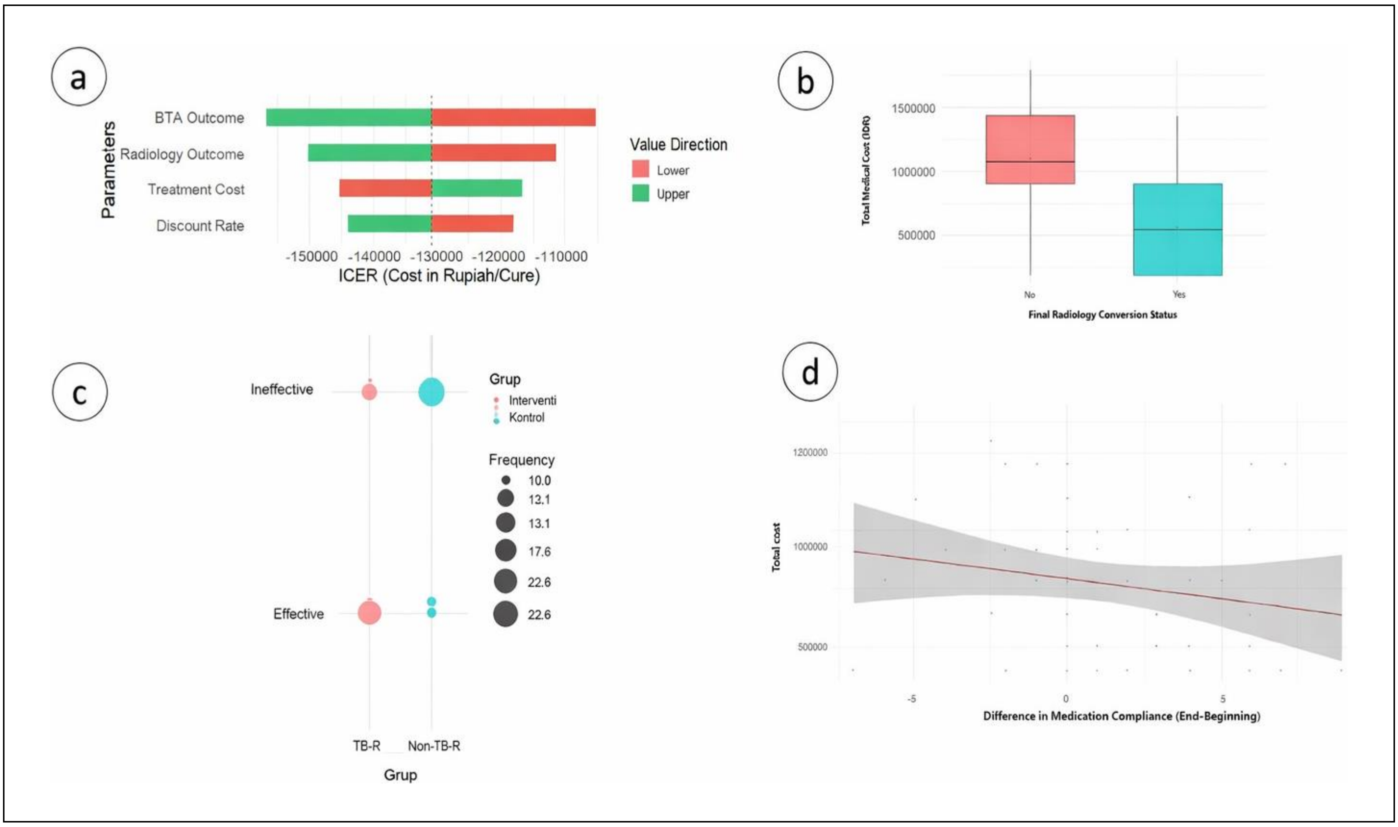

Figure 2. (a) Tornado Diagram of Sensitive Analysis Results. (b) Results of the Analysis of the Relationship between Radiology Results and Cost Burden. (c) Results of the Group Relationship Analysis and Cost Effectiveness. (d) Results of the Analysis of the Relationship between Compliance and Cost.

Although radiological conversion differences were not statistically significant, the observed trend toward better outcomes in the TB-R group is in line with Li et al. (2025), who emphasized that radiological healing requires longer treatment and is affected by cavitary lesions[31]. This suggests that longer follow-up is essential to capture TB-R's clinical benefits fully.

From a cost-effectiveness perspective, the negative ICER demonstrates TB-R as a “dominant” strategy, both cost-saving and clinically superior. This agrees with Kafie et al. (2024), who found that digital tools such as VOT were more cost-effective than conventional DOT[32]. Similarly, Miladi et al. (2025) showed that reminder technologies reduce costs by improving management and preventing complications[33]. According to Indonesian pharmacoeconomic guidelines, such interventions are highly recommended for integration into national TB programs[34].

The sensitivity analysis further confirms TB-R’s robustness, showing that clinical parameters (such as AFB and radiological results) were the most influential in determining cost-effectiveness. This resonates with WHO (2021), which identifies digital transformation in TB care as a global priority for achieving the End TB Strategy[1]. Nevertheless, the sensitivity to adherence probability and direct cost parameters highlights the importance of complementary strategies such as healthcare worker training, psychosocial support, and community-based approaches.

The discussion confirms that TB-R is effective in clinical and economic terms and aligns with international and national health priorities. Its implementation may contribute directly to strengthening Indonesia’s health system, reducing the burden of TB, and supporting the achievement of Universal Health Coverage (UHC).

Although the intervention group included a high proportion of elderly patients, the TB-R application was designed with a simple interface and was introduced with direct assistance from healthcare staff. In addition, some elderly patients were supported by family members in operating the smartphone, which may explain the relatively high adherence despite older age. Although the intervention group included a high proportion of elderly patients, the TB-R application was designed with a simple interface and was introduced with direct assistance from healthcare staff. In addition, some elderly patients were supported by family members in operating the smartphone, which may explain the relatively high adherence despite older age.

A key limitation of this quasi-experimental study is the potential for selection bias and confounding, particularly because medication adherence was significantly higher in the TB-R group. Patients who were willing and able to use the application may have been more motivated to adhere to therapy, which could partly explain the higher success rate observed. Therefore, the observed effectiveness difference may not be solely attributable to the TB-R intervention.

A limitation of this study is that the cost of implementing and administering the TB-R application was not included. This exclusion was due to the absence of an official reimbursement mechanism or standardized payer tariff for digital health interventions in Indonesia at the time of the study. Consequently, the findings reflect cost-effectiveness based on direct medical costs only, and future studies should incorporate intervention costs when reimbursement policies become available.

5. CONCLUSIONS

In conclusion, the results of this study indicate that the intervention group using TB-R showed a higher therapeutic success rate (63.6%) compared to the control group (30.3%), with a lower average total cost of care (IDR 698,182 vs. IDR 741,818 per patient). The Incremental Cost-Effectiveness Ratio (ICER) value of -IDR 130,909 indicates that this intervention is dominant, providing better clinical outcomes at lower costs compared to without TB-R.

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Conflict of interest

The authors of this study have no conflict of interest.

Ethics approval

This research has obtained Ethical Clearance from the Health Research Ethics Committee of Muhammadiyah University of Purwokerto (KEPK-UMP), registration number KEPK/UMP/148/II/2025. This ensures that all research procedures were conducted according to applicable research ethics principles.

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