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Research article

Impact of an interactive smartphone application on glycaemic and blood pressure control among diabetes and hypertension patients in Ghana: A quasi-experimental study

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A B S T R A C T

Background: Mobile technology has the potential to improve cardiometabolic disease management in sub-Saharan Africa, but data on its effectiveness are limited. In this quasi-experimental study, we investigated the impact of an interactive smartphone application (app) on glycated hemoglobin (HbA1c) and blood pressure in individuals with type 2 diabetes or hypertension in Ghana.

Methods: Individuals with type 2 diabetes or hypertension in Greater Accra public clinics were randomly assigned to an intervention or control group. The intervention group received smartphones with a health app providing alerts, medication reminders, and progress monitoring. The control group received standard care. The study assessed changes in HbA1c, glycaemic control (HbA1c < 48 mmol/mol), blood pressure (BP), and BP control (<140/90 mmHg) over six months. Multivariable linear, Cox, and Poisson regression analyses adjusted for demographics, lifestyle, comorbidities, baseline HBA1c, BP and medications were used to evaluate the outcomes. Clustering effects were accounted for using generalized estimating equations and frailty models.

Results: The study included 874 participants (mean age 58 years, 64.6% female). Over the six-month period, the proportion of individuals with optimal glycaemic control increased by 11.5% in the intervention group compared to 3.0% in the control group. In the fully adjusted model, the intervention was significantly associated with improved glycaemic control at the final visit (Relative Risk [RR] = 1.06, 95% CI: 1.01–1.10), though no significant association was observed for quarterly glycaemic control (Hazard Ratio [HR] = 0.93, 95% CI: 0.78–1.12).

For BP control, the intervention group improved by 15.2%, compared to 9.8% in the control group. In the fully adjusted model, the intervention was significantly associated with improved BP control at the final visit (RR = 1.19, 95% CI: 1.03–1.36) and for quarterly BP control (HR = 1.46, 95% CI: 1.17–1.83).

Conclusion: This study demonstrates that interactive smartphone application is associated with improvement in BP and glycaemic control among Ghanaian patients and highlight the potential of digital health solutions in chronic disease management. Future research should identify strategies to optimize the integration of interactive smartphone applications into standard care in Ghana.

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1. Introduction

The Sub-Saharan African (SSA) region is currently facing a rising prevalence of cardio-metabolic diseases, particularly hypertension and type 2 diabetes. In the span of three decades, the reported cases of diabetes surged by a substantial 83%, jumping from 2323 per 100,000 in 1990 to a staggering 4248 per 100,000 in 2021 [1]. Projections for the year 2050 are even more alarming, with an estimated 6649 individuals per 100,000 likely to be affected by diabetes [2]. Simultaneously, hypertension, a prevalent health concern SSA, affected 106 million adults in 2019, doubling from 46 million adults in 1990 [3]. The outlook for hypertension in SSA is equally concerning, with predictions suggesting a 66% increase to 217 million cases by the year 2030 without interventions [4].

Unfortunately, this surge in type 2 diabetes and hypertension has been accompanied by poor control rates. Studies conducted across SSA including Zambia, Kenya, Ghana, Malawi, and Nigeria, have revealed suboptimal blood glucose control rates ranging from 40% to 64% among individuals diagnosed with type 2 diabetes [5–8]Similarly, hypertension control rates in SSA have fallen short of expectations, with studies in Uganda, Ghana, and Cameroon reporting rates between 9% and 59% among individuals diagnosed with hypertension [9–11]. These figures pale in comparison to high-income countries, where control rates above 70% have been reported for type 2 diabetes and hypertensive individuals receiving treatment [12,13].

The implications of uncontrolled blood glucose and hypertension are grave, with the potential to lead to various complications, including cardiovascular diseases and end-stage kidney disease [14,15]. It is evident that an urgent need exists for improved blood pressure (BP) and glycaemic control in people diagnosed with type 2 diabetes or hypertension to avert these debilitating complications and prevent loss of life.

In recent years, smartphones equipped with interactive applications for blood glucose and BP management have revolutionized the management of diabetes in high-income countries, holding promise for a similar revolution in the SSA context. In high-income countries, mobile phone applications alone have yielded remarkable results, with between 30% and 47% improvement in glycaemic control rates among diabetes patients and an impressive 58% to 65% improvement for BP rates control among hypertensive patients [16–19]. This transformative impact of smartphone applications has emerged from addressing multiple factors affecting blood glucose and BP control, including patient education, medication reminders, data tracking, and dosage optimization.

Although mHealth interventions have been studied in Africa, most have relied on phone calls or SMS, sometimes combined with education and medication reminders [20–24]. Few studies have tested interactive smartphone applications that enable real-time tracking of health parameters, direct clinician communication, and dosage optimization. These gaps highlight the need for interventions that actively engage patients and integrate self-monitoring with clinician support.

With these previous shortcomings in SSA studies in mind, we hypothesized that the use of an interactive smartphone application, combined with real-time doctor messaging and access to health information, would significantly improve BP and glycaemic control compared to standard care. This study, therefore, aimed to assess the impact of an interactive smartphone application (app) on glycated haemoglobin (HbA1c) and BP measures (direct changes, as well as glycemic and BP control) in individuals with type 2 diabetes or hypertension in Ghana.

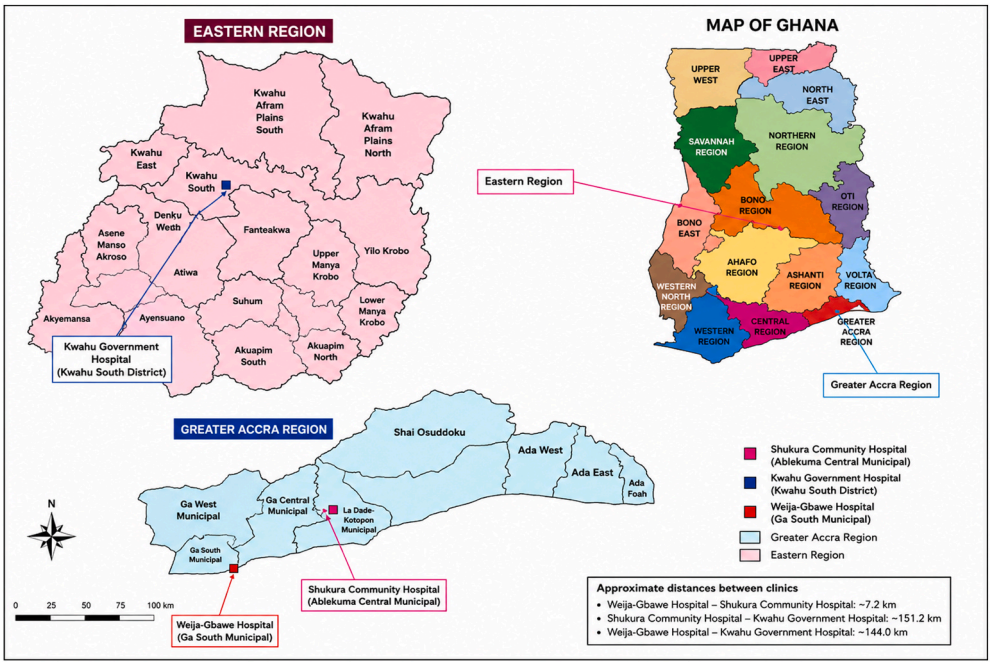

Fig. 1. Map showing the locations of the three study clinics in the Greater Accra and Eastern Regions of Ghana.

2. Methodology

2.1. Study design and population

This was a quasi-experimental study implemented over six months. The study used a cluster-controlled before-and-after design, in which three public clinics served as clusters; two were allocated to the intervention group and one to the comparison group.

Out of six public facilities specializing in outpatient treatment for type 2 diabetes and hypertension in Greater Accra and Eastern regions. The study involved three clinics in Greater Accra, Ghana. Weija-Gbawe Hospital, in the South-Western part of Accra is the first clinic, employs 576 health workers and sees 60-100 admissions and over 300 outpatients daily, managing 100-150 diabetes and hypertension patients weekly. Shukura Community Hospital, in Ablekuma Central Municipal is the second clinic, has a 50-bed capacity, attends to 300 daily patients, and manages 50-100 diabetes and hypertension cases weekly. Kwahu Government Hospital the third clinic, in the semi-rural Kwahu South district, serves a population of 230,000, with a diabetes clinic treating around 200 type 2 diabetes and 300 hypertension patients weekly. These geographically dispersed clinics range from approximately 7.2 km to 151.2 km from each other (Fig. 1). To prevent contamination of the intervention in the comparison group, the clinics were randomly assigned to either the intervention group (Kwahu Government Hospital and Weija-Gbawe Hospital) or the comparison group (Shukura Community Hospital).

It is worth noting that a related qualitative study (Aovare et al., 2025) [25] was conducted at these same clinics to explore user experiences with the mobile health application. However, the two studies are independent in terms of objectives, datasets, and analytical approaches. While the qualitative study focused on participant experiences and perspectives, the current quasi-experimental study evaluates the quantitative impact of the intervention on glycaemic and blood pressure control, providing complementary insights into the overarching project.

2.2. Inclusion and exclusion criteria

Inclusion Criteria: Participants were adults aged 18–85 years with a confirmed diagnosis of type 2 diabetes or hypertension, receiving outpatient care at one of three public clinics in Greater Accra, Ghana (Weija-Gbawe Hospital, Shukura Community Hospital, Kwahu Government Hospital) for at least one year. Participants were required to provide informed consent and have the ability, or willingness to learn, to use a smartphone for app-based data entry and health monitoring.

Exclusion Criteria: Individuals were excluded if they had severe comorbidities (e.g., advanced cardiovascular disease, severe renal disease, or stroke), cognitive impairments, recent significant medication changes (within three months), or were pregnant or breastfeeding. Non-residents or those likely to relocate during the study period, as well as participants in other clinical trials or interventions that could confound results, were also excluded.

2.3. Key assessments

Glycaemic control was assessed using HbA1c levels, with adequate control defined as HbA1c $<$ 48 mmol/mol ($<$6.5%), based on WHO criteria. Blood pressure control was defined as systolic BP $<$ 140 mmHg and diastolic BP $<$ 90 mmHg among individuals receiving treatment. Sociodemographic and lifestyle characteristics were also collected (see Appendix 1).

2.4. Follow-up and data collection

Participants attended monthly clinic visits for routine care, including medical reviews, lifestyle counselling, and medication adjustments. HbA1c was reassessed at three months, while final outcome measurements at six months mirrored the baseline procedures. Participants who missed appointments were contacted through up to five phone calls, followed by home visits where feasible. Individuals who could not be reached were classified as lost to follow-up.

2.5. Quality control

All clinical measurements were conducted by trained research assistants under supervision from experienced healthcare professionals. Standardized operating procedures were followed, and accuracy was ensured through device calibration, staff training sessions, periodic audits, cross-checking of clinical records, and double data entry procedures.

2.6. Sample size determination

We calculated the required sample sizes using G*Power software to detect statistically and clinically significant changes in glycaemic and BP control among the diabetes and hypertension groups, respectively. These calculations were based on parameters derived from relevant literature and intended to ensure sufficient power to detect meaningful improvements in health outcomes.

For the diabetes group, our calculation was based on detecting an improvement in the proportion of participants achieving adequate glycaemic control defined as an HbA1c level below 48 mmol/mol ($<$6.5%) from 25% to 50%, which reflects a significant shift consistent with goals in diabetes management. This baseline control rate of 25% is typical of similar populations in previous studies [26,27]. We assumed a moderate effect size (Cohen's d = 0.5), a statistical power of 80%, and an alpha level of 0.05. We also

estimated an SD of 0.55 for changes in glycaemic control, based on prior research in similar settings. Using these assumptions, the sample size calculation suggested 293 participants per group, accounting for a 5% attrition rate.

For the hypertension group, the sample size was calculated based on an expected improvement in BP control from 25% to 60%, a 35% improvement, which is consistent with goals for hypertension management. Again, baseline control rates below 25% have been reported in comparable populations [28,29]. Assuming a statistical power of 80%, an alpha level of 0.05, and an SD of 0.50 for changes in BP, we determined a minimum sample size of 126 participants per group, incorporating a 5% attrition rate.

While these calculations were based on established parameters, we recognize that the final sample size might appear large, particularly for the diabetes group. However, given the anticipated effect size and variability in the data, we ensured that the study was sufficiently powered to detect clinically meaningful changes.

2.7. Ethical considerations

This study was reviewed and approved by the Ghana Health Service Ethical Review Committee (GHS-ERC:004/08/20). Participants were selected based on their willingness to participate, and informed consent was obtained from each individual before their involvement in the study. This process ensured that participants were fully informed about the study's purpose, procedures, and potential risks, allowing them to make an informed decision regarding their participation.

In addition to the informed consent process, other key ethical considerations, such as data privacy and equity of access, consent forms and data handling procedures are provided in detailed in the appendices. In brief, given the sensitive nature of health data, especially in digital health interventions, we implemented strict data protection measures. These included encryption, secure storage, and controlled access to safeguard participants' personal and health information. Additionally, although the intervention aimed to be inclusive, challenges related to digital literacy, smartphone ownership, and internet access may have impacted some participants' ability to engage fully. We took steps to address these challenges by offering support to those with limited digital literacy and considering alternative access methods.

2.8. Baseline measurements

2.8.1. HbA1c and glycaemic control

Glycemic control was assessed by measuring HbA1c levels using the high-performance liquid chromatography (HPLC) method, HbA1c values are reported in IFCC mmol/mol, and glycaemic control, defined a priori as a secondary outcome, was categorized as HbA1c $<$ 48 mmol/mol ($<$6.5%) in line with WHO recommendations.

2.8.2. Blood pressure and its control

Blood pressure was measured three times on the right arm using an Omron sphygmomanometer (BP7450) with appropriate cuff sizes. Participants were seated for at least 5 min before measurement, and a 5-min rest interval was maintained between each reading. The mean of the last two readings was used for analysis.

2.8.3. Other measurements

Sociodemographic and lifestyle variables including age, sex, marital status, education, religion, physical activity, alcohol use, smoking status, and medication adherence were collected. Detailed measurement procedures and definitions are provided in Appendix 1.

2.8.4. Monthly visits

Patients followed the routine monthly clinic visits where they received standard care like medical tests, medication adjustments, lifestyle advice, complications monitoring and diabetes support. BP measurements using same procedures as at baseline were also included. Conversely, HbA1c was assessed during the third monthly visit, as HbA1c reflects blood glucose control over the preceding three months.

2.8.5. Final visit (six month)

Follow-up measurements matched baseline measurements and were recorded at the six-month study's end. Final visits occurred after the last monthly clinic visit. For unreachable patients, at least five phone attempts were made, followed by home visits if necessary. Participants who still did not attend the final visit were considered lost to follow-up.

2.8.6. Intervention

The study's intervention utilized a user-friendly Android application designed for Samsung smartphones (A3 core model) and tablets (Galaxy Tab 8.0). The selection of these devices considered cost-effectiveness and their popularity among users to ensure participant familiarity.

Developed by a collaborative team of software developers, designers, healthcare professionals, and researchers, the application prioritized an intuitive and engaging interface for patient involvement. It included clear visuals and easy-to-read graphs, enhancing its value as a tool for health data monitoring (Appendix 2). Unlimited monthly data bundles were given to participants to enable patient's seamless use of the app.

This application allowed users to enter and monitor various health metrics measured at their clinic visits including height (in

centimetres), weight (in kilograms), HbA1c (IFCC mmol/mol), SBP, DBP (in mmHg), waist circumference (in centimetres), hip circumference (in centimetres), total cholesterol (in mmol/L), LDL (in mmol/L), HDL (in mmol/L), and triglycerides (in mmol/L).

The application provided health data monitoring with analytics and educational content, empowering patients to make informed decisions and stay engaged. It enabled secure messaging with healthcare providers for proactive communication and included daily access to a health worker for expert guidance. Patients were trained in data collection and interpretation, promoting self-monitoring

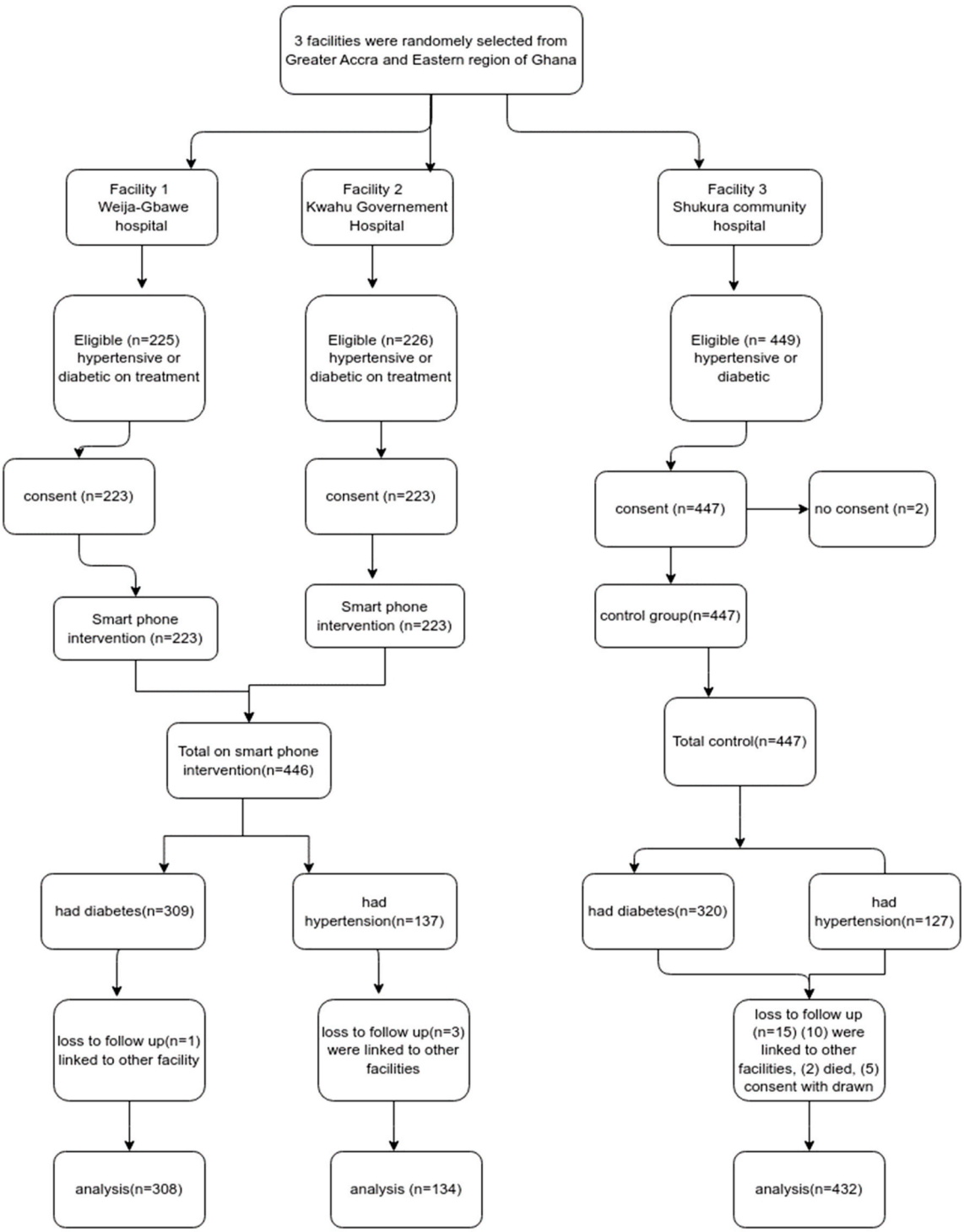

Figure: 2. flow chart of participants below.

Table 1
Background characteristics of study participants.

		Hypertensive (n = 256)			Diabetic (n = 618)		
Characteristics	Variable	Intervention (n = 134)	Control (n = 122)	Total (n = 256)	Intervention (n = 308)	Control (n = 310)	Total (n = 618)
Disease duration, (years)	(Mean ± SD)	7.74 ± 3.6	8.12 ± 2.5	7.92 ± 3.1	7.61 ± 3.2	8.20 ± 2.5	7.91 ± 2.9
Demographics							
Age(years)	(Mean ± SD)	59 ± 14	59 ± 13	59 ± 14	58 ± 13	58 ± 13	58 ± 13
Sex	Female (%)	75 (56%)	75 (61.5%)	150 (58.6%)	193 (62.7%)	206 (66.5%)	399 (64.6%)
	Male (%)	59 (44%)	47 (38.5%)	106 (41.4%)	115 (37.3%)	104 (33.5%)	219 (35.4%)
Education	None (%)	36 (26.9%)	27 (22.1%)	63 (24.6%)	80 (26%)	47 (15.2%)	127 (20.6%)
	Primary (%)	52 (38.8%)	32 (26.2%)	84 (32.8%)	100 (32.5%)	110 (35.5%)	210 (34%)
	Secondary (%)	26 (19.4%)	47 (38.5%)	73 (28.5%)	95 (30.8%)	115 (37.1%)	210 (34%)
	Tertiary (%)	20 (14.9%)	16 (13.1%)	36 (14.1%)	33 (10.7%)	38 (12.3%)	71 (11.5%)
Marital status	Never married (%)	15 (11.2%)	15 (11.3%)	30(11.7%)	37 (12.0%)	47 (15.2%)	84 (13.6%)
	Married (%)	116 (86.6%)	104 (85.2%)	220(85.9%)	214 (69.5%)	255 (82.3%)	469(75.9%)
	Ever Married (%)	3 (2.2%)	3 (2.5%)	6(2.3%)	5 (1.6%)	8(2.6%)	13 (2.1%)
Religion	Christian (%)	130 (97%)	112 (91.8%)	242 (94.5%)	292 (94.8%)	264 (85.2%)	556 (90%)
	Muslim (%)	4 (3%)	10 (8.2%)	14 (5.5%)	16 (5.2%)	46 (14.8%)	62 (10%)
Lifestyle factors							
Smoking	Yes (%)	0 (0)	0 (0)	0 (0)	2 (0.6%)	0 (0)	2 (0.3%)
	No (%)	131 (97.8%)	119 (97.5%)	250 (97.7%)	301 (97.7%)	307 (99%)	608 (98.4%)
	Past (Use to) (%)	3 (2.2%)	3 (2.5%)	6 (2.3%)	5 (1.6%)	3 (1%)	8 (1.3%)
Alcohol intake	Yes (%)	2 (1.5%)	3 (2.5%)	5 (2%)	10 (3.2%)	9 (2.9%)	19 (3.1%)
	No (%)	127 (94.8%)	113 (92.6%)	240 (93.8%)	291 (94.5%)	280 (90.3%)	571 (92.4%)
	Past (Use to) (%)	5 (3.7%)	6 (4.9%)	11 (4.3%)	7 (2.3%)	21 (6.8%)	28 (4.5%)
Physical Activity (High)	Yes (%)	5 (3.7%)	8 (6.6%)	13 (5.1%)	21 (6.8%)	16 (5.2%)	37 (6%)
	No (%)	129 (96.3%)	114 (93.4%)	243 (94.9%)	287 (93.2%)	294 (94.8%)	581 (94%)
Physical Activity (Moderate)	Yes (%)	2 (1.5%)	8 (6.6%)	10 (3.9%)	23 (7.5%)	23 (7.4%)	46 (7.4%)
	No (%)	132 (98.5%)	114 (93.4%)	246 (96.1%)	285 (92.5%)	287 (92.6%)	572 (92.6%)
Energy (KJ/day)	(Mean ± SD)	5.81 ± 1.54	6.24 ± 1.57	6.02 ± 1.56	6.01 ± 1.58	5.48 ± 1.6	5.74 ± 1.61
Anthropometry							
BMI (kg/m^2)	(Mean ± SD)	28.47 ± 3.94	32.31 ± 3.33	30.3 ± 4.13	29.6 ± 3.47	32.11 ± 4.01	30.86 ± 3.95
Waist circumference (cm)	(Mean ± SD)	96.7 ± 3.6	96.4 ± 3.7	96.6 ± 3.7	96.8 ± 3.6	95.3 ± 3.2	95.9 ± 3.4
Hip circumference(cm)	(Mean ± SD)	101.35 ± 8.69	100.33 ± 3.91	100.84 ± 6.83	100.58 ± 4.04	99.57 ± 3.35	100.08 ± 3.71
SBP (mmHg)	(Mean ± SD)	154.9 ± 8.65	152.3 ± 8.34	153.7 ± 8.59	153.1 ± 9.04	152.2 ± 11.1	152.7 ± 10.13
DBP (mmHg)	(Mean ± SD)	89.4 ± 10.08	89.3 ± 7.2	89.4 ± 8.81	89.6 ± 8.35	89.8 ± 8.44	89.7 ± 8.39
Lab values							
HBA1C(mmol/mol)	(Mean ± SD)	40 ± 5	41 ± 6	40.5 ± 5.5	63 ± 10	65 ± 10	64 ± 10
LDL (mmol/L)	(Mean ± SD)	1.32 ± 0.17	2.34 ± 0.76	1.71 ± 0.53	2.23 ± 0.26	2.43 ± 0.17	2.34 ± 0.19
HDL (mmol/L)	(Mean ± SD)	1.02 ± 0.02	1.94 ± 0.02	1.50 ± 0.42	1.64 ± 0.28	2.12 ± 0.17	1.67 ± 0.34
Triglycerides (mmol/L)	(Mean ± SD)	2.40 ± 2.73	1.98 ± 1.64	2.40 ± 2.73	2.04 ± 1.77	4.68 ± 0.34	2.59 ± 1.81
Medication factors							
Adherence to Medication	Adherent (%)	95 (70.9%)	112 (91.8%)	207 (80.9%)	39 (12.7%)	38 (12.3%)	77 (12.5%)
	Not Adherent (%)	39 (29.1%)	10(8.2%)	49(19.1%)	269(87.3%)	272 (87.7%)	541 (87.5%)
Where do you usually get medications	Current Facility (%)	100 (74.6%)	78 (63.9%)	178 (69.5%)	229 (74.4%)	246 (79.4%)	475 (76.9%)
	Different Facility (%)	34 (25.4%)	44 (36.1%)	78 (30.5%)	79 (25.6%)	64 (20.6%)	143 (23.1%)

Data are presented as mean (SEM). BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HBA1C, glycated haemoglobin; LDL, low-density lipoprotein; HDL, high-density lipoprotein; ADHERENCE *(Based on Medication Adherence Rating Scale, MARS*.
HbA1c values are reported in IFCC mmol/mol: <42 mmol/mol = normal, 42–47 mmol/mol = pre-diabetes, ≥48 mmol/mol = diabete.

and understanding of health goals. Follow-ups included setting targets, adjusting medications, and offering additional app guidance and educational resources. A coach portal allowed real-time monitoring by healthcare professionals for tailored support.

2.8.7. Control group

The control group received standard care at public clinics, without access to the smartphone application. Their care included lifestyle guidance, routine health monitoring, medication adjustments, and professional support as part of regular clinical management. Participants had in person consultations with healthcare providers during scheduled visits, where they received medical advice and adherence counselling. To ensure consistency in data collection, the same clinical measurements recorded in the intervention group including height, weight, HbA1c, blood pressure (systolic and diastolic), waist and hip circumference, total cholesterol, LDL, HDL, and triglycerides were manually documented. Unlike the intervention group, the control group did not have access to digital health tracking, real-time analytics, secure messaging with healthcare providers, or daily virtual consultations. Instead, they relied on periodic in-person interactions for health assessments and treatment modifications. While they received comparable medical care, the absence of automated reminders, self-monitoring tools, and interactive provider engagement distinguished the control group from the intervention group.

2.8.8. Implementation

The AfyaPro Connected Care system was introduced through a structured, phased approach to ensure integration into healthcare settings. After initial testing to verify functionality and compatibility, equipment installation and network setup ensured system connectivity. Staff training equipped healthcare workers with navigation skills, while two super users received advanced training for ongoing support, and IT specialists handled technical issues.

Data migration began with a pilot in the CVRM-DM Clinic before full-scale integration. Patients were enrolled, with nurses collecting vitals, medical history, and lab tests, followed by doctor assessments. Patients engaged with the mobile app for follow-up care, including reminders, self-monitoring, and continuous communication with clinicians via the chat function. The population management module enabled real-time tracking and feedback.

Evaluation and refinement incorporated feedback from patients, providers, and administrators to optimize functionality. Structured patient training, tailored for digital literacy levels, and a dedicated help desk supported adoption. Data security was ensured through encryption, secure storage, and restricted access. The app's user-friendly interface and personalized follow-up promoted engagement and adherence, supporting effective chronic disease management.

2.8.9. Statistical analysis

All statistical analyses were conducted using SPSS version 25.0. Baseline characteristics were summarized by disease type (hypertension vs. type 2 diabetes) and study group (intervention vs. control), with continuous variables reported as means (SDs) and categorical variables as percentages. Missing data (<5%), primarily due to loss to follow-up, were accounted for by increasing the sample size by 5% at study onset. To ensure fair comparisons, baseline HbA1c and BP were included as covariates in all models. Between-group differences in change in HbA1c were estimated using baseline-adjusted regression models. Glycaemic control was analysed both as a continuous outcome (HbA1c in mmol/mol) and as a pre-specified binary outcome (HbA1c $<$ 48 mmol/mol). Generalized Estimating Equations (GEE) with a Poisson family and Frailty models were used to adjust for intra-cluster correlation. Poisson regression estimated relative risks (RRs) with 95% confidence intervals (CIs), adjusting for baseline differences and confounders such as age, sex, lifestyle behaviors, and treatment access. Multivariable linear regression analyses were conducted, and results were presented as beta coefficients (95% CIs), treating app usage as a continuous variable and adjusting for demographic and clinical factors. Cox regression analysis was performed to estimate hazard ratios (HRs, 95% CIs) for glycemic and BP control, with time-dependent analyses conducted quarterly for glycemic control and monthly for BP control over six months. All analyses followed a predefined protocol, avoiding post hoc decisions on primary and secondary outcomes. Frailty models accounted for clustering effects, and all statistical tests were two-tailed with a significance level of 0.05.

3. Results

3.1. Study population

Between September 2022 and February 2023, the study initially recruited 900 participants from two intervention facilities (clinics) and one control facility (Fig. 2). However, after screening and inclusion criteria applied, the study ultimately included 874 participants. The participants had a mean age of 58 $\pm$ 13 years and an average disease duration 7.9 $\pm$ 2.9 years. Most of the participants were female (64.5%), married (83.4%), and identified as Christian (90%). Notably, 20.5% of the participants lacked formal education. Baseline health indicators showed average HbA1c levels of 64 $\pm$ 10 mmol/mol and SBP at 152.34 $\pm$ 8.34 and DBP 89.33 $\pm$ 7.2 (Fig. 2, Table 1).

3.2. Subgroups

Of these, 451 belonged to the intervention group, and 449 to the comparison group. A total of four participants (0.8%) in the intervention group and 15 (3%) in the comparison group were lost to follow-up. At the end of the study, there were 308 participants with type 2 diabetes and 134 with hypertension from the intervention group, along with 310 participants with type 2 diabetes and 122

with hypertension from the comparison group (Fig. 2, appendix 3).

3.3. Baseline characteristics

Among participants with type 2 diabetes, there were 308 individuals in the intervention group and 310 in the comparison group. The mean age in both groups was 58 ± 13 years, and the average disease duration was approximately 7.9 years. Female participants accounted for 62.7% in the intervention group and 66.5% in the comparison group. Most participants were married, with proportions of 69.5% in the intervention group and 82.3% in the comparison group, and the majority identified as Christian (94.8% in the intervention group and 85.2% in the comparison group). Educational backgrounds varied, with 26.0% of the intervention group and 15.2% of the comparison group having no formal education. Smoking and alcohol use were uncommon, and most participants reported low levels of physical activity.

Anthropometric measurements showed that the mean BMI was 29.6 ± 3.5 kg/m^2 in the intervention group and 32.1 ± 4.0 kg/m^2 in the comparison group. Waist circumference was similar between groups, averaging 96.8 ± 3.6 cm in the intervention group and 95.3 ± 3.2 cm in the comparison group. Lipid profiles indicated lower LDL and HDL cholesterol levels in the intervention group compared with the comparison group, while triglyceride levels were higher in the comparison group. Baseline medication adherence was low and comparable between groups (12.7% in the intervention group vs 12.3% in the comparison group).

In the hypertension group, there were 134 participants in the intervention group and 122 in the comparison group, with a mean age of 59 ± 14 years and mean disease duration of approximately 7.9 ± 3.1 years. The proportion of female participants ranged from 56.0% to 61.5%. Most participants were married (approximately 86%) and identified as Christian (91.8%–97%). The mean BMI was lower in the intervention group than in the comparison group, and waist circumference was similar between groups (approximately 96.6 cm). The intervention group had lower LDL and HDL cholesterol levels but higher triglyceride levels than the comparison group. Baseline medication adherence did not differ significantly between groups (see Table 1).

3.4. Absolute changes in HbA1c and BP

Among individuals with type 2 diabetes (Table 2; Fig. 3), both groups showed reductions in HbA1c concentrations over the study period, with a slightly smaller mean reduction in the intervention group compared with the control group (ΔHbA1c −5.5 vs −6.5 mmol/mol; between-group difference +1.0 mmol/mol, p = 0.001).After adjusting for baseline differences and other covariates in the regression models, the association remained statistically significant (adjusted Beta Coefficient = −0.080, 95% CI: −0.121 to −0.040) (Table 3).

Among individuals with hypertension, however, after adjusting for other factors in regression models, the intervention group showed a statistically significant reduction in SBP (adjusted Beta Coefficient = −1.191, 95% CI: −2.226 to −0.156), while the change in DBP remained non-significant (adjusted Beta Coefficient = −0.088, 95% CI: −0.814 to 0.637) compared to the control group (Table 3).

3.5. Associations between smartphone intervention with glycemic control

The proportion of individuals with adequate glycemic control improved by 11.5% in the intervention group compared with 3.0% in the control group (p = 0.083) (Table 2; Fig. 3). In the multivariable regression model, the interactive smartphone intervention was significantly associated with improved glycemic control at the final visit after adjustment. (Relative Risk [RR] = 1.06, 95% CI: 1.01–1.10; Table 4). However, there was no significant association between the use of an interactive smartphone application and quarterly glycemic control after adjustments (hazard ratio [HR] = 0.93, 95% CI: 0.78–1.12; Table 5).

Table 2
Change in mean HbA1c and blood pressure and control of glycaemic and blood pressure over the study period.

Measurement	Intervention			Control			Absolute change	P-value
	Baseline	End	Delta	Baseline	End	Delta	Intervention vs control	
HbA1c (mmol/mol)	73.2	67.7	−5.5	79.7	73.2	−6.5	+1.0	0.001
SBP, mean (SD), mmHg	154.2 (8.8)	153.8(9.0)	−0.47	152.3 (10.9)	151.9 (10.61)	−0.38	−0.09	0.124
DBP, mean (SD), mmHg	89.4 (8.8)	89.7 (6.5)	0.26	89.6 (6.26)	89.3 (6.87)	−0.27	+0.53	0.633
Glycemic control, N (%)	6 (8.2%)	15 (19.7%)	11.5%	6 (8.1%)	11 (11.1%)	3.0%	+8.5%	0.083
Blood pressure control, N (%)	1 (3.4%)	14 (18.6%)	15.2%	6 (3.6%)	18 (13.4%)	9.8%	+5.4%	0.259

P-value = P-value for the difference between intervention and control changes. HbA1c in mmol/mol, Systolic BP systolic blood pressure in mmHg. Start = beginning of study period, End = End of the study period 6 months after the start, Delta = difference between start and end measurements, P-value = p-value for difference between start and end measurements.
Chi-square test indicated n (%) of people that had their blood sugar and blood pressure under control at the end of the study compared to the start of the study. HbA1c values are reported in IFCC mmol/mol: <42 mmol/mol = normal, 42–47 mmol/mol = pre-diabetes, ≥48 mmol/mol = diabetes.

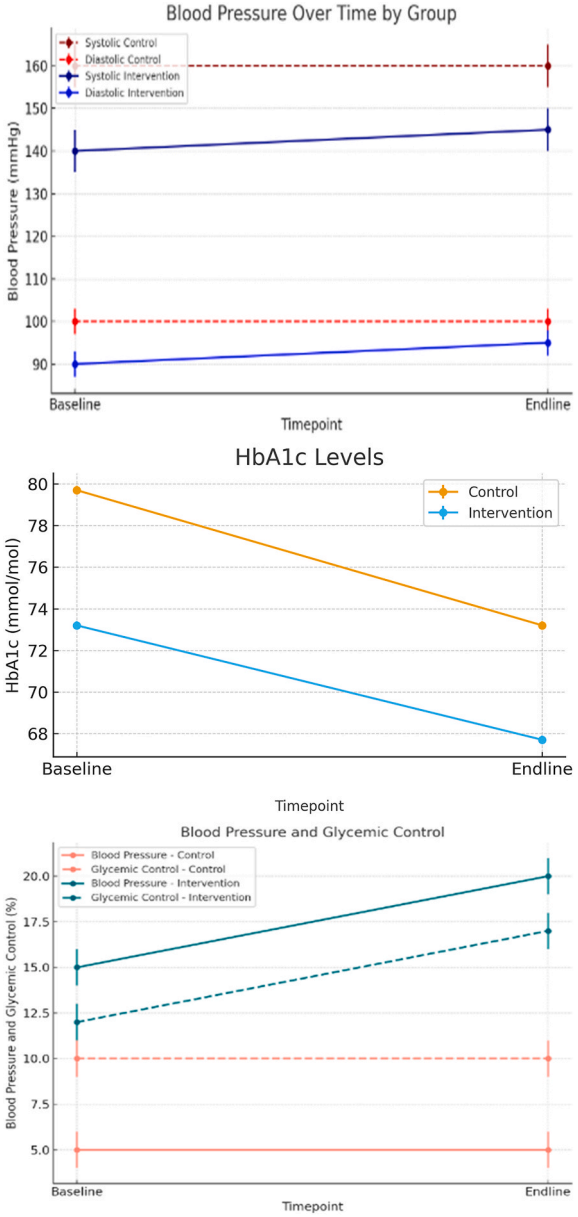

Fig. 3.

3.6. Associations between smartphone intervention and BP control

For BP control, the intervention group increased by 15.2% at the final visit, while the control group increased by 9.8%, resulting in a 5.4% difference ($p = 0.259$). (Table 2; Fig. 3). In the multivariable regression model, after adjustments, the use of an interactive smartphone application was significantly associated with higher odds of BP control at the final visit (OR = 1.19, 95% CI: 1.03–1.36; Table 4). The use of an interactive smartphone application was also significantly associated with improved BP control after adjustments (HR = 1.46, 95% CI: 1.17–1.83; Table 5).

4. Discussion

This study evaluated the impact of an interactive smartphone application on glycaemic and BP control in patients with type 2 diabetes and hypertension over six months. The intervention led to a modest but significant improvement in glycaemic control in the intervention group. However, its effect on quarterly glycaemic control was not significant after adjustments. For BP, the intervention was significantly associated with improved BP control.

Table 3
Associations between smartphone intervention with absolute HbA1c and blood pressure changes.

Study groups	Model 1	Model 2	Model 3
	Beta Coefficient (95% CI)	Beta Coefficient (95% CI)	Beta Coefficient (95% CI)
No smartphone use	1.00 (ref)	1.00(ref)	1.00(ref)
Smartphone use	−0.042 (−0.438 to 0.353)	−0.093 (−0.495 to 0.309)	−0.167 (−0.592 to 0.258)
Change in Glucose Levels			
No smartphone use	1.00(ref)	1.00(ref)	1.00(ref)
Smartphone use	−0.351 (−0.680 to −0.023)	−0.078 (−0.121 to −0.035)	−0.080 (−0.121 to −0.040)
Change in systolic blood pressure			
No smartphone use	1.00(ref)	1.00(ref)	1.00(ref)
Smartphone use	−1.428 (−2.337 to −0.519)	−1.240 (−2.172 to −0.308)	−1.191 (−2.226 to −0.156)
Change in Diastolic Blood Pressure			
No smartphone use	1.00(ref)	1.00(ref)	1.00(ref)
Smartphone use	−0.109 (−0.906 to 0.687)	0.215 (−0.558 to 0.988)	−0.088 (−0.814 to 0.637)

Intervention group is compared to the control group, control group serving as reference category.
Standardized coefficients (β) indicate the effect size, 95% confidence intervals (95% CI).
Outcome Type= Continuous (change in HbA1c Levels) = before - after.
Outcome Type: Continuous (change in glucose) before-after.
Outcome Type= Continuous (change in Systolic Blood Pressure) before-after.
Outcome Type= Continuous (change in Diastolic Blood Pressure) before-after.
Predictor= Smartphone Use (Smartphone Use vs. No Smartphone Use).
Model 1= Unadjusted.
Model 2= HbA1C time points, Adjusted for age, gender, education, marital status, religious affiliation and Facility.
Model 3 = Model 2 additionally adjusted for Baseline characteristics, including smoking status, alcohol intake, physical activity levels, and BMI categories.

Table 4
Association between interactive smartphone application and final visit glycaemic and BP control.

Study groups	Model 1	Model 2	Model 3
	RR (95% CI)	RR (95% CI)	RR (95% CI)
Glycaemic control			
No smart phone use	1.00(ref)	1.00(ref)	1.00(ref)
Smartphone use	1.06 (0.94 - 1.20)	1.05 (1.01 1.09)	1.06 (1.01 - 1.10)
blood pressure control			
No smart phone use	1.00(ref)	1.00(ref)	1.00(ref)
Smart phone use	1.20 (1.05 -1.38)	1.18(1.04-1.35)	1.19 (1.03-1.36)

Long-term Glycaemic Control: HBA1c < 6.5% (well-controlled), HBA1c > 6.5% (poorly controlled).
Blood Pressure Control: Systolic BP < 140 mm Hg and diastolic BP < 90 mm Hg (well-controlled); systolic BP > 140 mm Hg or diastolic BP > 90 mm Hg (poorly controlled).
RR: Relative Risk obtained using GEE with a Poisson family and robust standard errors.
Model 1: adjusted. For age, sex and facility.
Model 2: Adjusted for gender, education, marital status, and religious affiliation.
Model 3: Further adjusted for Baseline characteristics smoking, alcohol intake, physical activity, and BMI categories.

Our findings on the interactive smartphone application are among the first in Africa and align with studies from other regions demonstrating improvements in glycemic control at six months. In Sri Lanka, a smartphone app incorporating blood glucose monitoring, medication reminders, meal timing, and exercise tracking resulted in a 0.96% greater reduction in HbA1c in the intervention group compared to controls [30] Similarly, a systematic review in Spain reported a 1.05% greater HbA1c reduction in intervention groups using diabetes management apps than in controls [31].

On the other hand, we did not find a statistically significant link between use of interactive smartphone app and quarterly glycaemic control, suggesting that any effects of the app usage on glycaemic control may not be detectable at shorter intervals in our study population. These finding contrasts literature reporting that positive effects of interactive smartphone apps on glycaemic control may be observable over shorter periods and mid -term intervals [26](29). For example, a 2020 study in Korea using smartphone-based health application for glucose control for blood glucose tracking showed a 7.3% decrease in HbA1c levels in type 2 diabetes patients after three months [28]. Furthermore, a study in Singapore using a smartphone application to recommend daily insulin doses based on recorded blood glucose levels among type 2 diabetes patients resulted in an average drop of HbA1c from 9.9% to 8.8% after 6 weeks and to 8.2% after 12 weeks. [29]. Several factors could potentially explain this discrepancy in observed effects. These factors may include the time required for adaptation to the technology, as well as the extended duration necessary for behavioural modifications to manifest at the physiological level.

Among hypertensive patients, our study found a significant association between the use of an interactive smartphone application and BP control. These findings contrast with a 2019 study in Ghana, where a smartphone-based motivational messaging intervention

Table 5
Association between Interactive smartphone application and quarterly glycaemic and monthly blood pressure control.

Study groups	Model 1	Model 2	Model 3
	HR (95% CI)	HR (95% CI)	HR (95% CI)
Glycaemic control			
No smartphone use	1.00(ref)	1.00(ref)	1.00(ref)
Smartphone use	0.89 (0.76-1.0.039)	0.94(0.79-1.12)	0.93(0.78 - 1.12)
Blood pressure control			
No smartphone use	1.00(ref)	1.00(ref)	1.00(ref)
Smartphone use	1.37(1.12 - 1.67)	1.37 (1.11 - 1.68)	1.46 (1.17 - 1.83)

Glycaemic Control: Well-controlled (HBA1c < 6.5%) versus poorly controlled (HBA1c > 6.5%).
Blood Pressure Control: Well-controlled (systolic <140 mm Hg and diastolic <90 mm Hg).
Versus poorly controlled (systolic >140 mm Hg and diastolic >90 mm Hg).
Models.
HR (Hazard Ratio): Obtained from Cox regression using frailty models to account for unobserved heterogeneity.
Model 1: Unadjusted.
Model 2: Adjusted for age, gender, education, marital status, religious affiliation and Facility.
Model 3: Model 2 additionally adjusted for Baseline characteristics, including smoking, alcohol intake, physical activity, BMI categories.

did not lead to significant improvements and instead resulted in higher DBP in the intervention group at nine months [32]Similarly, a 2019 study in Iran using a smartphone app for medication tracking and self-management did not yield significant effects on BP control [33]. However, our results align with studies from the USA, where smartphone applications for medication reminders, adherence tracking, and BP monitoring have demonstrated improved BP control [34,35]These findings suggest that mHealth interventions can play a crucial role in hypertension management, particularly when they incorporate continuous monitoring, adherence support, and patient-provider engagement. Health literacy played a significant role, as individuals with higher health literacy better understood the app's benefits, leading to increased engagement [36]. Motivation and support from healthcare providers and family members also positively influenced adherence, while the perceived relevance of the app's features to participants' health management affected their commitment to usage [37,38].

The use of mobile health (mHealth) applications in chronic disease management has been shown to significantly improve self-management behaviors, medication adherence, and overall health outcomes. Studies have highlighted the importance of features like structured reminders, real-time tracking, and personalized health recommendations in driving sustained behavior change. Huang et al. (2023) emphasized that digital interventions incorporating personalized feedback and medication reminders were particularly effective in enhancing adherence and patient empowerment [39]. This study supports the notion that mHealth tools can foster greater self-management, ultimately improving long-term health outcomes for patients with chronic diseases.

4.1. Acceptance and usability of health IT and mobile apps

The success of mobile health (mHealth) interventions depends on user acceptance and usability, influenced by perceived usefulness, ease of use, and trust in technology. Privacy and security concerns also significantly shape engagement [40,41]. In this study, consistent participant use of the app was associated with improved glycaemic control and reduced SBP, likely facilitated by the app's simple interface, clear navigation, and intuitive design. Usability is critical for adherence and long-term engagement, and prior research emphasizes accessibility, intuitive design, and user-centered interfaces as key factors for sustained use [42,43].

Future iterations should integrate user feedback, incorporate hypertension-specific features, and undergo regular usability testing to optimize engagement and long-term chronic disease management.

4.2. Implications for research, practice, and policy

Understanding the mechanisms driving adherence to mHealth interventions remains critical. Future research should explore how health literacy, motivation, and user experience interact over time to influence sustained engagement, particularly for managing glycaemic and BP control. Longitudinal and mixed-methods studies can clarify behavioral, cognitive, and social determinants of adherence. Additionally, the long-term impact of digital interventions should be assessed, including potential digital fatigue, the need for booster sessions, and the sustained utility of app features over one to two years.

Tailoring digital solutions to diverse populations is essential. Differences in baseline education and digital literacy underscore the need for adaptable interfaces, culturally relevant content, and participatory design approaches to ensure equitable access and effectiveness. For healthcare providers, integrating mHealth into routine care, especially blended models combining digital and face-to-face care may enhance engagement and clinical outcomes. Policymakers should invest in digital literacy, strengthen infrastructure, ensure interoperability, promote data privacy, and support public-private partnerships to scale mHealth interventions sustainably, particularly in low- and middle-income countries.

4.3. Strengths and limitations

This study is among the first to evaluate mHealth for diabetes and hypertension management in Ghana, providing context-specific insights for SSA. Site-based separation of clinics minimized contamination, enhancing internal validity, while focusing on public clinics serving diverse socio-economic groups increases practical relevance. The development of a user-friendly Android application incorporating monitoring, education, and provider communication reflects an innovative approach to supporting patient engagement in chronic disease management.

The medium-term follow-up may not capture long-term effects, particularly for hypertension. Generalizability is limited by smartphone access, demographics, and healthcare context. Selection bias may exist, as app users could differ from non-users in motivation or digital literacy. Engagement varied due to individual factors, and limited connectivity or lack of personalized motivational strategies may have reduced intervention impact. Baseline differences in education, BMI, and lipid profiles, although adjusted for, could influence outcomes. The non-random assignment of participants within clinics and the absence of full blinding may affect internal validity. Finally, technological proficiency and infrastructure challenges, despite providing smartphones and data, could have limited participation, affecting broader applicability.

5. Conclusion

The interactive smartphone application was associated with a modest but significant improvement in glycaemic control. The intervention also showed a significant association with BP control. These findings highlight the potential of mHealth interventions in managing chronic diseases, especially in resource-limited settings. Future research should explore personalized engagement strategies and extended follow-up periods to optimize the impact of digital health solutions on both BP and glycemic control.

CRediT authorship contribution statement

Pearl Aovare: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Felix P. Chilunga:** Writing – review & editing, Validation, Supervision, Conceptualization. **Charles F. Hayfron-Benjamin:** Writing – review & editing, Methodology. **Amos Laar:** Writing – review & editing, Validation, Supervision, Conceptualization. **Nicolas Moens:** Writing – review & editing, Validation, Supervision, Conceptualization. **Eric P. Moll van Charante:** Writing – review & editing, Validation, Supervision, Conceptualization. **Charles Agyemang:** Writing – review & editing, Validation, Supervision, Conceptualization.

Consent to participate

Written informed consent was obtained from all study participants before their inclusion in the study.

Ethics statement

This study was approved by the Ghana Health Service Ethics Review Committee (GHS-ERC) under approval number GHS-ERC:004/08/20. Written informed consent was obtained from all participants prior to their inclusion in the study. The research was conducted in accordance with all relevant guidelines and regulations.

Contributors' statement

The study was conceived by CA, NM, and PA. Data was collected by PA and NM. PA and FC performed the data analyses. PA drafted the initial manuscript, and CA, NM, and FC provided critical revisions and feedback. All authors reviewed and approved the final version of the manuscript. Each author had full access to and verified the underlying data reported in the study.

Data and code availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Pearl Aovare reports financial support was provided by Africa eHealth Foundation and Philips Foundation,. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to

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Appendix A. Supplementary data

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