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Role of Digital Health During Coronavirus Disease 2019 Pandemic and Future Perspectives



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KEYWORDS

- Digital health • Artificial intelligence (AI) • Machine learning (ML) • Deep learning (DL)
- COVID-19 pandemic • Telemedicine • Remote monitoring

KEY POINTS

- COVID-19 pandemic brought a significant paradigm shift in mode of health care delivery.
- Adoption of digital health served as a necessary tool to ensure safety of patients and health care professionals.
- Telemedicine, a concept that existed pre-COVID, was used to deliver care in outpatient as well as inpatient care settings to restrict exposure and conserve PPE.
- Barriers to wide-scale availability of digital health are related to lack of infrastructure, digital literacy, and patients belonging to underserved and underrepresented population with socioeconomic constraints.
- Economics of digital medical care and insurance reimbursements will continue to be a matter of debate in the near future.

INTRODUCTION

The coronavirus disease 19 (COVID-19) pandemic has yielded an unparalleled global challenge in the delivery of health care. From nationally mandated quarantines and mass vaccination efforts to ushering in a new era of virtual communication, it has necessitated a new perspective on health care moving forward. Specifically, it has led to institutionalized changes to health care systems, hospitals, medical professionals, ancillary staff, training programs, and health care policies. Aims to both safely preserve the best qualities of face-to-face traditional patient care as well as integrate technology and virtual care have been at the

forefront of each specialty. Digital health care has been a revolution in this effort in effective management of patients with complex conditions. This paradigm shift has called for our advocacy to improve upon and incorporate even newer emerging digital health solutions as well as alleviate previous barriers to digital health care. Cardiac electrophysiology (EP) has been uniquely poised as a specialty that has been accustomed to using digital health techniques such as remote monitoring and artificial intelligence (AI) supplementary tools even in the prepandemic period.¹ In this article, we explain the obstacles encountered with in-person care during the pandemic, review currently available digital health platforms

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specifically in relation to cardiac EP, and explore further avenues for advancing digital and in-person care delivery in the future.

TRADITIONAL CARE DURING THE PANDEMIC

The COVID-19 pandemic has abruptly ushered in a foundational change to the traditional practice of medicine. Despite clinical research and advancements continually evolving and reshaping the field of medicine, the practice of face-to-face patient encounters had previously remained stable. Although face-to-face care was accepted as the norm for centuries, the pandemic forced us to revisit this idea as a community. This pandemic was the catalyst for not only a sudden but also a widespread paradigm shift in patient care, with nearly 80% of the US population indicating that they have used one form of digital health.^{2,3} The pandemic has also enabled health care providers and administrators to revisit the intricacies of in-person care delivery and improve overall efficiency. In-person care depends on a variety of supporting frameworks that include providers, administrative personnel, patients, caregivers, and family members and is very time and resource intensive. Testing for COVID-19 and limiting physical contact between personnel for in-person care made for a more complex, time-consuming, and inefficient process. One study advocated for creating a safe workplace by universal testing for COVID-19 in asymptomatic patients and health care workers. Out of 1670 subjects, 758 were patients and 912 were caregivers, Emergency Medical Service, and EP laboratory personnel. The study found 3.8% positivity rates in the asymptomatic population.⁴ While hospitals began cancellation of elective clinic and procedural visits in efforts to allocate health care resources toward tackling the pandemic, a steep decline in patient comfort levels in attending in-person visits was also noted. Several reports have indicated patient hesitancy to attend for in-person care even for concerning anginal symptoms. In fact, there was a reduction in patients presenting to the emergency room with acute myocardial infarction during the peak of the pandemic, and those that presented had higher mechanical complications due to late presentations.⁵ These data highlight the hesitancy and overt concern that patients may have to seek medical care in this current global crisis, which can sometimes be life threatening. Cardiac EP has also seen a decline in in-person visits across the globe during the pandemic. However, EP has an advantage of decision making being driven by abstract data such as rhythm monitors, electrocardiograms, and device

interrogations, which enabled a smoother transition to virtual care.

DIGITAL HEALTH IN ELECTROPHYSIOLOGY DURING CORONAVIRUS DISEASE 2019

Remote Monitoring

Cardiac EP has been a leader in digital health care. Over the years multitude of devices have been developed and implemented in clinical practice, and these services were increasingly used during the pandemic in addition to development of some novel tools. Remote cardiac monitoring can be classified into 3 broad categories:¹

- Medical-grade wearable monitors such as Holter monitor and external and internal loop recorder.
- Consumer-grade wearable monitors such as smartwatches.
- Cardiac implantable electronic devices (CIEDs) such as pacemakers and defibrillators.

These diverse range of devices generate different types of data. Holter and loop recorders only function as data collectors, whereas CIEDs can recognize critical findings and intervene based on programming. As a result, remote monitoring bears a prognostic value and helps in reducing worse outcomes. CIEDs received a class I recommendation for remote monitoring in 2015.⁶ However, in the prepandemic times remote monitoring was underused due to patient- and system-based issues. The pandemic made remote monitoring an important tool to help identify critical and noncritical issues and address them accordingly.⁷ Enrollment of existing patients in device clinics in remote monitoring was an important initiative undertaken by various EP programs in response to the pandemic.⁸ One Italian study reported an experience of 332 patients introduced to remote monitoring during the lockdown. Patients were categorized based on modality, divided between remote monitoring at home versus office. Study findings reported high patient satisfaction, and providers were better able to provide continuous health care coverage in eligible CIED patients.⁹

Remote monitoring enables informed triage of patients needing urgent procedures, clinical decision making and diagnosis, and implementation of appropriate therapeutic interventions while bypassing an in-person visit. Similarly, patients adopting digital health tools like pulse oximeters, automated blood pressure equipment, glucose monitors, and single-lead electrocardiography (ECG) recorders were able to provide their respective physicians with important data without risking exposure.

One important aspect of remote monitoring is the burden of data received and the challenge of trained personnel being available to accurately review and act upon the data. Development of novel AI tools that can incorporate machine learning (ML) can help stratify the findings, so that appropriate measures can be taken.¹

The concept of drive-through pacing clinics fills the gap for the subset of patients who may not be suitable for remote monitoring. This familiar concept involved patients driving up parallel to a kiosk occupied by a health care worker. A study by Akhtar and colleagues¹⁰ evaluated 316 patients of which 66.8% had pacemakers, 21.8% had cardiac resynchronization therapy (CRT) devices, and 4.1% had implantable cardioverter-defibrillators. A total of 50 wound inspections were performed, and 2 were diagnosed and treated for superficial infections. Seven were diagnosed with new-onset atrial fibrillation (AF) and were referred for anticoagulation. Device settings were adjusted in 16.1% of cases, and only 22 patients were referred to a physician for a variety of symptoms. Most patients (57.1%) preferred this drive-through format over the conventional methods.¹⁰

Telemedicine

The concept of telemedicine existed in the pre-COVID era, but it was limited and often complicated with reimbursement issues for physicians. The COVID-19 crisis led to rapid adoptions of virtual medical care. At present telemedicine is provided by telephones, secure messaging, and audio-video conference calls via commercial applications. The Office for Civil Right expressed willingness to forego penalties for Health Insurance Portability and Accountability Act noncompliance among providers enacting in good faith measures for telemedicine during the pandemic.¹¹

In an attempt to conserve personal protective equipment (PPE), avoid exposure for patients and clinicians, and limit both hospitalizations for non-COVID reasons and outpatient office visits, an array of tele-health care was provided to patients in inpatient and outpatient settings. The Heart Rhythm Society (HRS)/American college of cardiology (ACC)/American Heart Association (AHA) provided an early guidance for electrophysiologists on how to practice during the pandemic. The guidance advocated for virtual visits, emphasizing social distancing, conservation of PPE, and minimizing face-to-face encounters when possible; it also clearly addressed nonurgent/nonemergent procedures, protocols for performing procedures on patients with COVID-19.¹²

Berman and colleagues¹³ shared their experience of managing 29 inpatient EP consultations at the heart of the pandemic in New York. The investigators were able to manage 55% of patients remotely and were able to provide guideline- and evidence-based recommendations.¹³ Similar reports came from other specialties like OB/GYN in which they were able to provide telehealth to 1352 patients for prenatal care, of which 61.5% were maternal-fetal medicine visits.¹⁴ Another pilot study was reported by Renner and colleagues¹⁵ from Helsinki University Hospital in Finland. The investigators performed 25 tele-rounds in 15 patients in the pulmonary ward; they concluded that tele-rounding is feasible in select patients with COVID-19 and can improve health care workers' safety and conserve PPE.¹⁵

Whether the current exponential growth in telemedicine will continue to grow after the pandemic is over is yet to be seen. However, with mass-scale vaccinations being delivered globally and humanity seeking a return to normalcy, we do believe the unexpected outcome of COVID-19 is reliance upon digital health, which can be seen in forms like physical fitness, adherence to therapies, ordering medications, and disease screening tools as part of smartphone/tablet apps.

We hypothesize that these adoptions may improve patient satisfaction, avoid long wait times in offices, avoid travel, and discuss medical care at the comfort of their homes. A study by Han and colleagues³ reported that 60% of patients and 70% of clinicians would prefer to continue with virtual telehealth visits in future. This concept will also aid busy specialist physicians who tend to cover multiple hospitals to make recommendations via digital visits, improve recommendation times, and eventually improve hospital length of stay.

Artificial Intelligence Tools

AI has been incorporated into medicine for some decades now, but its incorporation to modern day clinical practice is reaching new horizons with the start of the COVID 19 pandemic. AI refers to machine-based processing of data that typically requires human cognitive function. ML is a subgroup of AI that uses algorithms to learn patterns empirically from data; it identifies nonlinear relationships and higher-order interactions between multiple variables, which are often difficult to obtain via traditional statistics. Deep learning (DL) is a powerful ML approach that analyzes large complex data sets and enables efficient decisions. AI tools have brought about significant change in cardiac EP and cardiovascular imaging as well. AI has shown promise in assisting in diagnosis,

disease prediction models, and response to treatment and prognosis.¹⁶

The concept of AI is not new in cardiac EP with automated ECG interpretations existing since the 1970s.¹⁷ However, interpretation of ECGs relies on expert opinion and requires training and expertise. Algorithms for the computerized automated diagnosis of 12-lead ECGs in prehospital setting can really aid emergency medical personnel or nonspecialist physicians to identify a condition and timely start treatment in high-risk patients. However, current automated ECG diagnosis algorithms lack accuracy and result in misdiagnosis if not reviewed carefully. There has been substantial progress in these areas where ECG-based deep neural networks (DNNs) have been tested to identify arrhythmias, classify supraventricular tachycardias, and predict left ventricular hypertrophy. A study by Attia and colleagues,¹⁸ which included 180,922 patients, in which AI-enabled ECG during normal sinus rhythm was able to identify AF with almost 80% accuracy. Another good example is the study by Ko and colleagues in which they used a trained and validated convolutional neural network using 12-lead ECG and were able to detect hypertrophic cardiomyopathy with a sensitivity up to 95%. We do believe that these DNN models require more refinement and validation but in future are likely to aid specialists and nonspecialists with improved ECG diagnosis and perhaps as screening tools.^{19–22}

Other dimensions related to ECGs are the use of implantable devices, smartwatches, and smartphone-based apps, which can generate large amounts of data sets that are not amenable for manual evaluation. Arrhythmia detection algorithms on DNNs on large sets of ambulatory patients with single-lead plethysmography have shown similar diagnostic performance as cardiologists and implantable loop recorders. Continuous monitoring provides the opportunity to pick up asymptomatic cardiac arrhythmias and overcome serious adverse events in future.²¹

Electroanatomic mapping in complex invasive EP procedures provides another opportunity. By combining data from diagnostic tools like MRI and fluoroscopy, previous electroanatomical mapping can help identify arrhythmogenic substrates and decrease the invasive catheter ablation times. There has been development in integrating fluoroscopy and electroanatomical mapping with MRI with ML.^{23,24}

The above-mentioned examples provide a framework of tools in AI, but their wide-scale validation and translation into clinical practice may not be that far away.

Electrophysiology-Specific Innovations

Some examples of EP-specific innovations are described in the following sections.

Tele-atrial fibrillation project

AF is the most common cardiac arrhythmia; its traditional management requires face-to-face evaluations with cardiologist and primary care doctors and checking heart rate (HR) and rhythm control with ECG. With lockdowns and health facilities under pressure, telehealth visits became the backbone for providing care. However, effective management is limited in patients with AF because it did not allow for measurements of HR or checking the rhythm during the telehealth visit. To overcome this and make a unified structure all over Europe, The Cardiology Department of the Maastricht University Medical Center+ (MUMC+) in Maastricht, the Netherlands, innovated a standard operating procedure document describing the TeleCheck-AF approach. This approach involved teleconsultation coupled with remote photoplethysmography-based HR and heart rhythm monitoring (FibriCheckVR) to allow the treating clinicians to manage their patients comprehensively. FibriCheckVR currently enrolls 2492 patients in about 40 clinical centers around Europe. Patients once enrolled are requested to check their HR and heart rhythm via the application twice a day for at least 7 days before doctor's visit. The physician evaluates the rhythms in real time and reports it in a user-friendly dashboard. Further changes in clinical management will be addressed by physicians via teleconsultations.

This is a great example in which varying infrastructure in different countries were able to set up the concept of mobile health (mHealth) in a short duration of time. FibriCheckVR was easy to use and install by patients. Further prospective trials are underway to assess if mHealth is noninferior to current standard care guided by face-to-face consultations.^{2,25}

Smartphone electrocardiographic surveillance

Another great example in this association is the use of smartphone for ECG surveillance to preserve hospital capacity during the pandemic. The idea was to empower primary care physicians and patients with appropriate tools to identify patients with concerns for clinical deterioration with stable COVID-19 infection. The study involved 21 primary care physicians who enrolled 521 patients. The physicians were equipped with 8/12-lead hospital-grade smartphone-operated ECG device (D-Heart). First ECG was done under the supervision of the physician, and they were instructed to record at least one ECG at day 4 of infection or

whenever cardiac symptoms were present during the first 10 days of infection. ECG was evaluated 24/7 within 15 minutes of arrival via telecardiology platform by cardiologists. This is reported to be the first study of its kind and enabled primary care physicians for early detection and avoiding a worse clinical outcome. The study concluded that the smartphone-controlled ECG devices are ideal for simple arrhythmia assessments but may not be adequate for complex ECG evaluation.²⁶ Certainly, this methodology lays a nice platform for multiparametric telemonitoring for patients in the future with improvement and acceptability of telehealth.

Home antiarrhythmic drug loading with smartphone tracings

Outpatient loading of antiarrhythmic drugs (AAD) like sotalol and dofetilide has been a matter of debate. Although outpatient initiation of sotalol is approved in certain cases, clinicians prefer to admit patients and monitor them closely for QT interval prolongation and development of ventricular arrhythmias. As COVID-19 stretched the health care systems all over the world, it led to delays in hospitalization for initiation of AAD and elective ablation procedures to help ensure maintenance of sinus rhythm versus rate control strategy. These circumstances led to the initiative of starting these medications in outpatient setting with patients who had CIEDs. Two separate studies by Mascarenhas and colleagues^{27,28} for dofetilide (n = 30 patients) and sotalol (105 patients) demonstrated that they were able to successfully initiate these medications in the outpatient setting with careful telemonitoring. In both studies Permanent Pace makers and Intra-cardiac defibrillators were programmed to provide a lower rate of pacing at 70 bpm and Implantable loop recorders were programmed to detect an HR greater than 150 to 160 bpm depending on the device used. A mandatory 2-hour manual transmission was obtained after initiation of medication. Patients were seen in office for the first 3 days of initiation of medication.^{27,28}

Although larger cohorts may be needed to validate these findings, these studies do lay a good foundation and direction for future studies. This outpatient initiative not only decreases the risk of nosocomial infections, including COVID-19, but also helps to decrease the cost burden by avoiding hospitalization of 3 days.

Heart logic

CRT devices have now been incorporated in multiple studies with ML to predict end points like heart failure or death after CRT by using multitude

of baseline variables. Heart Logic is a good example of a personalized, remote heart failure diagnostic and monitoring solution and has been validated to provide weeks of advance notice for early signs of worsening heart failure.²⁹

The ML models have outperformed current guidelines in predicting response and improved event-free survivals, although these findings are modest at this time. In other reports ML has been able to predict mortality better than preexisting clinical risk scores.^{30,31}

BARRIERS TO DIGITAL HEALTH DELIVERY

Virtual care and digital health were instrumental in care delivery during the pandemic. Cancellation of elective procedures and visits was the immediate response, whereas creation of alternative digital solutions such as virtual telemedicine visits and remote patient monitoring measures represented a long-term viable strategy.⁷ However, this transition was far from seamless and posed significant difficulties during its immediate implementation. First, the resource burden from the COVID-19 pandemic required a prioritization of essential procedures, and with this in mind a return to full force in the postpandemic period can place additional strain on digital health care delivery given that it continues to be evolving in terms of familiarity and efficiency.³² Furthermore, the sheer volume of data inflow that can be expected with CIEDs, both medical- and consumer-grade wearable monitors, and incorporated AI tools can be overwhelming. This burden of increased data can present challenges to incorporation into clinical practice and can be overwhelming once in-person care returns to full volumes. Additional quality control parameters are needed because the accuracy of some of these devices is still precocious.¹ Along with this data influx, an efficient and accurate triaging system must be in place, and AI tools, although improving, still lack this ability reliably.¹ In a comparative prepandemic and peripandemic survey regarding the changes in the digital health landscape among cardiac EP professionals, the most common barrier cited was a lack of infrastructure, which despite showing an improvement between the 2 surveys still remained a prominent problem even after reassessment and highlights the lag of a supportive framework despite advancements in digital health.³ This fact must be taken into consideration with the reintegration of face-to-face encounters, and with the progression of digital health moving forward. Our familiarity with digital health and its limits is still expanding, although more specifically this puts us as

providers in the impactful role to ensure digital literacy to our patients.³³ Although smartphone applications, digital wearable devices, and virtual telemedicine appointments have served to further patient care, this comes with a learning curve for the user itself and makes providers the fulcrum of digital literacy education and patient advocacy in this area. Furthermore, these digital health solutions also serve both themselves as social barriers to health and can further highlight already present health care disparities.³ Digital health usually requires access to Wi-Fi, Bluetooth, and/or smartphones, which may not be routinely available to all patients. Patients in underserved or underrepresented populations and with socioeconomic barriers are experiencing a compounded gap in care.³⁴ Specifically, a multivariate analysis consisting of 148,402 patients who had either completed or missed telemedicine appointments revealed that age greater than 55 years, Asian ethnicity, Medicaid insurance care, and non-English-speaking patients were most vulnerable to the digital divergence in care.³⁵ African American and Latinx communities with household incomes of less than \$50,000 had lower rates of video telemedicine visits compared with telephone visits, which could limit some of the offered video conference benefits such as medication reconciliations or virtual physical examinations.³⁵ The demand, therefore, for more applications of digital health must also be met with equal support for digital health equity, an equally vital social disparity in the current state of medicine.³⁴ Finally, a virtual move to collective educational platforms such as national and global health conferences has remained a topic of discussion, with some claiming its potential to reach a wider audience yet others highlighting the inability to provide hands-on experience, and interdisciplinary learning.³² As vaccination efforts continue to curb the impact of the pandemic, and in-person patient care has been slowly reintegrating, resurgences can halt this process, and the supplementary role of digital health must be continually reevaluated. Finding a steady state in which overreliance is not placed upon digital health while still using these resources to extract as much patient data to complement face-to-face interactions is paramount.

Fig. 1 summarizes the flow of digital health in clinical cardiac EP.

DIGITAL HEALTH IN THE POSTPANDEMIC PERIOD

Two main overarching factors will outline the future of digital health: digital health infrastructure and

government policies for reimbursement.³ Economics remains a fundamental driver for impacting changes in medical care. The Centers for Medicare and Medicaid have responded with base billing code implementation and addition for telemedicine to encompass a wide spectrum and acuity of patient encounters, and it remains to be seen if other insurance carriers will follow this pathway, as well as if this continues to be fostered and expanded in the future.^{1,32}

Other improvements have come in the form of applicability and accessibility. The utilization of learning models such as Project ECHO (Extension of Community Healthcare Outcomes) is a collaborative multispecialty videoconferencing program that aims to promote peer-to-peer, multidisciplinary learning to health care providers, as well as make them comfortable as a technology provider in the digital health landscape.³⁶ Furthermore, the advocacy seen from organizations such as Telehealth for Seniors, Inc, a Florida-based nonprofit organization aiding in provision of digital health devices and education for seniors, has emerged during the pandemic, as well as increases in telehealth platform funding from the Coronavirus Aid, Relief, and Economic Security (CARES) Act^{3,37}; these have contributed to the increase in accessibility to digital health, although these gaps in digital health disparity have not been bridged and advocacy for digital health equity must remain pressured.³⁴ Successful continued advocacy and resultant expansion of digital health can hope to present new telemedicine models to more remote areas and reach a wider spectrum of patients.

A further application of digital health in the future postpandemic period will hope to focus on the impact of digital health on clinical research and, namely, its recruitment. Predating the COVID-19 pandemic, efforts such as the MyHeart Counts and Heart eHealth studies used app-based recruitment and wearable monitoring devices to create larger cohorts and easier, prolonged periods of study.³⁸ Pairing this with the advancements necessitated in digital health, there is an optimistic outlook on the contribution of digital health tools in patient recruitment and ease of monitoring to contribute to higher cohorts in clinical research.

EP serves as a fertile foundation for the incorporation of AI, and the ideal role it plays in the future is still budding. The hope for AI to assist in triaging and risk stratification in various cardiac diseases provides for an enticing outlook, and it can be hoped that these advancements will continue to be cultivated, as their application currently remains limited.



Fig. 1. Central illustration.

SUMMARY

New digital health innovations and an accommodating digital health landscape have shown promise during this pandemic, and we find ourselves as a field faced with the challenge of continuing to cultivate and incorporate this aspect of medicine. Consumer-grade wearable monitors, AI triaging and diagnostic supplementary tools, and improved accessibility to technology mark some of the foreseen changes to the field of cardiac EP. This knowledge will allow us to focus on restructuring the comprehensive and traditional albeit resource-intensive in-person model of patient care, and we hope to transition to a more efficient, patient-centered, and communicative framework both incorporating digital health and reincorporating in-person care moving forward.

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