Effects of a mobile phone short message service on antiretroviral treatment adherence in Kenya (WelTel Kenya1): a randomised trial

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Summary

Background **Mobile (cell) phone communication has been suggested as a method to improve delivery of health services. However, data on the effects of mobile health technology on patient outcomes in resource-limited settings are limited. We aimed to assess whether mobile phone communication between health-care workers and patients starting antiretroviral therapy in Kenya improved drug adherence and suppression of plasma HIV-1 RNA load.**

Methods **WelTel Kenya1 was a multisite randomised clinical trial of HIV-infected adults initiating antiretroviral therapy (ART) in three clinics in Kenya. Patients were randomised (1:1) by simple randomisation with a random number generating program to a mobile phone short message service (SMS) intervention or standard care. Patients in the intervention group received weekly SMS messages from a clinic nurse and were required to respond within 48 h. Randomisation, laboratory assays, and analyses were done by investigators masked to treatment allocation; however, study participants and clinic staff were not masked to treatment. Primary outcomes were self-reported ART adherence (>95% of prescribed doses in the past 30 days at both 6 and 12 month follow-up visits) and plasma HIV-1 viral RNA load suppression (<400 copies per mL) at 12 months. The primary analysis was by intention to treat. This trial is registered with ClinicalTrials.gov, NCT00830622.**

Findings **Between May, 2007, and October, 2008, we randomly assigned 538 participants to the SMS intervention (n=273) or to standard care (n=265). Adherence to ART was reported in 168 of 273 patients receiving the SMS intervention compared with 132 of 265 in the control group (relative risk [RR] for non-adherence 0·81, 95% CI 0·69–0·94; p=0·006). Suppressed viral loads were reported in 156 of 273 patients in the SMS group and 128 of 265 in the control group, (RR for virologic failure 0·84, 95% CI 0·71–0·99; p=0·04). The number needed to treat (NNT) to achieve greater than 95% adherence was nine (95% CI 5·0–29·5) and the NNT to achieve viral load suppression was 11 (5·8–227·3).**

Interpretation **Patients who received SMS support had significantly improved ART adherence and rates of viral suppression compared with the control individuals. Mobile phones might be effective tools to improve patient outcome in resource-limited settings.**

Funding **US President's Emergency Plan for AIDS Relief.**

Introduction

Health programmes that use mobile communication technologies are emerging with the aim of strengthening health systems.[1–3] The United Nations Joint Programme on HIV/AIDS (UNAIDS) and WHO have added wireless communication technologies to their strategic plans.[4,5] However, at present no published clinical trial has reported the use of mobile health technologies to improve patient-centred outcomes in developing countries.

Present efforts to control the HIV/AIDS pandemic include treatment with antiretroviral therapy (ART), targeted prevention strategies, and treatment as prevention measures (ie, prevention of HIV spread by treating HIV positive people and thereby reducing the risk of onward transmission).[6,7] However, widespread progress at controlling the pandemic is restricted by poor infrastructure and increasing health-system costs.

The number of mobile (cell) phone users is rapidly expanding (4·5 billion mobile phone subscribers are expected worldwide by 2012),[8] mainly because of free market forces (ie, capitalism) and the demand for rapid wireless communications for personal use and to aid multi-sector economic development (eg, trade, tourism, and infrastructure); thus, mobile technology has the potential to be used in health systems worldwide. A wide range of medical services could be improved by providing patient-focused support and management through the health-care system.

Maximum adherence to ART in patients with HIV improves health outcomes and prevents drug resistance.[9] Adherence is also important for programme cost containment.[10] If mobile phone use does improve health outcomes in resource-limited settings, this mobile health technology could thus be included in health-system strategies and help improve health development goals.[11]

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In this trial, we aimed to assess whether mobile phone communication between health-care workers and patients initiating ART in Kenya[2,12] improved drug adherence and suppression of plasma HIV-1 RNA load.

Methods

Patients

Patients initiating ART were recruited from three different HIV clinics that are involved in intense ART provision scale-up. The University of Nairobi Pumwani Clinic serves a very low-income population in Nairobi[13] and the Coptic Hope Center for Infectious Diseases operates out of a faith-based hospital located in a higher-income area of Nairobi.[14] The Kajiado Clinic is a government health centre in a large rural district. We chose these three locations because they should represent the regional diversity of health settings.

Patients were eligible for study participation if they were over 18 years old, initiating ART for the first time, and able to access a mobile phone on a near-daily basis and communicate via short message service (SMS). People who did not own mobile phones were eligible if they had shared access (with corroborative agreement by the phone owner), and illiterate patients were eligible if assisted by a literate partner. Participants used existing mobile phone services; phones and network airtime credit were not provided.

Patients provided written or verbal informed consent at enrolment in a language they understood. The study protocol was approved by the University of Manitoba and Kenyatta National Hospital ethics review boards.

This trial is registered with ClinicalTrials.gov, NCT00830622.

Randomisation and masking

WelTel Kenya1 was an individually randomised, parallel, multisite controlled trial. Patients were randomly assigned (1:1) by simple randomisation[15] to the SMS intervention or to standard care (control group). A project statistician generated the randomisation numbers with a random number generating program. Written allocation of assignment was sealed in individual opaque envelopes marked with study identification numbers, which were distributed to all three study clinics. Target enrolment was estimated at a ratio of about 2:2:1 across clinics, with the urban centres having the higher enrolment. We did not do block randomisation because of the unpredictable scale-up rates at each clinic. Randomisation, laboratory assays, and analyses were done by investigators masked to treatment allocation; however, study participants and clinic staff could not be masked because the intervention required overt participation.

Procedures

Antiretroviral drugs were provided by the government of Kenya with support from the US President's Emergency Plan for AIDS Relief (PEPFAR), and consisted primarily of three drug combinations containing zidovudine or stavudine, plus lamivudine, plus efavirenz or nevirapine as first-line drugs. Initiation of ART was in accordance with national guidelines (CD4 count <250 cells per μL or WHO stage III or IV).[16]

Typically, the study site in Kajiado provided one counselling session at ART initiation and the two sites in Nairobi provided two counselling sessions before and one session 1 month after ART initiation. Disclosure of HIV status, pairing up with a treatment adherence partner, and participation in support groups was encouraged but not insisted upon. Additional brief counselling was provided at each site during dispensation of the drugs in the clinic or pharmacy.

We thought that regular, structured mobile phone communication between health-care workers and patients could improve patient outcomes by both reminding patients to take their ART and by providing support to the patients. The intervention was planned in consultation with investigators, clinic staff, and patients (in unstructured focus group sessions) with the goals of low cost and widespread usability.[2,17]

All intervention participants received brief training for use of the SMS intervention from the study clinicians. They were informed that the SMS support service did not replace existing adherence counselling or emergency services. On Monday morning of each week, the site nurse or clinical officer sent a text message via SMS to patients in the intervention group to inquire about their status and thus to remind them about the availability of phone-based support. Typically, the slogan "Mambo?" was sent, which is Kiswahili for "How are you?" The health workers used multiple recipient (bulk) messaging functions to improve efficiency. Patients in the intervention group were instructed to respond within 48 h that either they were doing well ("Sawa") or that they had a problem ("Shida"). The clinician then called patients who said they had a problem or who failed to respond within 2 days. Participants were instructed that health-care workers were available to respond during clinic hours only. All mobile phone communications between the health-care workers and patients were recorded in the study log.

The primary outcomes were self-reported adherence and suppression of plasma HIV-1 viral load. Self-reported adherence is the most practical method of assessing adherence because it closely represents the regional standard care;[18] however, this method of assessment has been reported to be an overestimate of adherence.[19] At 6 and 12 months follow-up, we asked participants how many pills they missed in the past 30 days; they were classed as adherent if they reported that they had taken more than 95% of the provided pills at both follow-up visits.[9] We measured adherence at two timepoints to assess the durability of adherence and to increase the sensitivity to detect adherence failures, because of the high levels of adherence rates recorded by self-report regionally.

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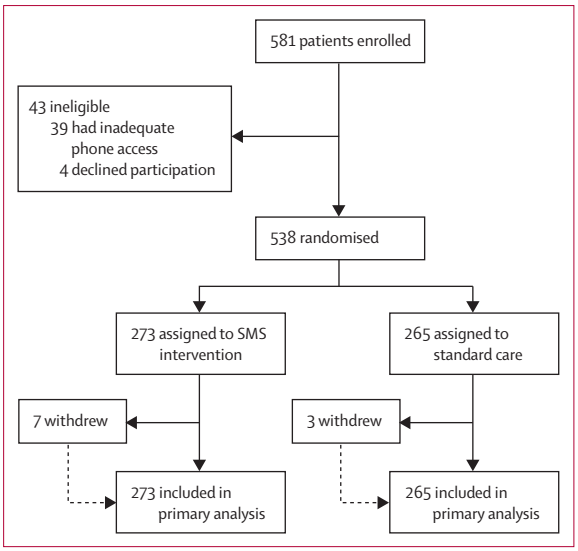

Figure 1: **Trial profile**

	SMS group (n=273)	Control group (n=265)
Women	177 (65%)	174 (66%)
Age (years)	36·7 (8·5, 19·0–65·0)	36·6 (7·9, 22·0–84·0)
Clinic		
University of Nairobi Pumwani Clinic	120 (44%)	131 (49%)
Coptic Hope Centre for Infectious Diseases	117 (43%)	92 (35%)
Kajiado Clinic	36 (13%)	42 (16%)
CD4 cell count per μL*	167·6 (121·7, 2·0–887·0)	160·9 (141·4, 1·0–1522·0)
WHO stage†		
1	52 (23%)	62 (26%)
2	67 (29%)	59 (25%)
3	101 (44%)	103 (43%)
4	9 (4%)	13 (5%)
HIV-1 plasma RNA load (log_{10} copies per mL)‡	4·59 (1·05)	4·83 (0·96)
Language literacy¶		
English only	1 (0%)	2 (1%)
Kiswahili only	48 (18%)	36 (14%)
Both	213 (79%)	215 (81%)
Other only	9 (3%)	12 (5%)
Education		
None	10 (4%)	14 (5%)
Primary	108 (40%)	86 (32%)
Secondary	106 (39%)	124 (47%)
Post-secondary	49 (18%)	41 (16%)
Monthly income§		
<2000 KES (<US$1/day)	72 (29%)	64 (28%)
<2000–10 000 KES ($1–5/day)	114 (47%)	98 (43%)
10 000–40 000 KES ($5–20/day)	46 (19%)	61 (27%)
>40 000 KES (>$20/day)	13 (5%)	7 (3%)
Mobile phone access		
Owns	239 (88%)	225 (85%)
Shares	34 (12%)	40 (15%)
Residence status		
Rural	51 (19%)	50 (19%)
Urban	222 (81%)	215 (81%)

Data are number (%), mean (SD, range), median (IQR), mean (SD). Percentages do not add up to 100% in some cases because of rounding. KES=Kenyan shillings. *Data missing for one patient in the SMS group and four in the control group. †Data missing for 44 patients in the SMS group and 28 in the control group. ‡Data missing for 21 patients in the SMS group and 25 in the control group; for 19 patients in the SMS group and ten in the control group, baseline viral load was below the limit of detection (400 copies per mL). Log of viral load for these patients was given as $log_{10}(400)$. ¶Data missing for two patients in the SMS group. §Data unavailable for 28 patients in the SMS group and 35 in the control group.

Table 1: **Demographics and baseline characteristics**

Viral load is an important composite endpoint for monitoring adherence and takes into account pharmacological, biological, and sociobehavioural factors. Participants were classed as virologically suppressed if their plasma HIV-1 RNA load at their 12-month visit was 400 copies per mL or less. Patients who did not achieve this outcome were classed as virologic failures. Plasma was taken from patients at the 12-month visit for assessment of HIV-1 RNA viral load (Amplicor, Roche Diagnostics, Mannheim, Germany) and was stored and analysed at a later timepoint in batches. Laboratory assays (CD4 count and HIV-1 RNA load) were all done at a central laboratory (University of Nairobi Institutes for Tropical and Infectious Diseases). CD4 count testing (FACScan, Becton Dickinson, Sunnyvale, CA, USA) was part of routine care at the urban sites and was provided for study purposes at the rural site.

Secondary outcomes included the rate of attrition (not having a final visit at 12 months) and rates of several categories of attrition (mortality, withdrawal from the study, transfer to non-study clinics, and loss to follow-up without identifiable cause). Other predefined secondary endpoints, including quality of life and social and economic outcomes, will be reported separately. We also assessed the effects of the SMS intervention in prespecified subgroups of patients subdivided by sex, urban or rural residence, clinic attended, disease stage, and whether they owned or shared a phone.[20] Finally, at one urban site and the rural site we ran semistructured focus group sessions with ten to 20 participants before, during, and after the start of the trial and asked for participant feedback.[20]

Statistical analysis

We calculated that a sample size of at least 534 would be required to detect a 10% improvement in adherence, with 80% power and 0·05 level of significance.[20,21] Demographic and covariate information were recorded at baseline (month 0) and at scheduled visits at 6 and 12 months. Self-reported adherence to ART was assessed by a standardised questionnaire at each follow-up visit. Study staff maintained a study register to record all SMS responses and other mobile phone communications with patients. Patients defined as lost to follow-up were those unable to be traced within 3 months of the study end date.

Detailed description of the analysis methods can be found in the trial protocol.[20] Briefly, we analysed the

	SMS group (number [%])	Control group (number [%])	RR (95% CI)*	p value
Primary outcome				
Intention-to-treat analysis†				
Self-reported adherence (>95%)	168 (62%)	132 (50%)	0·81 (0·69–0·94)	0·006
Viral suppression (<400 copies per mL)	156 (57%)	128 (48%)	0·85 (0·72–0·99)	0·04
Complete-case analysis‡				
Self-reported adherence§	168 (91%)	132 (91%)	1·00 (0·94–1·07)	0·94
Viral suppression¶	156 (75%)	128 (66%)	0·88 (0·77–1·00)	0·047
Secondary outcomes				
Total attrition (missing)	53 (19%)	61 (23%)	1·24 (0·82–1·89)	0·31
Loss to follow-up	17 (6%)	27 (10%)	1·69 (0·91–3·23)	0·094
Mortality	25 (9%)	30 (11%)	1·27 (0·72–2·22)	0·42
Withdrawal	7 (3%)	3 (1%)	2·26 (0·59–8·67)	0·34‖
Transfer out	4 (1%)	1 (0%)	0·25 (0·19–2·17)	0·38‖

Percentages do not add up to 100% in some cases because of rounding. *For non-adherence or virologic failure. †273 patients in the SMS group and 265 in the control group. ‡Because the intention-to-treat analysis classed all patients with missing data as non-adherent or having viral failure, the number of adherent patients and number of patients with viral suppression are the same here as in the intention-to-treat analysis. §185 patients in the SMS group and 145 patients in the control group. ¶208 patients in the SMS group and 194 patients in the control group. ‖Fisher's exact test.

Table 2: **Primary and secondary outcomes**

primary outcomes with the χ^2 test. The analysis of primary outcomes was by intention to treat. The primary analyses were not adjusted, as prespecified and recommended.[20,22] Relative risk (RR) was reported for non-adherence and virologic failure, with an RR less than 1 suggesting better outcome for the intervention group.

As a measure of absolute effect size, we also calculated the number needed to treat (NNT) and its associated 95% CI for both unadjusted primary outcomes.[23] We also did a per-protocol (complete-case) analysis of the primary outcomes, in which only participants who had complete primary outcome data (self-reported adherence at 6 and 12 months and viral load at 12 months) were included. We also did adjusted analyses by fitting a logistic regression model to the primary outcomes with adjustments for sex, age, baseline viral load, baseline CD4 count, and baseline WHO stage. We used multiple imputation (PROC MI and MIANALYZE in SAS, with five sets of imputations) to impute the missing values of covariates.

Secondary outcomes were compared with the χ^2 test. We used the Fisher's exact test for outcomes that were reported in five patients or less to estimate p values. In the subgroup analysis in the intention-to-treat population, we compared the intervention groups within each subgroup of patients with the χ^2 test. Heterogeneity of the effect of the intervention across subgroups was assessed by comparing logistic regression models with and without interaction term between treatment allocation and subgroup-defining variables (using the likelihood-ratio test).

The criterion for significance was set at α=0·05. Bonferroni correction with resulting p values of 0·01 (for five tests) was used for predefined exploratory secondary and subgroup analyses. For all models, the results are expressed as an estimate of effect size, with 95% CIs and p values. The response type throughout the study period was analysed by categorising time since random allocation to the first 3 months and afterwards, and doing a χ^2 test between time and response type. All statistical analyses were done with SAS (version 9.2, 64-bit edition).

Role of the funding source

The sponsors of the study had no role in the design of the original study protocol, data collection, data analysis, data interpretation, writing of the report, or decision to submit the manuscript for publication. RTL, TK, SK, MHC, MS, MN, and CM had full access to all the data in the study, RTL had final responsibility for the decision to submit for publication, and all authors approved the decision to submit.

Results

Between May, 2007, and October, 2008, we enrolled 581 participants (figure 1). Consecutive enrolment was attempted; however, one site enrolled alternate patients into separate studies. After screening, 39 patients were excluded because they had inadequate phone access and four declined participation. Accordingly, 538 patients were randomly assigned: 273 to the SMS intervention and 265 to standard care. Ten participants (seven in the SMS group and three in the control group) withdrew from the study after random allocation for personal reasons. Table 1 reports the demographics and baseline characteristics of both groups, which are generally similar to those of the AIDS epidemic in Kenya, including predominant female sex.[24]

More patients in the SMS intervention group than in the control group had self-reported adherence of over 95% at both visits (table 2). By contrast, in the complete-case analysis, adherence was not different between groups. After adjusting for baseline covariates, self-reported adherence remained significantly better in the SMS group than the control group (odds ratio [OR] 0·57, 95% CI 0·40–0·83; p=0·0028). The NNT for adherence was nine (95% CI 5·0–29·5).

More patients in the SMS group than in the control group had suppressed viral loads below the level of detection (<400 copies per mL) at 12 months (table 2). In the complete-case analysis there was also higher viral suppression in the SMS group than the control group. After adjustment, the intention-to-treat analysis showed weak evidence of improved suppression of viral load in the SMS group compared with the control group (OR 0·71, 95% CI 0·50–1·01; p=0·058). The NNT to achieve HIV-1 viral suppression was 11 (95% CI 5·8–227·3).

No secondary outcomes showed significant associations with the intervention (table 2). Figure 2 shows the results of the subgroup analysis and the heterogeneity of the intervention effect. Male sex, urban

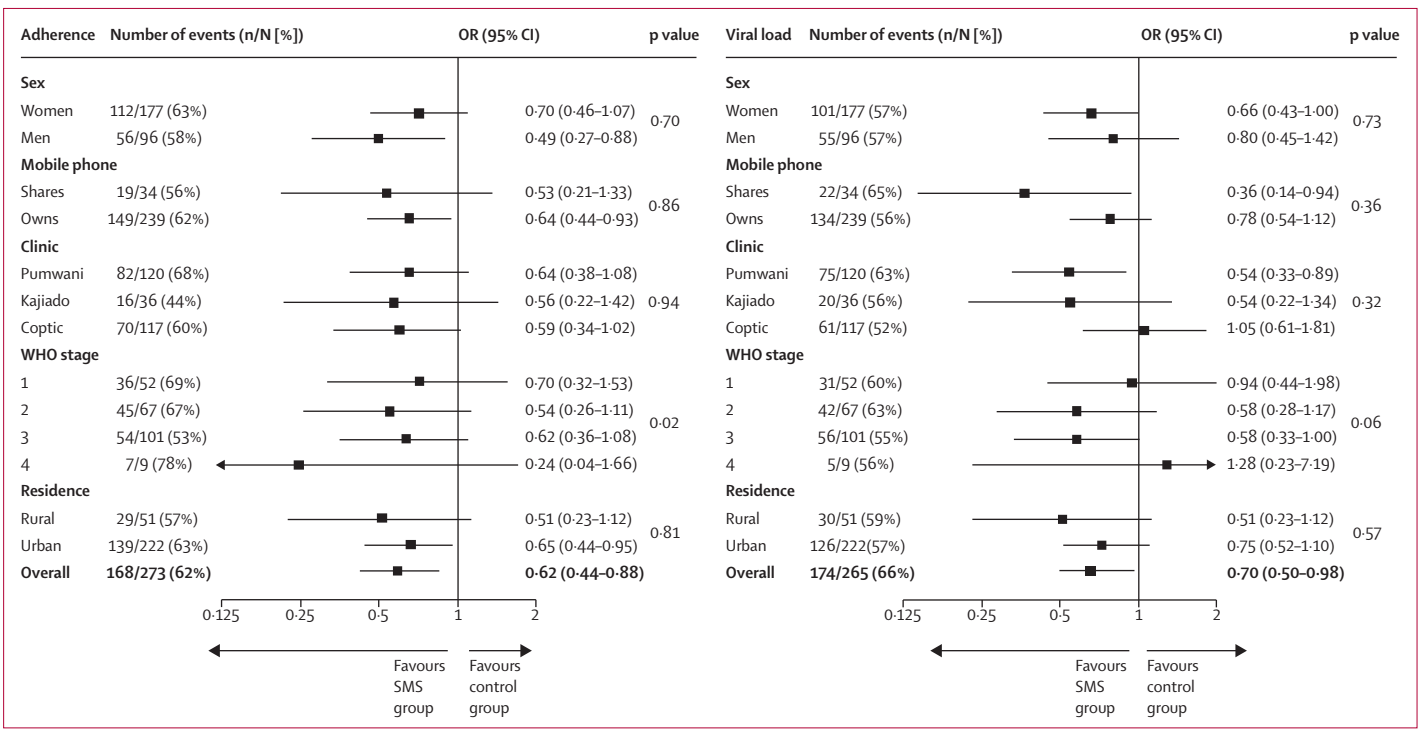

Figure 2: **Subgroup analyses**
Estimated intervention effects are reported as ORs and 95% CIs for risk of failure. p values for heterogeneity were derived from likelihood ratio statistics. OR=odds ratio.

residence, and mobile phone ownership all favoured adherence compared with the control group. However, none was significant after Bonferroni correction.

We recorded 11 983 valid responses to the SMS inquiries from intervention participants. Figure 3 reports the patient responses over time. There were 7812 "Sawa" responses, 391 "Shida" responses, and there were no responses or responses were not received on time on 3780 occasions. The proportion of Shida responses decreased from 6·1% in the first 3 months after recruitment to 2·0% afterwards (p<0·0001). The most common reason for a Shida response was a medical issue. Non-responders most frequently cited cost and other logistical factors or forgetting, rather than health issues, as the main reasons for not responding on time.

No adverse event directly attributable to the mobile phone SMS communication, such as breaches of confidentiality (eg, if non-participants found out the participant's HIV status in an unintentional way) or injury (eg, caused by driving or riding a bike whilst texting), was reported in the weekly study logs or during follow-up visits with health-care workers. At the end of the study, 191 of 194 patients in the intervention group reported they would like the SMS programme to continue, of whom 188 (98%) said they would recommend it to a friend. In the focus group sessions, many patients in the intervention group also reported that they thought the SMS support service was valuable (data not shown).

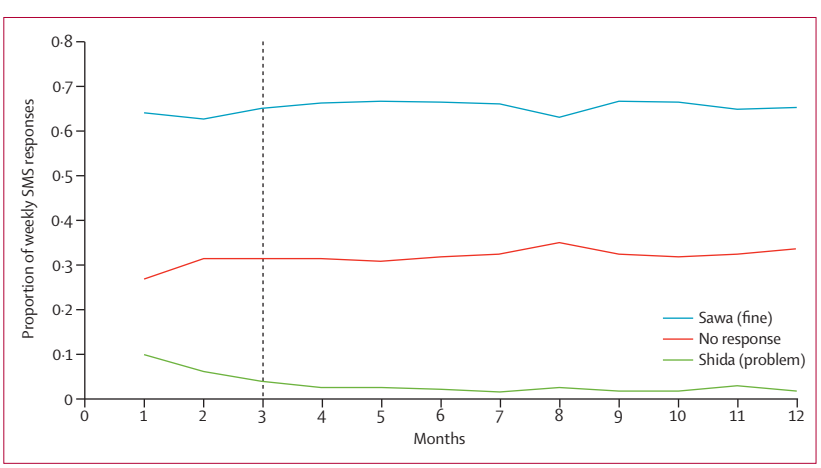

Figure 3: **SMS intervention response rates**
The graph is truncated at 12 months' follow-up. A line is drawn at 3 months indicating the usual transition to HIV disease stability and reduction in toxicities after initiation of antiretroviral therapy.

Discussion

This study shows that mobile health innovations can improve HIV treatment outcomes. Patients who received the SMS support were more likely to report adherence to ART and were more likely to have their viral load suppressed below detection levels than patients who received the standard care alone.

The primary analysis classed all-cause attrition as treatment failures. Thus, the higher follow-up rates and lower mortality reported in the intervention group

Panel: **Research in context**

Systematic review

We searched Medline, Cochrane CENTRAL, and Embase (from inception to Oct 24, 2010) using the MeSH terms "cellular phone and HIV". We did not identify any randomised controlled trials that have assessed mobile technology for treatment support in HIV patients.

Interpretation

This is, to our knowledge, the first randomised controlled trial of mobile technology to support adherence and viral suppression in patients with HIV/AIDS. We reported a statistically significant and clinically important increase in self-reported adherence and viral suppression.

contributed to the positive intervention effect for the primary outcomes. When only available data were included in the complete-case analyses, a significant reduction was preserved in viral suppression but not in self-reported adherence. This could be because of a recall or social desirability bias in self-reporting adherence among those who were followed up. Alternatively, patients might have been less likely to respond to follow-up if they had not adhered to ART. Nonetheless, we chose an intention-to-treat analysis for the primary outcome because contributions of loss to follow-up are important indicators for the durable implementation of ART programmes.[25–27]

Our reported adherence and viral suppression rates seem to be lower than in other studies;[28,29] however, our detection of adherence failures might have been more sensitive because we used two timepoints for adherence, and comparative data on viral suppression outside of heavily researched settings is limited.[30] However, the actual mean adherence rates reported by participants in this study was quite high, and because the SMS intervention was well received by patients and the study consent process informed participants of potential benefits of mobile phone communication, the study might have underestimated the actual intervention effect compared with the regional standard care. More mobile phone usage might have been promoted by the study overall; study nurses reported a higher number of calls from study control individuals compared with non-study clinic attendees (data not shown). Additionally, several participants reported forwarding their weekly text messages to non-intervention participants to share support. Adherence rates reported among participants in this study were higher than non-study participants within the same clinics as well as non-study clinics operated by the same ART programme providers (ART adherence data provided by individual programme managers; data not shown). The SMS intervention was well received by patients, many of whom reported that they felt "like someone cares"; most recommended for the SMS programme to continue (data not shown).

This is, to our knowledge, the first effectiveness trial assessing the ability of a mobile health technology intervention to influence HIV outcomes in a resource-limited setting (panel). However, pilot studies of mobile health technologies are emerging.[31–34] In developed countries, mobile health technology interventions are gaining a clear evidence base for management and prevention of a broad range of disorders.[3,35] Two randomised trials in the USA assessed a counselling intervention by landline telephone for patients taking ART and reported a significant benefit for adherence but not for virologic control.[36,37] However, in our study the intervention included regular SMS communications without additional counselling, so human resource and training requirements were minimal. Because only 3·3% of the weekly text messages identified a definitive requirement for follow-up (Shida), one nurse could potentially manage 1000 patients by SMS and expect to call only 33 patients per week. Additionally, the patient follow-up seemed to become more efficient over time, because the proportion of Shida responses from patients decreased after the first 3 months on ART; however, this decrease was after the period in which the most disease instability would be expected.[38]

Although some features of health care and communications are universal, developing and developed economic settings can have different challenges and opportunities. Developing countries have resource challenges but might benefit from bypassing less advanced technologies and instead using the most advanced methods available, which are more uniformly taken up and that allow fresh innovation. Kenya, for instance, led the world in mobile phone money transfers, allowing people who never previously accessed banks to safely transfer funds routinely.[39] Mobile phones could also be used to support and track patients who transfer between ART provision sites. The political turmoil in Kenya after the 2007 presidential elections when hundreds of thousands of civilians were internally displaced because of ethnic violence[40] occurred during our study period. Although some mobile phones were lost, others were used to request assistance from clinic staff, which was frequently met with counselling support and directions to new, safe locales where drug refills could be obtained. Thus, the SMS service seemed to be durable in a crisis.[41]

Overall, this study has implications for policy makers and global funders of ART programmes. First, this is one of the first adherence interventions to confer a reduction in virologic failures.[42] ART needs to be taken lifelong, thus optimal adherence is crucial to the prevention of antiretroviral drug resistance. Instances of drug resistance make future treatment options more challenging and progressively more expensive to deliver. Additionally, reducing viral replication through ART can decrease transmission of HIV-1 to new partners[43] and thus can play a preventive role at the population level to reduce the number of new infections.[44,45]

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The SMS intervention is inexpensive (each SMS costs about US$0·05, equivalent to $20 per 100 patients per month, and follow-up voice calls averaged $3·75 per nurse per month) and the mobile phone protocol uses existing infrastructure. This protocol is also probably less expensive than in-person community adherence interventions,[30,46,47] on the basis of travel costs alone. Thus, the intervention could be both cost effective and cost saving. The estimated NNT of 11 patients for each additional patient with viral suppression in the SMS group over the standard care group could theoretically translate into huge health and economic benefits if the programme was successfully scaled up. For example, if hypothetically applied to the 297 800 people who received ART in Kenya's PEPFAR programme in 2009 (and assuming the effect went beyond 1 year), the SMS intervention could have resulted in 26 354 additional people with fully suppressed viral loads. Innovations in management of automated text messaging and public–private partnerships with mobile health technology developers could improve programme efficiency and scalability.

The applicability of this study to other countries and other diseases remains to be assessed. Factors that influence adherence are often common within Africa and other global settings.[48,49] Although the uptake of wireless telecommunication devices is becoming ubiquitous, introduction of mobile health initiatives is variable.[1,50] We believe that the patient-centred communication effect, in particular the timely support of a patient by a health professional, is universal and can be improved by mobile telecommunication.

Contributors

RTL conceived the study and was the principal investigator of the funded public health evaluation. PR, AK, SK, MHC, WJ, JH, and EN designed the study and BE, LJG, and JK helped with implementation. RTL, MHC, LJG, JK, and FAP are holders of grants that broadly support the ART clinics and research programmes. EJM and LT provided statistical expertise in clinical trial design. MS and MN, supervised by CAM, did the primary statistical analysis. All authors contributed to refinement of the study protocol and approved the final manuscript.

Conflicts of interest

MA is an employee of the US Centers for Disease Control and Prevention (CDC). All other authors declare that they have no conflict of interest.

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