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Digital tools for improving antiretroviral adherence among people living with HIV in Africa

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ABSTRACT

Digital health technologies are revolutionizing healthcare delivery in Africa and across the globe. However, their impact on improving care for people living with HIV (PLHIV) in Africa has been relatively unexplored. The UNAIDS 95:95:95 targets face stark drawbacks from poor adherence to antiretroviral therapy (ART) and retention in care. Although digital tools have strengthened the HIV care cascade, particularly at the critical stages of initiation, adherence, and retention, their impact and synergistic potential remain uncertain. This review synthesized African evidence to assess the roles and impact of digital monitoring tools for improving ART adherence and retention among PLHIV in Africa. In addition, it summarizes potential facilitators and barriers to integrating these tools into the HIV care continuum in Africa. A literature search was conducted using PubMed, Google Scholar, Embase, and Cochrane Central. The websites of the World Health Organization (WHO) and the Joint United Nations Program on HIV/AIDS (UNAIDS) were also searched for additional data. The searches were restricted to studies published in English from January 2010 to November 2023. The review identified a significant trend towards utilizing mobile phones, SMS, and web-based applications for ART adherence and retention monitoring in Africa, where the use of mobile devices for periodic reminders and remote counseling has boosted HIV adherence in Nigeria, South Africa, and Uganda to about 75%. Novel interventions encompassing electronic pharmacy refill tracking, tele-counseling, and medication electronic monitoring systems such as smart pill containers have been utilized but with sparse usage. These tools have been invaluable in overcoming the barriers to antiretroviral adherence and retention, such as stigma, the digital divide, privacy concerns, and limited healthcare access. Collaboration between key stakeholders like local health professionals and

Abbreviations: PLHIV, People living with HIV; UNAIDS, Joint United Nations Programme on HIV/AIDS; DTs, Digital tools; WHO, World Health Organisation; U=U, undetected = untransmittable; ART, Antiretroviral therapy; QoL, Quality of life; IoT, Internet of Things; EMR, Electronic Medical Records; MEMS, Medication Event Monitoring Systems; RTMM, real-time medication monitoring; EDM, electronic dose monitors; EAC, enhanced adherence counseling; DMO, digital medication offering; FSW, female sex workers; MSM, men who have sex with men; PWID, people who inject drugs; RCT, randomized clinical trial; AI, Artificial Intelligence; YLH, Youth living with HIV; PrEP, Pre exposure prophylaxis.

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multinationals is crucial to overcoming these barriers. Furthermore, exploring other potential facilitators, such as tailored intervention and community engagement, is vital for maximizing the impact of these technologies.

1. Introduction

Estimates from the World Health Organization's (WHO) 2023 Epidemiological Fact Sheet indicate that globally, approximately 39 million people were living with HIV at the end of 2022 [1]. This figure highlights the global burden of HIV and the need for effective prevention, testing, and treatment strategies. Despite existing challenges, the global fight against HIV holds immense promise, as concerted international efforts have paved the way for a future with substantially reduced new cases. In 2022, approximately 1.3 million new cases of HIV infections were recorded, diminishing the progress made in prevention and treatment [1–4]. According to the WHO, more than two-thirds (about 25.6 million) of people living with HIV (PLHIV) reside in Africa [1]. As global efforts intensify toward achieving epidemic control, adherence to management modalities remains the most effective strategy for preventing worsening indices [1]. Antiretroviral therapy (ART) remains crucial for managing HIV infection and preventing transmission. However, adherence to ART remains a challenge in Africa, as data consistently reports retention in care as the most vulnerable component of the HIV care cascade [5].

Research reports that about 75% and 64% of patients who commenced ART remain in care after 24 and 64 months, respectively [6]. This interruption in treatment contributes significantly to treatment failure, unsuppressed viral load, and ART resistance. High-level treatment adherence and minimum retention rates of 95% are crucial for optimizing viral suppression. This often leads to undetectable viremia and the resultant inability to transmit the virus, as undetected levels imply the disease is untransmittable (U═U) [7–9]. Achieving U═U implies improved health outcomes, reduced risk of HIV-related complications, morbidity, and mortality, and an overall increase in the quality of life (QoL) and life expectancy for PLHIV [7,10]. Despite the established importance of ART adherence and retention, challenges persist, particularly in Africa. Various factors, including stigma, lack of ART adherence education, substance abuse, use of non-conventional medication, disinterest in continuing treatment, religious and cultural ideologies, drug stock-outs, associated side effects, poor healthcare service delivery, and overburdened care centers, have compounded the poor ART adherence in Africa [11–15]. The failure of traditional monitoring modalities such as directly observed therapy, physical pill count, support groups, and incentivization to achieve over 90% retention underscores the need for digital monitoring interventions [16–19].

Digital technologies offer promising solutions for improving ART access, delivery, and adherence monitoring [5,20]. Digital tools (DTs) are software programs or applications utilizing technology to perform tasks or deliver information. In context, they are software or applications using technology such as computers or phones to drive ART adherence and retention monitoring. Generally, they involve mobile Health (mHealth), web-based interventions, smart devices, and other digital means used to drive the HIV care cascade and similar disease conditions [21]. These interventions have recorded enormous success in upscaling retention among non-adherent patients and those at risk of treatment interruptions [22]. However, despite increasing interest and integration of these tools into the HIV care continuum in other climes, their usage in Africa, where the burden of HIV is most significant, seems limited and underreported. With the rapid proliferation of novel digital tools in the health industry and the use of these tools to bolster care provided at various stages, particularly in HIV care provision, there is a need to synthesize current evidence to reflect the state of digital intervention for ART delivery in Africa. The available tools in Africa, their impacts, and limitations are yet to be extensively explored and reviewed. This comprehensive review synthesizes evidence from existing research, identifies effective interventions, and highlights gaps in knowledge. It examines the use of digital technologies for improving ART adherence and retention in Africa and further enumerates potential factors enhancing and limiting their integration into the HIV care continuum in Africa.

2. Methodology

The literature used in this review was obtained through an online search across multiple electronic databases – PubMed, Google Scholar, Embase, and Cochrane Central. The search on PubMed utilized Medical Subject Headings (MeSH) terms. Key phrases such as "digital tools," "electronic monitoring," "adherence," "retention," "HIV," "Antiretroviral," "ART," and "care and retention" were combined in this search (Table 1). The websites of the World Health Organization (WHO) and the Joint United Nations Program on HIV/AIDS (UNAIDS) were also searched for additional information. Boolean operators (AND/OR) identified and distinguished vital phrases, while additional searches through the reference lists of the included papers provided more studies for review. All studies published in English discussing ART adherence monitoring and retention using digital tools, including mobile Health (mHealth), web-based interventions, and smart devices, implemented in any African country, and including at least one quantitative outcome measure of ART adherence were included in the review. Conversely, studies outside Africa not discussing a digital intervention for ART adherence, and

Table 1
Methodology for literature search.

Methodology Aspect	Description
Aim	• To assess the role and impact of digital tools on improving adherence and retention for PLHIV in Africa.
Search Strategy	• The review extensively sourced literature from online databases using MeSH terms and combined phrases such as 'digital tools,' 'electronic monitoring,' 'adherence,' 'retention,' 'HIV,' 'ART,' and 'care retention,' employing Boolean operators for search refinement.
Databases Searched	• PubMed, Google Scholar, Embase, Cochrane Central, and other pertinent databases. Search conducted from November 28 to December 19, 2023. The websites of the World Health Organisation (WHO) and the Joint United Nations Programme on HIV/AIDS (UNAIDS) were also searched.
Inclusion Criteria	• Studies published in English in full-text format • Studies discussing ART interventions implemented in any country in Africa. • Studies involving care implemented with a digital health intervention, encompassing mobile phones, apps, internet, and web-based health services. • Contained at least one quantitative outcome measure of ART adherence and retention. • Published between 2000 and 2023
Exclusion Criteria	• Studies that did not meet the inclusion criteria and duplicate publications.
Data Extraction	• Two authors conducted the data extraction. Author names, publication year, study location, study design, sample size, research objectives, type of intervention outcomes, and limitations of the tools employed were included in the table.
Data Synthesis	• Summarised findings from collected data, highlighting key themes, emerging trends, and valuable web-based resources integral to the review.

duplicate publications. The search was restricted to articles published from January 2010 to November 2023 to create a balance between incorporating foundational knowledge and prioritizing technologies actively developed and used in the 2020 s. It was conducted between 28 November 2023 and 10 December 2023. All studies that met the above criteria were further assessed for eligibility by two authors who independently reviewed the titles and abstracts of all retrieved papers. The authors conducted an independent selection of the documents, discussed the findings with each other, and cross-checked disparities with other authors. The selected studies were subjected to data extraction with essential data, such as author name, publication year, study locations, study design, sample size, research objectives, type of interventions, outcomes, and tool limitations, which were summarized into a data extraction table (Table 2). The findings from various sources – relevant articles, reviews, and letters, including website-based information resourceful to this review - were summarized and discussed in the review, trends were identified, and information synthesis was meticulously carried out.

3. Results

This review analyzed 28 studies exploring digital interventions used for ART adherence and retention monitoring in Africa (Table 2). Most articles in this review were published between 2015 and 2023, with reported studies conducted among groups of varying sizes ranging from 22 to 883 participants. These groups represented diverse categories of PLHIVs, such as adolescents, young adults, adults, pregnant women, and key populations. The distribution of publications by countries showed seven studies published in South Africa [23−27,44,47], followed by five studies each in Nigeria [28−31,48], and Uganda [22,32−34,53], four in Kenya [37,38,43,45], two each in Cameroon [35,36], and Tanzania [12, 42], and one each in Zimbabwe [39], and Botswana [40]. One paper, however, was a multi-country study [41] (Fig. 1). Segregating by study types, seventeen randomized clinical trials (RCTs) were included in the review, five pilot studies, two each for qualitative and observational studies, and one each for reports, and non-randomized trials. The type and features of digital tools found ranged from mobile phone-based interventions such as phone calls and Short Message Services (SMS) to more novel technologies like multimedia technology, electronic pharmacy refill tracking systems, mobile health (mHealth) technologies (smartphones and web-based), and electronic dose monitors (EDMs) (Fig. 2).

3.1. Digital interventions for ART adherence in Africa

3.1.1. Phone calls and short message services

These are technology-based reminders designed to track and remind patients of the ART intake schedule. They are delivered as phone calls and SMS reminders from caregivers or a centralized system to PLHIV on ART. SMS reminders could come in various forms and durations, such as weekly text messaging of any length (short or long messaging), daily or other frequency as determined by the care system [12,28,35,42,38,36, 43,32,31,33,40,27,44,45]. They have been studied to show varying impacts on patients' adherence and retention, discussed in later sections of this paper.

3.1.2. Multimedia technology for delivering high-quality adherence counseling

Traditional peer counseling can now be offered with multimedia technology and networks. This often involves the use of software and innovative technology-enhanced modalities to provide high-quality counseling to HIV patients. A South African counseling platform (Masivukeni) was designed to improve lay counselors' capacity to deliver quality ART adherence counseling to patients [23]. This multimedia software installed on laptops or sophisticated mobile devices enhanced the interactions between counselors, peers, and patients and was found to be an effective strategy [23].

3.1.3. Electronic pharmacy refill tracking system

This electronic system has been developed and used in Kenya, Malawi, and South Africa. A Moi Hospital – Indiana University School of Medicine collaboration led to the launch of the first-ever EMR in Sub-Saharan Africa for the care of PLHIV in Kenya, known as the AMPATH Medical Record System (AMRS) [46]. The AMRS allows community outreach teams to electronically identify patients who have missed appointments or defaulted treatment and visit them at their homes [46]. Similarly, a Malawian study comparing the efficiency of electronic pharmacy stock records to paper-based data reported that patient retention on ART was similar via paper registers or electronic data systems. However, less time and effort were used in estimating ART retention using electronic pharmacy stock records versus paper-based registers [47]. In South Africa, the Intelligent Dispensing of ART (iDART) system was developed as an electronic pharmacy stock record to minimize the resources necessary to determine retention in care among PLHIV [48].

3.1.4. Smartphone and web-based applications

With increasing smartphone accessibility, innovative mHealth applications have been designed to tackle various health conditions, even in resource-limited settings. In South Africa, the Smartlink Application designed to optimize ART linkage and monitor laboratory results showed promising results in linking and retaining PLHIV in care by providing information for appointment reminders and treatment-supportive guidelines [24]. Similarly, a Kenyan study (the ELIMIKA project) developed and tested a digital peer support platform to improve ART adherence among youths living with HIV in Kenya. It showed an improvement in the 3-month adherence rate and highlights the potential of eHealth interventions for improvements in ART adherence [37]. A similar study in Nigeria, utilizing social media to promote Adherence and Retention in Treatment (SMART) connections, showed a greater retention rate with no measurable effects [29]. In South Africa, 'MASI,' a comprehensive adherence-promoting mHealth smartphone application, was developed to address the barriers to ART adherence among adolescents and youths by leveraging behavioral change techniques [49]. This ongoing RCT is scheduled for completion by February 29, 2024. If proven to be practical and suitable, MASI could potentially be integrated into the care of adolescents and young adults living with HIV across various regions of the country [49]. Mobile and gaming interventions have been used as ART adherence strategies among adolescents and young adults (AYA) living with HIV. PEERNaija app, a gamified Android-based mHealth app, was created and tested in a pilot trial in Nigeria. This app has several features, including daily medication reminders, personalized adherence monitoring, and adherence scores based on tracking. It uses gamification mechanics such as a progress bar, badges, avatars, and leaderboards to motivate AYA for ART adherence and retention [50]. Additionally, the app allows users to compare their adherence scores anonymously with their peers while maintaining privacy [50].

3.1.5. Real-time medication monitoring with electronic dose monitors

Real-time medication monitoring tools generate objective real-time adherence information by providing dose-to-dose information about adherence over a period [51]. Several technologies exist or are under development to collect real-time adherence data and are here classified as medication event monitoring systems (MEMS) or electronic dose monitors (EDMs) [52], [53]. These are microelectronic monitors that track and record the opening of each medication bottle/box. It utilizes a wireless pillbox that tracks the date and time the pillbox is opened [53, 54]. EDMs, such as the Wisepill smart pill container produced by Wisepill Technologies and used for a pilot study in Uganda [53], could record the date and time of opening the ART pillbox. A similar device was used in a prospective single-arm observational pilot study in

Table 2
Studies in Africa assessing digital tools for ART adherence and retention.

Study Author & Year	Study location (Country)	Study Type	Sample Size (n)	Research Objective (s)	Type of DT/ Intervention utilized	Outcomes	Limitation of tools deployed
Sumari-de Boer et al. (2021) [12]	Tanzania	Randomized controlled trial	n = 249	Primary - to assess whether reminder cues using RTMM or SMS improve ART adherence among adult PLHIV in Kilimanjaro, Tanzania. Secondary - to examine the effect of our interventions on proportions who reached adherence goal and the effect on virologic outcome.	SMS Real-time medication monitoring (RTMM)	The results do not support the hypothesis that RTMM or SMS improve adherence to treatment. However, they increased the proportions of participants who reached adherence levels of 85% and 90% but did not have a significant effect on viral suppression.	The Hawthorne effect, meaning that being part of a study is influencing adherence positively, even in the control group.
Rana et al. (2015) [22]	Uganda	Qualitative study	n = 39	To report youths' opinions about SMS-based interventions targeted at improving their adherence	SMS	When viewed in the context of the widespread use of mobile phones, SMS-based interventions have promising potential to address adherence barriers among HIV-positive youth in a setting such as Uganda.	Restrictions on using mobile phones which is mostly faced by younger youth at schools. The second group includes some youth who might not be allowed to use the phone at home after a certain time at night. Another challenge includes phone sharing since text messages can disclose the HIV-status of youth to those with whom they share phones.
Robins et al. (2015) [23]	South Africa	Pilot study	n = 55	The study examined medication adherence and key psychosocial outcomes among non-adherent patients	Masivukeni or standard of care (SOC) counseling for ART non-adherence.	Masivukeni participants reported significantly more positive attitudes towards disclosure and medication social support, less social rejection, and better clinic-patient relationships than did SOC participants.	The sample size was restricted because clinic-based pill count data were not available on all participants
Venter WD et al. (2019) [24]	South Africa	Randomized controlled trial	n = 345	Evaluate SmartLink to improve linkage to care for newly diagnosed HIV-positive smartphone owners.	Installation of the SmartLink app	App-linked information and prompting can lead to increased linkage to care as the SmartLink app provided patients with laboratory results, and appointment reminders.	The Smartphone specifications required for installation excluded over 90% of candidates who volunteered to participate in the study.
You WX et al. (2020) [25]	South Africa	Qualitative study	n = 22	Explore potential facilitators and barriers to incorporating mobile phones and advanced technologies (e.g., biometric tools, mobile phone apps and chatbots) to deliver HIV-related interventions to Female Sex Workers living with HIV.	Digital technologies like biometrics as tools for identification, mobile phone apps, and chatbots.	While most FSWs are motivated to own or have access to a mobile phone.	Nearly all FSW expressed difficulty retaining phones and phone numbers as a result of financial instability, substance use, and theft.
Schwartz et al. (2015) [26]	South Africa	Pilot Study	n = 50	To assess the acceptability and feasibility of a cell phone-based case manager intervention targeting HIV-infected pregnant women on highly-active	Cell phones	Study found the pilot intervention to provide support to HIV infected women on HAART during late pregnancy and for 6 weeks postpartum to be feasible and highly acceptable	Cell phone ownership and ability to read English text messages

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Table 2 (*continued*)

Study Author & Year	Study location (Country)	Study Type	Sample Size (n)	Research Objective (s)	Type of DT/ Intervention utilized	Outcomes	Limitation of tools deployed
				antiretroviral therapy (HAART)			
Lippman et al. (2021) [27]	South Africa	Three-arm randomized controlled Trial	n = 752	To examine the efficacy of two personal support interventions at improving retention in HIV care.	One used only automated SMS communications to deliver support (SMS-only). The second paired SMS messages with peer navigation (SMS+PN). Both interventions were compared to the standard of care (SOC) in clinics	The intervention combining SMS appointment reminders, behavioural messaging and support from peer navigators nearly doubled the odds of recently diagnosed PLHIV being retained in HIV care over one year, relative to standard of care. An SMS-only intervention was not successful at improving retention.	The lack of a viral suppression outcome. Additionally, the technology component of the work was restricted to SMS, which has greater limitations than communication apps available through smartphones. The principal barriers to participants' mobile phone use – specifically, lack of connectivity and insufficient funds to purchase data – are obstacles for any phone-based messaging platform.
Maduka et al. (2013) [28]	Nigeria	Randomized controlled trial	n = 104	To investigate if adding adherence counselling and text message reminders to standard care improves ART uptake among non-adherent HIV patients in Nigeria.	Short service message (SMS) Adherence counselling	Results showed that the intervention group had a higher proportion of participants who achieved good adherence and had a larger increase in CD4 count.	Self-report of adherence introduced bias. The use of CD4+ estimation as a substitute for viral load as a proxy measure of adherence. Contamination risk due to influence of participants from other groups.
Dulli et al. (2020) [29]	Nigeria	Randomized controlled trial	n = 349	To test the effectiveness of the SMART Connections intervention on HIV treatment retention among youths aged 15–24 years and examine its on secondary outcomes of ART adherence, HIV knowledge, and social support.	SMART Connections	The intervention did not significantly improve retention or social support; however, HIV-related knowledge did improve significantly.	The results may not be generalizable to other youths outside the study areas. Recruitment lagged, because YLHIV enrolment in ART was substantially lower than estimated using HIV service data before the study.
Ekejiuba C et al. (2023) [30]	Nigeria	Non-randomized controlled trial	n = 484	To introduce phone EAC sessions for KPs who are virally unsuppressed and assess its effectiveness as compared to the routine physical EAC on achieving the expected viral suppression.	Phone-based Enhanced Adherence Counselling sessions	The intervention group achieved better suppression (90.5%) than the control group (86.7%).	Sampling bias e.g., those who consented may be more motivated to adhere to phone counseling than those who do not volunteer.
Abiodun et al. (2021) [31]	Nigeria	Randomized controlled trial	n = 209	To evaluate the feasibility, acceptability, and efficacy of interactive anad tailored short message reminders on antiretroviral therapy adherence among adolescents (15–19 years) living with HIV in southwest Nigeria.	Visual analog scale Viral load Pill count ACTG scores SMS Reminders	Interactive and tailored SMS reminders are a feasible, acceptable, and potentially effective way to improve ART adherence among adolescents living with HIV.	Single-center study, limiting generalizability. Relatively short follow-up period
Linnemayr et al. (2017) [32]	Uganda	Randomized, parallel, multisite controlled trial	n = 332	To assess the effectiveness of Short Message Service (SMS) reminder messages on antiretroviral and cotrimoxazole prophylaxis adherence	1-way and 2-way SMS	SMS reminder messages targeted at the population at 2 clinics in Uganda did not have an effect on multiple measures of their adherence to	The failure of SMS messages to improve adherence in our study suggests that it may be time to reconsider the potential such messages hold in the

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Table 2 (*continued*)

Study Author & Year	Study location (Country)	Study Type	Sample Size (n)	Research Objective (s)	Type of DT/ Intervention utilized	Outcomes	Limitation of tools deployed
				among HIV-positive youths as well as the relative effectiveness of SMS with and without a response option.		ART or prophylaxis medications. Furthermore, there was no differential effect on adherence between 1-way and 2-way messages.	long term, and under what circumstances they are effective.
MacCarthy et al. (2020) [33]	Uganda	Randomized controlled trial	n = 137	To report the acceptability, feasibility, and preliminary impact of the intervention.	SITA (SMS as an Incentive To Adhere) using a wisepill device	Both quantitative and qualitative data show that youth understood SITA and felt positively about it. Our pilot data suggests that it may also be used to improve ART adherence.	Of note, some initial technical problems occurred with the use of Wisepill to relay the adherence information, however the issues were subsequently resolved. There was also no clinical guidance to inform our definition of low adherers, so an arbitrary cutpoint was selected.
Kiwanuka et al. (2018) [34]	Uganda	Randomized trial	n = 661	A randomized trial of mobile phone reminders versus physical contact reminders, to assess retention rates using a follow-up schedule that mimicked an HIV vaccine efficacy trial.	Mobile phone or physical contact tracing reminders	Participants' reminders via physical contact tracing yielded statistically significant higher retention rates than mobile phones	Phone loss and unavailability due to lack of power at the time of reminders may have led to fewer reminders in the phone arm.
Mbuagbaw et al. (2011) [35]	Cameroon	Randomized controlled trial	n = 198	Primary: To evaluate the efficacy of sending weekly motivational text messages via mobile phones to enhance adherence. Secondary: To evaluate the effect of the intervention on BMI, quality of life, viral load, weight and so on.	Motivational SMS	There was no significant improvement in adherence experienced from sending motivational text messages.	Risk of disclosure of status with SMS. Interviews, the primary adherence measure used, might have resulted in overestimation of actual adherence. Adherence report in the last week may not show the true picture as adherence generally increases few days before a refill appointment.
Nsagha et al. (2016) [36]	Cameroon	Randomized controlled trial	n = 90	To test the effectiveness of mobile text message reminders and educational information in improving patient care.	SMS	Improved medication adherence observed with the intervention group (64.4%) against 44.2% in the control group.	Short study duration (6 months) limits long-term impact assessment. Generalizability might be limited as the study targeted urban patients.
Ivanova et al. (2019) [37]	Kenya	The ELIMIKA pilot project	n = 81	To report the evaluation results of the usability and the effectiveness of a pilot digital peer support system in improving HIV/ART knowledge, perceived importance of adherence, and perceived self-efficacy in adhering.	Interactive web-based peer support platform which included a blog with posts written by project coordinators, health care providers and young people on different topics, discussion section.	In general, the pilot digital platform was well accepted by participants - 95% stated their intentions to use the ELIMIKA again and 87% would recommend it to others.	The intervention did not lead to significant improvements in knowledge and adherence practices of young people involved in the intervention.
Lester et al. (2010) [38]	Kenya	Randomized controlled Trial	n = 538	To assess whether mobile phone communication between health-care workers and patients starting antiretroviral therapy in Kenya improved drug adherence and	WelTel Kenya1- weekly SMS messages	Patients who received SMS support had significantly improved ART adherence and rates of viral suppression compared with the control individuals.	Resource challenges but the country might benefit from bypassing less advanced technologies and instead using the most advanced methods available, which are more uniformly taken

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Table 2 (*continued*)

Study Author & Year	Study location (Country)	Study Type	Sample Size (n)	Research Objective (s)	Type of DT/ Intervention utilized	Outcomes	Limitation of tools deployed
				suppression of plasma HIV-1 RNA load.			up and that allow fresh innovation.
Mavhu et al. (2020) [39]	Zimbabwe	Cluster - randomized controlled trial	n = 496	To evaluate a peer-led differentiated service delivery intervention on HIV clinical and psychosocial outcomes among adolescents with HIV in Zimbabwe	Zvandiri, a peer-supported, community-based service delivery model.	Zvandiri significantly reduced the proportion of adolescents experiencing virological failure (undetectable HIV levels) after 96 weeks, compared to standard care.	Study conducted in rural Zimbabwe, may not be directly generalizable to other settings. Long-term sustainability and cost-effectiveness require further investigation.
Reid et al. (2017) [40]	Botswana	Randomized controlled trial	n = 108	To test the efficacy of SMS reminders on timeliness of ART pharmacy pickups at an urban clinic in Gaborone, Botswana.	SMS Reminders	Timeliness of ART pickup was not significantly improved by SMS reminders. Additionally, the intervention had no impact on immunologic or virologic outcomes in treatment-experienced patients.	SMS reminder may be only effective in treatment-naïve populations
Haberer et al. (2017) [41]		A summary of the discussion at the Bill and Melinda Gates foundation meeting convened to discuss promising ART adherence interventions for use at scale.	N/A	Discusses ART adherence interventions, specifically defined as strategies to improve adherence and/or relevant disease markers (i.e. HIV RNA, CD4 counts), and their potential for adaption and adoption across resource limited settings.	Education and counselling; information and communication technology (ICT)-enhanced solutions; healthcare delivery restructuring; and economic incentives.	The evidence base is promising for currently available, effective, and scalable ART adherence interventions for RLS	Cost can pose a barrier to implementing adherence interventions
De Sumari-de Boer et al. (2015) [42]	Tanzania	Prospective single-arm observational pilot study	n = 10	To test the feasibility of using RTMM among these HIV infected and TB patients in the Kilimanjaro region, Tanzania	SMS Real-time medication monitoring (RTMM)	This pilot study showed that RTMM was a feasible and acceptable way to measure adherence in our setting. All participants mentioned that the RTMM device reminded them to take their medicines and almost all found the device good or helpful	Network problems and the big size
Pop-Eleches C et al. (2011) [43]	Kenya	Randomized controlled trial	n = 431	This study tested the efficacy of short message service (SMS) reminders on adherence to ART among patients attending a rural clinic in Kenya.	SMS reminders	The data indicate that weekly SMS reminders increased the percentage of participants achieving 90% adherence to ART by approximately 13–16% compared with no reminder	No HIV-RNA determinations and, therefore, cannot corroborate that the differences in adherence were associated with differences in viral suppression
Madhvani et al. (2015) [44]	South Africa	Cross-sectional study	n = 883	To identify patient demographic groups least likely to use mobile phones as reminder tools in HIV care.	Mobile phones	Patient groups significantly associated with being less likely to use mobile phones as clinic appointment reminders were: a) patients 45 years or older, b) women, and c) patients with only primary or no schooling level. Patient groups significantly associated with being less likely to use	individuals volunteered to be part of the study: patients not randomly selected from the population might present common characteristics that differ from those of the general population. For example, people that volunteer to be part of a study might have a higher educational level and be more prone to the use of technology.

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Table 2 (*continued*)

Study Author & Year	Study location (Country)	Study Type	Sample Size (n)	Research Objective (s)	Type of DT/ Intervention utilized	Outcomes	Limitation of tools deployed
						mobile phones as medication reminders were: a) patients 35 years or older and b) patients with a lower monthly income.	
Smillie et al. (2014) [45]	Kenya	Randomized controlled trial	n = 20	To gain an understanding of 1) the perceptions and experiences of PLWHA who have attempted to engage in HIV care; and 2) the use of cell phones in everyday life, including perceptions of communicating via text message with Health Care Providers.	WelTel Kenya 1 and WelTel Retain	Most client participants and all HCP participants believed the WelTel intervention has the potential to be useful in increasing communication between the two groups, and listed potential benefits as having access to more timely information and improved communication.	shared access to phones and the implications for privacy and disclosure
Mulawa et al. (2023) [47]	South Africa	Pilot randomized controlled trial	n = 50	To describe the protocol for a pilot randomized controlled trial examining the feasibility, acceptability, and preliminary efficacy of MASI on self-reported ART adherence and social support.	MASI Mobile App	The most vulnerable youths have the most to gain from technological interventions, yet are often the least supported by digital interventions. MASI seeks to address this gap by creating a platform tailored to the needs of adolescents and young adults.	Excluding adolescents and young adults without smartphones may deepen existing inequities and leave out individuals with limited access to resources and social support. Furthermore, participants may lose access to their devices during the course of this study, which may impact study outcomes.
Peirce et al. (2023) [48]	Nigeria	Randomized controlled trial protocol	n = 50	To compare the feasibility, acceptability, appropriateness, adoption, and preliminary efficacy of the PEERNaija app without financial incentive (arm 1) versus the PEERNaija app with financial incentive (PEERNaija +, arm 2) for ART adherence and HIV viral suppression among AYA living with HIV	PEERNaija mobile app	This study will provide important data for the potential role of smartphones in delivering incentive-based medication adherence interventions along with essential peer support for vulnerable youth living with HIV. In addition, if proven to be effective, the inclusion of financial incentives will add additional costs that could impact scalability.	Loss of client privacy,
Harber et al. (2010) [53]	Uganda	Pilot study	n = 10	To assess adherence to antiretroviral therapy using the Wisepill real-time adherence monitoring tool.	Wisepill smart pill containers	Adherence levels measured by Wisepill, unannounced pill counts, and self-report were compared with each other, prior standard electronic monitoring, and HIV RNA. Continuous data achieved with median (interquartile range) adherence levels of 93% by Wisepill, 100% by unannounced pill count, 100% by self-report, and 92% by prior standard electronic monitoring showed transient, low-level viremia in about	Wisepill data was initially limited by battery life and signal transmission interruptions. Also, the study was conducted among a small sample size.

(*continued on next page*)

Table 2 (*continued*)

Study Author & Year	Study location (Country)	Study Type	Sample Size (n)	Research Objective (s)	Type of DT/ Intervention utilized	Outcomes	Limitation of tools deployed
						40% of study participants.	

Tanzania, which recorded a 90% effectiveness among users [42]. These devices have an automated alarm system to trigger and remind patients who missed their medications. An automated SMS reminder protocol sends a "dosing event" signal to the patient's mobile phone when a pill box is not opened within the designated time frame [55]. Electronic monitoring systems accurately track medication adherence, providing essential information to healthcare providers. This intervention allows them to intervene before a viral rebound occurs [56,57].

3.2. Impact of available interventions

A combination of two or more digital adherence modalities has been found to yield better outcomes than single modalities. According to a Ugandan study by Harberer et al., the combination of triggered reminders and real-time EDM improved adherence and decreased treatment interruptions in a pilot trial [58]. Complementary effects have also been reported between EDM and SMS to connect patients to clinics better and motivate them for better adherence [59]. Additionally, digitally delivered interventions strengthen the impact of traditional care modalities and increase adherence yield. In a Nigerian study, phone-based enhanced adherence counseling (EAC) had more impact than conventional contact EAC and was recommended both for key populations and those with distance barriers [30].

The positive impacts of tools such as SMS, digital mobile applications, and phone calls have been reported by some studies in Nigeria [28], Kenya [38], Cameroon [36], and Zimbabwe [39]. In Nigeria, Maduka and Tobin-West [28] found significantly higher self-reported adherence in the SMS group (79.6%) compared to the control group (55.8%). Lester and colleagues [38] conducted a study that showed that SMS-based interventions significantly improved adherence, viral load suppression, and reduced risk of virologic treatment failure over 52 weeks (RR 0.93, 95% CI 0.69–0.99). Similar findings were reported in Cameroon [36] and Zimbabwe [39]. A study by Nsagha et al. in Cameroon found that weekly pharmacy refill reminders via SMS improved adherence to 64.4% compared to the control group's 44.2% [36]. In a recently conducted RCT in Zimbabwe, Mavhu et al. [39] reported a significant link between digital tools and adherence, as evidenced by a lower treatment failure rate (25%) in the intervention group compared to the control group (36%). While studies have shown little or no impact of phone calls on ART adherence, SMS of short and long durations has demonstrated efficacy in upscaling adherence. A randomized clinical trial among two Kenyan studies showed significant findings [60]. While one study compared short weekly text messages against standard care, the other compared short daily, long daily, short weekly, and long weekly messages against standard of care. In the trial comparing only short, weekly text messages to standard care, text messaging was associated with significantly lower risks of both non-adherence at 12 months (RR 0.77) and virological failure at 12 months (RR 0.83) [60]. Further analysis showed that weekly mobile text messages yielded greater ART adherence at 48-52 weeks, noting a significant difference from short weekly text messaging.

There were mixed results in studies conducted in Uganda [32] and Kenya [43]. Linnemayr et al. reported no difference in adherence between 1-way or 2-way daily SMS groups compared to the control group while reporting that adherence was lower in both SMS groups than the control group [32]. Pop-Elches et al. found no significant difference in adherence between control groups and groups receiving SMS reminders (weekly, daily, or any length) at 12 months. However, they noted a higher risk of non-adherence with frequent (daily) SMS than weekly reminders of any length [43]. This finding suggests that frequency and content matter; repetitive and generic reminders may be counterproductive. Lower mean adherence over 48 weeks was reported in the SMS group compared to the control group: for the 1-way SMS intervention group (64%) compared to the control (67%) and for the 2-way SMS intervention group (61%) compared to (67%) [32]. Interestingly, Wald et al. [61] and Abiodun et al. [31] showed that 2-way text messages improved adherence compared to 1-way text. The researchers posited that 2-way text messages allow participants to respond and offer more communication, rather than just receiving reminders [31,61]. In 20 weeks, receiving two-way SMS reminders was significantly associated with lower mean and log viral load than the control group [31]. However, no significant differences were reported in adherence determined by pill count and self-reported measures [31].

Two studies in Nigeria [29] and Kenya [37] reported a significant improvement in ART adherence after implementing a social media-based support group (SMART) [29] and ELIMIKA [37], respectively. A study in Tanzania showed that RTMM or SMS did not improve treatment adherence [12]. In a study by MacCarthy et al. [33], participants received two tiers of intervention: the T1 group received only individual adherence feedback, while the T2 group received both personal and peer adherence feedback. The T1 group had a 3.8% lower ART adherence than the control group, while T2 had a 2.45% higher adherence rate. Similar findings had earlier been reported more recently by Mavhu et al. [39], highlighting the effectiveness of using multiple tools in synergy to address various barriers to adherence, such as self-esteem, treatment literacy, and chronic adherence. Also, a randomized trial in Uganda compared the effectiveness of traditional contact tracing and digital tools with mobile phones in attaining good retention and reported significantly higher rates of retention in participants who underwent physical contact tracing (86%) compared to those who received mobile phone reminders (82.1%) [34]. However, retention rates were reduced in both groups at 12 and 18 months, with physical contact tracing still showing higher retention rates: 91.5% versus 82.1% at 12 months and 82.8% versus 75.4% at 18 months. Those who underwent physical contact tracing were 1.56 times more likely to have reasonable retention rates (attending 5 out of 6 follow-up visits) than the mobile phone reminder group [34].

3.3. Barriers to utilizing digital tools for ART intervention in Africa

Multiple factors, including structural and individual barriers, hinder the seamless integration of DTs into ART care in Africa (Fig. 3). Structural factors such as low socioeconomic status, limited health system accessibility, technological literacy, and digital divide have significantly impacted the use of DTs for ART adherence [12]. Acquiring and sustaining ownership of smart devices can be challenging for individuals with low socioeconomic status due to limited financial resources. The cost of purchasing a smartphone and its accompanying accessories may be prohibitive, making it difficult for these individuals to take advantage of the benefits of digital technology. In hard-to-reach, resource-constrained communities where sophisticated healthcare systems are scarce, inadequate internet access may hinder adequate utilization of available tools [25,33]. It is worth noting that technological advancements can pose difficulties for elderly patients and those who lack the necessary skills to operate such devices [25]. Individual factors like privacy and stigma may affect the quality of adherence. Mobile

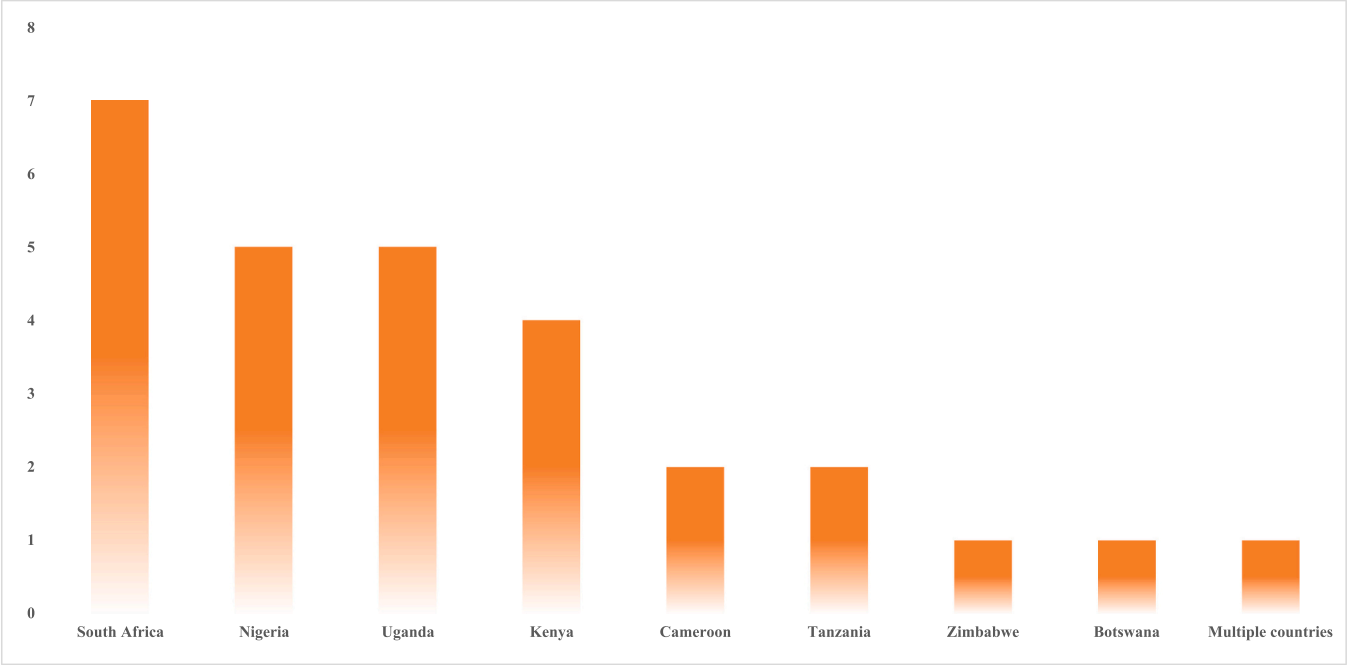


Fig. 1. Distribution of review studies classified by country of origin.

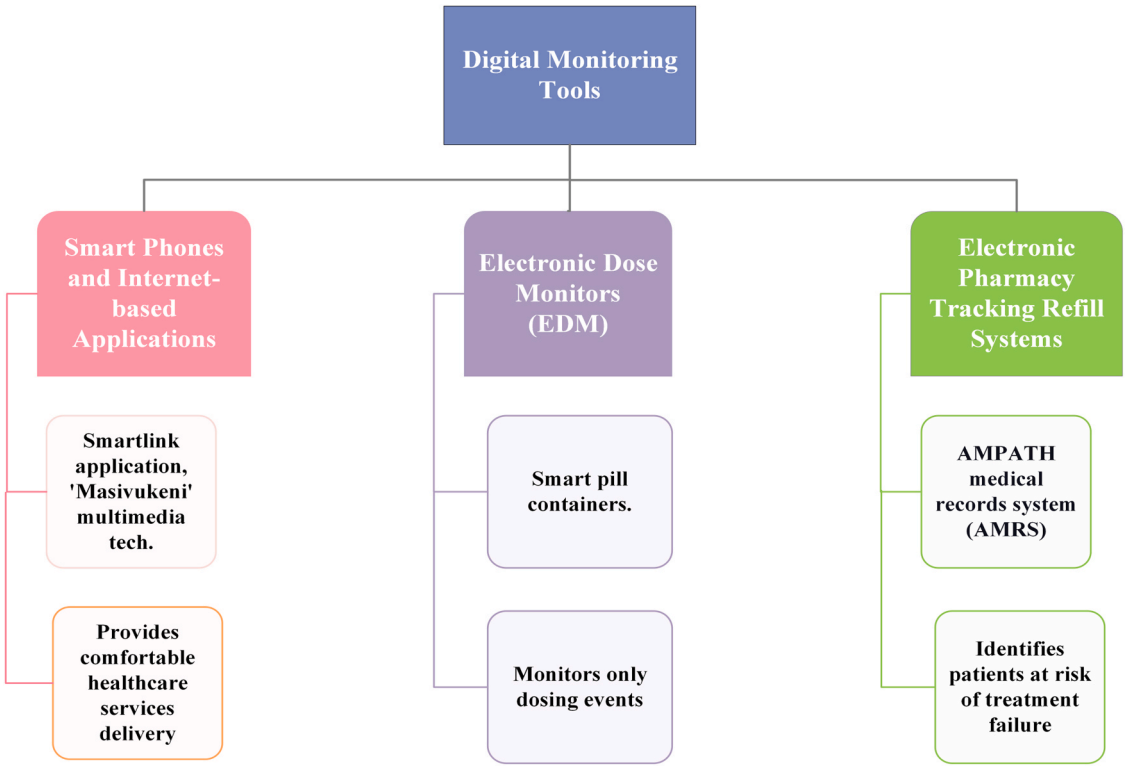


Fig. 2. Digital tools used for antiretroviral adherence monitoring in Africa.

reminders from caregivers to clients can compromise confidentiality if viewed by unauthorized persons. Electronic databases and biometrics capturing may also threaten patients' confidentiality in the event of unauthorized access. For FSW, fingerprint and iris scans, particularly, sparked privacy worries due to their use in police tracking [25]. There are concerns about consistency and compliance for people who inject drugs (PWID) or FSW who may present with a form of mental illness or cognitive impairment [25].

3.4. Facilitators of digital tools' use for ART intervention in Africa

The effectiveness of mobile phone messaging in improving the delivery of HIV/AIDS care has been proven through its high level of acceptance among users [62]. These technologies address challenges like geographical barriers and stigma – significant impediments to the UNAIDS 2030 95–95–95 targets – by providing discreet reminders for medication adherence, refill notifications, and access to psychosocial

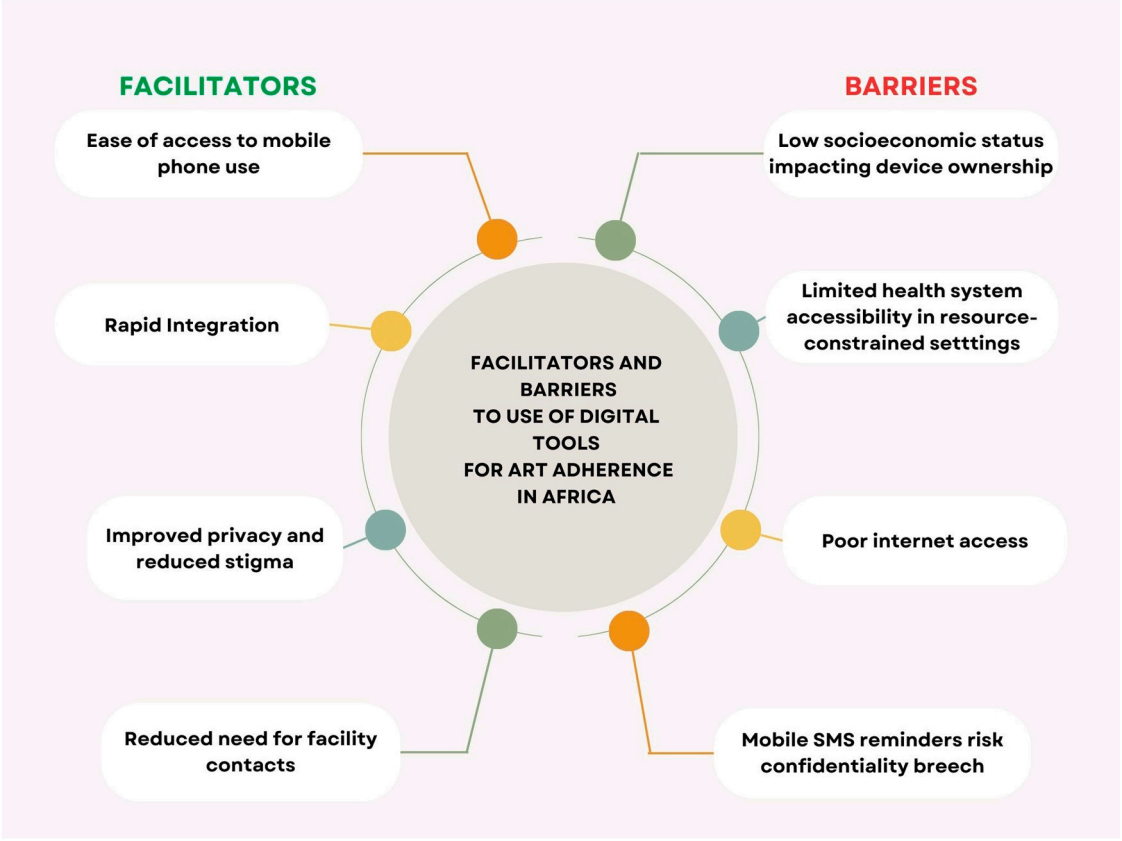


Fig. 3. Facilitators and Barriers to the use of digital tools for ART adherence monitoring and retention in Africa.

support resources [63]. Various factors have facilitated its rapid integration (Fig. 3). One primary facilitator of mobile phone use is its ease of access and use. With an exponentially growing number of subscribers and increasing mobile technology access, remote connections to this population have been upscaled [25]. A South African study assessing facilitators and barriers to incorporating digital technologies into HIV care among key populations showed a heightened positivity towards the use of phones to engage in HIV care [25]. A similar study by Reid et al. recorded a 100% pick-up of monthly ART among 85% of the study respondents who received SMS reminders, compared to a 70% pick-up rate in the control group [40]. Ease of contact was also highlighted across studies. Utilizing DTs like mobile phones and services helps case managers and contact tracers reach out to several clients at different locations within a limited time [26,34]. To reduce stigma and foster adherence, the use of DTs has dramatically improved patients' privacy by enhancing communication on a one-on-one basis, further incorporating patient convenience into the HIV care continuum [25]. The incorporation of artificial intelligence into mobile devices has facilitated ART adherence. By leveraging smartphone AI social supports like *Siri*, patients would receive regular and timely reminders to take their medications, present for a refill, or report for a clinic appointment [25].

4. Discussion

In this narrative review, we aimed to summarize studies researching the use of digital tools for monitoring ART adherence and retention in Africa. In addition to exploring the diverse landscape of digital tools being harnessed, we have highlighted their effectiveness, limitations, and potential barriers to full integration across various African countries. Our findings suggest that existing digital tools have the potential to support patients in adhering to and remaining on ART. This review has reported a robust use of digital interventions such as SMS reminders of varying duration, motivational text messages, smartphone- and web-based applications, and electronic dose monitors. While SMS reminders have demonstrated efficacy, the potential of digital tools extends beyond basic functionalities. Integrating features like two-way communication channels, phone and web-based applications, and electronic medication trackers can empower individuals, foster self-management, and address broader adherence challenges.

The effectiveness of digital tools hinges on context-specific adaptation. One-size-fits-all approaches are unlikely to yield optimal results across the diverse African continent. Culturally sensitive design, consideration of local infrastructure limitations, and addressing digital barriers are crucial for ensuring user engagement and maximizing impact. Trends in the global context have recorded striking similarities. An RCT in the USA, which utilized daily text reminders and follow-up texts to deliver care to YLH through HealthCentral Corporation, reported a 6-month ART adherence improvement among participants in the intervention group, showing a 10-point increase in adherence compared to the control group [64]. This finding was also in keeping with studies reported by Lippman et al. in South Africa [27], Abiodun et al. in Nigeria [31], Linneymayr et al. in Uganda [32], and Mbuagow et al. in Cameroun [35]. EDMs have been sparsely used across African countries. They include smart pill containers, blister packages, censored healthcare Internet of Things, ingestible digital medicines, breath analyzers, and other AI-enhanced adherence digital tools. Only the smart pill containers have been reportedly used in Africa among PLHIV in Tanzania and Uganda [12,42,53]. Numerous factors, including low socioeconomic status and consequent cost of procurement, lack of awareness of the availability of these devices, and lack of technical know-how among patients, caregivers, and healthcare providers, have contributed to this poor use [65,66]. Other EDMs, such as the blister packages, have embedded sensors to monitor the perforation of the blister [67]. They are yet to be utilized and reported in Africa, although

they have been robustly used across developed nations [68]. Many studies have appraised the sensitivity and objectivity of RTMM tools such as smart pill containers over other methods for adherence monitoring [54,69]; however, they are limited as they are only effective for single-use box-containing pills and need to be adequate for multiple tablet regimens. It is also an expensive method of ART adherence assessment for resource-limited settings and a cumbersome method to work with.

Besides the smart pill containers and blister packages, more advanced and novel interventions such as digital ingestible medicine and breath analyzers have been reported in Europe, the USA, and other developed climes with varied effectiveness and client receptiveness [70]. A study conducted in Los Angeles assessing the use of a digital medical program (DMP) with an ingestible sensor to monitor adherence to ART among PLHIV found that PLHIV and Health Centre Professionals (HCPs) had mixed responses to the DMP [71]. While some participants saw potential benefits, others raised concerns about the system's practicality, cost, and potential drawbacks. A second FDA-approved digital pill system, the etectRx ID-Cap system, was approved for adherence measurement in 2019 and uses a wireless sensor within the pill that sends signals to a separate, wearable device worn by the patient [72]. Proteus Discover is another example of an ingestible sensor developed by Proteus Digital Health. This system tracks medication intake through ingestible sensors, wearable patches, and mobile apps, allowing provider monitoring through a dedicated web portal and providing continuous real-time adherence measurement [73,74]. The application of this technology as co-encapsulated antiretrovirals (ARVs) with ingestible sensors (IS) was designed and randomized across 112 PLHIV in Los Angeles [75]. However, there are currently no published studies on the use of ingestible digital medicine to facilitate ART adherence monitoring in Africa.

A small RCT in China found that feedback from EDM during counseling led to significant increases in mean adherence rates ($P = 0.003$) but not mean CD4 counts ($P = 0.07$) at 12-month follow-up compared to controls who received counseling only [76]. Liu et al. developed an automated directly observed therapy (aDOT) platform for monitoring and supporting PrEP use among young men who had sex with men (YMSM) in San Francisco. This app greatly upscaled the median PrEP adherence to about 91% from a nonadherence baseline of over 50% within 8 weeks [77,78]. Video-observed therapy (VOT) allows caregivers to verify medication ingestion events visually. However, this modality raises privacy concerns and is as costly as most novel technologies [79]. Artificial intelligence (AI) technology by AiCure uses mobile artificial intelligence-based software to confirm medication ingestion by detecting motion and correlation with facial recognition [78]. Furthermore, researchers have created customized breathalyzers that can identify the ingestion of certain medications by analyzing the breath for a gas produced by a unique coating on the medication [78]. While simpler technologies such as SMS reminders and phone- and web-based applications have been widely used in Africa, highly sophisticated tools such as the EDM, Ingestible Digital Medicine, AI technologies, and other smart sensor devices have witnessed sparse usage or have yet to be utilized in Africa. This wide disparity can be associated with factors such as openness to new technology, poor patient education, socioeconomic factors, high cost of procuring these devices, poor research funding, high physician-to-patient ratio, and poor internet coverage in rural areas [80]. Cost, accessibility, and availability remain significant constraints to the wide use of these modalities in Africa.

Existing digital monitoring tools for HIV care show initial promise, but their long-term effectiveness and diverse user needs require further research. Our review has revealed a gap in available tools with a wide disparity among tools available in Africa and other continents. It has also highlighted the potential barriers to their practical use and integration and extensively elaborated on their effectiveness in African countries and other developed nations. These disparities are fuelled by various factors, which have been highlighted herein. Investigating engagement complexities, tackling technological disparities, and tailoring interventions to individual challenges are crucial for refinement. For public health and clinical practice, integrating AI for real-time data analysis of vast datasets offers unprecedented insights into patient behaviors and medication adherence patterns. By leveraging machine learning algorithms to identify subtle trends, anticipate potential adherence challenges, and personalize individual interventions, predictions of imminent interruptions in care and recommendations for optimization and prevention can be made. Policymakers can create an enabling environment for international collaborations and investments to increase tool availability and accessibility in Africa, particularly for cost-intensive options. Addressing technological disparities and tailoring interventions to diverse populations is crucial for broader acceptance. Health education and promotion, capacity building for community workers, and sustainability measures are crucial for successful implementation and wide-scale adoption.

This review had notable strengths. To our knowledge, this is the first narrative synthesis of evidence for digital tools of ART adherence and monitoring in Africa conducted in the last ten years or more. It combined findings from various studies, including non-randomized and randomized control trials, pilot projects, and qualitative research, to evaluate the effectiveness, acceptability, and accessibility of digital tools like mobile applications, text message reminders, and other modalities. A good number of studies conducted in the last one to two years were included in the review, incorporating evidence that may have yet to be captured in previous reviews. By synthesizing evidence from studies across various African studies spanning a broad range of years and employing a rigorous systematic methodology, the review has shed light on the potential of DTs to revolutionize HIV care delivery for PLHIVs. Additionally, our analysis has pinpointed thematic areas that can serve as a roadmap for future research and technological advancements. It highlights the need to integrate AI-powered digital tools into the HIV care continuum and identify gaps and areas needing further research, policy development, and strategies to improve ART adherence using digital tools. While our review provided valuable insights, some limitations were noted. The studies vary widely in tools, designs, interventions, and populations, making it difficult to generalize findings across contexts. Additionally, technology access and literacy differences might skew participant demographics, raising concerns about applying results to populations with limited digital access. Short follow-up periods in many studies limit understanding of the long-term effectiveness of these tools and a possible future effect on adherence and retention in care. Publication bias towards positive outcomes might inflate the perceived effectiveness of DMTs. Additionally, ethical concerns like data privacy, security, and patient autonomy have been raised and reported across a few studies and require further consideration. The African literature lacks reports on the use of some known tools for ART monitoring, indicating the need for longitudinal studies to examine the availability and accessibility of these digital tools.

5. Conclusion

Digitalization of ART delivery modalities has registered significant advances recently, promising a paradigm shift in optimizing care given to PLHIV. Through a systematic analysis of trends and synthesis of current evidence, this comprehensive review highlights the central role of digital tools in bolstering ART adherence and retention within the African context, drawing comparisons to global benchmarks. While phone-based applications like SMS, phone calls, and reminders have charted an efficient course to date, the future of ART adherence monitoring resonates around the applicability of digital tools. Novel technologies for real-time medication monitoring, such as smart pill containers, blister packages, censored ingestible digital medicines, smart wearable patches, and detectors, hold promises for ART adherence in Africa. Unfortunately, cost and technical know-how have hindered the availability and use of these tools in Africa, even among

populations most deserving of these interventions. While no 'gold standard' for efficient adherence monitoring exists, combining two or more digital tools has been advocated. The evolving nature of patient engagement and available healthcare models necessitate long-term studies to assess sustained impacts and potential fluctuations in adherence. International collaboration among specialist health professionals and multinationals is strongly recommended to make these tools, especially the electronic digital monitoring tools, designed to upturn the trajectories of HIV care in Africa, available, accessible, and affordable.

Declaration of Generative (AI) and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Google Bard AI to improve the language and readability of the article. After using this tool, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

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CRediT authorship contribution statement

BU, EU, and KU conceptualized and designed this study. BU and EU conducted a literature search to put together relevant studies. BU and NU conducted the data extraction table, which two external reviewers reviewed. BU, EU, KU, KA, NU, FD, and MG wrote the initial draft, edited by BU, KA, MG, FD, and TW. BU is the corresponding author and is responsible for the work's credibility.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: No conflict of interests applicable. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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