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IMPROVING TUBERCULOSIS CONTROL IN NIGERIA: AN mHEALTH INTERVENTION STUDY ON CLINIC-APPOINTMENT ATTENDANCE AND MEDICATION-ADHERENCE IN LAGOS STATE, NIGERIA

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ABSTRACT: ***Background***: *Tuberculosis (TB) remains a major public health challenge in Nigeria, with non-adherence to medication and clinic appointments significantly hindering disease control. Mobile health (mHealth) interventions, such as SMS and phone-calls, offer a promising approach to improve treatment adherence in resource-limited settings; however, evidence on their comparative and combined effectiveness remains limited in Nigeria. This study aimed to evaluate the impact of SMS and phone-call interventions on medication adherence and clinic appointment attendance among TB patients in Lagos State, Nigeria.*

Methods: *A quasi-experimental study was conducted across 12 Directly Observed Treatment Short-course (DOTS) centres in four Local Government Areas of Lagos State, Nigeria. A total of 128 adults receiving TB treatment were allocated to four groups: SMS reminders every two days, bi-weekly phone-call reminders, a combined SMS and phone-call intervention, and standard care (control). Data were collected at baseline, 6th week, and 12th week follow-up. Clinic appointment attendance and medication adherence were analysed using age and education-level-adjusted generalized estimating equation (GEE) models with robust standard errors.*

Results: *After adjusting for age and education, phone-calls and SMS significantly improved clinic appointment attendance compared to controls (phone-calls: OR = 2.97, 95% CI: 1.72–5.12; SMS: OR = 1.92, 95% CI: 1.05–3.50). Phone-calls were also most effective in improving medication adherence (OR = 18.09, 95% CI: 8.36–39.15), followed by SMS (OR = 7.72, 95% CI: 3.74–15.94). The combined intervention was not superior to the single-mode approaches. Time was a significant predictor of clinic attendance but not medication adherence. Estimated marginal means indicated that phone-call interventions consistently produced the highest predicted probabilities of adherence across outcomes.*

Conclusion: *mHealth interventions, particularly phone-call reminders, are effective in enhancing clinic attendance and medication adherence among TB patients in Nigeria. Programmatic integration of phone-based follow-up into national TB control strategies is recommended to support long-term treatment adherence and improve patient outcomes.*

KEYWORDS: Clinic appointment attendance, Medication adherence, mHealth, Phone-call, SMS, Tuberculosis.

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INTRODUCTION

Tuberculosis (TB) remains one of the leading causes of death globally from a single infectious agent. Despite sustained global efforts, progress toward TB elimination targets has been slow, with many benchmarks either unmet or off track (World Health Organisation, 2023a). The burden of TB is particularly severe in the African region, where mortality remains disproportionately high, and a small number of countries account for a substantial share of cases and deaths.

In 2021, the Democratic Republic of Congo, Nigeria, and South Africa collectively accounted for approximately 48% of all TB-related deaths in the African region (World Health Organisation, 2023b). In 2022 alone, an estimated 2.5 million people developed TB in Africa, representing nearly one-quarter of new global cases, while approximately 424,000 individuals died from the disease, out of an estimated 1.27 million deaths worldwide. Overall, more than one-third of global TB deaths occur within the African region (World Health Organisation, 2025).

Nigeria remains among the 30 high-burden countries for tuberculosis (TB) that collectively account for approximately 87% of the world's TB cases (World Health Organisation, 2023a). TB remains a major global health problem and continues to pose a serious threat to people living with HIV in resource-poor settings (Mburu G. & Richardson, 2013; Pathmanathan et al., 2017). With an estimated 268 TB-related deaths occurring daily, Nigeria bears the heaviest TB burden in Africa (Adebisi et al., 2019; Desalu et al., 2013; Sampson E et al., 2020). Most recently, the WHO Global Tuberculosis Report 2025 identified Nigeria among just eight countries accounting for 67% of the global TB burden, with the country contributing 4.8% of all new cases worldwide, reflecting not a reduction in burden but a sharper concentration of the epidemic in fewer high-burden nations (World Health Organisation, 2025). This sustained burden translates into substantial mortality and morbidity, particularly in resource-constrained settings where tuberculosis and HIV prevalence remain high (Letang et al., 2020; Okonkeo Ugwu et al., 2021; Stærke et al., 2022; Ubajaka et al., 2015).

Poor medication adherence and missed clinic appointments continue to undermine TB control efforts (Bea et al., 2021; Saadatifar et al., 2023). Non-adherence increases the risk of treatment failure, relapse, ongoing transmission, and the development of drug-resistant TB (Ruppar et al., 2017). Medication adherence and clinic appointment attendance are critical to reduce the infectiousness of TB, achieve a cure, and prevent death among TB patients (Gebreweld et al., 2018). Despite the provision of free anti-TB medications and ongoing national control programmes, adherence to TB treatment remains low. Poor adherence leads to increased individual suffering and mortality, as well as higher treatment costs due to prolonged treatment regimens and the development of drug resistance (Micheal & Harald, 2016).

Mobile health (mHealth) interventions have demonstrated effectiveness in improving medication adherence and clinic appointment attendance in several settings outside Nigeria (Choun et al., 2017; Gashu et al., 2021; Pradipta et al., 2020). Moreover, mHealth is a relatively new patient education technique with advantages, such as time and cost savings, remote training and follow-up (Kosaraju, 2021; Saadatifar et al., 2023), with the majority of treatment adherence reinforced by mHealth strategies such as the use of Short Message Service (SMS) text messaging and phone-calls (Lee et al., 2023; Nhavoto et al., 2017).

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Given Nigeria's substantial TB burden, there is an urgent need to identify innovative, context-appropriate strategies that strengthen medication adherence and clinic engagement. Leveraging SMS and phone-call interventions represents a potentially cost-effective approach, particularly in Lagos State, where mobile phone penetration is high, and access barriers persist (Ngwatu et al., 2018).

Although low-cost mobile devices offer potentially transformative opportunities for all those working to improve health outcomes, to date, there is little evidence on mHealth interventions implemented in Tuberculosis control and assessed for specific outcomes (Hall et al., 2014). This represents a critical knowledge gap in Nigeria, where tuberculosis mortality and morbidity rates are of profound concern.

To address this gap, the present study evaluated the comparative and combined effectiveness of SMS and phone-call interventions on medication adherence and clinic-appointment attendance among TB patients in Lagos State, Nigeria, one of Africa's highest-burden settings where such evidence remains scarce.

LITERATURE REVIEW/THEORETICAL UNDERPINNING

This study is guided by the Health Belief Model (HBM), which posits that individuals' health-related behaviours are influenced by their perceived susceptibility, perceived severity, perceived benefits, and perceived barriers. Mobile-based reminders act as cues to action that reinforce perceived benefits of adherence and reduce forgetfulness, a common barrier to treatment adherence (Alyafei & Easton-Carr, 2024; Green et al., 2021; Morris et al., 2012; Yamamoto et al., 2012). By applying this theory, the study examines how reminder interventions influence patients' adherence behaviours over time.

The Health Belief Model has been used in various interventional studies to improve medication adherence for various disease conditions (Heydari et al., 2014; Parwati et al., 2021; Tola et al., 2016).

In the context of tuberculosis (TB), perceived susceptibility and perceived severity relate to patients' understanding of their risk of TB complications and the severe consequences of incomplete treatment, including disease progression, drug resistance, and transmission. Perceived benefits reflect patients' beliefs about the effectiveness of adhering to TB medication and attending clinic appointments, while perceived barriers include forgetfulness, stigma, transportation challenges, and competing socioeconomic demands. These perceptions are critical determinants of adherence behaviour among TB patients, particularly in resource-limited settings (Gebreweld et al., 2018; Grigoryan et al., 2022).

The mobile-based interventions used in this study, such as phone-calls and SMS reminders, function as cues to action, a central component of HBM. These reminders prompt patients to take medication and attend clinic appointments, thereby reducing barriers to medication adherence and clinic attendance. Additionally, consistent reminders and follow-up communication may enhance self-efficacy by reinforcing patients' confidence in their ability to adhere to treatment over time. Perceived susceptibility and severity were targeted through educational components that emphasized the consequences of non-adherence, including disease progression, drug resistance, and continued transmission risk. Perceived benefits were

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enhanced by reinforcing the advantages of complete treatment, such as full recovery and reduced infectivity. Most critically, perceived barriers, including forgetfulness, stigma, and logistical challenges, were addressed through practical support mechanisms embedded in the SMS and phone-call interventions.

While perceptual constructs were measured and will be examined in a subsequent manuscript, the behavioural outcomes reported here, clinic attendance and medication adherence, represent the downstream behavioural consequences of the HBM pathway that the interventions were designed to activate.

Notably, clinic appointment attendance and medication adherence represent distinct behavioural types within the HBM framework: the former is event-based, driven primarily by cues to action and barrier reduction, while the latter is a continuous, daily behaviour that additionally depends on sustained self-efficacy. This theoretical alignment between intervention design and behaviour change mechanisms provides the conceptual basis for evaluating differential effects across intervention arms and outcome types in the analyses that follow.

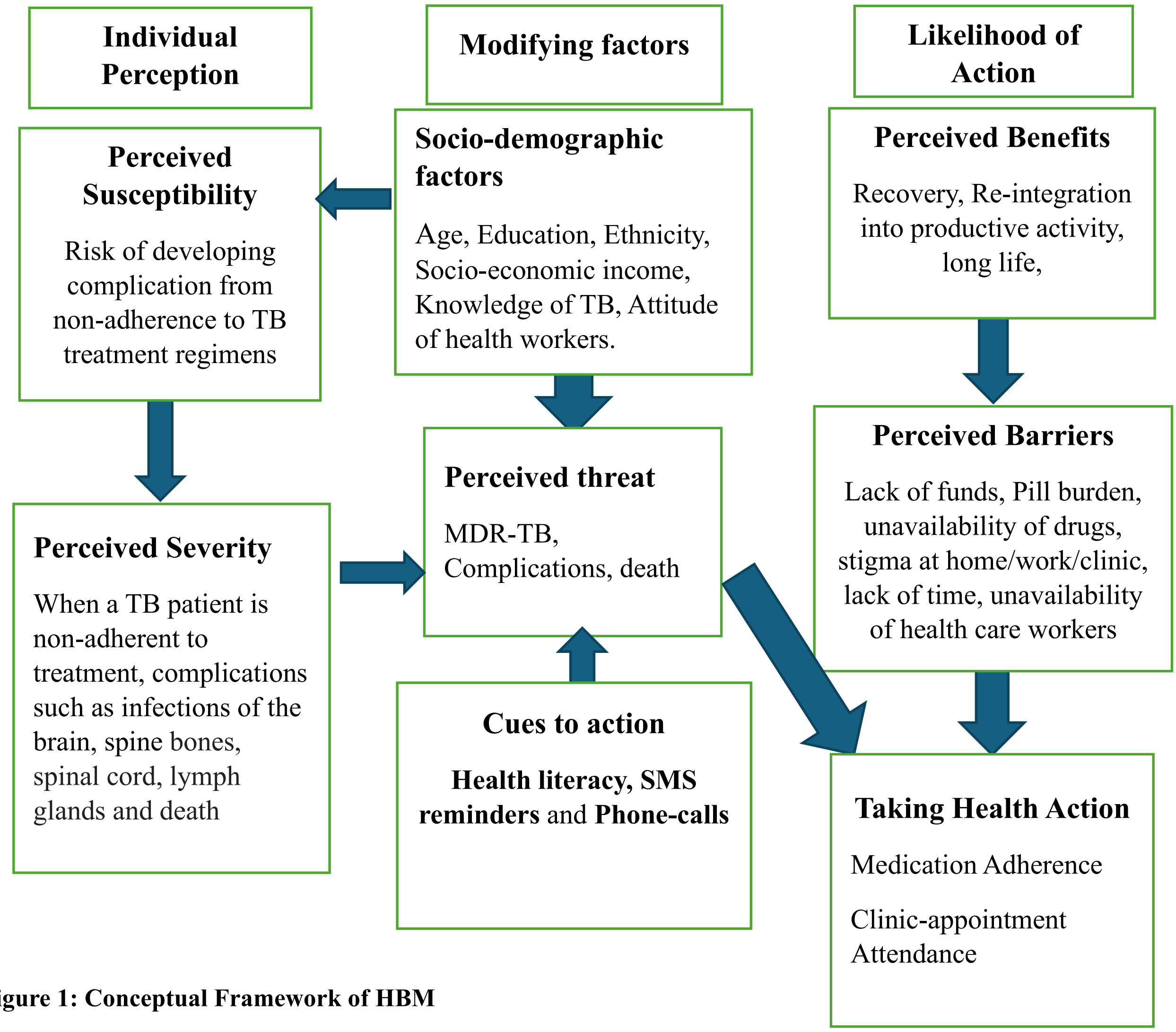

Figure 1: Conceptual Framework of HBM

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METHODOLOGY

Study Area

This study was conducted in Lagos State, which is located in Nigeria, the most populous country in Africa, the world's largest Black nation, and one of the most populous low and middle-income countries (Pontianus & Oruonye, 2021). Lagos State is the smallest yet most populous state in Nigeria, with a rapid population growth and uncontrolled spatial expansion. It is one of the largest and fastest-growing megacities in Africa, with a population of 13-27 million. The annual average growth rate is 3.2%, above the national growth rate of 2.6%, and has been projected to become the world's most populous city by 2100 (World Bank, 2023).

Lagos State is in the southwestern part of Nigeria on the narrow coastal plain of the Bight of Benin. It lies approximately at longitude 2°42' E to 4°20' E, latitude 6°20' N to 6°40' N. Lagos State lies in the south-western part of the Federation. It shares boundaries with Ogun State both in the North and East and is bounded on the west by the Republic of Benin. In the South, it stretches for 180 kilometres along the Atlantic coast. It occupies an area of 3,577 sq. km 22% or 787 sq. km, of which consists of lagoons and creeks.

Nigeria operates a mixed healthcare system that encompasses both public and private providers. All three tiers of government, Federal, State, and Local, share responsibilities for providing health services and programs in Nigeria. While the federal and state governments have the mandate to establish and manage public health facilities, the overall efficacy of healthcare delivery is contingent upon the quality, accessibility, and affordability of care (Ofekeze, 2020; Christian Connections for International Health, 2021). Nigeria Epidemiological reports in 2020 revealed that of the 13 standards for TB surveillance, five were met, three were partially met, and five were not met, indicating room for improvement (National Tuberculosis and Leprosy Control Programme, 2020). The Institute of Human Virology, Nigeria, has also identified Lagos as the epicenter of the disease in Nigeria due to its population density, landscape, and other factors (REDE-TB, 2021). Despite Nigeria's endowment of human and material resources, compared to its neighbors, there exists a contradiction as health indices are not commensurate with the inputs (Ogaii & Brisibe, 2015).

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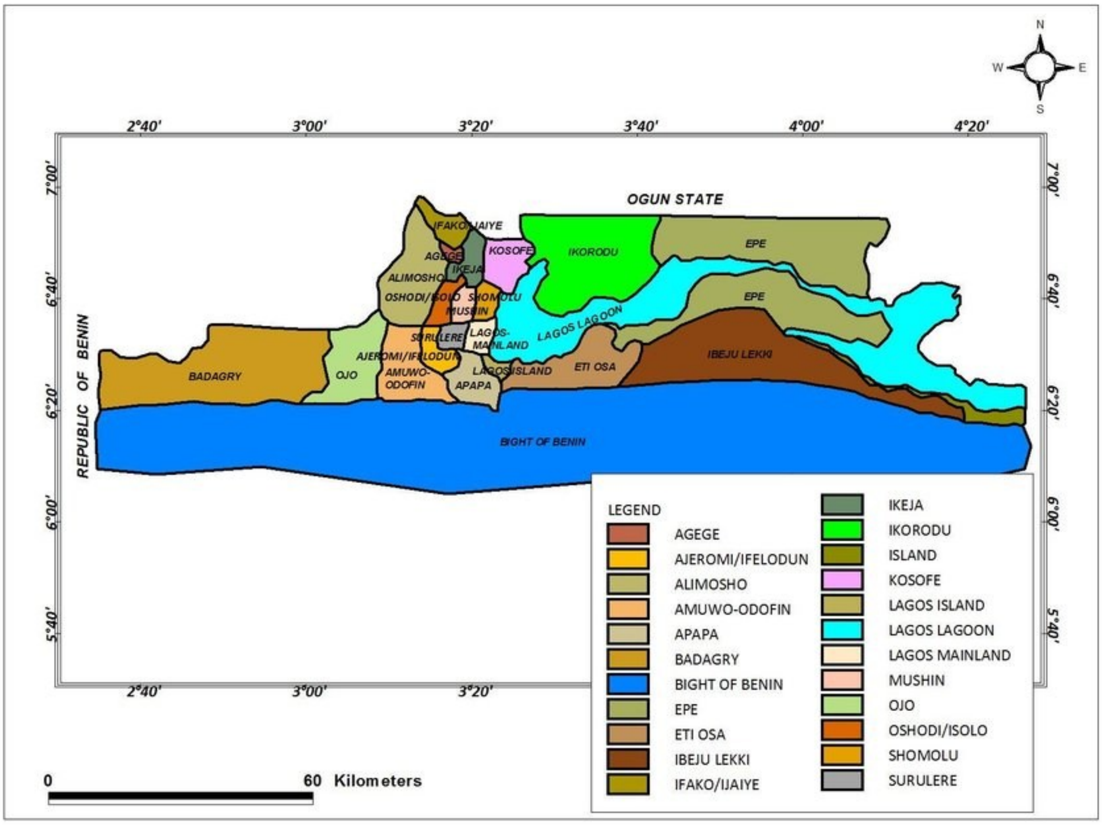

Figure II: Map indicating the LGAs in Lagos State

Source: Ministry of Physical Planning, Lagos State

Sampling and Sample size

Participants were recruited using a multi-stage sampling approach. In the first stage, four LGAs with the highest TB burden in Lagos State (Ikorodu, Alimosho, Ajeromi, and Lagos Mainland) were purposively selected (LSMOH, 2022) for the study groups. Alimosho, Ajeromi, and the Lagos Mainland LGAs were randomly assigned to the three experimental groups: Ajeromi LGA to the SMS arm, Lagos Mainland LGA to the phone-call arm, and Alimosho LGA to the combined phone-call and SMS arm. Ikorodu LGA was designated as the control site based on its geographic distance from the intervention LGAs, consistent with best practice in quasi-experimental designs to minimise contamination. Although the private, individualised nature of phone and SMS delivery made cross-group contamination inherently unlikely, geographic separation was maintained as an additional precaution to safeguard the integrity of the study arms. In the second stage, three DOTS facilities per LGA (two public, one private) were randomly selected, with this ratio applied uniformly across all four LGAs, including Ikorodu. In the third stage, eligible patients within each facility were stratified by sex, and participants were randomly selected within each stratum.

Sample size estimation was guided by anticipated differences in adherence rates between the control arm (60%) and the intervention arms (80%), representing a 20 percentage-point difference. This corresponds to a medium-to-large effect size (Cohen's h ≈ 0.45), which is appropriate for comparing proportions in studies with dichotomous outcomes (Cohen, 1988). Using standard approaches for comparing proportions with 90% statistical power at $\alpha = 0.05$,

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a minimum of approximately 25 participants per arm was required. The sample size was increased to 32 participants per arm to account for potential 20% attrition and to support the four-arm longitudinal design with three repeated measures.

Inclusion criteria were residence in Lagos State, ≥30 days on DOTS therapy for laboratory-confirmed TB, age ≥18 years, non-pregnant, and consent to participate. Exclusion criteria included non-DOTS patients, drug-resistant TB, and patients who were too ill at recruitment.

Intervention

All participants received standard care for TB management. This care encompassed the following components: health education and counselling by their health care providers, anti-tuberculosis treatment comprising an intensive phase (consisting of a four-drug regimen for the initial 2 months involving rifampicin, isoniazid, ethambutol, and pyrazinamide) and a continuation phase (a two-drug regimen from the third to the sixth month comprising rifampicin and isoniazid). Participants were scheduled for medication refills (weekly for the first 2 months and monthly from the third to sixth months), three medical laboratory tests at the conclusion of the second, fifth, and sixth months.

The intervention package consisted of three categories. Experimental group 1 received short message service (SMS) messages every other day (one-way SMS); Experimental group 2 was contacted by phone every two weeks; Experimental group 3 received both phone-calls (bi-weekly) and SMS messages (every other day); and the Control group received standard TB care. The SMS intervention involved sending one-way short text messages structured around the study's objectives and baseline results. These messages were sent regularly until the end of the study. They were designed to educate participants about TB disease, medication dosages and frequencies, potential adverse reactions, when to seek medical attention, the consequences of incorrect medication use, and the importance of attending clinic appointments as part of their treatment plan. The bi-weekly phone-calls aimed to achieve the same objectives as the SMS messages. The phone-calls were made by trained research assistants with prior experience in patient engagement. Prior to commencement, all research assistants underwent a standardized training session covering call scripts, communication protocols, and strategies for empathetic patient engagement. The language for the phone-calls was left to the discretion of the Research staff to ensure ease of communication. The SMS were bulk messages sent by the researcher. SMS messages were sent via the KudiSMS platform as standardized one-way bulk messages in the English language. Delivery receipts were monitored to confirm successful transmission. Messages were uniform across participants within the SMS arm, with content structured around themes identified from baseline findings.

Instrumentation

The instrument was a semi-structured and validated interviewer-administered questionnaire with a Cronbach's alpha reliability coefficient of 0.77. The Cronbach's alpha scores for each section were Knowledge (0.72), Perception (0.81), and Treatment Adherence (0.66), which included questions on Medication Adherence and Clinic Appointment attendance. Perception was not reported in this paper. Variables were measured on a Likert scale. The data were analysed using descriptive and inferential statistics (a non-parametric test) at the 5% significance level.

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Treatment adherence was measured using a 14-item Likert scale adapted from the Adherence Barrier questionnaire (Müller et al., 2015), which assesses potential risk factors for medication non-adherence and appointment-keeping. This section elicited patients' self-reports on treatment adherence. The total score obtainable was 56. The score was computed as follows: 4 = Not at all, 3 = Sometimes, 2 = Most times, 1 = All the time.

Medication adherence was measured using the 11-item Likert scale from the Treatment Adherence section of the questionnaire. All items were positively worded and scored on a 4-point scale, producing a maximum obtainable score of 44.

Appointment-keeping was assessed using a 3-item Likert scale of the Treatment Adherence Section of the questionnaire.

All items were positively worded except for one negatively phrased item, and the total obtainable score was 12.

DATA MANAGEMENT AND ANALYSIS

Data were collected between 16th February and 18th May 2023. Data were collected electronically using Google Forms, enabling real-time capture and minimizing entry errors. The completed forms were downloaded, reviewed for completeness and consistency, and then securely transferred to IBM SPSS Statistics (SPSS v21) for data cleaning and analysis. All datasets were stored on password-protected systems accessible only to the research team. All questionnaire data were coded using a codebook. The data and Identifiers were coded rather than the respondents' names, and the data were checked for frequency to identify missing or incorrect values.

Tests of symmetry were performed to assess the normality assumptions. Normality tests (Kolmogorov-Smirnov and Shapiro-Wilk) indicated non-normality ($p < 0.05$) *(Table 1)*.

Descriptive statistics were used to summarise participant characteristics and outcome distributions at baseline, midline (6th week), and 12th week follow-up. Binary outcomes were categorised as high when ≥ the median value at each time point of data collection for each variable (Median Clinic Appointment baseline: 6th Week: 12th week =12:9:9, Median Medication Adherence baseline: 6th Week:12th week = 44:44:44).

Since parametric methods that assume normality were inappropriate, we employed Generalized Estimating Equations (GEE) with robust standard errors. This semi-parametric approach accommodates non-normal data while accounting for within-subject correlation across three timepoints. GEE models used a binomial distribution with a logit link function, including intervention, time, and their interaction as fixed effects, with the control group and baseline as reference categories. Robust (sandwich) standard errors ensured valid inference regardless of working correlation structure. The unstructured working correlation structure provided the optimal fit, as indicated by Quasi-likelihood under the Independence model Criterion (QIC) values. Results are presented as odds ratios with 95% confidence intervals and Wald p-values, with statistical significance at $\alpha=0.05$.

This model has been used in longitudinal/clustered data analysis once the assumptions of the statistical approach are met (Austin et al., 2024; Ghisletta & Spini, 2004; Wang, 2014).

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Table I:

Test of Normality

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	d.f	Sig.	Statistic	d.f	Sig.
Knowledge	0.19	128	.000	0.83	128	.000
Perception	0.12	128	.000	0.96	128	.003
Medication-adherence	0.31	128	.000	0.65	128	.000
Clinic-appointment	0.18	128	.000	0.94	128	.000
a. Lilliefors Significance Correction						

Ethical approvals were obtained from Babcock University Health Research Committee (BUHREC/00G/23), Lagos University Teaching Health Research Ethics Committee (LUTHREC ADM/DSCST/HREC/APP/5657), while administrative approvals were obtained from the Lagos State Ministry of Health (LSMOH) and Lagos State Primary Health Care Board (LSPHCB).

RESULTS/FINDINGS

Descriptive Findings

There was no attrition recorded across the study period; all 128 participants completed all three data collection points, a finding that may partly reflect the short-term nature of the study. A total of 128 participants were included in the study, with 32 participants allocated to each arm. There were more male participants (81, 63.30%) than female participants (47, 36.7%) overall. In each arm of the study (SMS, phone-call, and a combination of SMS and phone-call), there were more male participants than female participants. Specifically, the SMS group had 68.80% males, the phone-call group had 59.40%, the combined SMS and phone-call group had 59.40%, and the control group had 65.60%. The mean age for all groups combined was 35.68 ± 11.07 years. Among the intervention groups, participants in the phone-call intervention arm had the highest mean age of (38.28 ± 10.84 years), followed by those in the combined phone-call and SMS intervention arm with (35.31 ± 9.71 years). Participants in the control group had a mean age of 34.81 ± 10.57 years, while those in the SMS group had a mean age of 34.31 ± 12.97 years. Regarding marital status, the majority were married (75, 58.60%), followed by single individuals (51, 39.80%), and a small percentage were divorced or separated (2, 1.60%). In terms of education, most participants (74, 57.80%) had attained secondary education, followed by tertiary education (33, 25.80%). Occupationally, 75 participants (58.60%) were self-employed across all study groups, 26 (20.30%) were employed, and 27 (21.10%) were unemployed. In terms of religious affiliation, 77 participants (60.20%) identified as Christians, while the remaining 51 (39.80%) identified as Muslims (*Table II)*.

Binary outcomes were categorized as high when ≥ the overall median at each time point, as described in Methods. Overall patterns showed divergent trajectories for the two outcomes (*Table III)*. Clinic appointment attendance exhibited a marked midline spike (85.90% high)

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before declining at follow-up (56.30% high), whereas medication adherence showed gradual improvement over time (baseline 53.90% → midline 57.80% → follow-up 61.70%).

Critically, intervention groups demonstrated higher baseline adherence than controls for both outcomes. The control group showed 0% high adherence at baseline for both clinic attendance and medication adherence, compared to 37.50–87.50% across intervention groups.The 0% high adherence recorded in the control group at baseline reflects the median-based binary categorisation applied, whereby all control group scores fell below the overall median at that time point, rather than indicating a complete absence of adherence behaviour. By follow-up, the phone-call group maintained the highest adherence across both outcomes (87.50% medication adherence; 53.10% clinic attendance), while the control group showed substantial improvement from baseline despite receiving no intervention (43.80% medication adherence; 78.10% clinic attendance).

Table II:

Socio-demographic Characteristics of Participants for all Study Groups

Variables	**SMS** N (%)	**Phone-call** N (%)	**SMS and Phone-call** N (%)	**Control** N (%)	**Total** N (%)
Sex					
Male	22 (68.80)	19 (59.40)	19 (59.40)	21 (65.60)	81 (63.30)
Female	10 (31.30)	13 (40.60)	13 (40.60)	11 (34.40)	47 (36.70)
Age					
18–30 years	3 (9.40)	22 (68.80)	23 (71.90)	3 (9.40)	51 (39.84)
31–45 years	12 (37.50)	9 (28.10)	6 (18.80)	18 (56.30)	45 (35.15)
46 years and above	17 (53.10)	1 (3.10)	3 (9.40)	11 (34.40)	32 (25.00)
Mean age ± SD	34.31 ± 12.98	38.28 ± 10.84	35.31 ± 9.71	34.81 ± 10.57	35.68 ± 11.07
Marital Status					
Married	15 (46.90)	21 (65.60)	17 (53.10)	22 (68.75)	75 (58.59)
Single	17 (53.10)	11 (34.40)	13 (40.60)	10 (31.25)	51 (39.84)
Divorced/Separated	0 (0.00)	0 (0.00)	2 (6.30)	0 (0.00)	2 (1.56)
Level of Education					
None	0 (0.00)	2 (6.30)	1 (3.10)	1 (3.10)	4 (3.10)
Primary	0 (0.00)	8 (25.00)	0 (0.00)	9 (28.10)	17 (13.30)
Secondary	28 (87.50)	17 (53.10)	15 (46.90)	14 (43.80)	74 (57.80)
Tertiary	4 (12.50)	5 (15.60)	16 (50.00)	8 (25.00)	33 (25.80)
Employment Status					
Self-employed	18 (56.30)	25 (78.10)	16 (50.00)	16 (50.00)	75 (58.60)
Employed	5 (15.60)	5 (15.60)	6 (18.80)	10 (31.30)	26 (20.30)
Unemployed	9 (28.10)	2 (6.30)	10 (31.30)	6 (18.80)	27 (21.10)
Religion					
Christianity	18 (56.30)	22 (68.80)	23 (71.90)	14 (43.80)	77 (60.20)
Islam	14 (43.80)	10 (31.30)	9 (28.10)	18 (56.30)	51 (39.80)

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The descriptive findings indicate improvements over time in medication adherence, while clinic appointment keeping showed a marked midline improvement followed by a partial decline at follow-up. Across outcomes, both high and low categories shifted over time, highlighting dynamic patterns warranting further investigation through longitudinal inferential analyses (*Table III)*. These descriptive patterns informed subsequent longitudinal analyses examining the population-average effects of time and intervention, using generalized estimating equations.

Table III:

Changes in Patient Outcomes across Baseline, 6th Week Post Intervention, and 12th Week Evaluation Phases by Intervention Type

Intervention	**Variables**	**Baseline** ***High / Low n (%)***	**6th Week Post Intervention** ***High / Low n (%)***	**12th week Evaluation** ***High / Low n (%)***
SMS	*Medication Adherence*	22 (68.80) / 10(31.20)	19 (59.40) / 13(40.60)	22 (68.80) / 10 (31.20)
	Clinic Appointment Attendance	28 (87.50) / 4 (12.50)	30 (93.80) / 2 (6.20)	9 (28.10) / 23 (71.90)
Phone-call	*Medication Adherence*	27 (84.40) / 5 (15.60)	25 (78.10) / 7 (21.90)	28 (87.50) / 4 (12.50)
	Clinic Appointment Attendance	26 (81.20) / 6 (18.80)	28 (87.50) / 4 (12.50)	17 (53.10) / 15 (46.90)
Phone-call & SMS	*Medication Adherence*	20 (62.50) / 12(37.50)	16 (50.00) / 16(50.00)	15 (46.90) / 17 (53.10)
	Clinic Appointment Attendance	12 (37.50) / 20(62.50)	25 (78.10) / 7 (21.90)	21 (65.60) / 11 (34.40)
Control	*Medication Adherence*	0 (0.00) / 32 (100.00)	14 (43.80) / 18(56.20)	14 (43.80) / 18 (56.20)
	Clinic Appointment Attendance	0 (0.00) / 32 (100.00)	26 (81.20) / 6 (18.80)	25 (78.10) / 7 (21.90)
Total	*Medication Adherence*	69 (53.90) / 59(46.10)	74 (57.80) / 54(42.20)	79 (61.70) / 49 (38.30)
	Clinic Appointment Attendance	66 (51.60) / 62(48.40)	110 (85.90) / 18 (14.10)	72 (56.30) / 56 (43.70)

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Inferential Findings

Generalized estimating equation (GEE) models were used to examine longitudinal changes in clinic appointment attendance and medication adherence across three time points (baseline, 6th week, and 12th week follow-up), adjusting for highest level of education attained and age category. All models were specified with a binomial distribution and a logit link and accounted for repeated measurements within participants. Working correlation structures were compared using the quasi-likelihood under the independence model criterion (QIC), and an unstructured working correlation matrix was specified and retained for all outcomes based on model stability, parsimony, and negligible differences in QIC values across alternative structures.

Model Effects

The adjusted GEE model demonstrated that both intervention type (Wald $\chi^2 = 15.54$, $p = 0.001$) and time (Wald $\chi^2 = 47.61$, $p < 0.001$) were statistically significant predictors of clinic appointment attendance. However, highest level of education (Wald $\chi^2 = 3.78$, $p = 0.287$) and age category (Wald $\chi^2 = 0.68$, $p = 0.713$) were not statistically significant predictors, indicating that clinic attendance differed across intervention groups and time points but was not independently associated with education or age after adjustment.

For medication adherence, intervention type was a statistically significant predictor (Wald $\chi^2 = 68.04$, $p < 0.001$), whereas time was not (Wald $\chi^2 = 1.82$, $p = 0.40$), indicating that medication adherence differed across intervention groups but remained relatively stable across time points *(Table IV*).

Clinic Appointment Attendance

Using the control group as the reference category, participants who received phone-call reminders had significantly higher odds of attending clinic appointments (B = 1.09, SE = 0.28, $p < 0.001$), corresponding to an odds ratio of 2.97. Participants who received SMS reminders also had higher odds of attendance (B = 0.65, SE = 0.31, $p = 0.034$; OR = 1.92). Although the combined intervention reached statistical significance in the overall GEE model, Bonferroni-adjusted pairwise comparisons of estimated marginal means did not demonstrate a statistically significant difference compared with the control group *(Table IV)*.

Estimated marginal means (EMMs) supported these findings, with predicted probabilities of high attendance of 0.76 for the phone-call group, 0.68 for the SMS group, 0.65 for the combined intervention group, and 0.52 for the control group.

Time had a strong effect on clinic appointment attendance, with participants having significantly higher odds of attendance at the 6th week than at baseline (B = 1.83, SE = 0.28, $p < 0.001$, OR = 6.24). There was a higher odds of clinic attendance at the 12th week follow - up; however, this was not statistically significant (B = 0.20, SE = 0.31, $p = 0.516$, OR = 1.22) when compared to baseline.

Age- and education-level-adjusted EMMs increased from 0.50 at baseline to 0.86 at 6th week, then declined to 0.55 at 12th week follow-up. Bonferroni-adjusted pairwise comparisons showed a significant increase from baseline to the 6th week ($p < 0.001$) and a significant decrease from the 6th week to follow-up ($p < 0.001$), whereas the difference between baseline and the 12th week follow-up was not statistically significant *(Table V)*.

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Medication Adherence

Compared to the control group, participants who received phone-call interventions had the highest likelihood of achieving good medication adherence (B = 2.89, SE = 0.40, p < 0.001, OR = 18.09). Participants who received SMS reminders also had significantly higher odds (B = 2.04, SE = 0.37, p < 0.001, OR **= 7.72**). The combined phone-call plus SMS intervention, while still highly effective compared to the control, demonstrated a smaller effect (B = 1.29, SE = 0.30, p < 0.001, OR = 3.62)*(Table IV).*

Estimated marginal means (EMMs) were 0.87 for the phone-call group, 0.74 for the SMS group, 0.58 for the phone-call plus SMS group, and 0.27 for the control group.

Although predicted probabilities showed a modest numerical increase over time, these differences were not statistically significant at 6th week compared with baseline (B = 0.19, SE = 0.27, p = 0.46, OR = 1.22), nor at the 12th week follow-up compared with baseline (B = 0.39, SE = 0.29, p = 0.18, OR = 1.48).

Age- and education-level-adjusted EMMs showed relatively stable adherence levels across baseline, 6-week, and 12th week follow-up, indicating that medication adherence was primarily driven by intervention exposure rather than temporal change.

Importantly, pairwise comparisons between the intervention groups revealed that the phone-call alone was substantially more effective than the combined phone and SMS intervention (mean difference = -0.29, p < .001), indicating that the combined approach was not only less potent than the phone-call but may have diluted its effect.

Although the overall effect of education level on medication adherence did not reach conventional statistical significance (Wald χ^2 = 6.91, p = 0.075), a borderline association was observed. Specifically, participants with secondary education had significantly lower odds of achieving high medication adherence compared to those with no formal education (B = -0.78, SE = 0.39, p = 0.047, OR = 0.46, 95% CI: 0.21–0.99). No statistically significant differences were observed between participants with tertiary education and those with no formal education (p = 0.692), nor between those with primary education and those with no formal education (p = 0.969). These findings suggest that formal education level, particularly at the secondary level, may be inversely associated with medication adherence, possibly reflecting differences in health beliefs, treatment perceptions, or competing socioeconomic demands across education groups *(Table V)*.

Table IV: Generalized Estimating Equation (GEE) Results for Clinic Appointment and Medication Adherence across Time and Intervention Groups

Effects	Parameter	B	SE	Wald χ^2	p-value	Exp(B) [OR]	95% CI
Clinic Appointment Attendance							
Intercept		-0.87	0.38	5.18	**0.02**	0.42	(0.20–0.89)
Intervention (Overall)		—	—	15.54	**0.00**	—	—
	Phone-call vs Control	1.09	0.28	15.28	**<0.001**	2.97	(1.72–5.12)
	SMS vs Control	0.65	0.31	4.48	**0.03**	1.92	(1.05–3.50)

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	Phone and SMS vs Control	0.55	0.28	3.90	**0.05**	1.73	(1.00–2.99)
Time (Overall)		—	—	47.61	**<0.001**	—	—
	6th week vs Baseline	1.83	0.29	41.32	**<0.001**	6.24	(3.57–10.90)
	12th week Follow-up vs Baseline	0.20	0.31	0.42	0.516	1.22	(0.67–2.22)
	Baseline (ref)	0	—	—	—	1.00	—
Medication Adherence							
Intercept		-0.58	0.41	2.01	0.160	0.56	(0.25–1.25)
Intervention (Overall)		—	—	68.04	**<0.001**	—	—
	Phone-call vs Control	2.89	0.40	53.37	**<0.001**	18.09	(8.36–39.15)
	SMS vs Control	2.04	0.37	30.73	**<0.001**	7.72	(3.74–15.94)
	Phone and SMS vs Control	1.29	0.30	18.99	**<0.001**	3.62	(2.01–6.52)
Time (Overall)		—	—	1.82	0.403	—	—
	6th week vs Baseline	0.20	0.27	0.54	0.461	1.22	(0.72–2.07)
	12th week Follow-up vs Baseline	0.39	0.29	1.82	0.178	1.48	(0.84–2.60)
	Baseline (ref)	0	—	—	—	1.00	—
Education (Overall)		—	—	6.91	0.075		
	Tertiary vs none	-0.16	0.40	0.16	0.69	0.85	(0.39–1.88)
	Secondary vs none	-0.78	0.39	3.94	**0.047**	0.46	(0.21-0.99)
	Primary vs none	-0.02	0.52	0.00	0.969	0.98	(0.35-2.74)
	None (ref)	0	—	—	—	1.00	—

***Note**: All models include Age and Education as covariates. Bold text = significant p-value.*

Table V: Estimated Marginal Means (EMM) and Pairwise Comparisons for Clinic Appointment and Medication Adherence across Time and Intervention Groups

Outcome	Factor	Level / Comparison	Mean / Diff	SE	p (adj)	95% CI Lower	95% CI Upper
Clinic Appointment Attendance							
Intervention — Estimated Marginal Means							
Clinic Appointment	**Intervention**	*Phone-call*	0.76	0.04	—	0.68	0.83

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		SMS	0.68	0.06	—	0.55	0.78
		Phone and SMS	0.65	0.05	—	0.56	0.74
		Control	0.52	0.05	—	0.42	0.62
Intervention — Pairwise Comparisons							
		Phone-call vs Control	0.24	0.06	**0.001**	0.08	0.40
		SMS vs Control	0.15	0.07	0.17	-0.03	0.34
		Phone and SMS vs Control	0.13	0.07	0.27	-0.04	0.31
		Phone-call vs SMS	0.09	0.07	1.00	-0.08	0.25
		Phone-call vs Phone and SMS	0.11	0.06	0.36	-0.04	0.26
		SMS vs Phone and SMS	0.02	0.07	1.00	-0.15	0.22
Time — Estimated Marginal Means							
	Time	*Baseline*	0.50	0.04	—	0.41	0.58
		6th week	0.86	0.03	—	0.78	0.91
		12th week Follow-up	0.55	0.05	—	0.44	0.65
Time — Pairwise Comparisons							
		6th week vs Baseline	0.36	0.05	**<0.001**	0.25	0.48
		12th week vs Baseline	0.05	0.08	1.000	-0.13	0.23
		6th week vs 12th week	0.31	0.06	**<0.001**	0.18	0.46
Medication Adherence							
Intervention — Estimated Marginal Means							
Medication Adherence	**Intervention**	*Phone-call*	0.87	0.04	—	0.78	0.93
		SMS	0.74	0.06	—	0.60	0.85
		Phone SMS	0.58	0.06	—	0.46	0.69
		Control	0.27	0.04	—	0.20	0.36
Intervention — Pairwise Comparisons							
		Phone-call vs Control	0.60	0.06	**<0.001**	0.45	0.75
		SMS vs Control	0.47	0.07	**<0.001**	0.28	0.66
		Phone and SMS vs Control	0.31	0.07	**<0.001**	0.13	0.48
		Phone-call vs SMS	0.13	0.07	0.460	-0.06	0.32
		Phone-call vs Phone and SMS	0.29	0.07	**<0.001**	0.11	0.48

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		SMS vs Phone and SMS	0.16	0.08	0.189	-0.03	0.35
Time — Estimated Marginal Means							
	Time	*Baseline*	0.60	0.05	—	0.49	0.69
		6th week	0.64	0.06	—	0.52	0.74
		12th week Follow-up	0.68	0.05	—	0.58	0.77
Time — Pairwise Comparisons							
		6th week vs Baseline	0.04	0.06	1.000	-0.10	0.19
		12th week vs Baseline	0.08	0.06	0.524	-0.07	0.25
		6th week vs 12th week	-0.04	0.06	1.000	-0.19	0.10

Note: *p (adj) = Bonferroni-adjusted p-value. — = not applicable for marginal mean rows. All models adjust for Age and Education*

DISCUSSION

This study demonstrated that mHealth interventions, particularly phone-call reminders, significantly improve clinic appointment attendance and medication adherence among TB patients in Lagos State, Nigeria. Our findings reveal that intervention type is a strong predictor of outcomes: Phone-calls produced the largest effects, SMS produced moderate improvements, and, importantly, the combined approach did not outperform single-mode interventions. These results align with a growing body of evidence that mHealth interventions improve health-seeking behaviour and treatment-related outcomes (Aku et al., 2024; Z. W. Chen et al., 2008; Choun et al., 2017; Gupta et al., 2020; Olugbenga et al., 2023; Santra et al., 2021). However, they contrast with studies reporting no statistically significant effects of mHealth interventions on treatment outcomes (Bediang et al., 2018; Saadatifar et al., 2023), highlighting heterogeneity in intervention effectiveness across contexts and designs.

The most consistent and robust finding across clinic appointment and medication adherence outcomes was the marked superiority of phone-call interventions over both SMS-only and combined approaches, underscoring the importance of interpersonal engagement in behaviour change. This finding aligns with existing studies that voice-based or interactive communication technologies are more effective than one-way messaging. Several studies have shown that phone-calls allow for clarification, personalised counselling, and immediate problem-solving, which are often necessary to address contextual barriers to healthcare utilization and adherence (Y. Chen et al., 2020; Donovan et al., 2022; Lance et al., 2021; Pouls et al., 2021).

The ineffectiveness of our combined intervention arm (bi-weekly phone-calls and SMS every two days) provides a critical lesson in intervention design. This aligns with principles from the Cognitive Load Theory, which posits that layering information does not automatically produce additive benefits and may, in some contexts, be seen as intrusive, create confusion, or message fatigue if not well integrated or if messages are duplicative (Sweller et al., 1998; Sweller et al., 2019; Sweller, 2024). The theory also underscores the importance of intervention design (timing, frequency, personalization, language, and interactivity) rather than assuming more

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channels equal better outcomes (Baxter et al., 2025; Bidargaddi et al., 2018). In this respect, our findings contrast with those of previous studies (Yang & Van Stee, 2019; Li et al., 2020; Arshed et al., 2024) where combined mHealth interventions were found to be more effective than a single mHealth intervention.

The differential impact of time on clinic attendance versus medication adherence has important clinical implications. While time appears to facilitate engagement with scheduled health services and improve clinic appointment attendance, it is insufficient to sustain daily treatment behaviours such as medication adherence. This distinction underscores the need for interventions that differentiate between event-based and continuous behaviours, ensuring that adherence strategies actively target motivational and perceptual determinants rather than relying on time or repeated exposure alone (Brown & Bussell, 2011; Kaleva, 2015).

When contextualized within the broader literature, our findings clarify the conditions under which phone-based interventions excel. For simple, one-time appointment attendance, automated reminders (both call and SMS) may be insufficient, as shown by Ekhaguere et al., (2019). To improve daily habits during acute recovery, frequent, didactic communication (daily SMS or bi-weekly calls) can be highly effective, as demonstrated Ebrahimi Tabas et al., (2020). Our study adds a critical third point: for the complex challenge of sustaining long-term adherence in chronic disease, lower frequency but high-quality motivational counselling calls are superior. This suggests a spectrum where the required interactivity of an intervention increases with the complexity and duration of the target behaviour change.

Our findings suggest that while mHealth interventions demonstrate clear potential as cost-effective tools for supporting TB treatment, their community-level impact ultimately depends on how effectively they are designed to address the specific behavioural, social, and contextual factors that shape individual adherence (Grady et al., 2018; Jose et al., 2022; O'Connor et al., 2022). Various factors contribute to the success of TB treatment, which may have influenced the study's diverse effects of mHealth on clinic appointments and medication adherence. Family support, individual beliefs, drug tolerance, and trust in health care providers are also crucial in enhancing medication adherence (Grigoryan et al., 2022; Munro et al., 2007). Notably, these are precisely the factors that phone-based communication is best positioned to address. Trained research assistants can detect emotional distress, reinforce trust, clarify misconceptions, and provide individualized encouragement in ways that one-way SMS messages cannot. This may help explain not only the superiority of phone-calls in our study but also the attenuated effect of the combined arm, where the relational quality of phone engagement may have been diluted by the volume of automated messaging. Future interventions should consider screening for these contextual factors at baseline and tailoring communication strategies accordingly.

IMPLICATION TO RESEARCH AND PRACTICE

Our findings suggest that TB programs may benefit from prioritizing well-timed, appropriately spaced, and contextually tailored reminders over high-frequency messaging to avoid message fatigue. Our results indicate that phone-call reminders offer superior value by enabling interpersonal engagement and real-time problem-solving, thereby enhancing responsiveness more than automated cues. Given Nigeria's substantial TB burden, this research supports

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integrating standardized mHealth, particularly phone-based follow-up, into the National Tuberculosis, Leprosy and Buruli Ulcer Control Program (NTBLCP). Programmatically, this should include: **(1)** using digital tools at DOTS facilities to monitor adherence patterns; **(2)** employing routine data to design targeted interventions; and **(3)** considering transport support for patients facing financial barriers to clinic attendance.

From a health systems perspective, mHealth can support TB treatment while potentially reducing costs and burdens for both patients and providers. This approach offers a cost-effective communication channel that may mitigate common barriers such as transportation costs, waiting times, and stigma-related concerns.

CONCLUSION

This study provides Nigerian-context evidence that structured mobile-based reminders, particularly phone-calls, produce clinically meaningful improvements in both medication adherence and clinic engagement among TB patients, with effects that persist independently of patient age and education level.

From a policy and programmatic perspective, incorporating structured phone-call follow-up into routine service delivery may yield substantial benefits, particularly when sustained engagement is required. However, given resource constraints, SMS remains a valuable complementary strategy where phone-calls are not feasible.

The current research excluded individuals unable to read or write in English, limiting the broad applicability of the findings. The assessment of medication adherence and clinic-appointment attendance relied more on participants' self-recollection than on objective verification (e.g., pill counts, pharmacy refills, electronic monitoring), introducing potential biases related to memory and social desirability. This study was not blinded because the nature of the interventions (SMS and phone-call reminders) made it impossible to mask participants from knowing which intervention they received. However, to minimize bias, participants were not informed about the existence of other intervention arms. This approach helped prevent resentful demoralization among control participants and compensatory rivalry among intervention groups. Furthermore, while the control LGA was designated based on geographic distance to minimise contamination, it is worth noting that the individualised and private nature of the phone and SMS interventions, delivered directly to participants' personal devices, made cross-group contamination unlikely regardless of proximity. This study was limited to specific local government areas in Lagos State, limiting its generalizability to broader regions or countries. However, the study also provides valuable insights for researchers to adopt or adapt as needed when developing methodologies that are efficient at driving behavioural change in public health research.

FUTURE RESEARCH

Future research should incorporate socio-cultural contexts and patient-centred preferences to enhance the design and acceptability of mHealth interventions for TB management. Multi-centre studies are needed to validate these findings across diverse settings, alongside systematic

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variation of intervention frequency and duration to identify optimal reinforcement schedules. Qualitative studies, including in-depth interviews, would further illuminate patient experiences and preferences, thereby strengthening the development of effective, scalable mHealth strategies. Future studies may therefore consider individual- or facility-level randomisation as a more rigorous alternative, allowing a fully randomised controlled design rather than a quasi-experimental one.

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