



Technology-Delivered Intervention Strategies to Bolster HIV Testing

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Abstract

Since the beginning of the HIV epidemic, there have been more than 75 million cases. Currently, there about 1.2 million living with HIV in the USA. Despite current testing recommendations, test rates continue to be suboptimal. Investigators have studied the use of digital technology to promote HIV testing, especially among high-risk populations.

Purpose of Review

This non-systematic review provides an overview of the scientific research between 2015 and 2020 focused on the use of digital technology to bolster HIV testing and suggests novel technologies for exploration.

Recent Findings

A total of 40 studies were included in the review that span a wide range of available technology. Studies effectively increased HIV testing among study participants. Generally, participants in the intervention/exposure groups had significantly higher rates of HIV test uptake compared to participants in the comparison groups at study follow-up.

Summary

For a variety of reasons (e.g., differences in ways the technologies were used and study design), no digital tool clearly performed better than others, but each have the capacity to increase outreach and self-testing. An exploration of the potential use of nascent technologies is also discussed, as well as the authors' experiences using a number of these technologies in our research.

Keywords HIV · Self-testing · Digital tools · Technology

Introduction

Increasing rates of HIV testing is one of the most important strategies in reducing the burden of HIV worldwide. Current estimates of prevalence report 38 million adults and children worldwide are diagnosed with HIV [1]. In the USA, 1.2 million Americans are currently living with HIV, and despite testing availability and accessibility, an estimated 14% are unaware of their infection [2]. Current US Centers for Disease Control and Prevention recommendations suggest testing all patients in healthcare settings ages 13 to 64 years at least once, with those at higher risk testing annually [3]. However, two-thirds of those at high risk for infection who visited a healthcare provider in the past year were not offered an HIV test [4]. Using electronic health records, investigators found that only 6.4% of Americans over 18 years had any laboratory evidence of a prior HIV test [5]. These findings fall

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far short of the United Nations' 90-90-90 treatment goal that by 2020, 90% of all people living with HIV will know their status, 90% of all people with diagnosed infection will receive sustained antiretroviral treatment (ART), and 90% of all people receiving ART will achieve viral suppression [6]. Investigators estimate that 40% of transmission during the non-acute phase is due to those unaware of their status [7]. This highlights the importance of testing, as individuals who become aware of their infection are likely to modify their risk behaviors [8, 9].

Digital technologies, such as social media, mobile and virtual reality applications (apps), chatbots and conversational agents, and blockchain technology, have the potential to increase HIV testing. Novel approaches that leverage digital technologies may be particularly helpful in efforts to reach high-risk populations [10]. Trend data indicate an upward pattern in social media use [11] and smartphone ownership [12] in most demographics, including African Americans and Hispanics. In addition, historically, gay, lesbian, and bisexual adults were earlier adopters of technology compared to their heterosexual counterparts [13, 14]. A similar increasing trajectory is seen in mobile app use [15], virtual reality market size [16], and smart speaker ownership [17]. Researchers have capitalized on the ubiquity and variety of technology to increase HIV testing. For instance, investigators found that social media interventions aimed at promoting HIV testing among men who have sex with men (MSM) were effective, and that test uptake was higher for intervention groups vs. controls [18, 19]. Similarly, investigators examining the effects of mobile health (online and smartphone apps) found increased HIV testing [19, 20] and decreased condomless anal intercourse [19, 20].

This manuscript seeks to provide an overview of the science behind technologies that can be incorporated to increase HIV testing. We focus specifically on publications published in the last 5 years, for this special issue. We have organized results of these publications in categories based on the specific type of technology they use. Technologies included are as follows: social media, study website, live chat, text messages, mobile applications, online videos, electronic health records, vending machines, conversational agents, virtual reality, and the potential use of blockchain technology and mobile payment services to increase HIV testing.

Methods

We conducted a non-systematic review of various technologies used in HIV testing research, designed to inform the reader of example technologies that have been leveraged to promote HIV testing, along with study results (when studies had been conducted with this type of technology). Many of these types of technologies were used in combination with one

another in HIV testing research (e.g., social media and data websites/apps were used to recruit participants to visit a website created specifically for the study). Therefore, the categories were not designed to be mutually exclusive but rather to provide the reader with examples of various types of technological approaches that might be incorporated into future research and clinical applications.

Three electronic reference databases (PubMed, Google Scholar, Web of Science) were searched for this non-systematic review using keywords and Medical Subject Headings for studies published between 2015 and 2020. Search terms included the following: (1) HIV testing, (2) digital tools, (3) social media, (4) chatbot, (5) conversational agent, (6) electronic health records, (7) vending machines, (8) blockchain, (9) virtual reality, (10) self-testing, (11) men who have sex with men, and (12) MSM. We included men who have sex with men and MSM in our key terms due to their high risk of HIV infection, though this review is not limited to this population but focuses on publications about technology used in HIV prevention research. We included completed studies as well as manuscripts that describe protocols of ongoing studies. A total of 40 studies were selected from the search that were representative of a variety of categories included in this non-systematic review. In addition, recent research conducted by study authors of relevance to the review was included.

Results

Social Media

Social media includes any digital tool used to create content and share ideas, opinions, and information with a virtual network of people and communities [21]. Research in the past 5 years suggests social media can be an effective tool for increasing HIV testing among high-risk populations, including MSM [18, 22, 23], as well as using “social big data” to monitor HIV-related outcomes [24–30].

Posts and advertisements placed on social media have been shown to be effective in encouraging social media users to request HIV test kits. For example, in a randomized control trial (RCT), Rhodes et al. engaged with MSM on social media sites (Adam4Adam, BlackGayChat, Craigslist, and [Gay.com](#).) via a public profile created specifically for the study. Posts included information about the importance of HIV testing, testing locations, and the process to access tests. After the 12-month intervention, participants in the intervention communities had higher rates of testing for HIV compared to the comparison communities who did not receive any information (AOR 2.9, 95% CI 1.8–4.7) [31]. Lemley et al. utilized paid advertisements on three different types of social media platforms (social media sites, dating sites/apps,

informational sites) to examine the effectiveness of the platforms to promote HIV testing among racial/ethnic minority MSM. Study recruitment ended in July 2020 and investigators will follow up with participants at two time points to compare the performance of each platform in promoting and encouraging HIV testing among users [32]. Washington and colleagues posted short videos on the intervention group social media page weekly and encouraged study participants (young, black MSM) to engage with the page. Compared to control participants who received weekly standard informative text posts (no videos), intervention participants were more likely to get tested (OR 7.0, 95% CI, 1.72, 28.33, $p=0.006$) [33].

Social media intervention studies have also included engaging study participants using peer leaders (i.e., MSM trained in how to reach out to other MSM peers on social media to increase HIV testing). For example, a study was efficacious in increasing uptake of HIV testing among MSM living in Peru. Participants were recruited using social media-targeted banner advertisements. Trained peer leaders engaged with intervention participants in private Facebook groups. Compared to the control group (no peer models in the Facebook groups), more participants in the intervention group engaged with the group and received an HIV test at a local community clinic (AOR 2.61, 95% CI 1.55–4.38) [34]. Young and colleagues recently completed a similar 5-year among minority MSM in Greater Los Angeles designed to increase HIV self-test requests. They have begun analyzing primary outcome with promising results. Similarly, in a randomized comparative trial, Patel and colleagues used peer models to engage participants on social media, a mobile app, or email based on participant preference and to deliver two-message framing strategies to promote HIV testing: (1) desirable outcome to be achieved and (2) undesirable outcome to be avoided. In addition, participants from both groups had access to a study website that offered free HIV test kits, condoms, and a list of services for sexually transmitted infections. Results showed that regardless of which message framing the participants were exposed to, testing increased between baseline and follow-up among participants (31.5 to 43.8%, $p=0.04$) [35]. Table 1 shows a brief summary of each study.

Study Website

Another effective communication tool to provide information about HIV and the importance of testing is a study-specific website (i.e., a website created specifically for a research study and designed to direct participants directly to it). Several investigators launched study websites with general information about HIV. Boni et al. offered free HIV self-test kits using a study website. The website was promoted via flyers at outreach events and gay- and MSM-friendly venues, as well as virtual messages on social media and posts on dating apps. The study website had 67,225 page views with 17,786 unique

visitors over the study period. A total of 3885 requests for HIV self-test kits were made and 2526 were delivered. Of those delivered, 21% of participants reported results, suggesting that an internet-based HIV self-test kit approach was feasible in the study population [36]. MacGowan and colleagues found similar results to Boni et al. in that offering free tests through study websites increased HIV testing. Intervention and control participants were given a link to the study website which provided HIV information and prevention, but intervention participants received free self-test kits that the control group did not. Intervention participants tested more frequently than control participants, and more had tested at least three times by the 12-month follow-up compared to controls (76.6% vs. 22.0%, $p<0.01$) [41]. Bauermeister and colleagues developed and provided a link to a personalized website for intervention participants that utilized theory-based sessions to promote positive sexual health and HIV testing compared to the attention-only controls who received information only. The website contained six sessions which included a core message, in-depth discussion of topics related to the core message, and interactive activities. Activities and videos presented were designed to build participant HIV risk reduction skills. Although the website was highly accepted among the participants, it did not increase testing at follow-up compared to controls who were provided a website with general HIV prevention information (46.7% vs. 40.0%, $X^2(1) = 0.49$, $p = 0.49$) [43]. Increasingly, instead of using study-specific websites that require a new type of website to be built for each study, researchers are beginning to use “research recruitment” websites that allow researchers to post their studies online and assist in recruiting participants to those studies using their outreach and participant databases. For example, ElevateU’s website, Moshemu (<https://moshemu.com/>) is a National Institute on Drug Abuse-funded website designed to help researchers identify participants for substance use and HIV-related studies (and to help potential participants find studies).

Live Chat with Human Staff

Live chat with humans during at home testing may facilitate future testing. Two studies examined the efficacy of chatting with study staff while taking a self-test at home in promoting future testing. Wang et al. found that intervention participants who watched a 7-min video and received a live video chat with study staff while taking a home self-test reported higher rates of testing at a 6-month follow-up compared to control participants who watched a 3-min online video only (89.8% vs. 50.7%, RR 1.77, $p<0.001$) [38]. Similarly, in a study looking at the efficacy of a home-based test paired with a video-chat counseling session during test administration, Stephenson and colleagues noted that all control participants (home-based self-test kit only) ordered self-test kits and reported their results to the study website. Of the 126

Table 1 Study characteristics by technology used

Author	Study type	Participants	Study results
Social media			
Patel et al., 2020 [26]	Randomized comparative trial to study feasibility, acceptability, and impact of peer-delivered messaging for HIV testing and consistent condom use. Two groups: (1) approach (desirable outcome to be achieved) group and (2) avoidance (undesirable outcome to be avoided) group.	18+-year-old MSM	Increased self-reported HIV testing from baseline to 6-months follow-up (31.5 to 43.8%, $P=0.04$). No significant difference in condom use between baseline and follow up. HIV testing and condom use did not differ between two different intervention groups.
Rhodes et al., 2016 [22]	Randomized community trial to increase HIV testing through posts on social media. Two groups: (1) two intervention communities received information about HIV testing information and (2) two control communities did not receive any information.	18+-year-old MSM	Post-test HIV testing for intervention group was 63.7% compared to 42.0% for comparison group (AOR 2.9, 95% CI 1.8–4.7).
Washington et al., 2017 [24]	RCT to examine feasibility of video intervention on Facebook to increase HIV testing. Two groups: (1) intervention group viewed five 1-minute videos weekly and (2) control group viewed standard HIV-related text information only.	18–30-year-old Black MSM	OR for 6-week post intervention HIV testing 7.0 (95% CI, 1.72, 28.33, $p=0.006$).
Young et al., 2015 [25]	RCT to examine the efficacy of peer models who engaged participants on Facebook to increase request for HIV test. Two groups: (1) intervention groups with peer models and (2) control groups without peer models.	18+-year-old MSM	HIV testing for intervention group was 17.0% compared to 7.0% for control group (AOR 2.61, 95% CI 1.55–4.38).
Study websites			
Bauermeister et al., 2019 [29]	RCT to determine the acceptability and efficacy of an online intervention to change sexual risk behaviors and HIV testing. Two groups: (1) intervention group received distinct and affective content designed to build HIV risk reduction skills and positive sexual health behaviors and (2) control group provided with general HIV prevention content.	18–24-year-old gay, bisexual, and MSM	45% of participants reported testing for HIV at 3-month follow-up, with no differences observed between the two groups (46.7% vs. 40.0%; $X^2(1) = 0.49$, $p = 0.49$).
Boni et al., 2019 [27]	Intervention study to examine the feasibility of an internet-based HIV self-test kit approach to increase HIV testing.	18+-year-old MSM	The study website garnered 67,225 page views with 17,786 unique visitors during the study period. A total of 2526 HIV self-test kits were delivered and 21% of participants reported results online or by mail.
MacGowan et al., 2020 [28]	RCT to evaluate the effect of providing HIV self-test kits on testing frequency, diagnoses of infection, and sexual risk behaviors. All participants received information through study website. Two groups: (1) intervention group which received a self-test kit in the mail and (2) control group which did not receive a kit.	18+-year-old MSM	HIV testing for intervention group at least 3 or more times during the trial was 76.6% compared to 22.0% for control group ($P<0.01$).
Live chat			
Stephenson et al., 2020 [31]	RCT to test an online HIV prevention intervention using telehealth and home-based HIV self-test kit. Two groups: (1) intervention group received an HIV self-test kit and an appointment with a remote counselor who supervised administration of the test and (2) control group that was mailed one HIV self-testing kit.	15–24-year-old transgender youth	65 participants randomized into the intervention group did not participate in the intervention. Of the remaining intervention participants, HIV testing during the trial was 96% compared to 91% for control group. At 3-months follow-up, STI testing for intervention was 72.5% compared to 42.9% for the control group ($p=0.001$), but declined by 6-months follow-up for both groups (intervention arm 19.2%, control arm 15.3%).
Wang et al., 2018 [30]	RCT to examine the efficacy of an online counseling session during a home-based HIV test. Two groups: (1) intervention group received the same video as control plus an additional	18+-year-old MSM	HIV testing of any test type for intervention group was 89.8% compared to 50.7% for control group at 6-month follow-up (RR 1.77, $p<0.001$).

Table 1 (continued)

Author	Study type	Participants	Study results
	video, an HIV self-test kit, a video chat counseling session and (2) control group received a 3-minute online HIV prevention video and encouragement to tested.		
Short message service/text message			
Kelvin, George, Kinyanjui, et al., 2019 [35]	RCT to test the efficacy of a text message reminder for a self-test HIV kit. Three groups: (1) intervention group received three text messages about the new self-test HIV kit, (2) enhanced standard of care group received the standard text message reminder for a finger-prick test administered at the clinic three times, and (3) standard of care group received the standard text message once.	18+-year-old male truckers (driver or assistant)	HIV testing during the study period for the intervention group was 3.5% compared to 1.3% for the enhanced standard of care group (OR 2.7, 95% CI 1.3–5.5). No difference was found in testing rates for enhanced standard of care group and standard of care group groups.
Kelvin, George, Mwai, et al., 2019 [36]	RCT to test the efficacy of a text message reminder for a self-test HIV kit. Three groups: (1) intervention group received three text messages about the new self-test HIV kit, (2) enhanced standard of care group received the standard text message reminder for a finger-prick test administered at the clinic three times, and (3) standard of care group received the standard text message once.	18+-year-old female sex workers	HIV testing during the study period for the intervention group was 10.8% compared to 6.1% for the enhanced standard of care group (OR 1.9, 95% CI 1.3–2.7). No difference was found in testing rates for enhanced standard of care and standard of care groups.
Njuguna et al., 2016 [33]	Quasi-experimental study to examine the effect of text messages in increasing HIV testing. Two groups: (1) intervention group received weekly HIV-related text messages and (2) control group did not receive text messages.	18–24-year-old college women	HIV testing at the 6-month follow-up for the intervention group was 67% compared to 51% for the control group (hazard ratio 1.57, 95% CI 1.28–1.92, p<0.001).
Wettermann et al., 2019 [32]	Proof-of-concept study to examine the feasibility of a text message campaign to encourage patients to facilitate HIV testing discussion with their physician and increase HIV testing. Two groups: (1) group received HIV testing text message and (2) group received vaccine or calcium intake text message (control message).	35–55-year-old patients in a healthcare system	35% of the group who received an HIV text message requested a test and none of the patients who received the control message requested an HIV test.
Ybarra et al., 2017 [34]	RCT to test the effect of a text messaging-based HIV prevention program. Two groups: (1) intervention group that received HIV informational text messages and (2) control group that received healthy lifestyle text messages.	14–18-year-old cisgender male who identified as gay, bisexual, and/or queer	HIV testing post intervention for the intervention group that was sexually active at baseline was 38.9% compared to 18.1% for the control group (AOR 3.39, p<0.001). At 90-day follow-up, testing for the intervention group was 55.1% compared to 28.2% for the control group (AOR 3.42, p<0.001).
Mobile/dating application			
Balán et al., 2020 [37]	Multi-phase study to develop and test a smartphone-based app to increase HIV testing among users and their partners.	18+-year-old MSM or transgender women who have sex with men	Participants found the app useful and engaging. Most watched the video tutorial before self-testing and scanned their test results with the app.
Horvath et al., 2020 [38]	RCT to test the feasibility, acceptability, and impact of a mobile app to increase HIV testing. Two groups: (1) intervention group had access to a mobile app with HIV-related information and (2) no treatment control group.	18+-year-old MSM	Overall, the app was feasible and well accepted by participants. At 4-months, repeat HIV testing for the intervention group was 17% compared to 4% of the control group. However, at 8 months, repeat HIV testing for the intervention group was 50% compared with 40% of the control group.
Pai et al., 2018 [39]	Cohort to investigate if mobile app increased referrals, detected new infections, and expedited linkages to care. Three groups: (1) supervised self-testing, (2) unsupervised self-testing, (3) control with conventional testing.	Patients from primary care clinics	Referrals for self-testing was 17.4% compared to control group 2.6% (RR 6.69, 95% CI 4.47–10.01) and many new infections 86 vs 57 (OR 1.55, 95% CI 1.1–2.2).

Table 1 (continued)

Author	Study type	Participants	Study results
Rosengren et al., 2016 [40]	Intervention study to examine the feasibility of banner ads placed in a dating app (Grindr) to distribute HIV self-test kits. Ads linked to a study website where participants were able to order a test kit.	18+-year-old Black and Latino MSM	Banner ads placed on Grindr were effective in reaching high-risk populations. The study website received 4389 unique visitors and 333 test requests. Participants were open to providing personal information to obtain a free test kit, which participants found acceptable and easy to use.
Sullivan et al., 2017 [41]	Intervention study to examine the acceptability and usability of an Android-based HIV prevention app.	18+-year-old MSM	Participants used the app for an average of 17.7 min over the study period. App users ordered condoms (63.3%) and HIV self-test kits (52.8%) through the app. During the study period, 77% of participants tested for HIV at least once and 56% tested multiple times. Participant thought the app was easy to use and 69% stated they would download the app again.
Wray et al., 2018 [42]	RCT to increase HIV testing, post-test follow-up care, and referral. Three groups: (1) eTEST group that was mailed a self-test kit in packaging attached to a device that alerted study investigators when the package was opened to initiate a follow-up call from a counselor, (2) standard group which received a self-test kit with no follow-up call, and (3) control group that was mailed informational letters about HIV testing lefts.	18+-year-old MSM	HIV testing for eTEST and standard groups during the study period was 100% compared to 72% for the control group ($p = 0.001$). There were no significant differences in testing behavior between the two groups that received self-test kits. Repeat testing was also higher for participant in these two groups compared to control participants (81% eTEST, 77.2% standard vs. 40.9%, $p < 0.001$). However, the eTEST group was significantly more likely to receive risk reduction counseling, prevention supplies, and PrEP referrals compared with the other two groups.
Zhu et al., 2019 [43]	RCT to test a mobile-based app designed to increase HIV self-testing. Two groups: (1) intervention group received two HIV self-test kits and access to study app that provided messages, videos, and referrals to health services related to HIV and (2) control group received two HIV self-test kits only.	18+-year-old MSM	HIV testing in the past 6 months at follow-up for intervention group was 92% compared to 68% for the control group ($p < 0.001$). Intervention group significantly increased HIV testing behaviors in the past 6 months compared to controls (ARR = 1.99, 95% CI 1.03–3.84, $p < 0.05$) and use of oral HIV self-test (ARR = 2.17, 95% CI 1.08–4.37, $p < 0.05$)
Informational videos			
Aronson et al., 2016 [44]	Intervention study to examine the feasibility and acceptability of a tablet-based video designed to address barriers to HIV testing in the Emergency Department.	18–24-year old Emergency Department patients	Of the 100 participants enrolled in the study, 98% completed the intervention (mean time <9 mins) and 30% accepted HIV tests offered by the tablets. Post-test showed significantly higher knowledge after than before the intervention ($t = -6.67$, $p < .001$). Overall, patients found the intervention highly acceptable, easy to use, and understandable.
Aronson et al., 2017 [45]	Intervention study to examine the feasibility and acceptability of a tablet-based video designed to provide opioid overdose prevention and response and facilitate HIV and HCV testing in community settings.	18+-year-old clients of a community-based syringe exchange program	Of the 11 participants enrolled in the HIV module, 91% accepted HIV tests offered by the tablet. All participants in the HCV module accepted the HCV test, but only 60% of the overdose prevention module agreed to receive additional naloxone training. Overall, participants in the three different modules accepted the intervention well with acceptability scores no less than 6.8 out of 10.
Tang et al., 2016 [46]	Non-inferiority RCT to compare first time HIV self-test rates among participants who viewed HIV test promotion videos. Two groups: (1) group that received crowdsourced HIV test video	16+-year-old MSM and transgender individuals	HIV testing for the crowdsourced group was 37% compared to 35% for the health marketing group. The estimated difference between the groups was 2.1% (95% CI -5.4 to 9.7%).

Table 1 (continued)

Author	Study type	Participants	Study results
	and (2) group that received health marketing HIV test promotion video.		Investigators conclude that crowdsourcing may be a feasible tool for effective HIV test promotion messaging.
Electronic health record			
Ahlström et al., 2019 [47]	Investigators examined the feasibility of using electronic registry data to predict HIV status using machine learning algorithms.	Members of a national hospital registry who met study criteria and at least 16 years old	Machine learning algorithms can learn from electronic health records to predict HIV cases and distinguish them from non-HIV cases with high accuracy. Further integration of prediction models may be complementary to condition-guided HIV testing and identification of patients suitable for PrEP.
Kershaw et al., 2018 [48]	Retrospective cohort analysis of electronic medical records before and after the implementation of a reminder in the electronic medical record for HIV screening.	18–65-year-old patients of a medical left	Overall, HIV testing increased to 30.7% after the reminder, up from 15.3% (RR 2.02, CI 1.95–2.09, $p < 0.0001$). The significant increase ($p < 0.0001$) was seen in all age groups.
Marcus et al., 2019 [49]	Investigators examined the feasibility of using electronic registry data to predict incident HIV diagnosis using absolute shrinkage and selection operator logistic regression to identify potential candidates for PrEP.	18+-year-old patients of a medical left who met study criteria	Prediction models using electronic health record data were able to identify incident HIV cases. Simpler models identified fewer patients and had lower sensitivity for incident HIV cases compared to the full model (6.0–28.9% vs. 38.6% of incident HIV cases).
Sha et al., 2019 [50]	Investigators examined the feasibility of a screening program of electronic health records to increase HIV testing, diagnosis, and linkage to care in the emergency department.	13–64-year-old patients of a medical left who met study criteria	Overall, HIV testing increased to 17.1% after electronic health record screening was implemented and 21.1% when HIV testing was linked to blood test orders, up from 2.5% at baseline.
Vending machine			
He et al., 2019 [51]	Intervention to examine the acceptability, feasibility, and effectiveness of a vending machine that dispensed HIV urine specimen collection kit for HIV testing.	University students	11 vending machines were placed in seven universities during an AIDS/STD educational campaign. Of 957 urine collection kits distributed by the campaign during the study period, 197 were sold through the vending machines and 760 were freely distributed. 64.5% of kits purchased from the vending machines were returned for analysis. 72.2% of kits purchased were from vending machines in dormitories and 27.8% from instructional buildings.
Lee et al., 2020 [52]	Cross-sectional structured survey to identify acceptability, preferences, and concerns about HIV test kits dispensed from vending machines.	16+-year-old Black African, Black Caribbean, and Latin American	Rates of willingness to use HIV self-test kits from vending machines were high in all groups except Black Caribbeans (Black Africans 77.9%, Black Caribbeans 53.6%, Latin Americans 81.8%, other non-white ethnicities 80.0%). Participants preferred vending machines located in healthcare settings over community settings.
Stafylis et al., 2018 [53]	Intervention study to increase HIV testing through delivery of free HIV self-test kits dispensed in vending machines.	MSM	Vending machines were placed in two commercial sex venues in the on-site STI testing room and social lounge. A total of 1398 kits were dispensed through vending machines, and 110 surveys were completed by patrons who obtained a free test kit. Of those surveyed and reported that the kit was used, 95% reported using the test kit themselves, and 17.7% of these participants reported a reactive result.
Vera et al., 2019 [54]	Intervention to examine the feasibility and acceptability of vending machines to dispense HIV self-test kits in community settings. Two	18+-year-old clients of a sauna frequented by MSM	A total of 265 test kits were dispensed through the vending machine. HIV testing was 34 tests per month through the vending machine compared

Table 1 (continued)

Author	Study type	Participants	Study results
	comparative methods: (1) test kits dispensed through vending machines and (2) test kits distributed through community workers.		with 6 tests a month through the outreach testing by community workers in the same venue. The vending machines were accepted by the participants with 94% of survey respondents stating they would use the vending machine or recommend it to others.
Young et al., 2014 [55]	Qualitative study to examine the usability and acceptability of using vending machines to dispense HIV self-test kit.	18+-year-old African American and Latino MSM	Overall, participants interviewed stated that obtaining an HIV self-test kit from a vending machine was acceptable. Participants differed in opinion regarding aesthetics of the vending machine but agreed that confidentiality and customization made using a vending machine acceptable. Participants felt confident that the test kit they obtained from the vending machine was an accurate medical device and sanitary. Other factors for acceptability of using a test kit from a vending machine included: ease of use, time efficiency, and confidentiality.
Chatbots/conversational agents			
Brixey et al., 2017 [56]	Implementation paper on designing a chatbot using Facebook application programming interface within its Messenger platform.		Developers used a variety of credible sources to create a body of questions and answers about HIV/AIDS which served as the foundation of knowledge for the chatbot. Developers used a response classifier and dialogue management system to drive responses to questions.
van Heerden et al., 2017 [57]	Experimental study to explore the feasibility of using a conversational agent embedded in a messaging mobile application to provide pre-test counseling prior to an HIV test.		Six of the 10 testers preferred a quick reply button instead of typing out responses to the chatbot and thought that both the aesthetics and appropriate responses made the interaction feel like a conversation with a human. Other testers thought the interaction was not realistic, and that the language was too formal. Seven testers felt that the interaction was private and anonymous and therefore, they would be willing to take a test with the chatbot.
Vermeij et al., 2019 [58]	Assessment of an online advice application with a chatbot feature that provides tailored advice based on user-provided information regarding personal characteristics, sexual behavior, sexual risk, and symptoms.		The online application was visited 337,736 times in 2018 with 113,257 visitors started the questionnaire, and 17,449 utilizing the chatbot. Around 60% of visitors finished the questionnaire, which led to 65,736 advice given, and 8700 clicks to online self-test providers.

RCT randomized control trial, *MSM* men who have sex with men, *PrEP* pre-exposure prophylaxis, *(A)OR* (adjusted)odds ratio, *CI* confidence interval, *(A)RR* (adjusted)relative risk, *HCV* hepatitis C virus

participants randomized to the intervention group (home-based self-test kit plus one-time video-chat counseling), only 61 ordered test kits and participated in the video-chat counseling session; two took the self-test prior to the scheduled counseling appointment. At 3-months follow-up, sexually transmitted infections (STI) testing was significantly higher in the intervention group than control (72.5% vs. 42.9%, $p = 0.001$), but was not significant at the 6-month follow-up (19.2% vs. 15.3%). The investigators concluded that programs should recognize the diverse needs of participants since not all may be willing to take an HIV self-test during a live chat [37].

Short Message Service/Text Messages

Text messages are a quick and convenient method to send HIV-related information to study participants. Several investigators used various messages to promote uptake of HIV testing. Wettermann et al. compared the number of HIV test orders by physicians between intervention and control groups. Thirty minutes prior to the participant's scheduled medical appointment, those in the intervention group received a message about HIV prompting them to discuss HIV with their physician while the control group received a message about a general health topic. Approximately 35% of intervention

participants requested a test, while none of the control group requested one [39]. Other types of messages were successful in increasing uptake of HIV testing among respective target populations. Investigators texted messages about HIV prevention and reproductive health [42], HIV information and testing, behavioral skills, relationship and coming out [59], and availability of self-test kits available at health clinics [40, 60]. Regardless of message type, text messages resulted in increases in testing among study participants.

Mobile Apps and Dating Apps

Investigators have also used apps and programs on mobile devices such as smartphones to educate about HIV and promote HIV self-testing in high-risk groups. Sullivan and colleagues examined the acceptability of a theory-based mobile phone app among MSM. Study results showed that over half of participants used the app to order condoms (63%) and HIV self-test kits (52.8%) [44]. Similarly, a study of an intervention to increase HIV testing delivered via a popular mobile app (WeChat) was conducted. Intervention group participants received two oral HIV self-test kits and access to the app which provided HIV information and referrals to health services, while the control group received two test kits only. Investigators found increased testing rates among those who received the intervention compared to the control group (92% vs. 68%, $p < 0.001$) [45]. Horvath et al. examined the feasibility and acceptability of an HIV testing reminder app (intervention group) among MSM to increase repeat testing. Findings showed that although more participants in the intervention group (17%) repeatedly tested at the four month mark compared to the control group (4%; no treatment), the difference between the two arms dissipated by the eighth month (50% vs. 40%) [46]. Investigators examined the feasibility and acceptability of a smartphone app that provided HIV information, test video instructions, and information on how to interpret test results. Self-test was conducted using a custom-built smartphone accessory or a rapid test [48], with or without supervision at various locations [50]. Participant feedback was positive for the feasibility and usability of the app. Wray et al. conducted a pilot three-arm randomized control trial to increase testing in a high-risk population. Two groups received test kits, with one group receiving kits equipped with devices and a follow-up call once the test kit is opened (eTEST) and the other group a standard kit with no follow-up call (standard). The third group received informative letters about testing locations and a reminder to get tested every 3 months (control). More participants who received a free home test kit tested at least once during the study period (eTEST and standard) compared to controls (100% vs. 72%, $p = 0.001$). Repeat testing was also higher for participants in these two groups compared to control participants (81% eTEST, 77.2% standard vs. 40.9%, $p < 0.001$). Participants who also received

a follow-up call after study staff were notified that the test kit was opened received more information about risk reduction counseling, prevention supplies, and PrEP referrals than controls and standard of care participants [49]. Based on the pilot study, Wray and colleagues have begun a longitudinal randomized control trial with an oversampling of African American and Latino MSM. The same three study arms will be used for the trial with a few differences: the control group will receive text messages instead of a letter every 3 months to remind them to get tested at a local clinic [47]. Another use of mobile health is an app that facilitates HIV testing such as Safely. Users can store their most recent test results as well as connect with a testing facility using the app [61]. Paid advertisements on a dating app site specifically for MSM were effective in attracting users to a study website where they can order an HIV test kit [52].

Informational Online Videos

Three studies utilized short informative videos to promote HIV testing. Aronson and colleagues conducted a pilot program targeting young adult patients in the emergency department (ED) who declined an HIV test at triage. Upon completing the intervention, watching the short video on a tablet, participants increased their knowledge about HIV and 30% accepted the HIV test offered by the tablet [53]. A similar intervention was tested in a community setting for people who inject drugs. Participants watched a short video on a tablet about HIV, HCV, or overdose prevention while visiting a syringe exchange program facility. Findings showed that participants found the intervention acceptable, increased knowledge after watching the short video, and accepted the HIV test (91%), HCV test (100%), or naloxone (60%) offered by the tablet [51]. Tang and colleagues compared the effect of two videos in increasing uptake of HIV testing in a non-inferiority randomized control trial. One video was created using a small marketing company while the other video utilized crowdsourcing for development. Investigators found no significant difference in first time HIV testing between the two groups (37% vs 35%), suggesting that crowdsourcing may be a novel approach to creating health messages and engaging the community [54, 62].

Electronic Health Records

The use of electronic health records (EHR) is another technology that may promote HIV testing. Investigators employed simple techniques to use artificial intelligence to increase HIV testing in the healthcare setting. Kershaw et al. examined the effect of incorporating a reminder in the EHR for HIV antibody to prompt physicians to screen patients. Findings showed a significant increase in screening after a reminder was incorporated for all patients age 18–65 (15.3% baseline

vs 30.7% post reminder, (RR 2.02, CI 1.95–2.09, $p < 0.0001$) [55]. To enhance HIV testing in the ED, Sha and colleagues screened ED EHRs using specified criteria and “Best Practice Advisory” and then auto ordered screening for complete blood count. Through this process, investigators were able to identify acute seroconverters, new chronically ill patients, and known infected patients (many who did not disclose their status) [56]. Investigators utilized machine learning algorithms that would identify patients at risk for HIV acquisition among adult members of a large healthcare organization [57] and national hospital registry [58]. In both studies, various models were tested to discriminate and correctly predict between HIV cases and non-cases.

Vending Machines

The use of vending machines to dispense HIV self-test kits has been shown to be acceptable and feasible in increasing testing. Investigators have found that dispensing HIV self-test kits in vending machines was acceptable among MSM [63] and blacks/African American, Hispanic/Latino, and other minorities [64]. Placement of vending machines may be particularly key in reaching populations at most risk. Stafylis and colleagues placed vending machines in commercial sex venues which dispensed 1398 test kits. Of kits that were used, 17.7% reported a reactive result [65]. He et al. placed vending machines with urine-based HIV self-test kits at universities. Forty percent of dispensed kits were submitted for testing, of which less than 2% were positive [66]. Vera and colleagues compared the amount of HIV test kits dispensed by a vending machine to that delivered by community workers. Vending machines placed in a sauna (British gay bathhouse) dispensed more HIV self-test kits (34 kits per month) than were delivered by community workers (6 test kits per month) [67]. Preferences for vending machine location and test kit placement varied among adult MSM; some preferred the vending machine to be customized to reflect that it was dispensing HIV self-test kits, while others preferred the test kits to be integrated with other items (i.e., snacks) to increase confidentiality [68].

Chatbot/Conversational Agents

Chatbot and conversational agents to promote HIV testing use natural learning processing to allow for real-time dialogue with artificial intelligence designed to answer questions about HIV and testing. Chatbot interfaces use text and audio to interact with users. For instance, Brixey and colleagues developed a chatbot using a response classifier and dialogue management system on a Facebook application programming interface that was programmed with information from state and federal public health agencies to populate responses to user questions. Once live, users will be able to engage with the text chatbot via Facebook Messenger [69]. A conversational agent

designed to provide HIV pre-test counseling was tested for technical feasibility and acceptance among users. Participants were provided a mobile phone with the app to facilitate discussion. Study findings indicated that users had a positive experience and that the interaction with the agent felt natural. Privacy, anonymity, and convenience of the chatbot compared to in-person methods were cited as benefits [70]. Vermey and colleagues developed a chatbot within an online advice website that provided personalized advice. Some of the site visitors used the chatbot features (17, 449 visitors) and clicked on online self-test providers (8700 clicks) [71]. Aside from research purposes, chatbots are used by an international HIV/AIDS organization to provide information about HIV to youth. Users have responded positively to the chatbot stating that the chatbot was “cool” and praised the developers for the project [72]. A potential use of virtual assistant applications (i.e., Alexa, Siri) in promoting HIV testing is to provide pre-test counseling, a directory of online vendors of home test kits, or nearby locations where users can get tested. As information seeking tops the list of requests for virtual assistants [73], they can be programmed with information aimed to encourage testing. The ability of a user to have a dialogue with the virtual assistants may minimize some of the perceived barriers such as stigma to get tested. Another use of the virtual assistants is placement of HIV test kits in a shopping cart or subscription service. Similar to a chatbot for opioid use disorder (OUD) currently in development by one of the co-authors of this paper (Young), a conversational agent that would facilitate locating HIV testing sites could be beneficial for communities at high risk for infection. The OUD chatbot aims to identify an appropriate treatment facility for those misusing opioids. Targeted for patients and family, the chatbot would engage users in dialogue until a facility that suits the needs of the patient can be identified.

Virtual Reality

Several investigators have used virtual reality (VR) in HIV research, which may have applications in promoting HIV testing. In one study, participants who used a VR scenario to practice HIV status disclosure to a partner said the simulations were easy to use, they would use it frequently, and most people would learn to use the system easily [74]. In another study, investigators examined the effect of VR on increasing antiretroviral therapy adherence. Study findings showed participant experience resulted in decreased viral load and increased CD4(+). Participants stated the experience was comfortable, educational, and that it would help increase adherence [75]. VR scenarios can be developed to help increase self-efficacy in discussing STI testing with sexual partners or with a healthcare provider. VR games can provide various situations and environments during which relevant conversations will

most likely occur to afford users with ample opportunities to respond, learn, and gain confidence.

Blockchain Technology

Nascent technology such as blockchain may facilitate promotion of HIV/STI testing. Blockchain is an immutable public ledger [76]; a publicly accessible electronic data storage that cannot be altered even by its owner. It is the underlying technology that runs cryptocurrency and has since been utilized in industries such as healthcare, ecommerce, and finance [77]. To date and to our knowledge, no study exists that examines the use of blockchain technology with respect to HIV research; however, some of its features may be applicable to increasing uptake of HIV testing. A smart contract, which is a contract between two parties without the need of a third party (i.e., public notary) to be executed [78], may be beneficial to users of social networking apps. For instance, after initial engagement through a dating app, both users can upload their current test results to blockchain as proof of testing. Users would meet only after blockchain has verified that both users have uploaded their test results. Another feature of the blockchain technology that may be useful in increasing HIV testing is the hybrid blockchain. A hybrid blockchain is managed by a network of stakeholders (i.e., healthcare provider, testing facility, insurance company), instead of the public or one central organization, that affords the owner of the blockchain a high degree of control of who can access the data [79]. This would allow patients to have access to their test results at their convenience and can facilitate testing conversation with potential sex partner before intercourse. In terms of cryptocurrency, payment using cryptocurrency may appeal to potential test takers. Researcher may also use cryptocurrency, or combine with gamification as reward, to pay for HIV self-test kits.

Mobile Payment Services

Alternative payment, such as mobile payment services, may incentivize HIV testing. Though no study to our knowledge has examined the effect of type of payment in obtaining HIV tests, the convenience of paying vendors through services such as Venmo, Apple Pay, or Zelle may attract those who prefer contactless payment. Trend data show increasing use of digital payment, and in the past year, even surpassed that of credit card and debit card use [80]. Merchants from all industries are reimagining their operating and payment models to accommodate the dramatic changes in on-demand movement [81]. The ease of using mobile payment services may appeal to those purchasing home self-test kits via online vendors, vending machines, or mobile apps.

Ethical and Implementation Considerations

Ethical concerns may affect the impetus to obtain an HIV test promoted through digital technology [82]. Despite some potential ethical concerns, participants in a social media study to increase HIV testing expressed that they felt comfortable participating in an online social media study and that they benefited from participation [82]. Another consideration when dealing with participants with potential medical diagnosis is the willingness of participants to share digital data with researchers. Romero and Young conducted a study that examined the willingness of patients with diagnosed medical conditions to share private data with researchers. Participants voiced concerns over privacy and confidentiality when determining how much data to provide scientific researchers. Though some patients expressed concerns about data storage, who will access the data, and if data will be used against them, most reported being comfortable or very comfortable sharing social media, GPS location, and electronic medical records with researchers who would be attempting to use the data for public health purposes [83]. As the field of applying digital technology to promote HIV testing continues to evolve, it is key that a parallel, priority focus embraces important scientific questions related to ethics and privacy to understand the array of related factors that may impact real-world adoption. To support this goal, ethics committees should be composed of members who are experts or knowledgeable of digital tools and can provide guidance in the appropriate use of technology for research and specific ethical considerations that warrant examination.

Researchers using technology to increase HIV testing may have additional implementation considerations to safeguard participant safety and engagement. Investigator and study staff should clearly indicate in the consent form what types of data (i.e., location, images, text messages with study staff) are being collected by the technology (i.e., app, smartwatch, wearable device) and what data are not being collected (i.e., contacts, phone calls, web browsing). An additional layer of transparency may obviate hesitation from potential participants and assuage any concerns about privacy and confidentiality risks. In recruiting participants for research using technology, one barrier to participation may be lack of access to technology necessary to participate in the study. Some devices and applications may only work with certain operating systems that may alienate potential participants who own devices that cannot support those systems. It would behoove investigators to supply the device to participants who may not be eligible otherwise. Lastly, as self-test kits come in different forms, a focus group with the target population might inform investigators of the type of home-based self-test kit that they prefer to use. Though participants will have their own preferences, some test kits are simpler to administer and less invasive than others.

Worldwide, the COVID-19 pandemic has resulted in significant decreases in HIV testing [1] and impacted the capacity of service providers to meet the needs of the community. This has underscored the importance of and ability to leverage technology in promoting testing and other HIV research and clinical services [84]. The flexibility and convenience of obtaining home test kits via vending machines or through trusted websites may offer alternatives to in-person testing when appointments are limited due to facility closures or limited office hours. The option of chatting with a provider on a smartphone for pre-test counseling or to assist in test administration may alleviate anxiety in taking a home test when in-person consultation is not available. Finally, when implementing technologies into HIV research, it is important to not rely solely on the technology but to ensure the use of technology is grounded in proper design and an evidenced-based model to improve effectiveness [85, 86].

Conclusion

Technologies continue to play an increasing and exciting role in HIV testing. Every new technology presents HIV researchers with an opportunity to explore whether this new tool might be used to increase HIV testing. It is important to note from the categories of studies in this manuscript that no particular type of technology appears to be consistently better or worse than other technologies. Rather, technologies are simply tools that can be used to increase reach, scalability, and efficiency. To properly use technologies to increase HIV testing, researchers need to choose the appropriate technology for the context and population, integrate that technology with an evidenced-based intervention, and have a plan for how to adapt to the changing trends and contexts in use of technologies [85, 87]. In addition, they should also consider the equity and digital divide, and how these interventions might facilitate increases in testing among the digital literati but also might miss some key populations such that more traditional and/or other innovative programs are still needed.

As technology continues to evolve, HIV researchers have incorporated digital tools for outreach, education, and promotion of HIV testing. The success of tools such social media, mobile apps, vending machines, and virtual reality have paved the way for nascent technology such as blockchain and virtual assistants to be adopted in the field. Although decades of efforts to mitigate the HIV epidemic have improved outcomes worldwide, much work continues to be needed to increase HIV testing. In a world that is markedly changing because of advances in digital technology, we have the opportunity to creatively embrace these diverse and ever-growing array of tools to identify new ways to increase access to HIV testing across diverse populations at a global level. Such technology affords wide scale use that may address barriers and

challenges faced by those who are at most risk for infection while providing a potentially low-cost, scalable tool for preventing the global spread of HIV. Ultimately, it is about enabling increased choice and options such that access to testing becomes normative and ubiquitous and interventions can reach those most disenfranchised.

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