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Transforming hypertension management with digital technology: a retrospective cohort study in four sub-Saharan African countries

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ABSTRACT

Introduction A chronic disease management programme anchored on a digital platform was scaled in Ghana, Kenya, Sierra Leone and Tanzania following successful pilot studies. We investigated blood pressure (BP) changes and their associated factors among patients with hypertension.

Methods In this retrospective cohort study, the primary outcome was the relative reduction in BP and an absolute reduction in systolic BP (SBP) of >5 mm Hg at 6 (±2) months post-enrolment. We used the paired t-test, McNemar's test and multivariable logistic regression to compare changes in mean SBP, compare changes in proportions and examine the association between patient characteristics and achieving >5 mm Hg SBP reduction, respectively.

Results As of May 2024, 131 912 patients with hypertension had completed at least 6 months of the programme. The study cohort included 63 003 (48%) patients with documented enrolment and 6-month BP measurements. The mean age was 60.8 years (SD: 13.1) and 74.7% were female. Mean SBP and diastolic BP decreased by 8.3 mm Hg (95% CI −8.5 to −8.1; p<0.001) and 4.5 mm Hg (95% CI −4.7 to −4.4; p<0.001), respectively. Patients with uncontrolled SBP (≥140 mm Hg) at enrolment (n=38 079) experienced a mean SBP reduction of 18.1 mm Hg (95% CI −18.3 to −17.8; p<0.001). The proportion of patients with controlled BP increased from 35% at enrolment to 53% at 6 months. Factors associated with higher odds of >5 mm Hg SBP reduction included follow-up by community health workers (adjusted OR (AOR)=1.06; p=0.041), ≥3 medical reviews (AOR=1.16; p<0.001) and ≥8 BP assessments (AOR=1.35; p<0.001).

Conclusion Significant BP improvements were observed under routine programme conditions among patients with 6-month documented measurements. Despite limitations in causal inference owing to the lack of a control arm and the high proportion of patients without a documented follow-up BP, the findings highlight the potential real-world value of digital-enabled community-based and decentralised care in hypertension management.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Hypertension is the leading cause of cardiovascular morbidity and mortality in sub-Saharan Africa.

⇒ Despite the proven effectiveness of digital interventions in managing non-communicable diseases, there are few examples of scaled digital hypertension models in the region.

⇒ A pilot study in Kenya and Ghana that evaluated the use of this digital-enabled programme showed that the model of care improved and sustained blood pressure (BP) control, especially among patients with elevated BP at enrolment.

WHAT THIS STUDY ADDS

⇒ Despite its pre–post nature, this study is one of the largest in sub-Saharan Africa to longitudinally track BP changes in a real-world setting using routinely collected data.

⇒ Using data from four countries, this study underscores the potential of digital technology to transform hypertension care by facilitating continuous monitoring of key clinical parameters.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Randomised controlled trials are needed to establish causality and assess the impact of various components of this digital health-enabled programme.

⇒ Future research should focus on exploring the scalability of this programme for other regions and diseases, assessing long-term outcomes such as complications/mortality, exploring innovative approaches to improve follow-up rates and more complete data capture in real-world settings and evaluating the intervention's cost-effectiveness and budget impact.

INTRODUCTION

Hypertension is the second leading cause of all-cause disability adjusted life years[1] and the leading cause of cardiovascular morbidity and mortality globally.[2 3] Of the 1.3 billion adults with hypertension globally, 75% reside in low- and middle-income countries.[3] The WHO estimates that 36% of adults in Africa have hypertension,[4] and less than half of those with hypertension in the African region are diagnosed, with only 1 in 3 being on treatment and 1 in 10 achieving control.[4 5] This low treatment coverage and control status is largely attributed to limited access to care, referral delays, inadequate patient education and awareness and insufficient data to drive meaningful decisions.[6 7]

Digital solutions facilitate the management of non-communicable diseases (NCDs) and streamline data collection and management.[8–12] Despite successful primary care-based digital health interventions in Asia, Europe and North America,[13–20] few examples of scaled, digitally enabled hypertension management models exist in sub-Saharan Africa (SSA).[13 21–23] Weak health information systems and a paucity of quality primary data are major barriers to the prevention, diagnosis and treatment of hypertension and other NCDs. Furthermore, data gaps hinder the tracking of progress towards attaining national and global commitments, such as universal health coverage.[24]

A technology-enabled NCD programme[25] was deployed across four SSA countries, bringing together Ministries of Health, non-profit organisations, faith-based health systems, private sector players and foundations. This programme was first piloted in the private sector in Ghana and Kenya from 2016 to 2019,[26 27] and then expanded into the public sector in Kenya in 2019, into the faith-based sector in Ghana in 2021 and eventually introduced in Sierra Leone and Tanzania (faith-based sector) in 2022. Each country adapted the programme to fit its local context with country-specific names, including Akoma Pa (Good Heart) in Ghana, Empower Health in Kenya, Afya Imara (Good Health) in Tanzania and Bette Lyfe (Better Life) in Sierra Leone. The programme currently supports a range of disease conditions, including hypertension, diabetes, mental health (depression, anxiety and substance use disorders) and maternal and child health.

Wider implementation of such interventions needs to be informed by evidence of intervention effectiveness in real-world settings. Findings from the Empower Health pilot study, involving 1266 patients in Ghana and Kenya, demonstrated that this model of care improved and sustained blood pressure (BP) control, especially among patients with elevated BP at enrolment.[27]

This study aimed to update the results of the previous study (pilot) and provide data from the scale-up phase, which covers additional countries, more health facilities, more patients and additional sectors (public and faith-based). Specifically, in patients with hypertension, we aimed to (1) assess the changes in BP over 6 months post-enrolment and (2) examine the factors associated with clinically significant BP changes.

METHODS

Study design

This retrospective cohort study quantified real-world BP changes among patients with hypertension who were enrolled in and receiving care through a digital health platform (DHP)-enabled programme between January 2019 and May 2024 in Ghana, Kenya, Sierra Leone and Tanzania. We describe the care provided to the patients, characterise their disease states and quantify their BP changes. Specifically, we conducted a before-and-after analysis for a subset of patients aged 18–90 years, with paired baseline and 6-month (±2 months) post-enrolment BP data. The 6-month post-enrolment follow-up window is in alignment with the WHO HEARTS Systems for Monitoring key performance indicator: 'Six-monthly control of BP among people treated for hypertension'.[28] The ±2 window around the 6-month follow-up was a pragmatic decision to cater for real-world variability in scheduling, aligning with similar approaches that have been used in studies using data from routine clinical practice.[29]

Operational definitions and study measurements

Definition of hypertension

Diagnosis of hypertension

Patients were classified as having hypertension if they met one of these three criteria: systolic BP (SBP) ≥140 mm Hg and/or diastolic BP (DBP) ≥90 mm Hg, self-reporting of a previous diagnosis of hypertension by a healthcare provider or currently taking antihypertensive medications.[4 30] Brachial BP was measured using a validated battery-powered automated machine (OMRON M2 device; Omron Healthcare, Kyoto, Japan) with universal cuffs. Measurement was taken after a 5-minute rest while the participant was seated. Three BP readings were taken 1 min apart. The average of the last two readings was considered as the final reading for analysis.[31] Self-reported previous diagnosis or current use of antihypertensive medication was corroborated with the patient records in the facilities in which they were diagnosed or undergoing management.

Control of hypertension

Hypertension control was defined as BP being within the recommended treatment targets for most patients; SBP <140 mm Hg and DBP <90 mmHg.[4 30 32]

Hypertension severity grading

Given the established correlation between BP severity and cardiovascular risk,[33] we classified patients based on the European Society for Hypertension grading of hypertension[32] as presented in online supplemental table 1. For the purposes of this analysis, we combined and labelled any readings in the 'optimal, normal and high-normal' ranges as being 'within target/control' as per the above-described definition.

Clinically significant reduction in systolic blood pressure

Based on previous studies,[34 35] a clinically significant reduction in SBP was defined as a reduction that would have meaningful implications for the risk of cardiovascular events. A >5 mm Hg SBP reduction at the 6-month follow-up was considered clinically significant.[34 35]

Cardiovascular risk score

The programme used the WHO non-laboratory risk score algorithm, embedded into the DHP, to estimate the 10-year risk of cardiovascular events. The scoring tool was designed to allow risk prediction in low-resource settings where laboratory testing may not be available. Scores were computed based on age, sex, smoking status, SBP and body mass index (BMI).[36 37]

Operational definitions of other variables are provided in online supplemental table 2.

Digital health-enabled patient management

This was a multicomponent programme encompassing training, care coordination, decentralisation of care, data literacy and digital technology. SPICE (not an acronym), the DHP used in the programme, is an open-source digital public good.[25 38 39] The programme was co-designed with stakeholders at every level of the health system, leveraging service design practices[40 41] and was grounded in human-centred design principles.[42] It spanned the entire patient journey and comprised screening, diagnosis, linkage to care, care planning and community-based follow-up (online supplemental figures 1 and 2).[43]

Awareness and community screening

Trained community health workers (CHWs; see online supplemental table 2 for country-specific terminologies) were provided with a point-of-care toolkit that included a BP monitor, glucometer and strips, lancing devices, swabs, weighing scale, height metre, safety boxes and a smartphone loaded with the DHP. During their routine household visits and at various community gatherings, CHWs conducted health education and screening, including BP measurements as per the procedure described above. Individuals with high BP (SBP ≥140 mm Hg and/or DBP ≥90 mm Hg) were automatically flagged and referred to the nearest health facility.

Clinical review and risk stratification

At the health facility, trained healthcare workers further assessed individuals to confirm the diagnosis and enrol them into long-term longitudinal care. Moreover, patients with an existing hypertension diagnosis in the participating sites were also enrolled in the programme. The programme included decentralising and task-sharing hypertension care to health centres (and dispensaries where local regulations allowed) to improve access, while strengthening district-level care in a hub-and-spoke approach. To ensure quality of care was maintained, the programme invested in quarterly site support visits and DHP-enabled algorithmic patient management and clinical decision support.

Longitudinal care

Follow-up was conducted at the community and facility levels. At the community level, CHWs conducted BP monitoring, blood glucose assessment (for patients with diabetes), symptom checks and adherence counselling monthly, aligned with their routine monthly household visits. At the facility level, follow-up was differentiated depending on the control status of the patient: monthly for patients with uncontrolled BP and/or after initiation or change of antihypertensive medications and every 3 months for patients with controlled BP as per WHO guidance.[30] Longitudinal data collected at the community and facility levels were visualised using a unified patient record on the DHP.

Data analytics and reporting

The DHP supported real-time generation of reports, patient line lists and trends visualised on dashboards relevant to each level of the health system, including screening coverage, linkage to diagnosis and care, retention in care, control rates, risk factors, prescription and dispensing data and complications. Moreover, the programme supported data review and quality improvement meetings at both the facility (monthly) and regional levels (quarterly).

Operational oversight and collaboration

The programme was embedded into the existing health system infrastructure for long-term sustainability and adoption. Health system staff delivered care to the patients, supported by operational and technical staff of Medtronic LABS. The ministries of health provided oversight, policy direction, clinical guidelines and training, while subnational teams and other health system partners, such as faith-based health networks, provided frontline implementation, mentorship and quality assurance. Ongoing development and maintenance of the DHP, tablets, mobile phones and data bundles were provided for the digital component. The programme was supported by financial contributions and technical support from donor partners, Medtronic LABS and health system stakeholders (online supplemental table 3), and academic support for ongoing evaluation.

Statistical analysis

The data were extracted from the SPICE database. Python V.3.12 (Python Software Foundation, Wilmington, Delaware, USA) was used for data wrangling and manipulation prior to analysis. All other statistical analyses were performed using Stata software (V.18.0; Stata Corporation, College Station, Texas, USA). Descriptive statistics were generated for all variables and compared between patients with and without 6-month BP data to assess the risk of attrition bias. Baseline characteristics were compared using Pearson's χ^2 test of independence and the independent-sample t-test for categorical and continuous variables, respectively. Additionally, standardised mean differences (SMD) were computed to assess the balance between those with and without follow-up BP measurements. An SMD <0.1 was considered indicative of good balance.[44] The large sample size supported the use of parametric tests, as the central limit theorem ensures that the sampling distribution of the mean approximates normality in large samples.

The paired t-test was used to compare mean changes in BP from enrolment to 6 months, whereas McNemar's test was used to compare changes in proportions across hypertension grades during the same period. We also analysed changes in SBP stratified by follow-up periods within the 6±2 months window (4–<5.5, 5.5–6.5 and >6.5–8 months) to assess variations associated with the timing of follow-up BP measurements.

The primary outcome measure was a relative reduction in BP and an absolute reduction in SBP of >5 mm Hg over 6 months post-enrolment. This threshold was selected based on its clinical significance in reducing cardiovascular risk, as demonstrated in previous studies.[34 35] Binary logistic regression analyses were performed to examine the association between SBP reduction and independent variables (age, sex, diabetes comorbidity, hypertension awareness at enrolment, type of enrolment facility, follow-up by a CHW, BMI, employment status and country of residence). Cardiovascular disease (CVD) risk score was excluded from the final model because it is a composite score of the other predictor variables in the model, as well as the outcome variable (age, sex, BMI and SBP).[37] Multicollinearity among the study variables was assessed using the variance inflation factor (VIF). In this analysis, all variables had a VIF <5,[45] therefore, no further investigations were performed (online supplemental table 4). Variables with a p value <0.25 in bivariate logistic regression were included in the final multivariable logistic regression model to control for potential confounding effects.[46] We evaluated the predictive performance of the logistic regression model using the area under the receiver operating characteristic curve (online supplemental figure 3). The multivariable logistic regression model demonstrated good discrimination (area under the curve (AUC)=0.79). Overall statistical significance of categorical variables in the multivariable logistic regression model was assessed using the Wald test ('testparm' command in Stata). Given the difference in country implementation, the multivariable logistic regression was also stratified by country (online supplemental table 9).

To assess the robustness of the findings to potential clustering effects, we also fitted a multilevel mixed-effects logistic regression model with a random intercept for country as a sensitivity analysis. Four models were fitted as follows: (1) a null model excluding all predictor variables to estimate the variation attributable to between-country clustering, (2) a model including individual-level clinical and socio-demographic factors, (3) a model including program-level factors only and (4) an adjusted model incorporating all covariates. The intraclass correlation coefficient (ICC=0.043) indicated that approximately 4.3% of the variation in achieving a >5 mm Hg reduction in SBP was attributable to differences between countries (online supplemental table 10).

Adjusted ORs (AORs) with 95% CIs were computed and statistical significance was evaluated at $p<0.05$.

Given that this analysis used routinely collected programme implementation data, the patterns of missingness were likely non-random; therefore, multiple imputation was not performed.

Patient and public involvement

Patients, community health personnel, health workers and health system leaders were involved in the programme design and refinement through group-based co-creation workshops and individual user feedback sessions as part of the human-centred design approach referenced earlier.

Reporting guidelines

This study was based on the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[47]

RESULTS

Baseline characteristics

From January 2019 to May 2024, 140 029 patients with hypertension were enrolled in the programme at 246 health facilities in the four countries. Among these, 131 912 (94%) had completed at least 6 months since enrolment in the programme, with 63 003 (48%) having documented enrolment and 6-month BP (figure 1) and constituted the study cohort to report the clinical outcomes.

Among the patients who had completed at least 6 months since enrolment in the programme, 47.8% of females, 49.1% of those aged 60–69 years, 50.3% of those with diabetes and 70.4% of newly diagnosed patients had both baseline and 6-month follow-up BP measurements documented in the DHP. Tanzania and Sierra Leone had the highest proportion of patients with documented 6-month follow-up BP (81.1% and 65.8%, respectively). Lower-tier facilities (health centres/dispensaries) had the highest proportion of patients with a 6-month documented BP (61.9%) compared with district/subcounty hospitals (44.2%) and regional/tertiary hospitals (41.4%).

The cohort with a documented baseline and 6-month BP recording (n=63 003) had a mean age of 60.8 (SD 13.1) years, mean SBP of 146.3 (SD 22.8) mm Hg and mean DBP of 85.2 (SD 13.6) mm Hg. Among them, 74.7% were female, 30.8% had diabetes comorbidity, 25.6% were newly diagnosed and 64.4% were enrolled in district/subcounty level hospitals. Although statistically significant differences were observed across most variables between those with and without 6-month BP follow-up, the SMD analysis showed that the magnitude of these differences was minimal (SMD<0.1). Notable exceptions included hypertension awareness status at enrolment, level of care and country of enrolment (table 1).

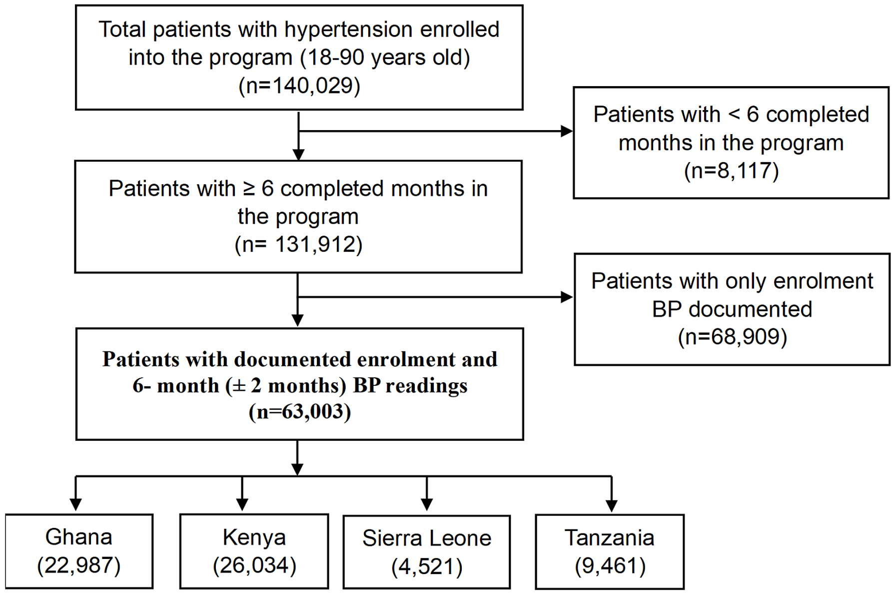

Figure 1 Flowchart showing the identification and selection of the study cohort. BP, blood pressure.

Magnitude of BP changes between baseline and 6 months

The proportion of patients with BP in the control range increased from 35% at enrolment to 53% at 6 months (p<0.001). The number of patients with grade 1, 2 and 3 hypertension reduced by 11%, 43% and 60% (all p<0.001), respectively, from enrolment to 6 months (figure 2).

Table 2 presents the changes in mean SBP and DBP after the 6-month follow-up period. The mean SBP and DBP reduced by 8.3 mm Hg (95% CI −8.5 to −8.1; p<0.001) and 4.5 mm Hg (95% CI −4.7 to −4.4; p<0.001), respectively. Patients enrolled with an elevated SBP (≥140 mm Hg; n=38 079) had a significant reduction in mean SBP of 18.1 mm Hg (95% CI −18.3 to −17.8; p<0.001) over the 6-month period.

Table 2 also shows the mean SBP changes between baseline and 6 months based on patient characteristics. Overall, SBP reduction was observed across most subgroups. The largest mean reductions were observed among patients with more frequent (≥8) BP assessments (−13.4 mm Hg; p<0.001), those who were newly diagnosed (−14.4 mm Hg; p<0.001), those enrolled in dispensaries and health centres (−13.5 mm Hg; p<0.001) and those who had at least one CHW-undertaken follow-up (−14.9 mm Hg; p<0.001).

Online supplemental table 5 shows mean SBP changes stratified by country. Tanzania had the highest SBP reduction across most characteristics, while Ghana had the least (overall reduction of −4.4 mm Hg; p<0.001). Online supplemental table 6 presents SBP changes stratified by timing of follow-up BP. Those with a shorter timing (4 to <5.5 months) had slightly less reduction in SBP (−7.4 mm Hg) compared with those whose follow-up BP was taken at 5.5–6.5 months (−8.8 mm Hg) and those whose BP was taken at >6.5–8 months (−8.3 mm Hg). This pattern was consistent across most subgroups, indicating that most of the patients whose follow-up BP was taken at ≥5.5 months had better improvements in BP.

Factors associated with SBP reduction of >5 mm Hg

Table 3 presents results from the bivariate and multivariable logistic regression. A total of 33 331 (52.9%) patients achieved >5 mm Hg reduction in their SBP. The association between age and SBP reduction was statistically significant overall (p<0.001; table 3). Significantly lower odds of >5 mm Hg SBP reduction were observed among patients aged 60–69 years and ≥70 years compared with those aged <40 years, while no statistically significant differences were observed in the 40–49 and 50–59 age groups (online supplemental table 8). Patients with eight or more BP assessments had 1.35 times greater odds of experiencing >5 mm Hg SBP reduction than those who had two to three assessments within the 6 months. Higher odds were also observed among those with three or more medical reviews (AOR=1.16, 95% CI 1.10 to 1.23) and those who received at least one follow-up from a CHW (AOR=1.06, 95% CI 1.00 to 1.11).

Patients enrolled at district/subcounty and regional/tertiary levels were 30% and 22% less likely, respectively, to achieve a >5 mm Hg reduction in SBP compared with those enrolled in dispensaries or health centres. Similarly, patients with diabetes comorbidity had lower odds of >5 mm Hg SBP reduction compared with those with a documented hypertension diagnosis only (AOR=0.80, 95% CI 0.77 to 0.83). While the association between BMI and SBP reduction was not statistically significant overall (p=0.070; table 3), patients with BMI ≥30.0 (obese) had significantly lower odds of achieving >5 mm Hg SBP reduction compared with those with normal BMI (AOR=0.94, 95% CI 0.90 to 0.99, p=0.020; online supplemental table 8). Results from the multivariable logistic regression analysis, stratified by country, are presented

Table 1 Baseline socio-demographic and clinical characteristics

Variables	Patients with baseline and 6-month BP data n=63 003, n (%)	Patients without 6-month BP data, n=68 909, n (%)	P value	SMD
Sex				
Female	47 036 (47.8)	51 389 (52.2)	0.734*	0.002
Male	15 967 (47.7)	17 520 (52.3)		
Age, years				
<40	3690 (46.7)	4209 (53.3)	<0.001*	0.042
40–49	8271 (47.3)	9235 (52.7)		
50–59	15 487 (48.2)	16 664 (51.8)		
60–69	18 613 (49.1)	19 298 (50.9)		
≥70	16 942 (46.5)	19 503 (53.5)		
Age, mean (SD)	60.8 (13.1)	61.0 (13.4)	<0.001†	0.014
Diabetes comorbidity				
No	43 617 (46.7)	49 750 (53.3)	<0.001*	0.065
Yes	19 386 (50.3)	19 159 (49.7)		
Hypertension awareness				
Known patients	46 902 (43.0)	62 122 (57.0)	<0.001*	0.420
Newly diagnosed	16 101 (70.4)	6787 (29.6)		
BMI, kg/m^2				
Normal (18.5–24.9)	23 434 (48.1)	25 244 (51.9)	0.058*	0.015
Underweight (<18.5)	2951 (46.5)	3390 (53.5)		
Overweight (25.0–29.9)	20 066 (47.7)	21 994 (52.3)		
Obese (≥30.0)	16 552 (47.5)	18 281 (52.5)		
Level of care				
Dispensaries/health centres	17 586 (61.9)	10 804 (38.1)	<0.001*	0.301
District/subcounty hospitals	40 555 (44.2)	51 234 (55.8)		
Regional/county/tertiary	4862 (41.4)	6871 (58.6)		
10-year CVD risk score				
<10%	37 209 (47.6)	40 890 (52.4)	<0.001*	0.056
10% to <20%	22 884 (47.7)	25 119 (52.3)		
20% to <30%	2530 (48.0)	2735 (52.0)		
≥30%	380 (69.7)	165 (30.3)		
Employment status				
Not documented	18 (16.1)	94 (83.9)	<0.001*	0.055
Employed	5063 (47.3)	5638 (52.7)		
Self-employed	29 358 (46.8)	33 355 (53.2)		
Unemployed	28 564 (48.9)	29 822 (51.1)		
HTN grade (ESH definition)				
Within target/control	21 980 (45.2)	26 621 (54.8)	<0.001*	0.079
Grade 1	22 717 (49.7)	22 951 (50.2)		
Grade 2	11 918 (48.5)	12 631 (51.5)		
Grade 3	6388 (48.8)	6706 (51.2)		
Country				
Ghana	22 987 (42.1)	31 621 (57.9)	<0.001*	0.471
Kenya	26 034 (44.3)	32 737 (55.7)		
Sierra Leone	4521 (65.8)	2350 (34.2)		
Tanzania	9461 (81.1)	2201 (18.9)		

Continued

Table 1 Continued

Variables	Patients with baseline and 6-month BP data n=63 003, n (%)	Patients without 6-month BP data, n=68 909, n (%)	P value	SMD
Baseline SBP				
Mean (SD)	146.3 (22.8)	144.8 (22.9)	<0.001†	0.067
Baseline DBP				
Mean (SD)	85.2 (13.6)	84.8 (13.8)	<0.001†	0.028

*Statistical significance of differences calculated using: the χ^2 test.
†Statistical significance of differences calculated using: the independent sample t-test.
BMI, body mass index; BP, blood pressure; CVD, cardiovascular disease; DBP, diastolic blood pressure; ESH, European Society for Hypertension; HTN, hypertension; SBP, systolic blood pressure; SMD, standardised mean difference.

in online supplemental table 9. Online supplemental table 10 presents the results from the multilevel logistic regression.

DISCUSSION

This study assessed changes in BP and their associated factors following the implementation of a digitally enabled NCD programme. The main findings included: (1) significant reductions in both SBP and DBP at 6-month follow-up, (2) the proportion of patients with controlled BP increased from 35% at enrolment to 53% at 6-month follow-up, whereas the number of patients with grade 3 hypertension decreased by 60%, (3) patients with baseline uncontrolled hypertension experienced the most significant reduction in mean SBP (–18.1 mm Hg; p<0.001) and DBP (–14.7; p<0.001) and (4) the main independent determinants of a clinically significant reduction in SBP (>5 mm Hg) were age, diabetes comorbidity, hypertension awareness at enrolment, number/frequency of medical reviews and BP assessments, CHW-based follow-up, level/type of health facility in which a patient was enrolled and baseline SBP. These findings build on a previous pilot that evaluated this model of care in the private sector in Ghana and Kenya over a 12-month period that reported similar findings (mean SBP reduction of 9.4 mm Hg and a higher SBP reduction of 17.6 mm Hg among the group enrolled with uncontrolled BP).[27]

The proportion of patients with controlled hypertension (BP <140/90 mm Hg) increased by 18 percentage points over 6 months. Such an increase is particularly significant, given that maintaining SBP below 140 mm Hg has been shown to reduce the risk of stroke, ischaemic heart disease, other major cardiovascular events and

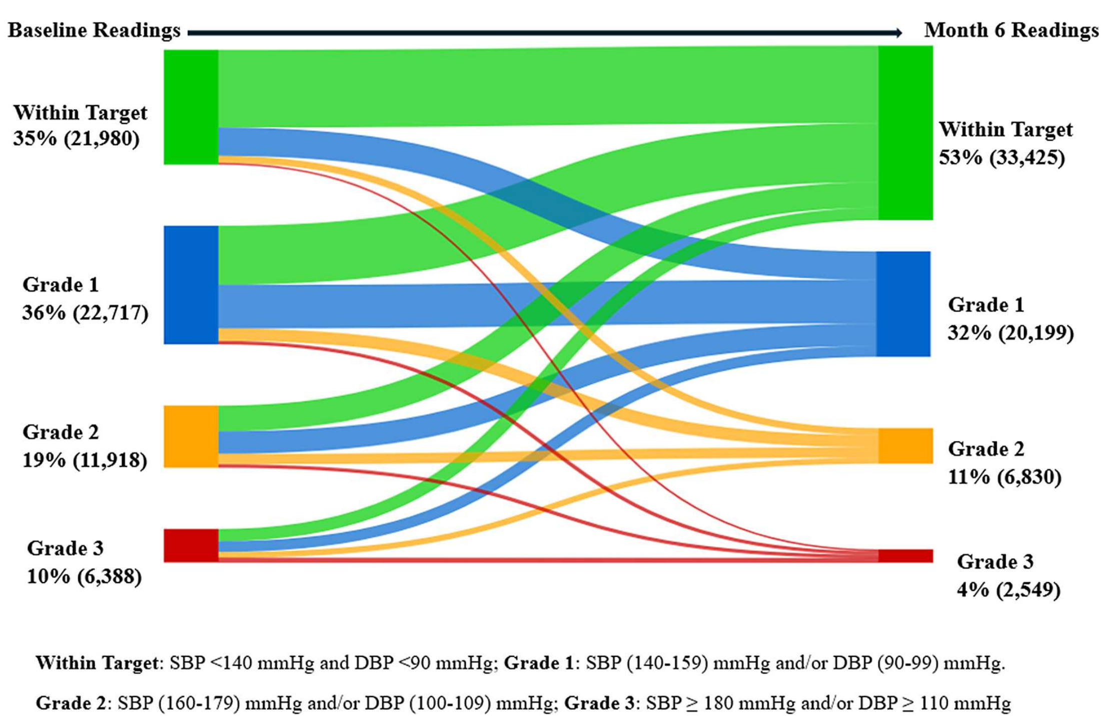

Figure 2 Transitions in hypertension severity from baseline to 6 months. DBP, diastolic blood pressure; SBP, systolic blood pressure.

Table 2 Mean* changes in blood pressure

Variable	n (%)	Baseline Mean (SD)	6 months Mean (SD)	Difference Mean (95% CI)
(a) Relative changes in blood pressure				
SBP (mm Hg)	63 003	146.3 (22.8)	138.0 (19.4)	−8.3 (−8.5 to −8.1)
DBP (mm Hg)	63 003	85.2 (13.6)	80.7 (11.6)	−4.5 (−4.7 to −4.4)
Baseline SBP ≥140 mm Hg				
Yes	38 079	160.1 (17.4)	142.1 (19.7)	−18.1 (−18.3 to −17.8)
No	24 924	125.1 (10.3)	131.7 (17.2)	6.6 (6.4 to 6.8)
Baseline DBP ≥90 mm Hg				
Yes	22 342	99.5 (9.4)	84.8 (11.9)	−14.7 (−14.9 to −14.5)
No	40 661	77.4 (8.0)	78.4 (10.8)	1.0 (0.94 to 1.16)
(b) Mean systolic blood pressure changes by patient characteristics				
Sex				
Female	47 036 (74.7)	145.5 (22.9)	137.7 (19.6)	−7.8 (−8.0 to −7.6)
Male	15 967 (25.3)	148.6 (22.1)	138.8 (18.8)	−9.8 (−10.2 to −9.4)
Age categories				
<40 years	3690 (5.9)	140.9 (21.7)	133.5 (17.3)	−7.4 (−8.2 to −6.6)
40–49 years	8271 (13.1)	145.1 (22.3)	135.8 (18.3)	−9.3 (−9.8 to −8.8)
50–59 years	15 487 (24.6)	145.5 (22.3)	137.5 (19.1)	−8.0 (−8.4 to −7.7)
60–69 years	18 613 (29.5)	146.4 (22.7)	138.6 (19.8)	−7.8 (−8.1 to −7.4)
70+ years	16 942 (26.9)	148.5 (23.5)	139.6 (20.1)	−8.9 (−9.3 to −8.5)
Diabetes comorbidity				
No	43 617 (69.2)	147.3 (22.9)	137.4 (19.1)	−9.9 (−10.1 to −9.7)
Yes	19 386 (30.8)	144.1 (22.3)	139.3 (20.2)	−4.8 (−5.1 to −4.4)
Hypertension awareness				
Known patients	46 902 (74.4)	144.5 (22.4)	138.3 (20.0)	−6.2 (−6.5 to −6.0)
Newly diagnosed	16 101 (25.6)	151.3 (23.1)	136.9 (17.6)	−14.4 (−14.8 to −14.0)
Number of medical reviews				
0	20 578 (32.7)	143.8 (22.2)	139.3 (20.2)	−4.5 (−4.9 to −4.2)
1–2	30 039 (47.7)	147.8 (23.0)	137.5 (19.0)	−10.3 (−10.5 to −10.0)
3+	12 386 (19.6)	146.7 (22.8)	136.8 (19.1)	−9.9 (−10.3 to −9.5)
Number of BP assessments				
2–3	34 048 (54.0)	145.8 (22.6)	138.9 (19.7)	−6.9 (−7.2 to −6.6)
4–7	25 006 (39.7)	146.6 (23.0)	137.1 (19.2)	−9.5 (−9.8 to −9.1)
8+	3949 (6.3)	148.7 (22.2)	135.3 (17.9)	−13.4 (−14.1 to −12.6)
Assessment by CHWs				
No	48 518 (77.0)	144.5 (22.4)	138.2 (20.1)	−6.3 (−6.6 to −6.1)
Yes	14 485 (23.0)	152.2 (22.9)	137.3 (17.0)	−14.9 (−15.3 to −14.5)
BMI (kg/m²)				
Normal (18.5–24.9)	23 434 (37.2)	146.4 (23.1)	137.8 (19.7)	−8.5 (−8.9 to −8.2)
Underweight (<18.5)	2951 (4.7)	145.3 (23.7)	137.1 (20.1)	−8.3 (−9.2 to −7.4)
Overweight (25.0–29.9)	20 066 (31.8)	146.2 (22.2)	138.0 (19.0)	−8.2 (−8.5 to −7.9)
Obese (≥30.0)	16 552 (26.3)	146.4 (22.8)	138.3 (19.3)	−8.1 (−8.5 to −7.8)
Level of care				
Dispensaries/health centres	17 586 (27.9)	149.5 (22.3)	136.0 (17.2)	−13.5 (−13.9 to −13.2)
District/subcounty hospitals	40 555 (64.4)	145.5 (22.9)	138.9 (20.1)	−6.6 (−6.8 to −6.3)
Regional/county/tertiary hospitals	4862 (7.7)	141.0 (21.8)	136.9 (20.7)	−4.1 (−4.8 to −3.4)

Continued

Table 2 Continued

(b) Mean systolic blood pressure changes by patient characteristics				
Employment status†				
Self-employed	29 358 (46.6)	146.1 (22.7)	137.8 (19.3)	−8.3 (−8.6 to −8.1)
Unemployed	28 564 (45.4)	146.6 (23.0)	138.3 (19.7)	−8.3 (−8.6 to −8.0)
Employed	5063 (8.0)	145.5 (21.8)	137.1 (18.5)	−8.4 (−9.1 to −7.7)
Baseline SBP				
<140 mm Hg	24 924 (39.6)	125.1 (10.3)	131.7 (17.2)	6.6 (6.4 to 6.8)
140–159 mm Hg	22 327 (35.4)	148.7 (5.7)	139.3 (17.6)	−9.4 (−9.6 to −9.2)
160–179 mm Hg	10 621 (16.9)	167.7 (5.7)	144.3 (20.1)	−23.3 (−23.7 to −22.9)
≥180 mm Hg	5131 (8.1)	194.2 (13.7)	149.3 (24.5)	−44.9 (−45.7 to −44.2)
Country				
Kenya	26 034 (41.3)	145.3 (21.9)	138.1 (19.8)	−7.2 (−7.5 to −6.9)
Ghana	22 987 (36.5)	142.7 (21.9)	138.3 (20.5)	−4.4 (−4.7 to −4.1)
Sierra Leone	4521 (7.2)	149.7 (24.4)	135.8 (18.9)	−13.9 (−14.7 to −13.1)
Tanzania	9461 (15.0)	156.1 (23.2)	137.8 (15.7)	−18.3 (−18.8 to −17.7)

All p values <0.001.
*Median changes presented in online supplemental table 7.
†Patients whose employment status (n=18) was not documented were excluded from this analysis.
BMI, body mass index; BP, blood pressure; CHW, community health worker; DBP, diastolic blood pressure; SBP, systolic blood pressure.

mortality.[48] Moreover, reductions of greater than 5 mm Hg SBP have been linked to a 10% reduction in the risk of major cardiovascular events, even among individuals with normal BP.[34 35 49] Notably, more than half (52.9%) of our study cohort achieved this clinically significant (>5 mm Hg) SBP reduction, highlighting the potential reduction in the risk of cardiovascular events, even over a short follow-up period.

Type 2 diabetes is associated with a twofold to fourfold higher risk of CVD, including myocardial infarction and peripheral artery disease.[50 51] In this study, one-third of the study cohort (30.8%) had diabetes comorbidity, with this subgroup experiencing a mean SBP reduction of 4.8 mm Hg (p<0.001), compared with 9.9 mm Hg (p<0.001) in those without diabetes. Patients with diabetes also had 20% lower odds of achieving a clinically significant SBP reduction of >5 mm Hg. Despite these differences, patients with diabetes achieved a mean SBP of 139.3±20.2 mm Hg at 6 months post-enrolment. Evidence from previous studies suggests that maintaining BP <140/90 mm Hg in individuals with diabetes substantially reduces the risk of all-cause mortality, myocardial infarction and heart failure.[52] These findings underscore the role of integrated multimorbidity management in mitigating CVD among patients with diabetes.[53]

Patients identified through screening experienced a higher SBP reduction and were 1.06 times more likely to experience a clinically significant reduction in SBP compared with known patients. Treating hypertension is generally more effective in its early stages, often before symptoms manifest, allowing for lifestyle modification, such as dietary changes and physical activity, to work better alongside low-dose antihypertensive medications.[54] These findings align with evidence showing that screening programmes are effective at identifying hypertension in earlier stages, where BP is more responsive to treatment, which results in better outcomes.[55] It is worth noting that patients enrolled via screening had a higher mean baseline SBP compared with known patients (151.3 mm Hg vs 144.5 mm Hg), which potentially contributed to the higher reductions observed.

Although previous studies have demonstrated sex differences in BP changes,[56] our findings showed minimal variation. Males achieved slightly greater mean SBP reduction compared with females (9.8 mm Hg vs 7.8 mm Hg) but had 4% lower odds of achieving an SBP reduction >5 mm Hg, although not statistically significant. Literature suggests that among premenopausal women, oestrogens exert a protective effect by inhibiting the sympathetic nervous system and the renin–angiotensin system, decreasing oxidative stress and reducing inflammation.[32 57] However, after menopause, there is a marked decrease in oestrogen levels, which is associated with an increase in BP. Approximately 80% of our enrolled patient population were aged 50 years and above, suggesting that a substantial proportion of the female participants were likely postmenopausal. This age distribution may partly explain the minimal difference in BP changes observed. Nevertheless, most patients in the study cohort were female (74.7%), which potentially reflects women's better health-seeking behaviour.[56 58]

The magnitude of SBP reduction varied across the age groups, with the odds of achieving a >5 mm Hg reduction in SBP decreasing with increasing age. This age-related

Table 3 Factors associated with >5 mm Hg SBP reduction among patients with follow-up

Variable	SBP reduction >5 mm Hg n (%) 33 331 (52.9)	COR (95% CI)	P value	AOR (95% CI)	P value*
Sex			<0.001		0.069
Female	24 424 (51.9)	Ref		Ref	
Male	8907 (55.8)	1.17 (1.13 to 1.21)		0.96 (0.92 to 1.00)	
Age (years)			0.001		<0.001
<40 years	1941 (52.6)	Ref		Ref	
40–49 years	4503 (54.4)	1.07 (1.00 to 1.16)		1.01 (0.93 to 1.11)	
50–59 years	8112 (52.4)	0.98 (0.92 to 1.06)		0.93 (0.86 to 1.02)	
60–69 years	9681 (52.0)	0.97 (0.91 to 1.04)		0.89 (0.82 to 0.97)	
70+ years	9094 (53.7)	1.04 (0.97 to 1.12)		0.85 (0.78 to 0.92)	
Diabetes comorbidity			<0.001		<0.001
No	24 260 (55.6)	Ref		Ref	
Yes	9071 (46.8)	0.70 (0.68 to 0.73)		0.80 (0.77 to 0.83)	
Hypertension awareness			<0.001		0.031
Known patients	23 086 (49.2)	Ref		Ref	
Newly diagnosed	10 245 (63.6)	1.80 (1.74 to 1.87)		1.06 (1.01 to 1.12)	
Number of medical reviews			<0.001		<0.001
0	9561 (46.5)	Ref		Ref	
1–2	16 833 (56.0)	1.47 (1.42 to 1.52)		1.14 (1.09 to 1.19)	
3+	6937 (56.0)	1.47 (1.41 to 1.54)		1.16 (1.10 to 1.23)	
Number of BP assessments			<0.001		<0.001
2–3	17 030 (50.0)	Ref		Ref	
4–7	13 856 (55.4)	1.24 (1.20 to 1.28)		1.19 (1.14 to 1.24)	
8+	2445 (61.9)	1.63 (1.52 to 1.74)		1.35 (1.24 to 1.47)	
Assessment by CHW			<0.001		0.041
No	24 071 (49.6)	Ref		Ref	
Yes	9260 (63.9)	1.80 (1.73 to 1.87)		1.06 (1.00 to 1.11)	
BMI (kg/m²)			0.069		0.070
Normal (18.5–24.9)	12 543 (53.5)	Ref		Ref	
Underweight (<18.5)	1526 (51.7)	0.93 (0.86 to 1.00)		0.92 (0.85 to 1.01)	
Overweight (25.0–29.9)	10 598 (52.8)	0.97 (0.93 to 1.01)		0.98 (0.93 to 1.02)	
Obese (≥30.0)	8664 (52.3)	0.95 (0.92 to 0.99)		0.94 (0.90 to 0.99)	
Level of care			<0.001		<0.001
Dispensaries/health centres	11 047 (62.8)	Ref		Ref	
District/subcounty hospital	20 094 (49.5)	0.58 (0.56 to 0.60)		0.70 (0.67 to 0.74)	
Regional/tertiary hospitals	2190 (45.0)	0.49 (0.45 to 0.52)		0.78 (0.72 to 0.85)	
Employment status†			0.268		
Self-employed	15 564 (53.0)	Ref			
Unemployed	15 029 (52.6)	0.98 (0.95 to 1.02)			
Employed	2727 (53.9)	1.03 (0.97 to 1.10)			
Baseline SBP			<0.001		<0.001
<140 mm Hg	6211 (24.9)	Ref		Ref	
140–159 mm Hg	13 783 (61.7)	4.9 (4.7 to 5.0)		4.6 (4.4 to 4.8)	
160–179 mm Hg	8654 (81.5)	13.2 (12.5 to 14.0)		12.7 (12.0 to 13.5)	
≥180 mm Hg	4683 (91.3)	31.5 (28.5 to 34.8)		29.1 (26.3 to 32.2)	

Continued

Table 3 Continued

Variable	SBP reduction >5 mm Hg n (%) 33 331 (52.9)	COR (95% CI)	P value	AOR (95% CI)	P value*
Country			<0.001		<0.001
Kenya	13 302 (51.1)	Ref		Ref	
Ghana	10 631 (46.2)	0.82 (0.79 to 0.85)		1.06 (1.01 to 1.11)	
Sierra Leone	2754 (60.9)	1.49 (1.40 to 1.59)		1.24 (1.14 to 1.35)	
Tanzania	6644 (70.2)	2.25 (2.14 to 2.37)		1.41 (1.32 to 1.51)	

Employment status had a p value >0.25 in bivariate logistic regression and therefore was not included in the final multivariable logistic regression model.
*Overall p values derived from the joint Wald test. Category-level p values presented in online supplemental table 8.
†Patients whose employment status (n=18) was not documented were excluded from this analysis.
AOR, adjusted OR; BMI, body mass index; BP, blood pressure ; CHW, community health worker; COR, crude OR; Ref, reference category; SBP, systolic blood pressure.

decline in treatment response may reflect arterial stiffening, the most significant pathophysiological factor of age-related increase in SBP,[32] which impairs arterial dilatation in response to BP changes.[59] These vascular changes usually manifest clinically as isolated systolic hypertension (ISH), characterised by a steady increase in SBP while DBP levels plateau at 50–60 years and decline thereafter.[32,60] This pattern is consistent with that noted in our study cohort, where most patients were above 50 years and a substantial proportion presented with ISH. This pattern has implications for cardiovascular risk and treatment decisions. While the SBP changes observed in our study have been associated with a lower risk of major cardiovascular events,[35,49] patients with ISH and DBP below 70 mm Hg may be at risk of organ hypoperfusion.[61] Therefore, treatment strategies should aim to balance optimal SBP reduction with maintaining DBP at levels that do not risk reduced organ perfusion. Despite these physiological differences, we observed clinically significant reductions in mean SBP across all age groups. These findings highlight the need for future studies to investigate age-specific interventions that optimise BP control while addressing the challenges of ISH management.

There is a growing move to decentralise NCD services to primary healthcare in low-resource settings to improve access and affordability.[62] Despite policy shifts, the fact that two-thirds of patients in this study received care at district/subcounty-level facilities supports evidence showing concentration of services at district-level facilities and a gap in service provision at health centres/dispensaries.[63] Previous studies show that these lower-tier facilities often remain under-equipped to manage NCDs, leading patients to seek care from higher-level facilities.[64] Nevertheless, lower-tier facilities (dispensaries/health centres) had a significantly higher proportion of patients with a documented 6-month BP follow-up (61.9%) compared with district/subcounty hospitals (44.2%) and regional/tertiary hospitals (41.4%). Furthermore, the mean SBP reduction was significantly higher among patients receiving care at dispensaries and health centres (13.5 mm Hg) than among those attending district or subcounty hospitals (6.6 mm Hg) and regional, county or tertiary hospitals (4.1 mm Hg). Given that dispensaries and health centres are often located closer to patients, particularly in rural communities, they facilitate consistent follow-up and ongoing support for chronic disease management. These findings underscore the critical role that digitally enabled lower-level facilities can play in controlling hypertension and other chronic conditions, especially in low-resource settings.

This study showed that CHW follow-up and a higher number of medical reviews were positively associated with a >5 mm Hg SBP reduction. These findings are consistent with previous ones, where equipping CHWs with digital platforms was shown to improve linkage to care and BP control.[65] Interventions by CHWs, such as home-based lifestyle modification and BP monitoring, have been shown to be effective in managing hypertension.[66] Previous studies have also shown that patients with frequent clinical reviews have better rates of BP control.[67,68] The DHP used in this study generated unique care plans in line with hypertension guidelines, which assigned high-risk patients to more frequent BP assessments and medical reviews.

Although the mean and median SBP reduction were 8.3 and 7 mm Hg respectively, only 52.9% of patients achieved an SBP reduction of >5 mm Hg. This potential skewness and heterogeneous BP improvement pattern has implications for future programme deployments. As outlined above, the study identified key determinants of BP improvement. Based on these factors, programme intensification may need to be tailored for patients with minimal SBP reduction, such as targeted CHW visits and more frequent follow-up. Nevertheless, further investigation is needed to determine why some patients with similar characteristics experience differential BP improvement.

This study has some limitations. Owing to its observational nature and the lack of a control group, care should be taken when drawing causal inferences or attributions, and the BP improvements observed may not be attributed solely to the intervention. The high proportion (52%) of patients without documented follow-up BP may have increased the risk of attrition bias. The missing data may have contributed to underestimation or overestimation of the observed BP changes and may limit the generalisability of the findings. Nevertheless, the SMD analysis indicated that participants with and without 6-month follow-up BP data were largely comparable. Huguet *et al* identified reasons for attrition in electronic health record (EHR)-based studies, including patients seeking care at a health facility not covered by the EHR, or deaths that may not be captured systematically by most EHR systems.[69] Moreover, unlike traditional longitudinal cohort studies, where researchers have control over follow-up of participants, data capture in real-world EHR-based studies is driven by less structured clinical and administrative factors and may have more missing data at both the variable and observation levels.[69 70] Furthermore, the variations in follow-up rates across countries (42%–81%) and across levels of facilities (41%–62%) warrant further investigation. The observed differences in follow-up rates and data completeness may partially explain the observed heterogeneity in SBP reduction across countries. For instance, Tanzania, which had the highest follow-up rates, also experienced the greatest SBP reduction. These differences may limit the direct comparability of outcomes between settings. Overall, the observed attrition rates highlight the need for stronger community engagement and retention strategies in these countries to ensure continuity of care.

Future research should explore the scalability of this model to other regions and diseases, assess long-term outcomes such as complications/mortality and evaluate the cost-effectiveness and budget impact of the programme. Furthermore, more robust randomised controlled trials are needed to compare the programme with usual care and assess the impact of its various components. In addition, causal inference methods, including propensity score modelling or inverse probability weighting can strengthen treatment effect estimation from observational data by approximating a counterfactual scenario.[71]

In conclusion, significant BP improvements were observed among patients enrolled in a digitally enabled programme, especially among those enrolled with uncontrolled hypertension. Though the absence of a control group and high proportion of patients without a documented follow-up BP limit causal inference, the findings reflect the potential real-world value of this model of care.

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Contributors ASh, ONO, GG, FM, JM, HRW and DO conceptualised the study and acquired ethical approval. GG, EO, JD, GTK, ASt, JN and EA were responsible for the programme design, management, administration and implementation. JMM, SO, XS and RP-S analysed the data with technical inputs from ASh, JOO, GG and ONO. ASh and ONO wrote the initial draft of the manuscript, which was subsequently revised by JOO, GG, JM, FM, JD, HRW and SO. All authors read, reviewed and approved the final manuscript for publication. The views presented in this manuscript do not represent the positions of their respective organisations. ONO is the guarantor.

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Competing interests ONO, JMM, ASt, JN and EA are employees of Medtronic LABS, which developed the SPICE digital platform, while XS is an employee of Medtronic. The other authors declare no competing interests.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

Ethics approval Ethical approval was obtained from all participating countries. Ethical approval was obtained from the AMREF Ethics and Scientific Review Committee (ESRC P1513/2023) in Kenya, the National Institute for Medical Research in Tanzania (NIMR/HQ/R.8a/Vol. IX/4198), Ethics and Scientific Review Committee (V1.0 of 04 April 22) in Sierra Leone and the CHAG Institutional Review Board (CHAG-IRB02072023) and Kwame Nkrumah University of Science and Technology

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