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Cell Phone-Based and Adherence Device Technologies for HIV Care and Treatment in Resource-Limited Settings: Recent Advances

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Abstract Numerous cell phone-based and adherence monitoring technologies have been developed to address barriers to effective HIV prevention, testing, and treatment. Because most people living with HIV and AIDS reside in resource-limited settings (RLS), it is important to understand the development and use of these technologies in RLS. Recent research on cell phone-based technologies has focused on HIV education, linkage to and retention in care, disease tracking, and antiretroviral therapy adherence reminders. Advances in adherence devices have focused on real-time adherence monitors, which have been used for both antiretroviral therapy and pre-exposure prophylaxis. Real-time monitoring has recently been combined with cell phone-based technologies to create real-time adherence interventions using short message service (SMS). New developments in adherence technologies are exploring ingestion monitoring and metabolite detection to confirm adherence. This article provides an overview of recent advances in these two families of technologies and includes research on their acceptability and cost-effectiveness when available. It additionally outlines key challenges and needed research as use of these technologies continues to expand and evolve.

Keywords Cell phones · Electronic adherence monitoring · Technology · HIV antiretroviral therapy

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Introduction

Approximately 33 million out of a total 39 million people living with HIV/AIDS (PLWHA) reside in low- and middle-income countries [1]. Scale-up of antiretroviral therapy (ART) programs has contributed to decreases in HIV/AIDS mortality rates, particularly in resource-limited settings (RLS) [2] and will likely decrease HIV incidence through prevention of secondary transmission [3]. Despite these successes, structural barriers (e.g., long distances to clinic, inadequate healthcare infrastructure) continue to contribute to HIV spread, morbidity, and mortality. New electronic technologies—which we define here as electronic machinery and equipment designed to solve a particular problem [4]—have been developed for or deployed in RLS to overcome some of these barriers. Other devices attempt to bypass limitations in HIV clinical management and research and are becoming more commonly used in RLS. For instance, electronic adherence monitors (EAMs) offer an objective means of measuring medication-taking behavior, which may be more accurate than self-reported adherence. New technological developments in HIV diagnosis and care have capitalized on expansion of supporting technologies and infrastructure, such as cellular network coverage and cell phone ownership, both of which have grown dramatically in developing countries [5].

In this article, we review recent advances in HIV-related cellular-based and electronic adherence monitoring technologies that are being studied and/or deployed in RLS. Whenever available, we present studies assessing the acceptability and cost-effectiveness of these technologies. We aim to highlight key advances and current knowledge gaps in using these technologies in RLS, as well as point the reader to recent review articles. We drew from relevant peer-reviewed articles and abstracts by searching PubMed, Google Scholar, and reference sections of recent review articles. We focused on data published from 2013 to the time of writing (mid-2015), although we included sources published before this time that were thought to highlight particularly important technological developments. However, this paper is not a systematic review.

Cell Phone-Based Technologies

Cell phone-based technologies constitute a large portion of mHealth technologies, which the World Health Organization defines as “medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants, and other wireless devices” [6]. While Internet/computer-based technologies have garnered significant attention in the developed world, cost and infrastructure demands often limit their application in RLS. Cell phone-based technologies, however, are widely available in RLS and are the focus of a substantial body of recent research. The Pew Research Center, in a survey of cell phone ownership and use in seven sub-Saharan African countries, found that 83 % of individuals surveyed owned a cell phone [7]. Meanwhile, the International Telecommunications Union has estimated that by the end of 2015, there will be 7 billion cell phone subscriptions worldwide [8].

Widespread cellular network coverage and cell phone availability in RLS have provided a platform for novel HIV-related technologies, including interventions for HIV education and prevention, clinical appointment and adherence reminders, and adherence monitoring [9]. Development of these technologies has come with challenges. A recent review of mHealth technology deployed in low- and middle-income countries noted limitations to HIV-related mHealth interventions, such as lower ownership of cell phones among key groups (e.g., women), highlighting the need for creation of interventions that are equitable and consider vulnerable or disenfranchised groups [10]. Furthermore, despite numerous pilot studies reporting success of novel cell phone-based interventions, research on scaling these interventions is lacking [10, 11]. Several compendia of mHealth strategies include descriptions of HIV-related programs in RLS [12, 13]. Here, we describe research on recent programs that use cellular technology for HIV education, monitoring, and care.

HIV Education

A variety of cell phone-based programs to improve training and education related to HIV have been developed, yet there is minimal published literature evaluating them. One recent pilot study of a quiz-based system to disseminate HIV knowledge in Uganda found relatively low response rates (24 %) to text messages, highlighting a potential limitation of responsive short message service (SMS)-based educational programs [14]. In that study, twice as many men as women responded to SMS, which raises questions about etiologies of gender discrepancies. Moreover, as others have noted, the issue of equity arose in this study, in that the study provided free HIV tests to respondents among other incentives, which were disproportionately accessed by particular subgroups (e.g., literate English speakers and those able to respond to SMS messages) [10, 15].

Linkage to and Retention in Care

Several published studies have evaluated cell phone-based systems to improve linkage to HIV care in RLS. Siedner and colleagues evaluated the acceptability and efficacy of three SMS formats to notify rural Ugandan adults of routine HIV laboratory results and to request return to care for those with abnormal results [16]. These formats included (1) direct messages indicating the laboratory results and request to return if appropriate, (2) messages requiring a personal identification (PIN) code before the direct message could be read, and (3) “coded” messages that stated a message unrelated to the laboratory test but that the participant knew referenced the laboratory test. Notably, literacy significantly impacted receipt of the messages and prompt return to clinic, and participants who received PIN-protected messages were less likely to return to clinic than those receiving messages in the other two formats. This team also reported that SMS notifications coupled with travel reimbursements significantly reduced time to clinic return after an abnormal lab result compared to a pre-intervention control group [17]. An ongoing, randomized trial in Kenya—WelTel Retain—is underway to evaluate a weekly, response-based SMS intervention to improve retention in care immediately after HIV diagnosis [18]. This study builds on the successes of the WelTel study, in which weekly SMS reminders with the option for receiving a call back was associated with improved ART adherence and viral suppression, as described below [19].

Substantial attention has been given to cell phone-based interventions to improve retention among mothers and children. A trial in Kenya evaluated the HITSystem, an Internet-based system designed to increase patient retention for early infant diagnosis (EID) of HIV infection [20]. This system integrated automated SMS within the Kenyan EID cascade. Compared to pre-rollout “control” patients, a significant increase was seen in the proportion of HIV-exposed babies following up with EID care at 9 months of age, and a significantly decreased time to result reporting. This study also found a significant increase in ART initiation among HIV-infected infants following start of the intervention compared to pre-rollout (100 vs. 14 % respectively in an urban setting; 100 vs. 64 % respectively in a peri-urban setting). Likewise, the MORE CARE trial, a single-blinded, randomized trial among caregivers of children with or exposed to HIV in Cameroon, evaluated SMS alone, SMS plus a call, call alone, or no reminder (control) to increase retention in follow-up (i.e., arriving for scheduled follow-up appointments) [21]. Compared to control, each of the interventions significantly increased retention in follow-up, although there were no significant differences between interventions. A similar pilot study from South Africa evaluated an SMS- and phone call-based EID intervention from a case manager both before and after pregnant women delivered [22]. In this study, 50 prospectively identified women were compared with 50 retrospectively identified controls. Infants born to women who received the intervention were significantly more likely to undergo HIV testing by 10 weeks of age than infants born to pre-enrollment women. No difference, however, was observed in mothers' engagement in HIV care at either 10 weeks or 12 months post-delivery.

While the aforementioned interventions interface directly with individuals, SMS-based tools have also been evaluated to support clinics. For example, in a cluster randomized trial from Botswana, health centers received or did not receive CD4 results from a central testing center by SMS [23]. The intervention reduced time-to-patient receipt of results but did not increase ART initiation.

Disease Tracking

Cell phone-based technologies may also be useful for coordinating HIV care and collecting epidemiologic HIV data. Nsanzimana and colleagues report on a combined cell phone- and Internet-based reporting system (TRACnet) in Rwanda, which was used to monitor the national ART program to prevent stock-outs [24]. Notably, cell phone-based reporting was substantially more common than Internet-based reporting (86 vs. 14 % of clinics, respectively). Overall, the system allowed for standardized and timely reporting of key clinical data. In another Rwandan study, Chin and colleagues report on a portable, ELISA-based HIV testing system with the ability to transmit results automatically to a cellular network—in this case TRACnet—in order to gather data on disease trends [25]. Notably, these programs represent mHealth interventions that have been brought to scale.

ART Adherence Reminders

A number of studies describe cell phone-based interventions to improve ART adherence. A systematic review and meta-analysis by Finitsis and colleagues identified eight randomized studies (four from RLS) evaluating the effect of SMS interventions on adherence [26•]. Overall, SMS interventions significantly increased adherence and/or other outcome measures compared to control (OR=1.39; 95 % CI=1.18–1.64). In sensitivity analyses, messages sent less than daily, systems that permitted participant communication with providers, personalized messages, and messages timed to individual dosing schedules were associated with increased effect. An earlier, more restricted review and meta-analysis that only included studies from RLS (including overlap with studies in the Finitsis review) found similar results and additionally found that greater baseline participant education (primary education vs. no education) led to increased effect of SMS on adherence [27]. Similarly, a recent network meta-analysis concluded that weekly SMS and SMS plus counseling were associated with improved adherence and virologic suppression [28]. Several key trials included in these reviews/meta-analyses, as well as trials that were excluded or that were published since, bear further discussion, below.

Two prominent trials provided promising evidence that SMS reminders can be effective adherence interventions. The WelTel Kenya1 trial, a randomized study comparing weekly SMS reminders to standard of care among 538 individuals initiating ART, found that SMS reminders improved both self-reported adherence and rates of virologic suppression [19]. In a separate study from Kenya, Pop-Eleches and colleagues compared standard of care (control), short versus long SMS reminders, and daily versus weekly reminders using electronic monitors to track adherence among 431 individuals newly initiated on ART [29]. Overall, weekly reminders led to decreased risk of treatment interruption compared to controls, although there were no differences between participants receiving daily reminders and participants in the control arm or between short versus long messages. A Cochrane systematic review and meta-analysis combining the results from these two trials found overall strong evidence that weekly SMS reminders improved ART adherence [30]. Importantly, results from both studies have garnered scrutiny due to significant attrition in WelTel Kenya1 and potential for diminished significance of results if statistical calculations had accounted for the multiple hypotheses in the report by Pop-Eleches [31].

Five recent studies on SMS interventions in RLS were not included in the aforementioned reviews/meta-analyses. Three of these showed positive effects of SMS on adherence, while two showed either mixed effects or no effect.

Two of the three studies showing positive effects found net improvements in the proportion of participants reaching adherence of >95 %. First, a cohort study that evaluated weekly picture SMS plus an interactive voice response (IVR) call among 150 ART-experienced HIV patients in South India found that the proportion of patients with ≥95 % pill count adherence increased significantly over the course of the study [32]. Notably, using a Likert-based rating scale, participants were significantly more likely to rate IVR as helpful for adherence than SMS. Second, a study among 104 ART-experienced, non-adherent (i.e., a history of <95 % self-reported adherence) patients in Nigeria randomized patients into a control arm or a biweekly SMS reminder plus counseling arm [33]. The intervention was associated with a significantly greater proportion of participants achieving ≥95 % self-reported adherence, as well as a significantly higher median CD4 count compared to the control arm. Notably, the study's design precluded assessment of the effect of SMS alone, and a key limitation of the study is the potential for inaccuracy with self-reported adherence [34]. The third study, in China, enrolled 120 ART-experienced patients and used a real-time electronic adherence monitor to track effects of an SMS-based intervention [35•]. Following a pre-randomization adherence monitoring period, participants were stratified into adherent (≥95 % adherence) and non-adherent (<95 % adherence) groups. After 3 months, patients were randomized to intervention (individualized SMS reminders only if non-adherence was detected by the monitor, plus monitor-data driven counseling) or control groups within each adherence category. Participants in both the pre-randomization adherent and non-adherent arms who then received SMS plus counseling were significantly more likely to achieve adherence of ≥95 % than patients in the control arm after 6 months. No differences in cellular or virologic markers of HIV progression were seen between groups; however, this study was not designed to detect such differences.

In contrast to the three studies that reported success with SMS-based interventions, two studies found no effect. First, a partial blinded, randomized study of 200 patients in Cameroon found no significant difference in self-reported or pharmacy refill adherence between ART-experienced participants receiving weekly motivational SMS and participants receiving standard care [36]. Second, a large (N=631) study of ART-naïve patients in South India, following pilot research described above [32], randomized patients to receive standard care (control) or weekly customized IVRs and a picture message on their cell phones [31]. After 96 weeks of follow-up, no difference was seen in the proportion of participants with virologic failure or with suboptimal adherence (<95 %, based on pharmacy pill counts) between the intervention and control arms. Also notably, time to virologic failure was nearly identical in both arms, suggesting that "alarm fatigue" likely did not account for differences between this study's results and results from shorter-duration studies.

In sum, the results from trials on cell phone-based adherence interventions are mixed. Potential reasons for differences may include the types of participants (e.g., those with and without prior ART experience), perceptions of technology in various settings, and the content or delivery of the messages themselves. Further research examining the mechanisms of effect from cell phone-based interventions and the potential value of two-way communication is needed.

Cost-Effectiveness

Little has been published on the costs or cost-effectiveness of cellular technologies used for HIV education, retention in care, disease tracking, or adherence support, in either resource-rich or resource-limited settings. One recent study estimated that after accounting for system development and fixed and marginal costs, rollout of a cell phone-based adherence intervention among the 600,000 PLWHA in India on first-line ART would cost between \$1.27 and \$1.77 per individual per year [37]. After start-up costs, the cost of most individual-centered cell phone-based interventions (excluding the cost of the phone itself, which most individuals own), is quite low (e.g., each SMS in Uganda is approximately \$0.04 [38]). Some evidence also suggests that individuals would be willing to pay for cell phone-based adherence support. In an acceptability study in Vietnam, participants (who had not used cellular adherence support) stated that they would be willing to pay an average of \$2.50 per month for adherence reminders, out of an average monthly income of \$100 [39].

Uptake/Acceptability

Several studies have evaluated the acceptability of cell phone-based interventions for HIV, often in conjunction with the trials described above. While expectations about an intervention do not always equate with actual experiences, these studies indicate substantial potential with cell phone-based approaches. Specifically, studies have found high rates of acceptability for laboratory notification and adherence and appointment reminders. A study from Uganda evaluated individuals' interest in an SMS-based laboratory notification system and found that all 50 participants would like to receive such notifications; the majority cited expectations for improved communication and improved clinical care [38]. Similarly, in a pre-rollout qualitative acceptability study of WelTel Retain, both HIV-infected individuals and clinicians felt that the SMS intervention would improve communication and lead to early identification of clinical problems, resulting in improved retention [40]. In a small study of SMS reminders to improve adherence among Brazilian women, most participants reported that SMS helped them adhere; one participant noted that the messaging system "helps me not to give up" [41]. Likewise, a focus group-based study in Uganda among HIV-positive youth participants reported that an SMS-based adherence reminder system would help them to adhere [42]. A large (N=301) study of caregivers of children with HIV in Cameroon (an acceptability study for the MORE CARE mHealth trial) similarly found high acceptability of SMS reminders for appointments [43]. Finally, a survey-based study from China found that SMS reminders would be acceptable and that, among other factors, participants who were younger and more highly educated were more accepting of the intervention [44].

These acceptability studies have also identified challenges to individual-based cell phone interventions. In particular, participants have expressed concerns about disclosure from SMS [38, 42]. In the study among Ugandan youths, participants were concerned that friends and family, with whom participants frequently shared cell phones, would read the SMS [42]. Systems designed to prevent this type of disclosure may not always be effective. Although a majority of participants in the SMS-based laboratory notification study described above [16] thought that a PIN-based SMS would be desirable [38], this type of messaging led to significantly decreased identification of the notification message and return to clinic within 7 days of receiving the SMS [16]. Lack of ownership of a cell phone, as well as inability to communicate in a national language, has been shown to decrease effectiveness of SMS reminders [43].

Importantly, exposure to an SMS-based intervention may improve acceptability. One qualitative study in Botswana assessed acceptability of an SMS adherence and clinical outcome reminder system among 83 individuals who had been randomized to either receive or not receive the messages as part of a separate study [45]. At the end of the trial, individuals who had been randomized to receive the SMS message were significantly more likely to think that a reminder system would be helpful and were significantly less likely to be concerned that it would lead to inadvertent HIV status disclosure.

Ongoing Challenges

Although cell phone-based interventions to improve adherence and linkage to and retention in care have been a qualified success, challenges exist with these technologies. A technical and implementation study in Mozambique investigated an integrated system merging SMS adherence and appointment reminders, educational and motivational messages, and accompanying databases and message distribution system for patients with HIV or TB [46]. Investigators demonstrated that a "home-grown system" could be developed and scaled to local health centers in Mozambique and identified six areas of consideration for effective rollout of such a system: (1) data collection methods, (2) costs, (3) SMS content, (4) privacy/data security, (5) connectivity, and (6) scalability. While many of these broad concepts are applicable wherever SMS interventions may be rolled out, the success of such interventions will likely hinge upon careful consideration of these concepts in individual settings.

Adherence Monitoring

EAMs are widely used to study adherence behaviors in several diseases [47]. Given the importance of consistent adherence for achieving and maintaining benefits of HIV treatment [3, 48], considerable attention has been paid to the use of EAMs for monitoring ART. The most widely used device, the Medication Event Monitoring System (MEMS) cap, records date-and-time stamps when the cap is removed and replaced on a pill bottle. Although this record does not confirm actual ingestion of pills, electronically measured adherence is typically considered more accurate at estimating adherence than self-reports [34]. Inaccuracies, however, may result from device non-use or removal of multiple doses with one opening of the bottle. Prior research has relied heavily upon MEMS, which involves downloading data during face-to-face encounters (e.g., clinic visits) [49–52]. While MEMS caps are still widely used, recent research on EAM technology has focused on real-time transmission of adherence monitoring data via cellular networks. Although currently too expensive for RLS, research has explored real-time adherence monitoring in this context in anticipation of lower costs in the future.

Real-Time Adherence Monitors

Although multiple real-time EAMs exist on the market, one real-time EAM, Wisepill, has been used extensively to study HIV in RLS. This device is a pill container that holds 30–60 tablets and transmits a date-and-time stamp every time it is opened via a general packet radio service (GPRS) or SMS signal. A modified version of the device ("Wisebag") monitors the opening of a bag that can be used to hold liquids, applicators, or other non-pill medication formulations. Wisepill monitoring was shown to be feasible and acceptable in an early pilot study among ten PLWHA in rural Uganda in 2010 [53]. Wisepill adherence in that study was comparable to pre-enrollment MEMS adherence levels but lower than adherence measured by unannounced pill counts, a visual analog scale, and report of missed doses. In a follow-up study among 49 adults and 46 caregivers of children with HIV in the same setting, participants were monitored with Wisepill or Wisebag, while also being queried weekly about missed doses using IVR or SMS [54]. Notably, Wisepill-recorded adherence, but not adherence per IVR or SMS, was associated with loss of virologic suppression. A study from South Africa evaluated the feasibility and acceptability of Wisebag for measuring adherence to a pre-exposure prophylaxis microbicide gel [55]. Women generally found Wisebag acceptable, and adherence per Wisebag was significantly lower than that of self-report. It is unclear if the lower adherence seen in both of the Ugandan and South African studies was due to actual lower adherence, non-use of the device, or a combination of these factors.

One of the chief promises of real-time adherence monitoring is the ability to intervene when non-adherence is detected, thereby enabling proactive responses to adherence lapses that might otherwise have resulted in viral rebound and resistance [56]. This proactive response may be particularly valuable in RLS where ART options to treat resistant HIV strains are not widely available. Recently, one study from China (described above) found that an SMS and counseling-based intervention, employed when late dosing or non-adherence was detected by Wisepill, significantly improved adherence compared to control [35•]. In another study from South Africa, individuals initiating ART were similarly randomized to standard of care or SMS reminders triggered by late dosing or non-adherence [57•]. The SMS reminders linked to late doses reduced the number of treatment interruptions >72 hours but did not significantly improve overall adherence or viral suppression. Importantly, neither the Chinese nor the South African studies were designed to detect differences in viral suppression. Additionally, Wisepill was used in rural Uganda to monitor adherence among 479 individuals in a longitudinal cohort study [58]. Interruptions in adherence of ≥48 h were investigated as they were occurring to determine the risk of virologic rebound. Although the study was not designed as an intervention, participants involved in nearly half of the adherence interruptions resumed taking their ART when visited by a research assistant. Moreover, 83 % of participants with viremia detected during the adherence interruption had undetectable virus at subsequent routine viral load assessments, thus providing proof-of-concept for benefits of real-time adherence intervention.

Table 1 Summary of key points, remaining challenges, and research gaps for use of cell phone-based electronic adherence monitoring technologies in resource-limited settings

	Key points	Challenges	Future research recommendations
Cell phone-based technologies			
Education	1. Several programs have rolled out cellular technologies to improve education 2. These programs typically use SMS to provide information to community health workers and/or individuals	1. There are few published efficacy studies on these programs 2. These interventions may suffer from low response rates	1. Definition of key outcome variables and metrics for education interventions are needed 2. Efficacy data for education interventions are needed
Linkage to and retention in care	1. SMS may be effective at linking individuals to care following laboratory testing and for early infant diagnosis 2. SMS may also increase retention in routine follow-up	1. Literacy and familiarity with technology may impact usefulness of SMS reminders	1. More data are needed to define optimal intervention methods among a variety of available technologies (e.g., SMS and IVR) 2. More data are needed to better identify what information should be included in SMS message, and how the message should be delivered
Disease tracking	1. Cell phone technologies have been used to facilitate national drug tracking programs 2. Cellular-enabled testing devices may permit automatic disease reporting	1. Cellular-based epidemiological tracking would require wide-scale use of tracking systems 2. Limited data exist evaluating tracking systems	1. Additional studies and program assessments of tracking systems are needed 2. Studies of the ethics of automated disease-status reporting would be valuable
Adherence reminders	1. SMS and IVR reminders may be effective methods to improve adherence and biologic markers of HIV suppression in RLS 2. Less frequent reminders may be more effective than daily reminders 3. Costs of wide-scale rollout of cell phone-based adherence interventions may be low 4. SMS-based reminders appear to be widely acceptable	1. Disclosure is a key concern in use of cell phone-based adherence interventions 2. Systems designed to prevent disclosure may be less usable than direct messages 3. Lack of cell phone ownership may inhibit uptake of interventions 4. Lack of knowledge of a national or common language may inhibit uptake of interventions	1. Data to inform scale-up of mHealth interventions are still missing [11] 2. More data on local barriers to intervention uptake are needed to inform roll-out of interventions in specific settings 3. Further data on cost and cost-effectiveness of interventions are needed
Adherence monitors			
Real-time adherence monitoring	1. EAMs have been used extensively to characterize adherence in RLS 2. Earlier studies relied upon devices like MEMS caps, which provided researchers with adherence data during clinic visits 3. More recent studies have investigated real-time adherence monitors that use cellular signals to transmit adherence data as they are collected 4. EAMs appear to be acceptable 5. EAMs designed to measure different types of medication administration are under development	1. EAMs currently in use to study HIV adherence do not measure or correlate perfectly with actual medication ingestion	1. Further research could evaluate linkage of EAM data to adherence interventions 2. Additional data are needed on costs of EAMs and, in the future, cost-effectiveness of EAM-based interventions

Future EAMs

Newer EAMs are in development, including ingestion monitors [59] and metabolite detectors [60]. The best-described ingestion monitor, Proteus, involves pills embedded or encapsulated with a microchip that, upon contact with digestive fluids, transmits a signal to a transponder (a disposable patch) worn by an individual. The transponder then transmits a signal via Bluetooth to a cell phone or computer to record adherence. Metabolite detectors measure adherence by assessing a medication byproduct or taggant, which indicates ingestion. One device, Exhale, measures the metabolite via a breathalyzer. Additionally, biometric monitors (e.g., vaginal rings) are also being explored, but thus far only in animal models [61]. No publications of these measures have involved RLS to date. Feasibility, acceptability, and cost studies will be important as development progresses.

Uptake/Acceptability

Several recent studies have investigated the acceptability of real-time adherence monitoring for HIV. In the studies described above, Wisepill and Wisebag were found to be generally acceptable and convenient to use, and most participants liked using the devices [53–55]. Likewise, in a feasibility and acceptability study of Wisepill among HIV-positive injection drug users in China, the device was found to be generally acceptable, although several participants reported concerns about potential disclosure from the device [62].

Conclusions

A host of technologies designed to improve treatment and study of HIV infection has been employed in RLS. Here, we described technologies that rely upon cell phones and/or that electronically monitor adherence. Some of these technologies have garnered significant recent scholarship (e.g., cell phone-based adherence reminders), whereas others have been relatively unstudied (e.g., cell phone-based education strategies). Importantly, while some technologies have been used in both research and clinical settings (e.g., linkage to care and education), others (e.g., EAMs) have yet to enter clinical care (e.g., EAMs). Additionally, a potential exists to combine these technologies, as demonstrated by the linkage of SMS reminders with real-time adherence monitoring. We provide a summary of recommendations for further research of these technologies in RLS in Table 1, as well as a summary of key points and challenges relevant to these technologies. The recent advances reviewed here highlight the promise that new technologies hold to improve understanding and management of HIV, as well as lingering questions and potential pitfalls associated with these innovations.

Compliance with Ethics Guidelines

Conflict of Interest Dr. Haberer reports grants from NIH, during the conduct of the study; personal fees from World Health Organization, personal fees from FHI 360, personal fees from NIH, outside the submitted work. Mr. Campbell reports grants from NIH, during the conduct of the study.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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