Remote Monitoring for 5P (Predictive, Preventive, Participatory, Personalized, and Precision) cardiovascular medicine: Progress Amidst COVID-19 Pandemic

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The novel coronavirus disease 2019 (COVID-19) has emerged as a global pandemic that has affected the lives of billions of people. Clinical studies have reported an association between COVID-19 and cardiovascular diseases. Remote monitoring powered by wearable sensors impacts medical care by enabling health monitoring outside of the clinic. Wearable devices can provide a noninvasive and continuous multi-parameter assessment of ECG, Heart Rate Variability, arterial blood pressure, oxygen saturation and respiratory rate evaluation. Such monitoring may help predict and prevent cardiovascular events related to COVID-19 addresses the growing demand for a novel 5P (Predictive, Preventive, Participatory, Personalized, and Precision) medicine approach. This article aimed to review current and prospective advances in wearable devices for cardiac monitoring and their progress toward clinical application during the COVID-19 pandemic. We performed bibliometric analysis by Scopus, the largest and well organized bibliographic database and analyzed the top-cited articles in this field. Our analysis includes an overview of the most widespread practical implications of CVD-focused remote patient monitoring techniques based on wearable personalized devices. Assessment for both COVID-related conditions and general cases is included in the analysis. Recent studies have reported that cardiovascular abnormalities present in 19.7–27.8 % of hospitalized patients with COVID-19. COVID-19 associated myocarditis and heart rate abnormalities frequently occur. Additionally, patients with pre-existing CVD and hypertension are at high risk of worse outcomes. Data from several studies have identified atrial fibrillation as the most common form of arrhythmias in COVID-19 patients. Worsening of existing atrial fibrillation in COVID-19 patients is also a serious clinical concern. Implementation of wearable ECG devices for remote monitoring can improve the management of patients with atrial fibrillation and those at high risk for its development. Telecardiology based on wearable devices and remote monitoring allow out-of-hospital control of COVID-19 patients and patients suffering from chronic diseases at high risk of acute cardiovascular events, ensuring their early detection and tracking.

Keywords: Personalized medicine, COVID-19, remote monitoring, wearable devices, telemedicine, digital health, arrhythmias, cardiovascular diseases, myocarditis.
Introduction

The novel coronavirus disease 2019 (COVID-19) has emerged as a global pandemic that has affected the lives of billions of people. Clinical studies have reported an association between COVID-19 and cardiac diseases [1]. Patients with pre-existing comorbidities such as cardiovascular disease (CVD) and hypertension have an increased risk of poor outcomes, including death. COVID-19 may induce myocarditis, arrhythmia, myocardial infarction, and venous thromboembolism [2, 3]. Potential adverse effects of COVID-19 treatment, e.g. QT prolongation, are also becoming a serious concern [4].

Remote monitoring powered by wearable sensors impacts medical care by enabling health monitoring outside the clinic. Wearable devices can provide a noninvasive and continuous multi-parameter assessment of ECG, Heart Rate Variability (HRV), arterial blood pressure (BP), oxygen saturation and respiratory rate evaluation [5]. Such monitoring may help predict and prevent cardiovascular events related to COVID-19, addressing the growing demand for a novel 5P (Predictive, Preventive, Participatory, Personalized, and Precision) medicine approach [6]. Furthermore, the increased use of remote patient monitoring techniques goes far beyond the COVID-19 cases. Techniques that are becoming more widespread during the pandemic affect global public health. This shift will aid healthcare professionals working with cardiovascular diseases, the leading cause of death globally.

This article aimed to review current and prospective advances in wearable devices for cardiac monitoring and their progress toward clinical application during the COVID-19 pandemic. Current unmet challenges and existing gaps are also discussed.

Methods

We performed bibliometric analysis by Scopus, the largest and well-organized bibliographic database and analyzed the top-cited articles in this field. For literature retrieval, we used the following National Library of Medicine (NLM) Medical Subject Headings (MeSH) terms: (TITLE-ABS-KEY “wearable devices” OR “wearable technology” OR “remote monitoring” AND COVID-19 AND “ECG” OR “heart attack” OR “arrhythmia” OR “myocardial infarction” OR “acute coronary syndrome” OR “heart failure”).

The measurement of the social impact of articles was made using Altmetric data (https://www.altmetric.com/). The societal impact of articles was evaluated in view of alternative metrics available on Altmetric.com. Additionally, we have created visualization maps of authors and keywords co-occurrence using the VOSviewer version 1.6.15 software tool. We limited the number of keywords and authors to create a visualization network and used the most influential one. The minimum threshold for keyword occurrence was set at six and five for authors.

Our analysis includes an overview of the most widespread practical implications of CVD-focused remote patient monitoring techniques based on wearable personalized devices. Assessment for both COVID-related conditions and general cases is included in the analysis.

Results

As of November 27, 2021, there were 271 articles tagged with the above-mentioned MeSH terms in the title, abstract, or keywords. The retrieved manuscripts were manually analyzed for their relevance and their relation to the issue of cardiovascular monitoring.

A limited number of researchers are involved in remote cardiovascular monitoring studies amidst the COVID-19 pandemic. Some of these researchers author the same works (Figure 1). The US is the leading country in this area of research (88 articles), followed by Italy (45) and the UK (27). According to the number of articles, the top five journals were Sensors Switzerland, Sensors, Electronics Switzerland, IEEE Access, and Europace. Cleveland Clinic Foundation, Harvard Medical School and David Geffen School of Medicine at UCLA affiliations are associated with the highest number of articles. National Institutes of Health, Medtronic, Horizon 2020 Framework Program made the most significant contribution in funding researchers in this field. The main keywords in this research area centered around remote monitoring, wearables, wearable devices, telemedicine, artificial intelligence, machine learning, internet of things, physiological monitoring, mobile health, telehealth, e-health (Figure 2).
Discussion

Recent studies reported cardiac abnormalities in 19.7–27.8 % of hospitalized patients with COVID-19 [1,2]. COVID-19-associated myocarditis and heart rate abnormalities occur frequently. Additionally, patients with pre-existing CVD and hypertension are at high risk of worse outcomes. The underlying mechanisms of heart involvement in coronavirus disease remain unknown. Several factors may play a role, which are SARS-CoV-2 direct myocardial
injury, activation of the sympathetic nervous system, indirect impact of immunopathology and hyperinflammation, respiratory failure and hypoxia, and disturbances of electrolytes.

Data from several studies identified atrial fibrillation (AF) as the most common form of arrhythmias in COVID-19 patients [3]. The worsening of existing AF in COVID-19 patients is also a serious clinical concern. Implementing wearable ECG devices for remote monitoring can improve the management of patients with AF and those at high risk for its development [5]. The US Food and Drug Administration approved the direct-to-consumer mobile devices Apple Watch 1-lead ECG to diagnose atrial fibrillation.

Screening and monitoring COVID-19 QT-prolonging therapy (azithromycin, lopinavir, ritonavir etc.) is of particular concern [4]. The recent validation study found that Apple Watch 1-lead ECG technology allows adequate remote QT monitoring in up to 94% of cases, including COVID-19 outpatients on QT-prolonging treatments [4].

Active implementation of continuous cardiovascular monitoring by wearable devices in healthcare practice would be beneficial for different reasons during the COVID-19 pandemic.

First, advances in wearable technologies help shift the health care burden from hospital to in-home and public domain monitoring, thereby ensuring inpatient care for patients who need to be admitted into a hospital and reducing cross-contamination by avoiding infection during hospital visits. Second, wearable technologies allow medical care providers to remotely monitor the health status of self-isolated Covid-19 patients with mild severity and quarantined at home over time, particularly those at high risk of cardiac involvement, e.g., older age, pre-existing CVD, hypertension and diabetes. Third, the remote home monitoring of non-COVID-19 patients with chronic illnesses is also crucial for early screening of any sudden cardiac deterioration in times of limited access to proper medical care during the pandemic.

Adhesive biosensor patches (Figure 3) and wristwatches like the Apple Watch are the most common wearables for remote ECG monitoring. Notably, the results of randomized clinical trials showed that some wearable devices have superior performance in detecting hidden arrhythmias than traditional Holter monitoring.

![Figure 3. An example of a biosensor patch is a multi-sensor single-use device for cardiac monitoring (up to 7 days: 2 lead EKG, temperature, HRV, respiratory rate): Single-use and no battery recharging](image)

There are several steps involved in remote cardiac monitoring (Figure 4). The patient’s vital signs are being recorded out-of-hospital. The readings are synchronized with the cloud by using an intermediary storage device, like a smartphone, or directly from remote monitoring medical equipment. Cloud storage and AI analytics provide
healthcare professionals with a tool for remote patient data tracking. If symptoms of cardiac dysfunction develop, the data is sent via the secure cloud platform to the health care provider, ensuring timely intervention in emergencies.

Figure 4. Illustration of the remote ECG monitoring and data processing

The use of personal devices for remote patient monitoring may be limited by several factors, with the most significant challenge being the reliable generation of the data stream in real-life conditions. If the device is poorly designed for homecare use, patients may struggle with it, preventing them from measuring accurate data. The device’s connectivity may pose a particular challenge in terms of user experience and connection quality. Battery life is another limitation of the measurement process. Another important consideration is the quality of vital sign measurements. While numerous consumer-grade wellness wearables are on the market, most lack the measurement quality needed for remote patient monitoring. It is evidenced by a low number of FDA-cleared devices from non-medical brands.

In conclusion: Telecardiology based on wearable devices and remote monitoring allows out-of-hospital control of COVID-19 patients and patients suffering from chronic diseases at high risk of acute cardiovascular events, ensuring their early detection and tracking.

References

