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TECHNOLOGY AND INFECTIOUS DISEASE (C HEBERT, SECTION EDITOR)

# The Current and Future Use of Telemedicine in Infectious Diseases Practice

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## Abstract

**Purpose of Review** Novel technologies, such as high-definition cameras, encryption software, electronic stethoscopes, microfluidic diagnostic systems, and widely available broadband Internet have expanded the potential for telemedicine. This narrative review presents current and future uses of telemedicine in the prevention, diagnosis, treatment, stewardship, and management of infectious disease.

**Recent Findings** Beginning in the 1990s, early approaches to telemedicine in infectious disease focused largely on treatment of HIV/AIDS, hepatitis C, and tuberculosis. However, recent innovations allow for targeting of additional diseases and in increasingly remote settings. Telemedicine allows virtual visits between patients in the home and remote providers, permitting outpatient management of complex conditions, such as post-surgical site monitoring, and non-urgent infectious maladies, such as uncomplicated urinary tract infection. Remote provider education by videoconference and integrated clinical decision support tools create avenues to improve inpatient care, including antimicrobial stewardship. Technological strides from miniaturization of diagnostic tests to robotic telepresence physical exams improve access to infectious disease care in isolated and infrastructure-poor environments, from cargo ships to other resource-limited settings.

**Summary** Telemedicine in the field of infectious disease is rapidly expanding in clinical, technological, geographical, and human capacity. Recent innovations narrow gaps in access to care for populations traditionally underserved, stigmatized, isolated by remote geography, or lacking technological infrastructure. Current and future approaches will transform inpatient, outpatient, and remote care.

**Keywords** Telemedicine · Telehealth · Health information technology · Telediagnostics

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## Introduction

Telemedicine (also known as telehealth) is the use of audio-video technologies to improve patient health by facilitating interactions between patients and clinicians or between two or more clinicians through "videoconferencing, transmission of still images, e-health including patient portals, remote monitoring of vital signs, continuing medical education, and nursing call centers" [1]. These interactions can be synchronous, wherein parties engage in real-time, two-way communication (e.g., a video call), or asynchronous, wherein parties share information that can be reviewed and responded to with a delay of time between communication (e.g., e-mail) [1]. Telemedicine can increase patients' and primary care providers' access to specialists (e.g., e-visits, e-consults), be used to deliver continuing medical education (CME), and provide access to programs and resources for small or rural hospitals (e.g., tele-antimicrobial stewardship) [2]. The benefits of telemedicine in infectious disease (ID) for patients are well-understood, including saving time, reducing travel and missed workdays, increasing access to specialty care, and increasing satisfaction and involvement in care [3]. Telemedicine is also beneficial for clinicians, as its use is associated with reductions in canceled or late appointments [3]. Furthermore, there is evidence that telemedical infectious disease care is at least as cost-effective as traditional infectious disease care [3].

Telemedicine has been in use for managing infectious disease since the 1990s, with early work focusing on treatment of HIV/AIDS [4, 5], hepatitis C [6], and tuberculosis [7, 8]. Today, as technology has advanced, the potential of telemedicine has expanded in innovative directions, and the use of telemedicine has expanded to the treatment of a wider array of both acute and chronic infections. Today's approaches incorporate novel technologies, such as high-definition cameras, encryption software, and electronic stethoscopes, otoscopes, and ophthalmoscopes [9••]. These technological advances drive innovative uses of telemedicine for prevention, diagnosis, treatment, and management of infectious diseases. As technology has continued to advance, new work at the intersection of telemedicine and ID has proliferated. The purpose of this narrative review is to describe current and future uses of telemedicine in the field of ID, highlighting recent innovations. Notably, in the current study, we exclude patient-facing mobile health (mHealth) consumer technologies. We made this decision because such technologies, typically autonomously used by patients and largely or fully detached from the clinical care setting (e.g., mobile apps and smartwatches), are conceptually distinct from telemedicine technologies that require active clinician engagement for management of infectious diseases.

## Recent Developments in Telemedicine for Infectious Disease

Areas of ID with recent developments in telemedicine include prevention, treatment, and management of sexually transmitted and blood-borne infections (STBBIs), ID home care, ID care in-hospital, and care on the "frontier" (i.e., in remote, resource limited, and isolated environments).

### Telemedicine for Sexually Transmitted and Blood-Borne Infections (STBBIs)

Treatment of sexually transmitted and blood-borne infections (STBBIs) is complicated by unique barriers to care in the form of real and perceived stigmatization. Patient-reported barriers include embarrassment and fear of judgment in the face-to-face consultation setting, a culture of silence around STBBI testing and treatment, fear of being seen accessing STBBI services, medical distrust, and concerns for privacy and confidentiality [10–12]. These social barriers are amplified by structural barriers to obtaining care, such as low socioeconomic status and geographical remoteness [13••]. Because telemedicine interventions can reduce the need for in-clinic visits, they have the potential to improve access to care by addressing both social and structural concerns.

#### Hepatitis C

Hepatitis C virus (HCV) is a significant, global cause of morbidity and mortality from cirrhosis, end-stage liver disease, and hepatocellular carcinoma, infecting over 180 million people globally [14]. In the developed world, HCV disproportionately affects vulnerable and difficult-to-access populations, including racial minorities, indigenous populations, persons who inject drugs, men and transwomen who have sex with men (MSM), prisoners, and homeless persons [14–16]. Telemedicine can reduce barriers to care that these populations may frequently encounter in a tertiary hepatology setting [16–18].

Successful recent telemedicine interventions in the treatment of HCV implement initiatives for high-risk populations are led by nurses, pharmacists, and primary care providers with support from remote hepatology specialists. For example, nurse-led care initiatives in the prison setting, where incarcerated persons have a high estimated HCV seroprevalence between 8 and 57% [19], supplemented by nurse-provider consults and patient-physician videoconference e-visits, have been effectively implemented in Australia and Northern England [20]. Similarly, studies in rural and remote settings of HCV treatment have found success with pharmacist-[18] and nurse-led [21, 22] care, reducing the frequency of face-to-face specialist consultations via web-based e-portals and e-consultations. The United States Department of Veterans Affairs (VA), the largest provider of treatment to patients with HCV in the USA, cares for a population challenged by lack of transportation, rural distribution, homelessness, substance abuse, mental illness, and medical comorbidities [23]. VA best practices include the use of telemedicine to expand HCV treatment capacity through non-physician providers based on the Project Extension for Community Healthcare Outcomes [24, 25] (ECHO) model, an HCV virtual training program for primary care providers based on case-based education [23]. In a study of 4173 primary care providers at 152 VA sites responsible for the care of 38,753 patients, Project ECHO increased incidence of direct-acting antiviral treatment and decreased time to treatment while allowing patients to achieve sustained virological responses that were similar between specialists and primary care providers [26]. Project ECHO has recently been implemented beyond the treatment of HCV for perinatal treatment of human immunodeficiency virus (HIV) [27] and prescribing of pre-exposure prophylaxis (PReP) [28] in the

Northwestern USA and for education on antimicrobial stewardship among inpatient providers at rural VA hospitals [29].

## Treatment of HIV

HIV and acquired immunodeficiency syndrome (AIDS) are global problems, with an estimated 33.3 million people worldwide living with the infection at the end of 2015 [30]. Increasingly widespread use of highly active anti-retroviral therapy (ART) has led to reductions in new infections and a 43% reduction in HIV-related deaths since 2003. Administering and encouraging compliance with ART was one of the earliest, widespread applications of telemedicine in the treatment of infectious disease. In the past decade, the most common target of HIV-associated telemedicine has been ART adherence [31]. HIV telemedicine interventions since 1996 have implemented various modes of digital engagement, including web-based interventions and educational modules, text messages, chat rooms, and social media [13, 32]. A 2017 systematic review of 99 studies conducted between 1996 and 2017 showed that telemedicine interventions on HIV treatment improve clinic attendance rates and adherence to ART and reduce risky behaviors [13], although not all interventions translate smoothly across cultural and linguistic boundaries [33, 34].

Further, telemedicine holds promise to expand access to specialty HIV care to isolated populations. For example, a tertiary care network in the UK and Ireland has implemented a model wherein a multi-disciplinary specialist team asynchronously reviews cases from a regional network of general pediatricians caring for infants and children perinatally infected with HIV on a monthly basis. This allows children to be treated in near-home, often rural, settings [35].

An emerging telemedicine application in HIV/AIDS treatment combats cytomegalovirus (CMV) retinitis, a complication of AIDS and leading cause of blindness in HIV-infected populations with limited access to ART. Challenges to screening result from shortages of ophthalmologists, particularly in rural and resource-poor settings. Building on prior work on teleophthalmology for the diagnosis of diabetic retinopathy or retinopathy of prematurity, two studies in Thailand used mosaic fundus photography on dilated eye exam with asynchronous evaluation by remote raters for CMV screening [36, 37]. However, some evidence suggests this evaluation was suboptimal compared to in-clinic, expert, ophthalmologist raters [36, 37], suggesting that more work needs to be done.

## Prevention of HIV

Pre-exposure prophylaxis (PrEP) by tenofovir-emtricitabine regimens, as a strategy for HIV/AIDS prevention and elimination, is recommended for persons at risk of sexual- and drug-related HIV transmission [30, 38]. The recent evidence for telemedicine's role in HIV/AIDS prevention appears to be mixed. Telemedicine is favorably adopted by MSM for HIV/AIDS treatment and prevention due to increased privacy [39, 40•], especially MSM who are young with high school education or higher [40•]. Traditional barriers to PrEP, including confidentiality, convenience, and peer stigma, can be reduced by the use of online platforms for STI testing and telemedicine visits [12]. However, videoconferenced e-visits, which can facilitate PrEP prescribing, have been associated with an increase in missed PrEP doses and skipped follow-up visits [41]. In another study, the University of Washington recently supported community providers to provide PrEP in primary care settings in 6 US northwestern states [28]. Physicians reported improved educational outcomes with lingering concerns, including patient adherence, identifying appropriate candidates, drug resistance, toxicity, and costs [28].

## Other STIs

Sexually transmitted infections (STI) are widespread, with 376 million cases of chlamydia, gonorrhea, syphilis, or trichomoniasis per year, and over 290 million women living with human papillomavirus (HPV) [42]. Despite this prevalence, as previously mentioned, there remain structural barriers to STI screening, including limited availability of STI services in primary care, and lack of access to health services among vulnerable populations such as adolescents, people who inject drugs, or MSM, creating a need for telemedicine in this area [42].

Chlamydia trachomatis, one of the most commonly reported bacterial STIs, disproportionately affects people ages 16–24 years old [43••]. Patients in this age group have high usage, comfort, and availability of smartphones and internet and are considered "rapid adopters of new technology," making them ideal targets for telehealth approaches [44•, 45]. A novel, integrated approach to STI treatment, the eSexual Health Clinic (eSHC), was developed by UK's National Health Service (NHS). Patients with untreated chlamydia enter eSHC, a web portal that links patients to an automated online consultation, test results, health promotion, prescription antibiotics, a telephone helpline, a place to facilitate partner notification, and features for surveillance [43••, 44•]. Similar programs using an online portal to integrate extra-clinic STI testing with phone consultations and remote prescribing have been successfully implemented in for youth in Canada [46] and for young women in California [47]. Users of these approaches report high satisfaction, including easier and faster use, trustworthiness of the system, reduced stigma or embarrassment, improved privacy and confidentiality, and recognized advantages in convenience and privacy in the e-testing system over an in-clinic visit for testing [10, 45, 47]. Some users cited a desire for human support after a positive test, but a telephone helpline was considered sufficient and was implemented in eSHC [10, 43••, 45]. Although user responses were overwhelmingly positive, online testing systems had limited reach with youth with high school or less than high school education, youth with low literacy, and minority populations [47].

## The Emerging Role of Telemedicine in ID Home Care

Mobile technologies open new doors to enhance quality of remote physical exam and home care for many infectious diseases, including surgical site infection and tuberculosis. Telemedicine for home care may take the form of a direct-to-consumer (DTC) e-visit to address a non-urgent infectious disease (i.e., a video- or telephone-supported conversation between patient and provider) [48–51], or as provider support for nursing care in the home.

### Surgical Site Infection

Surgical site infection (SSI) is the most common cause of nosocomial infection in surgical patients, with 50% of SSIs developing after discharge [52]. Discharged patients in the home setting face difficulties with physical and cognitive self-efficacy, education, and provider communication for wound monitoring [53]. As a result, patients often are unable to recognize early signs of SSI [54]. Telemedicine provides the opportunity to fill an important gap in at-home postoperative wound monitoring. Recent pilot studies have implemented platforms in which patients submit smartphone photographs of the post-surgical site for remote, asynchronous review by medical personnel [55, 56], which significantly improves the accuracy of a remote physician assessment over chart review alone [57]. Although smartphone ownership and willingness to use a mobile home-monitoring system are high among targeted patient populations [55, 58], patients who are older, [55, 58], obese, or who have wounds in less accessible areas (e.g., the groin) [55], experience increased difficulty in implementing a smartphone-based system. This approach to wound monitoring is emerging, with small sample sizes and variable diagnostic sensitivity [56, 57]. Work remains to improve diagnostic accuracy and patient experience.

### Tuberculosis

Tuberculosis (TB) is the leading cause of death from a single infectious agent worldwide [59]. Although curative antibiotics are widely available, treatment failure and drug resistance result from missed doses and early discontinuation of lengthy antibiotic regimens [60]. To improve adherence, the World Health Organization (WHO) recommends that antibiotics are administered as directly observed therapy (DOT), with a healthcare worker supervising the ingestion of each dose [61]. However, daily transit to a health clinic for DOT may be burdensome [62]. Prior work found that DOT in a health facility did not significantly improve rates of treatment completion compared to observed DOT in the home setting, observation by a family member, or self-administered antibiotics [60]. Therefore, WHO encourages the use of communication, information, and mobile technologies to support DOT at home [61]. A new approach, video directly observed therapy (VDOT), allows patients to synchronously or asynchronously document drug ingestion using a smartphone camera. A 2018 survey found that VDOT led to equal or higher treatment adherence and completion compared to in-person DOT, with associated cost savings and benefits of patient and staff satisfaction [63]. A recent study examined the use of VDOT plus SMS message reminders in high- (San Diego, CA, USA) and low-resource settings (Tijuana, Baja California, Mexico), and found a mean adherence of 93% among patients in the USA and 96% in Mexico [62]. Patients reported high satisfaction, convenience, and perceived confidentiality, although poor video capture of pill ingestion occasionally prevented confirmation that a dose had been taken properly [62].

### Non-Urgent Care at Home

Direct to consumer (DTC) telemedicine, in which synchronous care delivery occurs via real-time audiovisual conferencing, is increasingly used to address low-acuity infectious disease care, including respiratory tract and urinary tract infections [48, 50, 64•, 65]. However, DTC does not always result in consistent care: quality of care, including history-taking, diagnostic accuracy [51], follow-up rates, and sequential testing [50, 65, 66] can vary between providers. For example, compared to in-person care, some providers via DTC prescribe antibiotics at increased rates [50, 67], while others prescribe at lower rates [68]. Similarly, rates of broad-spectrum antibiotic use and adherence to best-practice antimicrobial stewardship guidelines are appropriate in some providers [49, 65, 69] but mismanaged in others [49, 67]. Antimicrobial stewardship best practices are complicated by a drive for patient satisfaction: Patients who do not receive antibiotics rate their care poorer [70] and require longer patient encounters [71]. Despite these limitations, DTC creates cost savings compared to other methods of low-acuity care delivery, including urgent care clinics, primary care providers, and emergency departments [50]. Future work should seek to improve the care processes, particularly antimicrobial stewardship, around DTC for infectious diseases.

## Novel Uses of Telemedicine for In-Hospital ID Care

The remote e-consult between providers is a well-established mode of telemedicine delivery. Historically, e-consults have been implemented asynchronously within the electronic medical system via chart review [72]. Although remote providers may have positive opinions of the potential of e-consults to improve access to timely care [73], some consulting subspecialists express concerns about their abilities to provide "high-quality consultation" through a chart review [74]. In recent models in ID, providers in a hospital lacking a staff ID physician have e-consulted with a remote specialist through synchronous or audiovisual technologies. An in-network "hub-and-spokes" model for delivering physician continuing education or specialist care to off-site providers has been implemented in inpatient [72, 74, 75] and clinic [76] settings. Some implementations facilitate intra-hospital specialist infectious disease consults [77•, 78].

### Antimicrobial Stewardship

Antimicrobial stewardship is a core quality improvement concern in hospital care. Effective from 2017, The Joint Commission standard for all US hospitals and nursing care centers requires access to a multi-disciplinary antimicrobial stewardship team of an ID physician, infection preventionist, and pharmacist to encourage accountability, drug expertise, and education of providers and patients [79]. Given limited resources, some small or rural hospitals have chosen to comply with the antimicrobial stewardship team mandate via telemedicine, commonly in the form of asynchronous clinical decision support tools, with varying success. Howell et al. [80] report an electronic health record (EHR)-based clinical decision support tool, in which a remote, ID-trained pharmacy specialist conducted daily chart reviews, triggered by an automatic alert system, to electronically communicate recommendations to providers. Although the guideline-compliant intervention reduced costs, acceptance of suggested interventions was low (11% accepted, 6% accepted modified) resulting from barriers in workflow, consistency, and communication. A similar implementation in a US long-term care attempted daily e-mail recommendations in response to remote specialist chart review [81]. This resulted in 48% acceptance, reduced use of antibiotics, and decreased incidence of hospital-acquired *Clostridium difficile* infection [81]. In a regional hospital in Brazil, a web-based system providing almost immediate, text-based, post-prescription feedback from ID physicians to remote providers was associated with an increased rate of appropriate antimicrobial prescription and reduced costs [82•]. In a synchronous implementation in Sicily, a biweekly case-based teleconference combined with limited use of synchronous and asynchronous teleconsultation decreased costs and the isolation rate for multi-drug resistant infections, though it did not reduce average length of ICU stay [83].

### Sepsis

To facilitate more rapid and attentive management of sepsis, Machado et al. implemented a sepsis alert in the ED of an urban, US hospital. The alert activates a team of physician and staff responders and a "wheeled electronic intensive medicine unit (eICU) cart," which allows a direct link between the patient and an eICU intensivist, who supervises sepsis care in the ED from elsewhere within the hospital. This novel technological innovation led to faster time to antibiotic administration and shortened ED length of stay, without significant impacts on other sepsis management bundle guidelines, hospital length of stay, patient outcomes, mortality, or costs [77•].

## Telemedicine on the Frontier

Trailblazing advances in telemedicine incorporate novel, high-tech solutions to provide infectious disease care in remote and isolated settings, including rural areas, geographically remote indigenous communities, resource-limited settings, and cargo ships.

### Remote Locations

MacRury et al. [84•] reported on an intervention for management of potentially infected diabetic foot ulcers in rural, remote areas of Scotland, where patient access to care is impeded by long distances and lack of transport, but in-home telemedicine is impaired by poor Internet connectivity. In this pilot study, a podiatrist traveled to each patient home to administer an exam and virtual visit with a remote physician, including still and video images of ulcers. To overcome barriers from poor Internet connectivity, participating podiatrists transported a battery-operated wireless router in their staff vehicles to create a local WiFi connection at the patient home via cellular networks to permit a virtual private network (VPN) connection to a hospital-based provider. Participating providers reported high community and physician provider satisfaction with improved patient outcomes.

Monkowski et al. [75] describe an intervention to provide infectious disease e-consults to a small, rural hospital within a multi-hospital network. The rural hospital implemented a mobile exam cart equipped with microphone, speakers, electronic stethoscope, and hand-held exam camera to facilitate a remote specialist exam, significantly reducing the need for patient transfers to a central hospital, while maintaining similar patient outcomes between transferred and mobile-managed patients.

### Remote Indigenous Populations

Some indigenous populations, including Canadian First Nations peoples, experience an elevated burden of infectious disease, including TB and HIV, with limited access to health services due to remoteness and limited road access [85]. Such communities often rely solely on air travel for medical transfer for infectious disease consultation, at high cost [86]. While e-consultations facilitated by digital photography and video for these patients can reduce barriers to care and are associated with high patient satisfaction, remote providers cite poor image resolution and inability to conduct a hands-on physical exam as impediments to care [86]. Khan et al. reviewed recent healthcare innovations in remote First Nations in Saskatchewan and found that a novel Remote Presence Robotic Technology system, which uses maneuverable robots and portable devices allowing for ultrasonography and liver fibroscans, better simulates face-to-face experiences than traditional video or photography alone [85].

### Resource-Limited Settings

The diagnosis of infectious diseases, especially in situations of outbreak, requires laboratory testing, microscopy, and, increasingly, molecular diagnostics and omics. In limited-resource settings, limited access to laboratory facilities may delay results [87]. Innovations for performing diagnostic laboratory testing in resource-limited settings must be low-cost, require only small biological samples, and tolerate limited access to refrigeration, electricity, and clean water while maintaining standards for cost, quality, and usability [88, 89].

Telemicroscopy has been explored since the 1990s for diagnostic purposes, using mobile phone cameras paired with conventional microscopes [90]. One example is a low-cost telemicroscopy system using a digital camera and computer-based internet videoconferencing to allow a remote physician to view and interpret a microscopy operated by a technician [87]. In other cases, miniaturized microscopy components implementing a variety of novel hardware solutions allow the mobile phone to be used as the primary microscopic device [90]. Recent cell phone attachments in experimental setups have permitted the visualization of viruses, bacteria, mycobacteria, and protozoa [90].

Innovations in miniaturization and cost reduction are creating opportunities to administer molecular and high-throughput testing in low-resource settings [88]. Microfluidic systems that analyze very small liquid volumes (i.e., microliters) within a single device address issues of size, contamination, and implementation [89]. Over the past 8 years, isothermal loop-mediated amplification, an amplification assay to quantify targeted RNA sequences, and polymerase chain reaction (PCR) have been implemented on a hand-held scale using disposable microfluidic cartridges read by battery-powered devices for the diagnosis of a variety of microorganisms, including viruses, bacteria, mycobacteria, and parasites [88]. New technologies have been piloted in experimental contexts that can be operated using a smartphone, with smartphone cameras used to read assays of PCR-amplified DNA in the diagnosis of Kaposi's sarcoma [91], fluorescent immunoassays for avian influenza subtyping [92], and microfluidic electrochemical immunosensing or antibodies for HIV/HCV co-infection [93]. Miniaturized assays can produce results at high accuracy: Wang et al. report on a mobile phone microplate reader to detect IgG to 96 infectious diseases with accuracy > 97.5% [94].

### Cargo Ships

Commercial cargo ships are medically isolated environments, with limited onboard medical assistance. A unique environment for infectious disease exposure is created by crowded living conditions and visits to multiple ports. Lack of access to care onboard ship is aggravated by ineffective, counterfeit medicine, and variable quality of care in ports of access [95]. Commonly reported infections include TB, vector-borne illness such as malaria [95], skin infections [95, 96], infectious gastrointestinal illness, and genitourinary infections [96]. The Toulouse Tele-Medical Assistance Service (TMAS) provides e-consultation by radio supplemented by Internet transmission of photographs between a France-based physician and sailors on cargo ships in response to an alert raised by the captain, who receives medical training, renewed every 5 years [96]. At the direction of the remote physician, ship personnel can administer a physical exam and onboard medication, including antibiotics. Based on the severity of the patient's condition, ships may be re-routed for patients to receive additional management, or patients may be evacuated to land-based hospitals [97]. As wireless technology (e.g., battery-operated wireless routers, mobile hotspotting) continues to improve and provide greater coverage, future work should examine the use of more media-rich forms of telemedicine (e.g., videoconferencing) in this setting.

## Conclusions

Telemedicine has become integral to the field of ID over the past 20 years, with advances in technology continually improving the way infectious diseases are diagnosed, treated, and managed. From foundational approaches laid in the 1990s for the care of HIV/AIDS, HCV, and TB, recent innovations break down barriers to diagnosis, treatment, and prevention. The targets of telemedicine have broadened to new diseases and new, increasingly remote settings. In the outpatient setting, increasing travel time to ID specialists has traditionally driven patients to use primary care providers closer to home [98]. Telemedicine allows for outpatient management of complex conditions, such as post-surgical wounds and treatment of non-urgent conditions at home. Within small or rural hospitals lacking ID staff, telemedicine creates avenues to bolster antimicrobial stewardship and improve sepsis. Technological strides have opened doors to new approaches, from video-based medication adherence programs and smartphone cameras leveraged for wound monitoring to mobile phone molecular diagnostics and robotic telepresence physical exams.

## Future Work

Telemedicine innovations have historically targeted moderately remote or underserved areas, including rural settings, prisons, or minority communities, of the developed world, especially Europe, Australia, and the USA. Isolated or underserved environments, including cargo ships or other resource-limited settings, will benefit from improving global Internet access, which will increase opportunities for media-rich telemedicine interventions in difficult-to-access settings. Geographically and technologically isolated environments, with limited technological infrastructure and difficult logistics of deploying healthcare team members, simultaneously represent existing disparities and directions ripe for future research. Although such sites may face unique challenges to using telemedicine, they serve as sites for the most exciting innovation in the field.

## Compliance with Ethical Standards

**Conflict of Interest** Caitlin E. Coombes and Megan E. Gregory declare that they have no conflict of interest.

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

## References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance


1. Americal Telemedicine Association. Telemedicine glossary. Available at: https://thesource.americantelemed.org/resources/telemedicine-glossary. Accessed April 3, 2019.
2. Pottinger PS, Kassamali Z, Wright TC, Scott JD, Martinez-Paz N, Lynch JB. Tele-antimicrobial stewardship in action. Current Treatment Options in Infectious Diseases. 2018;10:229–39.
3. Parmar P, Mackie D, Varghese S, Cooper C. Use of telemedicine technologies in the management of infectious diseases: a review. Clin Infect Dis. 2015;60:1084–94.
4. Becker C. High-tech treatment: federal grant allows HIV/AIDS patients to receive treatment through telemedicine. Mod Healthc. 2002;32:18–9.
5. Makulowich JS. AIDS and telemedicine. AIDS Patient Care STDs. 1996;10:387–8.
6. Rossaro L, Aoki C, Yuk J, Prosser C, Goforth J, Martinez F. The evaluation of patients with hepatitis C living in rural California via telemedicine. Telemed J E Health. 2008;14:1127–9.
7. DeMaio J, Schwartz L, Cooley P, Tice A. The application of telemedicine technology to a directly observed therapy program for tuberculosis: a pilot project. Clin Infect Dis. 2001;33:2082–4.
8. DeMaio J, Sharma D. Tuberculosis therapy and telemedicine. Expert Opin Pharmacother. 2002;3:1283–8.
9.•• Siddiqui J, Herchline T, Kahlon S, et al. Infectious Diseases Society of America position statement on telehealth and telemedicine as applied to the practice of infectious diseases. Clin Infect Dis. **2017**;64:237–42 **Comprehensive position statement outlining goals for HIPAA, licensure and credentialing, scope of care, quality, and liability**.
10. Aicken CR, Fuller SS, Sutcliffe LJ, et al. Young people's perceptions of smartphone-enabled self-testing and online care for sexually transmitted infections: qualitative interview study. BMC Public Health. 2016;16:974.
11. Friedman AL, Brookmeyer KA, Kachur RE, Ford J, Hogben M, Habel MA, et al. An assessment of the GYT: get yourself tested! Campaign: an integrated approach to sexually transmitted disease prevention communication. Sex Transm Dis. 2014;41:151–7.
12. Refugio ON, Kimble MM, Silva CL, Lykens JE, Bannister C, Klausner JD. Brief report: PrEPtech: A telehealth-based initiation program for HIV pre-exposure prophylaxis in young men of color who have sex with men: a pilot study of feasibility. J Acquir Immune Defic Syndr. 2019;80:40–5.
13.•• Daher J, Vijh R, Linthwaite B, et al. Do digital innovations for HIV and sexually transmitted infections work? Results from a systematic review (1996–2017). BMJ Open. **2017**;7:e017604 **Scoping review of efficacy and treatment outcomes from HIV/STI telemedicine interventions, including mobile phone/SMS, Web application, or social media.**
14. World Health Organization. Guidelines for the screening, care and treatment of persons with chronic hepatitis C infection. World Health Organization, 2016.
15. Gonzalez SA, Fierer DS, Talal AH. Medical and behavioral approaches to engage people who inject drugs into care for hepatitis C virus infection. Addict Disord Their Treat. 2017;16:S1–s23.
16. Mohsen W, Chan P, Whelan M, Glass A, Mouton M, Young E, et al. Hepatitis C treatment for difficult to access populations: can telementoring (as distinct from telemedicine) help? Intern Med J. 2019;49:351–7.
17. Talal AH, McLeod A, Andrews P, Nieves-McGrath H, Chen Y, Reynolds A, et al. Patient reaction to telemedicine for clinical management of hepatitis C virus integrated into an opioid treatment program. Telemed J E Health. 2018.
18. You A, Kawamoto J, Smith JP. A pharmacist-managed telemedicine clinic for hepatitis C care: a descriptive analysis. J Telemed Telecare. 2014;20:99–101.
19. Morey S, Hamoodi A, Jones D, Young T, Thompson C, Dhuny J, et al. Increased diagnosis and treatment of hepatitis C in prison by universal offer of testing and use of telemedicine. J Viral Hepat. 2019;26:101–8.
20. Lloyd AR, Clegg J, Lange J, Stevenson A, Post JJ, Lloyd D, et al. Safety and effectiveness of a nurse-led outreach program for assessment and treatment of chronic hepatitis C in the custodial setting. Clin Infect Dis. 2013;56:1078–84.
21. Keogh K, Clark P, Valery PC, McPhail SM, Bradshaw C, Day M, et al. Use of telehealth to treat and manage chronic viral hepatitis in regional Queensland. J Telemed Telecare. 2016;22:459–64.
22. Yoo ER, Perumpail RB, Cholankeril G, Jayasekera CR, Ahmed A. The role of e-health in optimizing task-shifting in the delivery of antiviral therapy for chronic hepatitis C. Telemed J E Health. 2017;23:870–3.
23. Belperio PS, Chartier M, Ross DB, Alaigh P, Shulkin D. Curing hepatitis C virus infection: best practices from the U.S. Department of Veterans Affairs. Ann Intern Med. 2017;167:499–504.

24. Arora S, Kalishman S, Thornton K, Dion D, Murata G, Deming P, et al. Expanding access to hepatitis C virus treatment–extension for community healthcare outcomes (ECHO) project: disruptive innovation in specialty care. Hepatology. 2010;52:1124–33.
25. Arora S, Thornton K, Jenkusky SM, Parish B, Scaletti JV. Project ECHO: linking university specialists with rural and prison-based clinicians to improve care for people with chronic hepatitis C in New Mexico. Public Health Rep. 2007;122(Suppl 2):74–7.
26. Beste LA, Glorioso TJ, Ho PM, Au DH, Kirsh SR, Todd-Stenberg J, et al. Telemedicine specialty support promotes hepatitis C treatment by primary care providers in the Department of Veterans Affairs. Am J Med. 2017;130:432–8.e3.
27. Ness TE, Annese MF, Martinez-Paz N, Unruh KT, Scott JD, Wood BR. Using an innovative telehealth model to support community providers who deliver perinatal HIV care. AIDS Educ Prev. 2017;29:516–26.
28. Wood BR, Mann MS, Martinez-Paz N, Unruh KT, Annese M, Spach DH, et al. Project ECHO: telementoring to educate and support prescribing of HIV pre-exposure prophylaxis by community medical providers. Sex Health. 2018;15:601–5.
29. Stevenson LD, Banks RE, Stryczek KC, Crnich CJ, Ide EM, Wilson BM, et al. A pilot study using telehealth to implement antimicrobial stewardship at two rural Veterans Affairs medical centers. Infect Control Hosp Epidemiol. 2018;39:1163–9.
30. World Health Organization. Global health sector strategy on HIV, 2016–2021. World Health Organization, 2016.
31. Henny KD, Wilkes AL, McDonald CM, Denson DJ, Neumann MS. A rapid review of e-health interventions addressing the continuum of HIV care (2007-2017). AIDS Behav. 2018;22:43–63.
32. Schnall R, Travers J, Rojas M, Carballo-Dieguez A. E-health interventions for HIV prevention in high-risk men who have sex with men: a systematic review. J Med Internet Res. 2014;16:e134.
33. Kurth AE, Chhun N, Cleland CM, Crespo-Fierro M, Parés-Avila JA, Lizcano JA, et al. Linguistic and cultural adaptation of a computer-based counseling program (care+ spanish) to support HIV treatment adherence and risk reduction for people living with HIV/AIDS: a randomized controlled trial. J Med Internet Res. 2016;18:e195.
34. Kurth AE, Spielberg F, Cleland CM, Lambdin B, Bangsberg DR, Frick PA, et al. Computerized counseling reduces HIV-1 viral load and sexual transmission risk: findings from a randomized controlled trial. J Acquir Immune Defic Syndr. 2014;65:611–20.
35. Le Doare K, Mackie NE, Kaye S, Bamford A, Walters S, Foster C. Virtual support for paediatric HIV treatment decision making. Arch Dis Child. 2015;100:527–31.
36. Jirawison C, Yen M, Leenasirimakul P, Chen J, Guadanant S, Kunavisarut P, et al. Telemedicine screening for cytomegalovirus retinitis at the point of care for human immunodeficiency virus infection. JAMA Ophthalmol. 2015;133:198–205.
37. Yen M, Ausayakhun S, Chen J, Ausayakhun S, Jirawison C, Heiden D, et al. Telemedicine diagnosis of cytomegalovirus retinitis by nonophthalmologists. JAMA Ophthalmol. 2014;132:1052–8.
38. Centers for Disease Control and Prevention. Pre-exposure prophylaxis (PReP) for HIV prevention. Available at: https://www.cdc.gov/hiv/pdf/PrEP_fact_sheet_final.pdf. Accessed July 7, 2019.
39. Muessig KE, Bien CH, Wei C, Lo EJ, Yang M, Tucker JD, et al. A mixed-methods study on the acceptability of using e-health for HIV prevention and sexual health care among men who have sex with men in China. J Med Internet Res. 2015;17:e100.
40.• Udeagu CN, Shah S, Toussaint MM, Pickett L. Sociodemographic differences in clients preferring video-call over in-person interview: a pilot study of HIV tele-partner services. AIDS Behav. **2017**;21:3078–86 **Insight into demographic characteristics defining user preferences in telemedicine implementations**.
41. Stekler JD, McMahan V, Ballinger L, Viquez L, Swanson F, Stockton J, et al. HIV pre-exposure prophylaxis prescribing through telehealth. J Acquir Immune Defic Syndr. 2018;77:e40–e2.
42. World Health Organization. Global health sector strategy on sexually transmitted infections, 2016–2021: World Health Organization; 2016.
43.•• Estcourt CS, Gibbs J, Sutcliffe LJ, Gkatzidou V, Tickle L, Hone K, et al. The e-sexual health clinic system for management, prevention, and control of sexually transmitted infections: exploratory studies in people testing for chlamydia trachomatis. Lancet Public Health. 2017;2:e182–e90 **An exemplary telemedicine system implemented through a Web portal**.
44.• Gibbs J, Sutcliffe LJ, Gkatzidou V, et al. The e-clinical care pathway framework: a novel structure for creation of online complex clinical care pathways and its application in the management of sexually transmitted infections. BMC Med Inform Decis Mak. **2016**;16:98 **This report outlines a framework for developing a telemedicine pathway, incorporating clinical needs and usability**.
45. Aicken CRH, Sutcliffe LJ, Gibbs J, Tickle LJ, Hone K, Harding-Esch EM, et al. Using the e-sexual health clinic to access chlamydia treatment and care via the internet: a qualitative interview study. Sex Transm Infect. 2018;94:241–7.
46. Chabot C, Gilbert M, Haag D, Ogilvie G, Hawe P, Bungay V, et al. Anticipating the potential for positive uptake and adaptation in the implementation of a publicly funded online STBBI testing service: a qualitative analysis. BMC Health Serv Res. 2018;18:57.
47. Spielberg F, Levy V, Lensing S, Chattopadhyay I, Venkatasubramanian L, Acevedo N, et al. Fully integrated e-services for prevention, diagnosis, and treatment of sexually transmitted infections: results of a 4-county study in California. Am J Public Health. 2014;104:2313–20.
48. Uscher-Pines L, Mehrotra A. Analysis of teladoc use seems to indicate expanded access to care for patients without prior connection to a provider. Health Aff (Millwood). 2014;33:258–64.
49. Uscher-Pines L, Mulcahy A, Cowling D, Hunter G, Burns R, Mehrotra A. Antibiotic prescribing for acute respiratory infections in direct-to-consumer telemedicine visits. JAMA Intern Med. 2015;175:1234–5.
50. Gordon AS, Adamson WC, DeVries AR. Virtual visits for acute, nonurgent care: a claims analysis of episode-level utilization. J Med Internet Res. 2017;19:e35.
51. Schoenfeld AJ, Davies JM, Marafino BJ, Dean M, DeJong C, Bardach NS, et al. Variation in quality of urgent health care provided during commercial virtual visits. JAMA Intern Med. 2016;176:635–42.
52. Berrios-Torres SI, Umscheid CA, Bratzler DW, et al. Centers for disease control and prevention guideline for the prevention of surgical site infection, 2017. JAMA Surg. 2017;152:784–91.
53. Sanger PC, Hartzler A, Han SM, Armstrong CAL, Stewart MR, Lordon RJ, et al. Patient perspectives on post-discharge surgical site infections: towards a patient-centered mobile health solution. PLoS One. 2014;9:e114016.
54. Whitby M, McLaws ML, Collopy B, et al. Post-discharge surveillance: can patients reliably diagnose surgical wound infections? J Hosp Infect. 2002;52:155–60.
55. Gunter R, Fernandes-Taylor S, Mahnke A, Awoyinka L, Schroeder C, Wiseman J, et al. Evaluating patient usability of an image-based mobile health platform for postoperative wound monitoring. JMIR Mhealth Uhealth. 2016;4:e113.
56. Totty JP, Harwood AE, Wallace T, Smith GE, Chetter IC. Use of photograph-based telemedicine in postoperative wound assessment to diagnose or exclude surgical site infection. J Wound Care. 2018;27:128–35.
57. Wiseman JT, Fernandes-Taylor S, Gunter R, Barnes ML, Saunders RS, Rathouz PJ, et al. Inter-rater agreement and checklist validation

for postoperative wound assessment using smartphone images in vascular surgery. J Vasc Surg Venous Lymphat Disord. 2016;4: 320–8.e2.

58. Wiseman JT, Fernandes-Taylor S, Barnes ML, Tomsejova A, Saunders RS, Kent KC. Conceptualizing smartphone use in outpatient wound assessment: patients' and caregivers' willingness to use technology. J Surg Res. 2015;198:245–51.
59. World Health Organization. Global tuberculosis report 2018. World Health Organization, 2018.
60. Karumbi J, Garner P. Directly observed therapy for treating tuberculosis. Cochrane Database Syst Rev. 2015:Cd003343.
61. World Health Organization. Handbook for the use of digital technologies to support tuberculosis medication adherence. World Health Organization, 2018.
62. Garfein RS, Collins K, Munoz F, et al. Feasibility of tuberculosis treatment monitoring by video directly observed therapy: a binational pilot study. Int J Tuberc Lung Dis. 2015;19:1057–64.
63. Macaraig M, Lobato MN, McGinnis Pilote K, Wegener D. A national survey on the use of electronic directly observed therapy for treatment of tuberculosis. J Public Health Manag Pract. 2018;24: 567–70.
64.• Poon SJ, Schuur JD, Mehrotra A. Trends in visits to acute care venues for treatment of low-acuity conditions in the united states from 2008 to 2015. JAMA Intern Med. **2018**;178:1342–9 **Large-scale claims data analysis of utilization and cost comparing telemedicine to other methods of acute care delivery**.
65. Shi Z, Mehrotra A, Gidengil CA, Poon SJ, Uscher-Pines L, Ray KN. Quality of care for acute respiratory infections during direct-to-consumer telemedicine visits for adults. Health Aff (Millwood). 2018;37:2014–23.
66. Tan SJ, Ingram PR, Rothnie AJ, Whitmore TJ, Robinson JO, Hatch JB, et al. Successful outpatient parenteral antibiotic therapy delivery via telemedicine. J Antimicrob Chemother. 2017;72:2898–901.
67. Ray KN, Shi Z, Gidengil CA, Poon SJ, Uscher-Pines L, Mehrotra A. Antibiotic prescribing during pediatric direct-to-consumer telemedicine visits. Pediatrics. 2019;143:e20182491.
68. Davis CB, Marzec LN, Blea Z, Godfrey D, Bickley D, Michael SS, et al. Antibiotic prescribing patterns for sinusitis within a direct-to-consumer virtual urgent care. Telemed J E Health. 2019;25:519–22.
69. Halpren-Ruder D, Chang AM, Hollander JE, Shah A. Quality assurance in telehealth: adherence to evidence-based indicators. Telemed J E Health. 2019;25:599–603.
70. Martinez KA, Rood M, Jhangiani N, Kou L, Boissy A, Rothberg MB. Association between antibiotic prescribing for respiratory tract infections and patient satisfaction in direct-to-consumer telemedicine. JAMA Intern Med. 2018;178:1558–60.
71. Martinez KA, Rood M, Jhangiani N, Boissy A, Rothberg MB. Antibiotic prescribing for respiratory tract infections and encounter length: an observational study of telemedicine. Ann Intern Med. 2018.
72. Strymish J, Gupte G, Afable MK, Gupta K, Kim EJ, Vimalananda V, et al. Electronic consultations (e-consults): advancing infectious disease care in a large veterans affairs healthcare system. Clin Infect Dis. 2017;64:1123–5.
73. Driessen J, Chang W, Patel P, Wright RM, Ernst K, Handler SM. Nursing home provider perceptions of telemedicine for providing specialty consults. Telemed J E Health. 2018;24:510–6.
74. Najafi N, Harrison JD, Duong J, Greenberg A, Cheng HQ. It all just clicks: development of an inpatient e-consult program. J Hosp Med. 2017;12:332–4.
75. Monkowski D, Rhodes LV, Templer S, et al. A retrospective cohort study to assess the impact of an inpatient infectious disease telemedicine consultation service on hospital and patient outcomes. Clin Infect Dis. 2019.
76. North F, Uthke LD, Tulledge-Scheitel SM. Internal e-consultations in an integrated multispecialty practice: a retrospective review of use, content, and outcomes. J Telemed Telecare. 2015;21:151–9.
77.• Machado SM, Wilson EH, Elliott JO, Jordan K. Impact of a telemedicine eICU cart on sepsis management in a community hospital emergency department. J Telemed Telecare. 2018;24:202–8 **This study reports a novel telemedicine solution to the treatment of sepsis using mobile telepresence**.
78. Morquin D, Ologeanu-Taddei R, Koumar Y, Bourret R, Reynes J. Implementing a tele-expertise system to optimise the antibiotic use and stewardship: the case of the Montpellier University Hospital (France). Stud Health Technol Inform. 2015;210:296–300.
79. The Joint Commission. Approved: new antimicrobial stewardship standard. Joint Commission Perspectives. 2016;36.
80. Howell CK, Jacob J, Mok S. Remote antimicrobial stewardship: a solution for meeting the joint commission stewardship standard? Hosp Pharm. 2019;54:51–6.
81. Beaulac K, Corcione S, Epstein L, Davidson LE, Doron S. Antimicrobial stewardship in a long-term acute care hospital using offsite electronic medical record audit. Infect Control Hosp Epidemiol. 2016;37:433–9.
82.• Dos Santos RP, Dalmora CH, Lukasewicz SA, et al. Antimicrobial stewardship through telemedicine and its impact on multi-drug resistance. J Telemed Telecare. 2019;25:294–300 **This study reports successful asynchronous approach for antimicrobial stewardship**.
83. Ceradini J, Tozzi AE, D'Argenio P, et al. Telemedicine as an effective intervention to improve antibiotic appropriateness prescription and to reduce costs in pediatrics. Ital J Pediatr. 2017;43:105.
84.• MacRury S, Stephen K, Main F, Gorman J, Jones S, Macfarlane D. Reducing amputations in people with diabetes (RAPID): evaluation of a new care pathway. Int J Environ Res Public Health. 2018;15 **A two-phase pilot for a unique technical solution for low Internet connectivity settings**.
85. Khan I, Ndubuka N, Stewart K, McKinney V, Mendez I. The use of technology to improve health care to Saskatchewan's first nations communities. Can Commun Dis Rep. 2017;43:120–4.
86. Mashru J, Kirlew M, Saginur R, Schreiber YS. Management of infectious diseases in remote northwestern Ontario with telemedicine videoconference consultations. J Telemed Telecare. 2017;23: 83–7.
87. Prieto-Egido I, Gonzalez-Escalada A, Garcia-Giganto V, Martinez-Fernandez A. Design of new procedures for diagnosing prevalent diseases using a low-cost telemicroscopy system. Telemed J E Health. 2016;22:952–9.
88. Gulley ML, Morgan DR. Molecular oncology testing in resource-limited settings. J Mol Diagn. 2014;16:601–11.
89. Maffert P, Reverchon S, Nasser W, Rozand C, Abaibou H. New nucleic acid testing devices to diagnose infectious diseases in resource-limited settings. Eur J Clin Microbiol Infect Dis. 2017;36:1717–31.
90. Dendere R, Myburg N, Douglas TS. A review of cellphone microscopy for disease detection. J Microsc. 2015;260:248–59.
91. Jiang L, Mancuso M, Lu Z, Akar G, Cesarman E, Erickson D. Solar thermal polymerase chain reaction for smartphone-assisted molecular diagnostics. Sci Rep. 2014;4:4137.
92. Yeo SJ, Choi K, Cuc BT, Hong NN, Bao DT, Ngoc NM, et al. Smartphone-based fluorescent diagnostic system for highly pathogenic H5N1 viruses. Theranostics. 2016;6:231–42.
93. Zhao C, Liu X. A portable paper-based microfluidic platform for multiplexed electrochemical detection of human immunodeficiency virus and hepatitis C virus antibodies in serum. Biomicrofluidics. 2016;10:024119.
94. Wang LJ, Naude N, Demissie M, et al. Analytical validation of an ultra low-cost mobile phone microplate reader for infectious disease testing. Clin Chim Acta. 2018;482:21–6.

95. Carter T, Jepsen JR. Exposures and health effects at sea: report on the NIVA course: maritime occupational medicine, exposures and health effects at sea, Elsinore, Denmark, May 2014. Int Marit Health. 2014;65:114–21.
96. Marimoutou C, Tufo D, Chaudet H, Abdul Samad M, Gentile G, Drancourt M. Infection burden among medical events onboard cargo ships: a four-year study. J Travel Med. 2017;24.
97. Dehours E, Saccavini A, Roucolle P, Roux P, Bounes V. Added value of sending photograph in diagnosing a medical disease declared at sea: experience of the French tele-medical assistance service. Int Marit Health. 2017;68:122–5.
98. Ohl ME, Richardson K, Kaboli PJ, Perencevich EN, Vaughan-Sarrazin M. Geographic access and use of infectious diseases specialty and general primary care services by veterans with HIV infection: implications for telehealth and shared care programs. J Rural Health. 2014;30:412–21.