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INTEGRATED MOBILE HEALTH INTERVENTIONS ON CD4 COUNT OUTCOMES AMONG HIV/TB CO-INFECTED: AN IMPACT BASED NARRATIVE REVIEW

Osuoha Chinyere Beatrice[1], Treasure Njideka Njoku-Obi[2], Igiri Vivian Chika[3], Ugonma Winnie Dozie[4], and David Chinaecherem Innocent[5]

[1,3,4,5]Department of Public Health, School of Health Sciences, Federal University of Technology, Owerri, Imo State, Nigeria.

[2]Department of Microbiology, Imo State University Owerri, Imo State, Nigeria.

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ABSTRACT: ***Background:*** *HIV and tuberculosis (TB) co-infection is a major worldwide health issue, particularly in Sub-Saharan Africa and Southeast Asia, where the dual disease burden impairs clinical outcomes and healthcare system performance. Monitoring CD4 cell count is critical for managing HIV in co-infected populations since it is a crucial biomarker for immune system function, disease progression, and treatment success. Despite advances in viral load monitoring, CD4 count is still critical for commencing prophylaxis, determining ART timing, and predicting TB-related morbidity.*
Aim: *This narrative review investigates the effect of integrated mobile health (mHealth) treatments on CD4 count outcomes in HIV/TB co-infected patients receiving clinical care.*
Methods: *A comprehensive search was undertaken throughout PubMed, Scopus, Cochrane Library, and WHO Global Health Library. The included studies assessed mHealth modalities such as SMS reminders, mobile apps, and teleconsultations in terms of ART adherence, clinic involvement, and CD4 restoration.*
Findings: *In many low- and middle-income countries, mHealth technologies promote treatment adherence and retention in care, which is indirectly connected to higher CD4 counts. However, the data is inconsistent, with some interventions having low or mixed impacts depending on context, gender, and access inequities.*
Conclusion: *mHealth has the potential to improve immunological results in HIV/TB co-infected people. Nonetheless, its efficacy is context-dependent, emphasising the importance of specialised, regionally adapted tactics that address infrastructure constraints, digital literacy, and patient participation. Future research must prioritise implementation science approaches in order to maximise scale-up and sustainability.*

KEYWORDS: mHealth, CD4 Count, mobile health intervention, ART adherence, implementation science, resource limited settings, digital health, HIV/TB co-infection.

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INTRODUCTION

One of the most important global public health issues is the syndemic of Human Immunodeficiency Virus (HIV) and Tuberculosis (TB) [1-4]. According to Farmer *et al*. [2], a syndemic is defined as the synergistic interaction of two or more diseases that increase negative health outcomes, particularly in the context of poverty and structural inequality. Similarly, Singer *et al*. [3] claim that syndemics are more than just co-infections; they are rooted in a framework of biological interaction and social difference. HIV/TB co-infection exemplifies this concept, as one disease accelerates the pathogenesis of the other, resulting in increased mortality and care complexity [4, 5]. According to the World Health Organisation [6], around 214,000 persons living with HIV died from TB-related illnesses in 2020 alone, making TB the main cause of death among HIV patients. UNAIDS [7, 8] agrees, reporting that over 7.7 million people worldwide live with HIV/TB co-infection, with Sub-Saharan Africa carrying more than 70% of the burden, and these staggering figures highlight the critical need for integrated, innovative, and context-specific interventions that address both diseases simultaneously.

Sisnowski *et al*. [5] stated that the CD4 count is a key biomarker of immunological function in HIV-positive people, measuring the amount of CD4+ T-lymphocytes in the blood, and also that the CD4 cell counts continue to be an important diagnostic and prognostic tool in the start and monitoring of antiretroviral therapy (ART), especially in resource-limited situations where viral load testing is unavailable. In contrast, the Panel on Antiretroviral Guidelines for Adults and Adolescents [7] states that, while viral load is the gold standard for treatment monitoring, CD4 count is still important for assessing the risk of opportunistic infections and TB progression. Fitzpatrick *et al*. [9] posited that low CD4 levels are the most consistent predictor of tuberculosis in HIV-positive patients, often preceding clinical symptoms, suggesting with evidence that TB further reduces CD4 numbers, producing a detrimental loop, thereby agreeing that the CD4 dynamics act as a surrogate marker for evaluating disease severity and treatment effects in HIV/TB co-infection settings. Mobile health (mHealth), defined by the Global Observatory for eHealth [10] as medical and public health practice enabled by mobile devices, has emerged as a game-changing tool for managing chronic diseases in low-resource settings. Hamine *et al*. [11] define mHealth as a set of interventions aiming at promoting patient engagement and adherence, including SMS reminders, mobile apps, wearable sensors, and teleconsultations. Kavanagh [12] claims that SMS interventions are the most extensively accepted types of mHealth in HIV care, given its low cost, scalability, and capacity to reach rural populations. However, Labrique *et al*. [13] suggest that the effectiveness of mHealth is dependent on intervention design, literacy levels, and technological infrastructure.

According to recent data from the GSMA [14], mobile phone adoption in Sub-Saharan Africa has reached 76%, laying the groundwork for digital health integration. However, Chib *et al*. [15] caution that digital inequalities, such as gender disparities in mobile access and irregular network coverage, present barriers to fair mHealth adoption. Despite these limitations, mHealth is becoming regarded as a viable alternative to traditional care models for improving adherence and clinical outcomes in HIV and TB care [16]. The reason for focusing on CD4 count as an outcome of mHealth intervention in HIV/TB co-infected people stems from its clinical, operational, and policy implications [8]. Mbuagbaw *et al*. [17] argue that, while most mHealth research focus on medication adherence or appointment reminders, few have directly related these interventions to immunological outcomes like CD4 restoration. Che *et al*. [18] argue that even slight increases in CD4 count can considerably lower the incidence of opportunistic infections and hospitalisation, particularly in co-infected people. Furthermore, Auld [19] believe that monitoring CD4 trends enables health systems to detect therapy failure early,

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adjust regimens, and avoid avoidable morbidity, and the absence of this linkage in many digital health studies indicates a crucial knowledge gap, particularly in places where CD4 remains the primary immunologic indicator. This review investigates the effect of integrated mobile health treatments on CD4 count outcomes in HIV/TB co-infected individuals in clinical care settings and it seeks to synthesise information on the efficacy, contextual variables, and limitations of mHealth tools in boosting immunological recovery, in order to inform future programmatic and policy orientations.

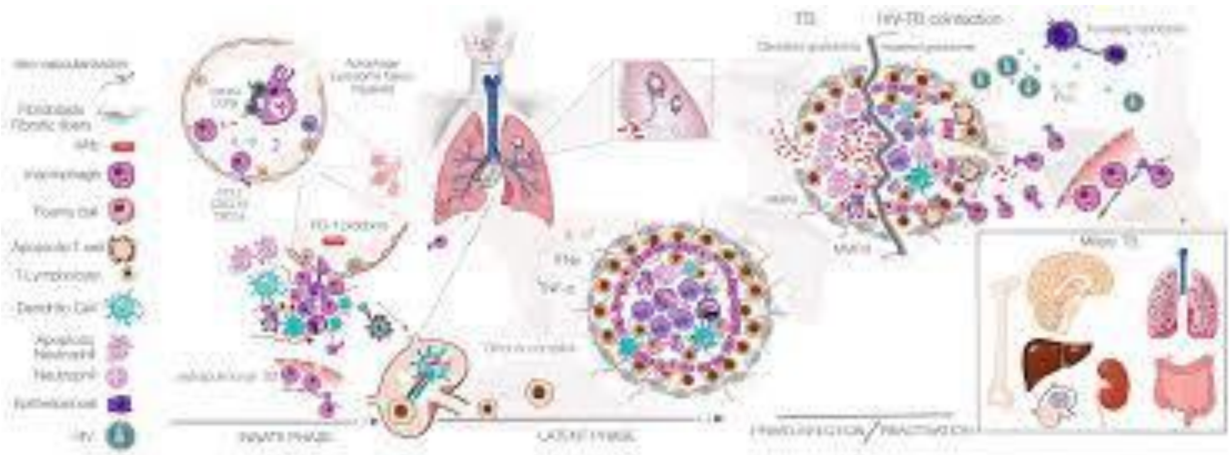

Figure 1.0: HIV/MTB Co-infection (Source: World Health Organisation [1])

METHODS

This review used a narrative synthesis method, which was chosen explicitly due to the variability of study designs, populations, and outcome measures found in the literature on mHealth, HIV/TB co-infection, and CD4 count outcomes. Popay *et al*. [20] define narrative synthesis as a systematic strategy for summarising and interpreting data from various research when statistical pooling (meta-analysis) is ineffective or misleading. This is consistent with Greenhalgh *et al*. [21] who argue that narrative synthesis is better suited to complex public health questions involving multifaceted interventions like mHealth, especially when studies differ in methodology, setting, and metrics. The approach enables critical thematic exploration, pattern recognition, and contextual interpretation across disparate data sets. The search strategy was comprehensive and deliberately inclusive, using four major databases: PubMed, Scopus, Cochrane Library, and WHO Global Health Library. These sources were chosen for their global reach, peer-reviewed legitimacy, and focus on public health, biomedical research, and low- and middle-income country (LMIC) data. According to Bramer *et al*. [22], database selection influences evidence visibility and potential bias; thus, employing both general and domain-specific databases was a technique to reduce publishing and database bias. The inclusion criteria were purposely broad to capture global trends: studies including HIV/TB co-infected individuals, with explicit mHealth interventions (e.g., SMS, mobile apps, voice calls), and reported CD4 count outcomes were taken into account. This decision underscores the review's goal of understanding the immunological impact of digital tools across areas and healthcare systems. Petticrew and Roberts [23] contend that result specificity—in this case, the CD4 count—ensures analytical clarity and comparability despite methodological variety. To ensure internal validity, exclusion criteria were defined: studies were excluded if they featured non-integrated interventions (i.e., mHealth not embedded in HIV/TB care) or failed to

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report quantitative CD4 data, which is the central outcome of interest. Studies lacking these criteria would dilute the analytical emphasis and impede interpretation of mHealth's biological efficacy. The date (2010-2024) was deliberately chosen to mirror the period when mHealth interventions gained prominence in global health practice, particularly following WHO's 2011 designation of mHealth as a crucial tool for health system strengthening and this time frame includes both foundational and contemporary research, allowing for trend analysis and tracking evolution in intervention design, scale, and implementation contexts.

CONCEPTUAL FRAMEWORK

This narrative review investigates how mobile health (mHealth) interventions improve health outcomes for people living with HIV and tuberculosis, particularly in terms of improving CD4 count. Free *et al*. [24] define mHealth as the use of mobile and wireless technology to support health-care system goals, emphasising its role in enhancing access, continuity of care, and behavioural change. In contrast, Labrique *et al*. [13] widen the definition of mHealth to encompass not only clinical decision assistance and patient tracking, but also behaviourally targeted treatments that promote self-efficacy and medication adherence, and these definitions, while different in their operational focus, agree on the notion that mHealth serves as both a technological and behavioural conduit within the HIV/TB care continuum. According to Michie *et al*. [25], the efficacy of any digital intervention is determined not only by its technological architecture, but also by how well it employs theoretical frameworks such as the Behaviour Change Wheel (BCW), which emphasises capability, opportunity, and motivation (COM-B) as prerequisites for sustained behavioural engagement.

This review endorses this theory-based approach, acknowledging that the utility of mHealth for persons with multiple illnesses should be evaluated not just in terms of how well it works, but also in terms of how it influences patients' beliefs and decisions. At the centre of the framework is the HIV care cascade, which depicts the processes from diagnosis to viral suppression and where mHealth interventions are thought to have an impact, particularly on medication adherence and care retention. Kavanagh [12] find that adherence-focused mHealth initiatives, particularly SMS reminders, can increase antiretroviral medication (ART) adherence rates by 15-25%, particularly among marginalised groups. This finding is consistent with Che *et al*. [18], who believe that digital nudges, such as appointment alerts and medication reminders, improve patient accountability and reduce loss to follow-up two (2) important predictors of long-term viral suppression. Free *et al*. [24] claim that the effectiveness of mHealth is enhanced when interventions are interactive and tailored rather than generic, emphasising the importance of targeted design in resource-constrained contexts. CD4 count restoration, the immunologic result under consideration, is theoretically connected to upstream adherence behaviours modified by mHealth. Fitzpatrick *et al*. [9] posit that ART adherence greater than 95% is essential for effective immunological reconstitution, especially in co-infected patients whose immune systems are doubly impaired and, as a result, this model indicates a cause-and-effect relationship in which mHealth improves adherence, which leads to decreased viral levels and CD4 cell recovery, so stabilising the immune system. Labrique *et al*. [13] opine that, in low-resource settings with unreliable laboratory results, mHealth not only promotes patient behaviour but may also help doctors make decisions through symptom tracking and remote monitoring.

Furthermore, the inclusion of the Health Belief Model (HBM) in the framework allows for an examination of how mHealth influences patients' perceived susceptibility to disease progression, perceived benefits of treatment, and cues to action, reinforcing adherence

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behaviour via psychosocial levers [26]. This paradigm is thus both technological and behavioural, incorporating theories such as COM-B and HBM to investigate how digital health interventions influence care cascade outcomes and it lends support to the concept that mHealth can influence biologically meaningful outcomes like CD4 count recovery by intervening at critical behavioural junctures. While Free *et al*. [24] highlight empirical efficacy, this paradigm places their findings into a larger behavioural and health systems context, recognising the structural, cognitive, and social barriers to care that mHealth must overcome in order to achieve measurable immunological change.

HIV/TB BURDEN AND THE NEED FOR CD4 MONITORING

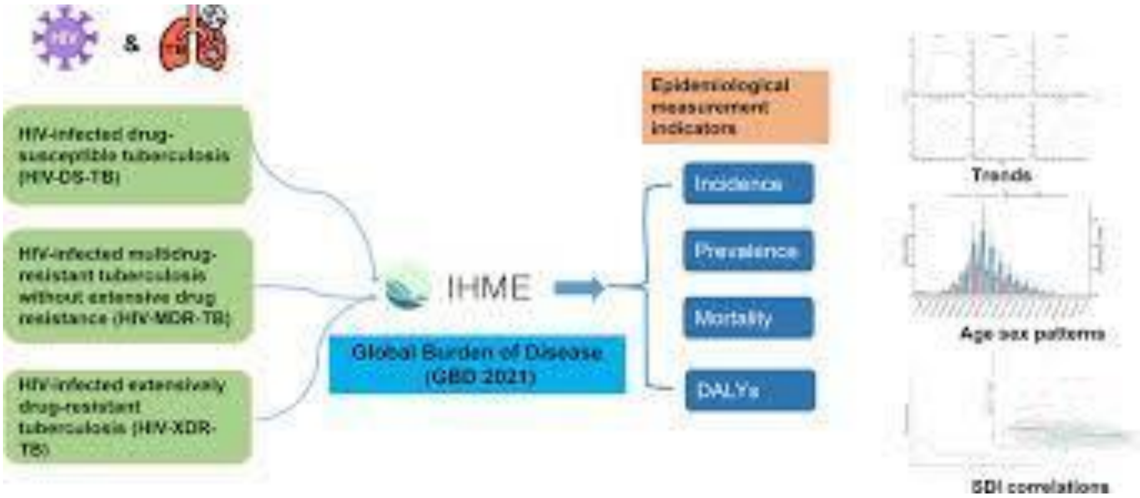

Figure 2.0: Epidemiological Features and Temporal Trends of the Co-infection Between HIV and Tuberculosis (Sources: Zhang et al. [27]).

The World Health Organisation [4] defines HIV/TB co-infection as the presence of active tuberculosis in people living with the Human Immunodeficiency Virus (HIV), emphasising that the interaction of the two pathogens severely weakens host immunity. UNAIDS [8] emphasized that individuals living with HIV (PLHIV) are up to 18 times more likely to acquire active tuberculosis than those without HIV, making TB the major cause of mortality among PLHIV, accounting for one-third of all AIDS-related fatalities worldwide. According to the WHO [4], Sub-Saharan Africa has the highest number of cases, accounting for approximately 74% of all HIV/TB co-infections worldwide, owing to late diagnoses, insufficient ART coverage, and inadequate health infrastructures. Bastos *et al*. [28], on the other hand, claim that despite greater global attention, systemic inequities in access to diagnoses and treatment continue to worsen mortality among co-infected populations, particularly in low-income countries, and CD4 count, a major immunological measure that indicates the strength of an individual's immune system, is critical for tracking HIV disease progression and treatment response. Fitzpatrick *et al*. [9] define CD4 monitoring as the number of CD4+ T-lymphocytes in a microlitre of blood, emphasising its importance in determining when to initiate ART and preventing opportunistic infections. While viral load (VL) testing has become the new gold standard for evaluating ART efficacy, Qi *et al*. [29] argue that CD4 count is still clinically relevant, particularly in resource-limited areas where VL infrastructure is either nonexistent or unreliable.

CD4 monitoring is crucial for identifying individuals with extensive immunosuppression (CD4 <200 cells/mm³) who are more susceptible to opportunistic infections, such as tuberculosis.

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Despite global health recommendations that VL testing should be prioritised, WHO [31] guidelines continue to support CD4 testing as a necessary adjunct for clinical decisions in fragile settings. Qi *et al*. [29] endorse this position, noting that CD4 data provides crucial triage information in crises and is still indispensable in triaging patients for differentiated care, such as fast-tracking those with low counts for additional assistance. Furthermore, Yan [30] find that countries such as Mozambique and Uganda witnessed CD4 test stockouts in more than 40% of clinics between 2014 and 2018, indicating persistent logistical failures in critical diagnoses and these shortages are exacerbated by health workforce constraints, such as poorly qualified workers and equipment breakdowns, which impede consistent test delivery in rural and peri-urban clinics. Murray *et al*. [32] contend that these structural inadequacies are part of a larger health-care system fragility characterised by uncertain funding, poor data systems, and reliance on donor supply chains. WHO [6] further emphasises that a shortage of point-of-care CD4 devices remains a challenge in decentralised clinics across Sub-Saharan Africa, limiting diagnostic reach in impoverished communities.

Overview of mHealth Interventions in HIV/TB Management

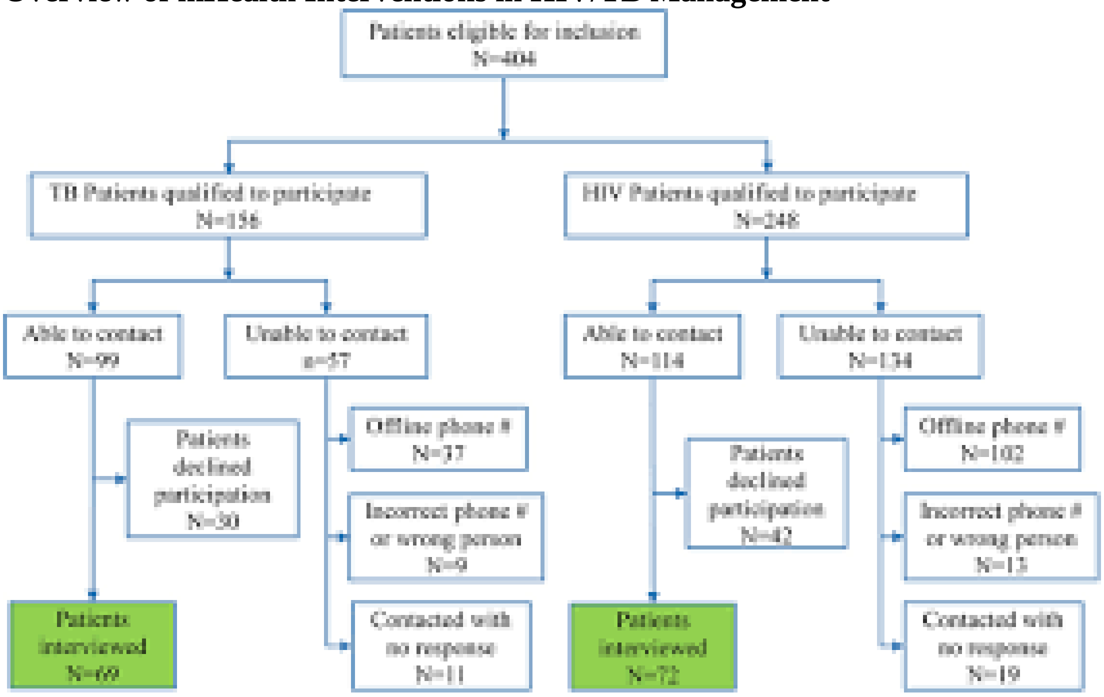

Figure 3.0: Participant Interview Enrollment Flowchart (Source: Nhavoto et al. [33])

Labrique *et al*. [13] broadly describe mobile health (mHealth) as the use of mobile and wireless technologies to improve health information and service delivery, particularly in resource-constrained contexts. This definition is consistent with Free *et al*. [24], who define mHealth as a strategic health systems intervention that includes everything from SMS reminders to teleconsultation tools and claims the potential to transform chronic disease care through improved communication, adherence, and clinical monitoring. Lester *et al*. [34] contend that mHealth tools, particularly short message service (SMS) reminders, can significantly improve antiretroviral therapy (ART) adherence, with a study in Kenya showing a 12% increase in adherence and viral suppression in patients who received weekly motivational text messages. These findings are supported by Finitsis *et al*. [16], who found that mHealth adherence interventions had a pooled effect size of 0.34 in 19 studies from low- and middle-income

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countries, indicating moderate but statistically significant improvements in medication taking behaviour. In contrast, García García *et al*. [35] discovered that, while SMS and voice call reminders work well in HIV/TB care, how these reminders are set up and how patients interact with them can have a significant impact on the results, indicating that using the same approach for everyone may not be the best way to ensure success. Poushter [36] posits that mobile phone adoption in Sub-Saharan Africa has exceeded 75%, paving the way for app-based solutions.
However, Aker and Mbiti [37] advise that, while access to advanced mobile features such as applications is increasing, actual use remains skewed by digital literacy, economic inequality, and device type, particularly among women and rural people and two-way messaging systems, which allow patients to respond to reminders and request explanation, have been demonstrated to increase participation. Lester *et al*. [34] argue that two-way systems foster a sense of relational care, as opposed to one-way alerts, which can be perceived as impersonal or mechanical. Finitsis *et al*. [16] argue that interactive platforms increase the chance of behavioural adherence, particularly when combined with counselling components. In the context of TB/HIV co-infection, mHealth interventions perform several functions, including adherence monitoring, appointment reminders, side-effect tracking, and symptom reporting [4]. García García *et al*. [35] state that when mHealth solutions are integrated into integrated care models, they increase coordination between TB and HIV services, reduce missed visits, and enable rapid symptom escalation, all of which are critical for high-risk patients with reduced immunity and they also highlight how real-time adverse drug reaction (ADR) monitoring using mobile platforms lowers morbidity caused by medication toxicity, which is a common problem in co-infected persons on complex regimens. Chib *et al*. [15], argued that literacy levels, phone sharing, and network availability all severely hinder equal access to mHealth tools, particularly in remote areas, and gender disparities in phone ownership, particularly in rural Africa, have surfaced as a significant barrier.
According to the GSMA [38], women in Sub-Saharan Africa are 23% less likely than males to own a mobile phone and 41% less likely to utilise mobile internet services, indicating a significant digital divide that undercuts the potential impact of mHealth in female-dominated patient groups. Furthermore, Tomlinson *et al*. [39] contend that localization, both in terms of language and health beliefs, is critical for success, and that failing to adjust interventions to community norms may result in disengagement or misinterpretation and while the literature supports the broad efficacy of mHealth interventions in HIV/TB management, particularly through tools such as SMS reminders, voice calls, and symptom tracking apps, Finitsis *et al*. [16] warn that unless social and infrastructural barriers are addressed, these gains will be unevenly distributed.

Evidence on mHealth and CD4 Count Outcomes

Mobile health (mHealth) is the use of mobile devices and digital communication technologies to improve healthcare delivery, patient monitoring, and health promotion, particularly in environments with limited [13]. Cooper *et al*. [40] define mHealth as the use of mobile tools to facilitate clinical decision-making, improve medication adherence, and increase care involvement, particularly for chronic diseases such as HIV, and the research provides a variety of subtle insights into its impact on CD4 count outcomes in people living with HIV (PLHIV), particularly those co-infected with tuberculosis. Fitzpatrick *et al*. [9] suggest that CD4 count is an important immunological parameter that predicts disease progression and informs therapy decisions, especially in contexts where viral load data is unavailable or inconsistent. Qi *et al*. [29] agree, stating that, despite the global shift towards viral load surveillance, CD4 remains

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an important marker in resource-limited settings due to its availability, simplicity and predictive usefulness for opportunistic infections, and that the potential to improve antiretroviral medication (ART) adherence is central to the empirical evidence supporting mHealth therapies' positive influence on CD4 outcomes.

In a randomised controlled trial in Cameroon, Mbuagbaw *et al*. [17] found that weekly motivational SMS significantly improved ART adherence rates, leading to improved immunological outcomes, including CD4 count increases of more than 50 cells/mm³ among intervention participants over six months. Che *et al.* [18] report a similar trend in South Africa, where mobile phone-based ART support was connected to improved retention in care and moderate CD4 improvements in patients who had previously low adherence. These findings are consistent with Finitsis *et al*. [16] who find that mHealth tools, particularly interactive SMS and voice-based interventions, result in considerable adherence gains, thereby contributing to immunologic recovery. Lester *et al*. [34] emphasise that frequent two-way SMS contact fosters relational trust and accountability between patients and physicians, which they believe leads to continued ART use and gradual CD4 restoration. Pop-Eleches *et al*. [41] support this finding by demonstrating that patients who received timed SMS reminders were 24% more likely to achieve viral suppression and CD4 count stabilisation than those in control groups. However, a subset of research found that mHealth had neutral or mixed impacts on CD4 count outcomes, raising concerns regarding over-generalisation and in a systematic analysis of 20 mHealth research from Asia, Africa, and Latin America, Cooper *et al*. [40] found that while adherence improvements were prevalent, only 40% of studies revealed statistically significant CD4 gains, believing that adherence gains do not necessarily translate into immunologic responses, particularly among patients with advanced immunosuppression, medication resistance, or intermittent follow-up. Wang *et al*. [42] discovered that while the intervention group had better self-reported adherence, their CD4 levels did not differ substantially from the control group after 12 months. This is consistent with Rodrigues *et al*. [43] who claim that CD4 recovery is influenced by a variety of factors, including baseline CD4, coinfections, drug quality, and socioeconomic determinants, complicating linear causal relationships between mHealth use and immunological outcomes and when comparing rural and urban locations, infrastructure levels, and health-care system capacity, the contextual diversity of mHealth's impact on CD4 results becomes clear.

According to Che *et al*. [18], mHealth treatments in urban Johannesburg improved CD4 rates more than peri-urban clinics, owing to better mobile network availability, higher literacy levels, and more responsive healthcare infrastructure. Mbuagbaw *et al*. [17] contend that cultural receptivity and technological proficiency both influence intervention success, noting that in some rural Cameroonian communities, low literacy and phone-sharing habits compromise message privacy and effectiveness. Tomlinson *et al*. [39] warn that poorly contextualised mHealth applications may exacerbate health inequities by favouring urban, male, literate users, undermining the egalitarian goals of digital health. According to GSMA [38] research, in Sub-Saharan Africa, rural women are 37% less likely to own a mobile phone and 50% less likely to utilise mobile internet than urban men, indicating significant gender and regional gaps in digital health access.

Regionally, mHealth treatments have yielded a variety of effects, using applications that have been thoroughly evaluated in Sub-Saharan Africa, where the HIV/TB syndemic is at its most severe. In Malawi, García García *et al.* [35] found that integrating SMS reminders with DOT (Directly Observed Therapy) for TB and ART services improved dual adherence and resulted in modest CD4 increases (~60 cells/mm³ over 12 months). Rodrigues *et al*. [43] discover that mobile adherence programs helped maintain CD4 stability but did not result in significant

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immunologic benefits without additional psychosocial or dietary support. Meanwhile, Li [44] find that a pilot mHealth project in Peru that included mobile reminders and virtual counselling yielded promising adherence results, but CD4 reductions remained statistically insignificant, underscoring the importance of late-stage disease and structural care constraints. Several mediating factors influence the effectiveness of mHealth in driving CD4 outcomes. According to Labrique *et al*. [13], health system integration determines whether mHealth tools are stand-alone solutions or components of a coordinated care approach. Free *et al*. [24] posit that mHealth outcomes improve significantly when interventions are integrated with electronic health records, timely follow-ups, and provider alerts. Michie *et al*. [25] advocate for adding behaviour change theories, such as the COM-B model (Capability, Opportunity, Motivation-Behavior), into mHealth design to increase patient engagement and long-term behavioural shifts. This concept contends that for adherence (and consequently CD4 gains) to occur, interventions must improve patients' capability (knowledge and skills), opportunity (reminders, access), and motivation (perceived advantages, cues to action).

LIMITATIONS AND GAPS

A thorough examination of current research on mHealth interventions and CD4 count results in patients with HIV and tuberculosis reveals many significant flaws and gaps in information that undermine the reliability and broader applicability of the findings. First, a major limitation is the scarcity of long-term research linking mHealth therapies to persistent CD4 count improvements over time, and while many short-term therapies show encouraging results in the first few months of adoption, there is a lack of evidence to determine if these advantages last beyond a year or translate into long-term immunological healing and reduce morbidity. Second, there is significant variation among studies in terms of intervention types and outcome measures and the interventions range from unidirectional SMS reminders to elaborate, interactive mobile applications that include symptom tracking, instructional courses, and virtual therapy. This variance hampers cross-study comparisons and undermines efforts to make uniform conclusions about which mHealth aspects are most helpful for improving CD4 counts. Furthermore, outcome metrics differ greatly, with some research highlighting ART adherence as a proxy for CD4 improvement and others reporting actual immunological or virological data, further fragmenting the evidence base. Third, research conducted in high TB-burden settings are significantly under-represented, particularly in rural or resource-limited locations where integrated HIV/TB care is most needed. Much of the current data is orientated towards urban areas or countries with relatively strong health infrastructure, limiting its relevance to locations where mobile health solutions have the potential to bridge large gaps in healthcare delivery. This geographical bias raises problems about mHealth's viability, scalability, and cultural acceptability in settings of poverty, stigma, and systemic healthcare inadequacies.

Furthermore, there is a crucial gap in our understanding of qualitative patient experiences with mHealth devices. Few research have looked into patients' views, acceptability, and actual usage patterns of these digital tools, leaving us with a limited grasp of how and why these interventions work or fail in real-world settings, and this omission ignores critical, human-centered information that could help create more contextually relevant and user-friendly mHealth solutions. Furthermore, structural variables, such as gender discrepancies in mobile phone ownership, literacy difficulties, and socio-cultural resistance to digital technologies, are rarely addressed in detail, despite their potential impact on adoption and efficacy.

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POLICY AND PROGRAMMATIC IMPLICATIONS

More research has been conducted into how mobile health (mHealth) programs improve health outcomes for people with HIV and tuberculosis, but there are still numerous gaps in our understanding. Simen-Kapeu *et al*. [45] point out that, while short-term results such as sticking to ART and going to the clinic appear promising, there is a notable absence of long-term research linking mHealth use to long-term changes in CD4 count trends. According to Labrique *et al*. [13], while short-term results such as sticking to ART and visiting the clinic appear promising, there is a notable paucity of long-term research linking mHealth use to long-term changes in CD4 count trends and this time gap hinders the field's ability to assess long-term health and immune system recovery, particularly in populations struggling with recurrent tuberculosis infections and severe HIV disease progression.

According to Free *et al*. [24], the range of mHealth interventions, such as SMS reminders, interactive smartphone apps, and telemonitoring platforms, makes it challenging to compare and aggregate study data, and the lack of consistency in intervention design, delivery frequency, and technical sophistication has resulted in an evidence base with methodological discrepancies. For example, Lester *et al*. [34] discovered that weekly SMS assistance increased CD4 counts in a Kenyan trial, whereas Che *et al*. [18] observed no effect in South Africa with a more complicated digital adherence platform. These variations are frequently caused by unstandardised measurements and varying follow-up periods, making it difficult to generalise findings across geographies and healthcare systems. Labrique *et al*. [13] stress that, despite the global proliferation of mHealth tools, there is still a lack of convincing evidence in tuberculosis-endemic settings, particularly in rural or resource-constrained parts of Sub-Saharan Africa and Southeast Asia, and this spatial bias reduces external validity and undermines policy application in places where the HIV/TB syndemic burden is highest. Evidence on how integrated mHealth interventions improve CD4 count restoration is poor or fragmented in places with high co-infection prevalence, such as Nigeria, Mozambique, and India. Furthermore, Kavanagh [12] fault the existing literature for under-representing qualitative components, including patient experiences, perceptions, and the acceptance of mHealth platforms and while quantitative metrics like CD4 counts and adherence rates dominate outcomes, a lack of rich qualitative research obscures how cultural, gendered, and socioeconomic factors influence engagement with digital health technologies.

According to García García *et al*. [35], concerns such as gender disparities in mobile phone ownership, gaps in digital skills, and stigma associated with utilising HIV-related technology are understudied, despite the fact that they may reduce the effectiveness of interventions. Furthermore, Michie *et al*. [25] point out that few studies apply or analyse behaviour modification theories such as the Health Belief Model or the COM-B Framework, despite the fact that these conceptual tools could provide light on how mHealth affects behaviour and clinical outcomes.

CONCLUSION

To summarise, mobile health (mHealth) interventions have significant potential for clinical care of HIV/TB co-infected people, particularly in terms of enhancing immunological outcomes such as CD4 count restoration. As discussed throughout this review, mHealth tools such as SMS reminders, mobile applications, and telemonitoring systems have demonstrated the potential to improve ART adherence, reduce missed appointments, and facilitate timely clinical decision-making, all of which may contribute to higher CD4 counts. The review

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pointed out that such digital platforms have a particularly significant impact in resource-constrained situations where traditional care methods are hampered. However, while the evidence is encouraging, it is not conclusive. Many trials show short-term benefits without enough longitudinal follow-up to establish long-term CD4 recovery, and there is significant variation in both intervention design and outcome measurements, making direct comparisons and generalisation difficult.

Furthermore, the under-representation of high-burden tuberculosis settings, particularly in rural Sub-Saharan Africa and Southeast Asia, reduces the external validity of current findings, and to turn potential into tangible population-level effects, localised, scalable, and properly assessed interventions are desperately needed. This includes not just developing contextually relevant mHealth programs, but also integrating them into national health systems via clear policy channels, funding mechanisms, and infrastructure support. Moreso, digital health interventions should progress beyond the pilot stage and be evaluated using implementation science frameworks that assess real-world effectiveness, scalability and sustainability, and future research should use context-sensitive methodologies that account for cultural, social, and infrastructure realities. Furthermore, understanding user preferences, bridging gender and digital differences, and ensuring that marginalised groups are not left behind are all critical.

Mixed-methods research that includes both quantitative outcomes (e.g., CD4 counts) and qualitative insights (e.g., patient acceptability and usability) can help improve intervention design and implementation. Additionally, while mHealth is not a cure-all, it represents a significant step towards equitable, patient-centered HIV/TB care, especially in areas with the highest health burdens and limited resources. Strategic investment, local ownership, and consistent political will are required to realise its full potential.

Authors' Contribution

All authors contributed to the review process.

Final Approval of Manuscript

All authors.

Ethics Approval and consent to Participate

Not applicable.

Consent to Publish

Not applicable.

Availability of Data and Materials

N/A

Competing Interests

Authors have declared that they have no competing interests.

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