

Review Article



Recent Technology-Driven Advancements in Cardiovascular Disease Prevention

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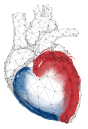
ABSTRACT

Recent dramatic developments in information and communication technologies have been widely applied to medicine and healthcare. In particular, biometric sensors in wearable devices linked to smartphones are collecting vast amounts of personal health data. To best use these accumulated data, personalized healthcare services are emerging, and digital platforms are being developed and studied to enable data integration and analysis. The implementation of biometric sensors and smartphones for cardiovascular and cerebrovascular healthcare emerged from the research on the feasibility and efficacy of the devices in the clinical environment. It is important to understand the recent research trends in data generation, integration, and application to prevent and treat cardiovascular and cerebrovascular diseases. This paper describes these recent developments in treating cardiovascular diseases.

Keywords: Cardiovascular disease; Cerebrovascular disease; Mobile applications; Mobile health units; Patient generated health data

INTRODUCTION

The World Health Organization estimated that about 17 million people died from cardiovascular problems worldwide in 2016.¹⁾ Cardiovascular diseases have the highest mortality rate in the world and, in Korea, with 119.6 cardiovascular-related deaths per 100,000, these diseases had the second-highest mortality rate after cancer.²⁾ To prevent cardiovascular and cerebrovascular diseases, it is important to prevent their risk factors and help people to maintain healthy lifestyle behaviors through lifestyle management.³⁾ Recent innovations in information and communication technologies and their diverse applications in medicine have created a new phenomenon in which patients voluntarily and independently try to maintain healthy lifestyles.⁴⁾ In particular, vast amounts of personal health data are accumulating through people's uses of various biometric readers and sensors (that are wearable devices) linked to smartphones.^{5,6)} Customized healthcare services for individuals that use these data are increasing and many platforms are being developed and researched regarding integrating and analyzing the data.^{7,8)} In other words, a diversity of ways for



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Conflict of Interest

The authors have no financial conflicts of interest.

Author Contributions

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patients to change their behaviors to achieve/maintain good health and prevent diseases are emerging. This development has important implications because diverse health information is being exchanged between patients and their healthcare providers in the process.⁹⁾

Ultimately, it would be foolish to ignore the vast amount of data being collected from patients. Currently, big data is the most important issue in medicine. The definition of “big data” is “intelligence assets that feature bulk storage, fast formation speeds, and diversity that mandate specific technologies and analysis methods to convert them into value.”¹⁰⁾ In medicine, the term “Real World Data (RWD)” is a more common concept than “big data.”¹¹⁾¹²⁾ The United States Food and Drug Administration defines RWD as data used to make decisions about monitoring and reducing safety hazards and side effects or to develop tools for decision-making and practical guidelines for clinical practices.¹³⁾

Korea mainly uses 4 types of health-related RWD: 1) claim data provided by the National Health Insurance Corporation and the Health Insurance Review and Assessment Service, 2) electronic medical record data generated at hospitals, 3) genomic data, and 4) patient-generated health data (PGHD) based on lifelogs. PGHD are compiled and measured by individuals using tools and devices at home, such as blood pressure monitors, blood sugar testers, pedometers, and so on.¹⁴⁾¹⁵⁾ PGHD might be the most important new phenomenon in healthcare considering the changes occurring in medicine in the current fourth industrial revolution, which are reflected in digital healthcare and the emergence of telemedicine and telehealth. Data generation and measurement are essential to achieving customized healthcare using PGHD, and organic harmony among services to correctly apply analyzed data through data integration is needed to successfully manage patients.

DATA GENERATION AND MEASUREMENT

PGHD can be collected by smartphones linked to wearable devices. PGHD collected this way are generated outside the hospital/clinical setting and must be verified a variety of different sample or populations of people. Some studies have used new methods to measure the diverse PGHD and confirm their practicality. Most clinical studies on digital healthcare via smartphone applications is related to PGHD.¹⁶⁾¹⁷⁾ **Table 1** lists 9 studies about data generation and monitoring via PGHD for diagnosing, preventing, and managing cardiovascular and cerebrovascular disease.¹⁸⁻²⁶⁾

Using smartphones and wearable devices to influence cardiovascular and cerebrovascular health developed from the study of the feasibility of their efficacy in the clinical environment.²⁷⁾²⁸⁾ Several studies have found positive influences of data obtained this way for cardiovascular and cerebrovascular health in improved everyday behaviors and self-care regarding the disease.¹⁶⁾¹⁷⁾ The approach was found to be an effective way to lower healthcare costs because consistent patient care, even remotely applied, was possible.²⁹⁾ PGHD have received more attention than other types of patient data because they are accumulated outside hospitals, where patients spend most of their time. Just counting the number of steps walked outside the hospital setting, which is the simplest PGHD, was verified as clinically useful.³⁰⁾ Wearable devices that measure health status, such as electrocardiographs, heart rate monitors, thermometers, partial electromyography, and perspiration pH are under development.³¹⁻³⁵⁾ Studies on the uses of these devices suggest clinical practicality of PGHD for preventing cardiovascular and cerebrovascular disease and for cardiac rehabilitation.

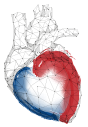


Table 1. A sample of studies on patient-generated health data for the prevention and management of cardiovascular diseases

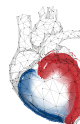
Study	Data	Research purpose/method	Findings	Limitations/future work
Lee et al. ¹⁸⁾	Blood pressure	Proposed blood pressure estimation algorithm using the relationship between blood flow and electrocardiogram results	Pulse wave velocity was strongly correlated with blood pressure	Stronger correlation with diastolic blood pressure than systolic blood pressure, which directly related to pulse wave
Prokhorov et al. ¹⁹⁾	Low-frequency oscillation of the pulse and blood flow (index [which may worsen during acute myocardial infarction and hypertension])	Developed a mobile app to measure 24-hour pulse and blood flow data to assess cardiovascular status in real time, continuously record photoplethysmogram signals from the finger, and monitor synchronization of pulse and vibration of blood flow	The difference between the index s value calculated only using the photoplethysmogram and the index s value calculated on the electrocardiogram as well was less than 2%	Earlobe data for photoplethysmograms will be added
Ahn and Cho ²⁰⁾	Heart sounds	Machine learning technique assessed cardiovascular disease using heart sounds obtained via smartphone	Age negatively related to the ease of the analysis of heart murmur	Results confirmed only on android devices using limited data (no atrial fibrillation and diastolic murmur)
Lee and Jung ²¹⁾	Heartrate	Photoplethysmogram sensor measured heartrate and transmitted the RR interval* to a personal computer	Statistically significant correlation with heartrate measurement equipment	Further miniaturization and measurement on smartphone
Fang et al. ²²⁾	Electrocardiogram, heartrate, blood pressure, globin insulin, electroencephalogram, and so on	Device measurement and patient self-measurement	Designed a mobile early warning system that immediately alerts the patient's guardian, medical staff, and/or nearby hospital	After collecting data, it is necessary to identify anomalies to further develop and implement the system
Lee et al. ²³⁾	Electrocardiogram, arterial pulse wave, pulse wave velocity, accelerated arterial pulse wave	Monitored cardiovascular system via wrist device with data sent to smartphone via Bluetooth in real time	Arterial pulse wave measurement error less than 1%	Needs future verification with many other patients
Villamil et al. ²⁴⁾	Mobile electrocardiogram	Calculated cardiovascular risk with electrocardiogram data transmitted to electronic medical records	Cardiovascular risk assessed on android devices in low- and middle-income countries	Needs verification with electrocardiogram measured using 3 leads
Shyamkumar et al. ²⁵⁾	Electrocardiogram, heartrate, blood pressure	- Shirt sensor (e-bro) for men and bra sensor (e-bra) for women - Transmits electrocardiogram, heartrate, and blood pressure data to personal computer and smartphone	- Tracked chronic conditions related to autonomous nervous regulation of cardiac activity - Detected t-wave inversion	Needs an app to check the data using a wearable sensor that monitors breathing and blood oxygen levels
Kim ²⁶⁾	Aging index	Detect and evaluate vascular stiffness in real time using a smartphone	Vascular stiffness monitoring provided a preventive approach	Needs verification by many other patients in more diverse environments

*The time elapsed between 2 successive R-waves of the QRS signal on the electrocardiogram and its reciprocal, the heartrate; a function of intrinsic properties of the sinus node as well as autonomic influences.

However, although some devices, such as smart watches and smart shirts, demonstrated potential for generating and measuring data, most wearable devices are not easy to use and they are inconvenient, and, thus, their clinical effectiveness is difficult to verify. In Korea's current legal and clinical contexts, it is too early to implement patient services that include feedback based on PGHD collected by healthcare providers.

DATA INTEGRATION

Platforms are needed to merge data for analytical purposes, and studies on a variety of platforms have been conducted regarding aspects of health other than cardiovascular and cerebrovascular diseases. The integrated platform named Beiwe includes a research portal, mobile application, database, data modeling, and analytical tools to identify symptoms and signs of disease at home and to instantly quantify the data.³⁶⁾ Platforms must be as simple as possible and easy to intuitively operate. In Korea, a design study was conducted on the Heartbeat integrated mobile platform, which supports patients' physical exercise, management of hypertension or diabetes medications, management of blood pressure/blood sugar, and smoking cessation, all aimed at preventing cardiovascular and cerebrovascular



diseases.³⁷⁾ Additional studies are needed to verify the applicability and efficacy of these platforms for preventing and managing cardiovascular and cerebrovascular diseases.

PRACTICAL USES OF PGHD DATA

An important characteristic of PGHD is that it consistently measures patients' present conditions, meaning that this approach monitors patients in real time. It would be even better to add direct monitoring and feedback from healthcare professionals to this function, but, with the current technology, that is an unrealistic goal. However, as diverse high-quality data accumulate and methodological analytical methods continue to improve, data-focused feedback is likely to become a patient service.

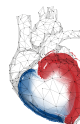
PGHD for providing services

The main reason to collect PGHD is to develop services for preventing and managing cardiovascular and cerebrovascular diseases. One study about changes to everyday behaviors of a high-risk group by providing specific services positively influenced waist circumference and dyslipidemia levels.³⁸⁾ It is expected that sensors will soon enable data analysis, and medical professionals will be able to give direct accurate feedback.³⁹⁾ The American Psychiatric Association has created a smartphone application evaluation workgroup and the Massachusetts Psychiatric Association's Health Information Technical Committee has developed a mobile application evaluation model, online application evaluation standards, and an online format for managing mental health.⁴⁰⁾ However, in Korea, even when medical professionals have the opportunity to evaluate data from mobile applications, using the data to inform actual treatment decisions is challenging owing to the brief length of consultations. Thus, in Korea, there is growing interest in increasing the utilization of data-based clinical decision support systems.

PGHD to support clinical decisions

A fundamental goal of digital healthcare is the exchange of medical data between medical professionals and patients. Remote healthcare services for disease management and prevention, referred to in Korea as “telemedicine,” are in high demand in Korea, but there are many challenges.⁴¹⁾ For one thing, to improve digital healthcare, patients need to be skilled in obtaining their health information. Patients need to understand their situations to be able to interpret their health status and to correctly manage their health data. Therefore, diverse health feedback must be consistently provided to remote patients. Significant efforts are being made to develop algorithms to enable patients to independently analyze and interpret their personal data without direct, real-time interventions by healthcare professionals.

The effects of mobile clinical decision support systems, which help to diagnose cardiovascular disease based on heart rates measured by mobile sensors and transmitted via smartphones, have been verified.⁴²⁾ The U.S. National Heart, Lung, and Blood Institute makes simple diagnoses using a score algorithm and a mobile app cardiovascular disease prediction and prevention system developed from data on about 4,000 people collected over 10 years.⁴³⁾ This tool lowered the risk of cardiovascular disease and provided healthy guidelines for changing lifestyle behaviors. A 2016 survey of doctors in Europe revealed that most of them knew the guidelines for preventing cardiovascular disease, but only 36–57% of them followed them because they lacked time or knowledge. These obstacles might be overcome if technologies such as mobile apps were used.⁴⁴⁾ As information and communication technologies continue



to develop, smartphone apps, such as chatbots, will be able to converse, and new tools, such as augmented reality and virtual reality, will become available. Healthcare professionals must familiarize themselves with these technologies to make appropriate clinical decisions.⁴⁵⁾

CONCLUSION

This paper describes the recent research trends in data generation, integration, and application for preventing and treating cardiovascular and cerebrovascular diseases using PGHD. Traditional healthcare services are expected to continue for the short term in Korea because of technological limitations in healthcare professionals' abilities to provide active feedback. However, ultimately, the most important factor to interpreting PGHD is whether the data yield medically valid and practical results. Mobile technologies, such as smartphone apps, are being emphasized as viable tools for preventing cardiovascular and cerebrovascular diseases, but we have verified their potentials and effects only in controlled environments. To obtain useful results for feasible clinical applications, we need to move beyond data collection. Medical concept applications are essential to developing PGHD into practical knowledge. Healthcare professionals must maintain their interest and focus on this matter.

SUPPLEMENTARY MATERIAL

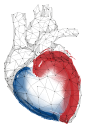
Supplementary Data 1

Recent Technology-Driven Advancements in Cardiovascular Disease Prevention in Korea (Korean version)

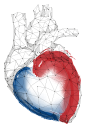
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