Cardiac and Cardiovascular Research (2021) Volume 2 Issue 2,*11 pages*.
doi: 10.54517/ccrr.v2i2.1907

Asia Pacific Academy of Science Pte. Ltd.

REVIEW ARTICLE

Current situation and research prospect of home monitoring technology for cardiovascular system

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ABSTRACT

Cardiovascular disease has become the leading cause of death in China. Home medical monitoring of cardiovascular circulatory system (cardiovascular system for short) is of great significance for the early detection, diagnosis and treatment of cardiovascular diseases. Physiological parameters of the cardiovascular system mainly include blood pressure, cardiac output, blood glucose content, blood oxygen saturation, ECG, respiration, etc. These physiological parameters need long-term daily monitoring to find the abnormalities and changes of the system. Therefore, home medical monitoring is necessary. This paper reviews the current situation of home monitoring technology for the main parameters of cardiovascular system in recent years, and prospects its future research trend.

Keywords: cardiovascular system; cardiovascular disease; household monitoring; medical instruments; research prospect

1.Introduction

As one of the eight systems of the human body, the blood circulation system plays an irreplaceable role in the normal work of the human body. As an important part of the blood circulation system, the monitoring of the physiological parameters of the cardiovascular system, such as blood pressure, cardiac output, blood glucose content, blood oxygen saturation, ECG, respiration and so on, has a decisive significance for human health.

Cardiovascular and cerebrovascular diseases with hypertension, arteriosclerosis and stroke as the main symptoms have become one of the main causes of death in China. According to the "salt and hypertension", a publicity book on Hypertension Day in 2009, the prevalence of hypertension among adults in 2002 was 188%, an increase of 31% over 1991. It is estimated that there are 200million people suffering from hypertension in China, and 2 of every 10 adults have hypertension. In some areas of northern China, the prevalence rate of hypertension was 30%. However, the awareness rate, treatment rate and control rate of hypertension are very low. In 2002, the above three rates were 30%, 25% and 6% respectively; In recent years, thanks to the vigorous publicity and hard work of the government, professional groups and the media, the above three rates have increased to 45%, 30% and 8% respectively. Cardiovascular and cerebrovascular diseases account for the first death among residents, accounting for about 35%~40%, which has become an important public health problem in China. Moreover, the prevalence and incidence rate are still

ARTICLE INFO
Received: September 8, 2021 | Accepted: October 15, 2021 | Available online: Novemebr 11, 2021

CITATION
Qu X, Lu S, Zhang T, et al. Current situation and research prospect of home monitoring technology for cardiovascular system. Cardiac and Cardiovascular Research 2021; 2(2): 11 pages.

rising by 5% every year. However, there are still many unknown parts about the pathogenesis of hypertension, which is the inducement of various cardiovascular and cerebrovascular diseases. Because blood pressure changes dynamically, in order to understand the causes and pathogenesis of hypertension, we must increase the monitoring of blood pressure and master more data of blood pressure changes.

Recent studies have confirmed the importance of continuous blood pressure monitoring. Hypertension before and after getting up, i.e. Hypertension in the morning and at night when the blood pressure does not drop during bedtime, are closely related to the incidence of stroke, myocardial infarction and other cardiovascular and cerebrovascular diseases. Therefore, continuous monitoring of blood pressure before and after getting up and during bedtime is very necessary [1].

Among the people aged 18 and over in China, the number of patients with diabetes is 116%, and the number of potential patients with diabetes is 501%. This shows that one in 10 people in China is a patient, and nearly 500million adults may become diabetes patients in the next few years. As an important parameter of cardiovascular system, cardiac output reflects the strength and normality of cardiac ejection function. It is usually used for intraoperative monitoring and intensive care. In home monitoring, cardiac index (cardiac output / body surface area) and stroke index (cardiac output / (heart rate × The readmission rate of heart failure patients with low body surface area for a long time is generally high [2]. Continuous monitoring of cardiac output and blood pressure can also predict the changes of vascular terminal impedance [3].

In addition, the monitoring of blood oxygen saturation and heart beats, the use of oxygen therapy for the treatment of cardiovascular and respiratory diseases among the elderly at home in an aging society, and the discrimination of stress symptoms such as dizziness, chest tightness, fatigue, lethargy, sluggish response, and inattention of office workers under the pressure of daily work are of great significance.

With the increasing aging of the population in China, the health problems and pension problems of the empty nest elderly have become more prominent. Family medical technology and its family medical monitoring, especially the daily monitoring of the cardiovascular system, play a more prominent role in the early prevention, early diagnosis and early treatment of cardiovascular and cerebrovascular diseases. It can be predicted that home medical monitoring technology and instruments will usher in a new stage of development, and the use of home medical technology will be more popular.

2. Current situation of home monitoring technology for cardiovascular system

2.1. Research status of blood pressure monitoring technology

Blood pressure monitoring technology suitable for families should generally have the conditions of non-invasive detection and simple operation. Mercury sphygmomanometer based on Coriolis sound method and electronic sphygmomanometer based on Oscillographic method are popular household blood pressure measuring instruments at present. Mercury sphygmomanometer is the "gold standard" for noninvasive blood pressure measurement. It is also the main instrument widely used by medical institutions and widely recognized by the industry. However, the mercury sphygmomanometer has high professional requirements, so it is necessary to accurately judge the vascular sound during cuff decompression during daily blood pressure

monitoring at home. It is difficult for ordinary people, especially the empty nest elderly, and even the subjective measurement error introduced by the use can not be underestimated [4].

The electronic sphygmomanometer adopts the principle of Oscillographic method, and obtains the systolic and diastolic blood pressure of arterial blood vessels through the method of waveform characteristics and amplitude coefficient. This detection method is constantly improved [5-7]. However, there is no unified calculation standard for this detection method, and the difference of measurement results is large, so the accuracy of blood pressure detection cannot be fundamentally solved [8].

Accurate grasp of blood pressure changes and daily effective monitoring, and use the continuous blood pressure detection technology to achieve 24-hour (settable) continuous blood pressure monitoring. The research on continuous blood pressure monitoring technology can be traced back to the 1960s, starting from Europe and Japan, and then spread to many countries and regions in the world. After decades of continuous research, a number of scientific research achievements have been made. Its representative detection methods include the tension measurement method proposed by Pressman et al. And Mackay et al. [9-10]; gribbin et al. Proposed using pulse wave propagation velocity method (PWV) [11]; penaz detection method [12-13] or volume compensation method [14-15] proposed by shanyuexianyi et al. The principle of tensiometry is simple. It does not need cuff and its air compression system, nor does it cause peripheral vascular congestion. When the physiological state of the subject changes, the pressure applied outside the blood vessel can not change synchronously with the average blood pressure inside the blood vessel, resulting in measurement error. Moreover, the system itself cannot calibrate the blood pressure, so other indirect methods should be used for calibration. In addition, small changes in the detection position will bring about large changes in the detection value. Colin Co., Ltd. Of Japan has developed a prototype of a continuous blood pressure detection device by using this method. However, due to the strict restriction on the detection position and cumbersome calibration, the practicality of the system has plagued the promotion of the system for many years.

The method of indirect measurement of blood pressure through pulse wave parameters completely eliminates the restraint of inflatable cuff on subjects, so there is no need for inflatable cuff in the measurement process. Only the pulse wave conduction time is detected, and the blood pressure per stroke can be calculated indirectly. Therefore, as a new way of continuous blood pressure measurement, many scholars began to explore this method [16-17]. The experimental results show that the pulse wave propagation velocity changes with blood pressure, but PWV is not completely linear with blood pressure, and is related to the characteristic parameters of the measured individual. In order to improve the accuracy and practicability of detection, researchers have proposed a variety of specific methods and conducted experimental research [18-19]. However, the method of indirect measurement of blood pressure by pulse wave parameters is still far from being practical.

At present, the more mature method for continuous blood pressure detection is penaz detection method or volume compensation method. The detection principle is to calculate the photoelectric volume value of the artery in the unloaded state by pressurizing the artery. At the same time, the servo pressurization system is used to compensate the change of the arterial photoelectric volume caused by the change of the arterial internal pressure, so as to maintain the arterial photoelectric volume in the unloaded state. At this time, the internal pressure of the cuff is approximately equal to the arterial pressure, and the arterial blood pressure can be

measured indirectly by measuring the internal pressure of the cuff [20]. Since the invention of volume compensation method, improving its detection accuracy and detection conditions has always been the main problem discussed and studied.

Penaz first suggested that the photoelectric volume value of the artery corresponding to the pressure at 1/3 of the arterial pressure waveform should be used as the photoelectric volume value of the unloaded state, and pressure compensation should be carried out accordingly. Shan Yuexian and others found through experimental research that the photoelectric volume value corresponding to the average blood pressure is the photoelectric volume value in the unloaded state. According to the principle of penaz detection method, CN system of Austria and FMS of the Netherlands have developed a continuous blood pressure detection device with the finger artery as the detection object. These devices have been used in clinical practice and have good effects, but they are large in size. In order to realize daily monitoring at home, they need to be further miniaturized. Tanaka Zhixin et al. And Japan medisense Co., Ltd. Developed a portable continuous blood pressure detection device using the volume compensation method to detect the digital artery or the prefrontal artery [21-22]. This device takes the finger artery as the detection object, and can successfully detect the change of each pressure wave of blood pressure by using the whole week compression cuff compression, which is in good agreement with the invasive method. However, the problem caused by venous occlusion is difficult to solve. In recent years, in order to overcome the problem of congestion caused by the digital artery as the detection object, songyilin and others have developed a three-dimensional finger local pressure continuous blood pressure detection device [23], which partially solves the problem of congestion during long-term continuous blood pressure detection. However, the experiment shows that the blood pressure measurement value is easily affected by the peripheral nerve activity when the finger artery is the detection object. Tanaka Zhixin et al. Tried to take the radial artery of the wrist as the test object, and used the disc cuff to implement the continuous pressure detection method [24]; gaoshumei et al. Improved and conducted experimental research on the continuous blood pressure detection system with radial artery as the detection object [25].

In recent years, researchers have mainly focused on improving detection accuracy, reducing detection discreteness and comfort in long-term detection, that is, solving the problem of peripheral blood vessel congestion. For this reason, the researchers proposed a solution of taking the radial artery as the detection object and using local compression cuff [26]; in order to solve the problem of rapid correction of servo target value in continuous blood pressure monitoring, Yoshizawa and others also put forward relevant improvement methods to improve this situation [27].

At present, the research of home blood pressure monitoring technology mainly focuses on improving the detection accuracy of blood pressure and the practicability of the device.

2.2. Study on cardiac output monitoring technology

Current cardiac output (CO) reflects the functional status of the whole circulatory system, including cardiac mechanical work and hemodynamics, preload and afterload, heart rate and myocardial contractility. In anesthesia and ICU, CO is often used to monitor critically ill patients and those with hemodynamic instability to guide the treatment of patients and observe the progress of the disease [28-29].

Although cardiac output monitoring is an important means for medical institutions to observe the condition, its daily family monitoring is also of great significance to

understand the cardiac function. Cardiac output measurement methods have developed from invasive to non-invasive, from static to dynamic, and have formed several relatively mature methods. Typical cardiac output measurement methods include thermal dilution method and Fick method, which are invasive methods, also known as the "gold standard" for cardiac output measurement. However, due to the factors such as invasive detection, complex operation and safety of use, it has not been widely used. In recent years, minimally invasive and non-invasive measurement methods such as ultrasonic Doppler, partial CO2 rebreathing, nuclear magnetic resonance, pulse wave tracing and electrical impedance have attracted great attention.

The main consideration in home medical monitoring is the noninvasive measurement of cardiac output. Therefore, the cardiac output monitoring instrument based on chest electrical impedance method has great advantages. The chest electrical impedance method is based on nyboer's chest cylinder model and Kubicek's stroke volume (SV) estimation formula [30]. When the traditional chest impedance method is used to measure cardiac output, the strip electrode is usually used. Long time monitoring with electrodes will cause redness, swelling, dermatitis, sweating, falling off and other problems. For this reason, the researchers put forward a scheme to replace the strip electrode with a point electrode [31]. When using point electrode to measure cardiac output, it needs to meet the equal gradient change of chest impedance and no current concentration at the electrode bonding position. The researchers discussed the optimal electrode configuration for unrestrained cardiac output measurement based on electrical impedance method and the applicability of the chest cylinder model when using point electrode for noninvasive cardiac output measurement [32-33]. The further research on home monitoring methods of cardiac output is still focused on improving the detection accuracy and comfort.

2.3. Current situation of blood glucose monitoring technology

The stability of blood glucose concentration in human body is very important for the normal work of various organs and tissues and the maintenance of normal metabolism. The fasting blood glucose concentration of normal people is 39~61 mmol/ L. Fasting blood glucose concentration >70 mmol/ L is called hyperglycemia, blood glucose concentration <39 mmol/ L is called hypoglycemia, and blood glucose concentration <28 mmol/ L is called hypoglycemia [34-35].

Diabetes comes from the high blood sugar level in the body. Diabetes not only brings great pain and inconvenience to patients, but also various possible acute and chronic complications of diabetes seriously affect the health of patients and even threaten their lives. For example, diabetes foot, diabetic nephropathy and cardiovascular diseases caused by diabetes. At this stage, the research and development of accurate, effective and convenient blood glucose detection is the premise to help diabetes patients effectively control blood glucose [36].

The early hypoglycemia symptoms are mainly nerve excitation, especially sympathetic nerve excitation, manifested as palpitation, fatigue, sweating, hunger, pale face, tremor, nausea and vomiting, and the more serious hypoglycemia is often accompanied by the central nervous system glucose deficiency, resulting in confusion, mental disorder, limb paralysis, incontinence, sleepiness, coma and other symptoms [37].

Whether blood sugar is high or low, it will cause certain harm to human body. For patients with diabetes, taking some hypoglycemic drugs is a common control method, and it is necessary

to monitor blood glucose and master blood glucose data. The existing home-based method for detecting blood glucose is an electronic instrument for measuring blood glucose level. The current blood glucose meter can be divided into photoelectric type and electrode type from the working principle. The photoelectric blood glucose meter is similar to a CD player. It has a photoelectric probe. The photoelectric probe is exposed to the outside for a long time and is vulnerable to external environmental pollution. The detection error is about ± 08. The price is low and the service life is short. The structure of electrode type blood glucose meter is built-in at the electrode mouth, which can effectively avoid external pollution to the electrode. The detection error is about ± 05. It does not need calibration for normal use and has a long service life.

Blood glucose detection methods include wiping blood and sucking blood. Blood smearing method usually takes a large amount of blood, and patients will have a certain sense of pain. Excessive blood collection will affect the test results, while insufficient blood collection will lead to operation failure and waste of test paper. The blood glucose detection methods of this blood collection method are mostly photoelectric. The blood sucking method controls the blood volume by itself, which does not produce result deviation because of the blood volume. The operation is relatively convenient. The measurement can be realized by clicking a blood drop with a test paper [38].

With the development of science and technology, blood glucose detection has changed from invasive methods to minimally invasive methods, and then to non-invasive methods. There are more and more methods combined with household medical instruments. The reverse ion electroosmosis analysis method can be well combined with household medical monitoring instruments. In the non-invasive blood glucose detection, if the glucose molecules in the blood can gather on the surface of the skin, the blood glucose detection is convenient. The usual ion permeation method uses electric current to transmit the drug through the skin. When the reverse ion permeation method is used for noninvasive blood glucose detection, the movement direction of glucose molecule is just opposite to that of the usual drug. The skin surface of normal human body is negatively charged. A small constant current with positive ions is applied to the skin surface. When the current is energized, the positive ions migrate to the negative pole, forming an ion circulation from the positive pole to the negative pole. The ion circulation can move glucose under the skin to the surface of the skin. The glucose concentration carried by the ion circulation is correlated with the blood glucose concentration. The blood glucose concentration can be obtained by monitoring the glucose concentration on the surface of the skin and calculating through the relevant formula [39].

According to the principle of reverse ion electroosmosis, Cygnus company of the United States has developed a glucose detection watch. Wearing it can realize non-invasive continuous blood glucose measurement without blood collection, which is convenient to use. When the reverse ion electroosmosis method is used to detect blood glucose, attention should be paid to the problems of sweating and high body temperature at the detection part, which will affect the normal operation of the current circuit. In addition, constant current applied to human skin for a long time will cause skin tingling, redness and swelling. Therefore, reverse ion electroosmosis also needs research and development [40].

In addition, the non-invasive blood glucose measurement method using spectroscopy is also being studied and applied.

2.4. Research status of oxygen saturation monitoring technology

Spo2 is an important parameter of respiratory and circulatory system. The metabolism of the human body is carried out by obtaining oxygen through respiration, oxygen enters the blood through oxygen cooperation, and the blood is sent to the tissue cells of various parts through the circulatory system. Monitoring arterial oxygen saturation can evaluate the ability of hemoglobin to carry oxygen and the ability of blood to deliver oxygen. Therefore, daily monitoring of blood oxygen saturation is of great significance in both clinical diagnosis and daily health management [41]. The oxygen saturation of normal human arterial blood is 95%~98%, and that of venous blood is about 75%.

The traditional method for measuring blood oxygen saturation is to collect blood from human body first, and then use the blood gas analyzer for electrochemical analysis to measure the partial pressure of blood oxygen PO2 and calculate the oxygen saturation of bleeding [42]. This method belongs to in vitro measurement, which is relatively troublesome due to the need for blood collection. Moreover, it brings some pain to patients and is difficult to apply to family monitoring.

With the development of science and technology, many non-invasive methods for measuring blood oxygen saturation have been proposed. The two wavelength spectrophotometry is suitable for monitoring blood oxygen saturation at home. At present, the household oxygen saturation monitor uses a fingertip photoelectric sensor, which takes the finger as the detection object. The two sensors used in the sensor head are red light with a wavelength of 660 nm and near-infrared light with a wavelength of 940 nm. During measurement, the finger is inserted into the rubber channel and fully extended, the sensor head is injected into the light source, the light transmission intensity through the tissue bed is measured, and the hemoglobin concentration and blood oxygen saturation are calculated. Fingertip oxygen saturation monitor is a convenient, continuous and non-invasive blood oxygen detection instrument [43].

The oxygen saturation detected by finger cuff oxygen saturation generally indicates the arterial oxygen saturation. In order to correctly grasp the consumption of blood oxygen, sometimes it is necessary to detect the oxygen saturation of venous blood. When two wavelength spectrophotometry is used to detect arterial and venous oxygen saturation, considering the different absorption of transmitted light or reflected light by different tissues at the detection site of the human body, the detection site can be simplified into an optical absorption model composed of muscle tissue, artery and vein. When the test part is pressurized through the cuff, the optical properties of the muscle tissue can be considered to be unchanged because the muscle tissue is incompressible, that is, its thickness does not change during the compression process. Under the cuff pressure, the volume of venous vessels and arterial vessels will decrease until they are closed, which brings about changes in light absorption characteristics. The pressure of venous vessels was low, and they were deformed and closed completely under the action of cuff pressure; the arterial blood vessels are gradually pressurized, so that the arterial blood vessels are completely closed. The changes of light absorption characteristics during cuff compression were recorded. It was found that there was an inflection point on the light absorption characteristic curve due to the different mechanical properties of static and arterial vessels. The former part of this inflection point is the change of light absorption characteristics of venous blood, and the later part is the change of light absorption characteristics of arterial blood. With the inflection point as the dividing point, the components of static and arterial blood are separated by light absorption characteristics [44].

The sensing device for detecting arterial and venous oxygen saturation by two wavelength spectrophotometry can be improved on the basis of the photoelectric sensing device for blood pressure detection to form a composite sensing device. By using a set of sensing devices to measure multiple physiological parameters, the number of sensors affixed to the user is reduced.

2.5. Current status of ECG monitoring technology

ECG plays a very important role in the physiological information parameters of human body. In many cases, patients will be tested for ECG signals in hospitals [45-46].

At present, portable ECG monitor is the main instrument suitable for home heart detection and self-monitoring. The detection principle of the portable ECG monitor is the same as that of the ECG machine used in medical institutions. Its advantages are easy to carry, simple to operate, timely detection and adaptive adjustment of ECG display amplitude. It provides an effective detection means for the early detection of heart diseases and the early prevention of sub-health people. At the same time, the daily monitoring of the instrument is also helpful to judge the cause of clinical symptoms, it is beneficial to monitor and reduce the risk of stroke, myocardial infarction and sudden heart failure death, and effectively feedback the treatment effect and actual efficacy.

The onset of heart disease is often sudden and transient. Many patients with heart disease cannot detect the relevant information of heart function at that time because they do not have ready-made detection instruments; when going to the hospital, the heart function often returns to normal, which is difficult to recover to the condition at the time of onset, so that the cause of the disease can not be found. Therefore, the portable ECG monitor can be used to monitor the ECG at any time and anywhere, especially when the heart is uncomfortable, so as to timely capture and record the abnormal waveform and heart rate of the heart, which has laid a good foundation for the diagnosis and etiology of heart disease.

3. Research prospect

China's aging population is further accelerated, and the number of empty nester families is further increased. Family medical monitoring is an effective means to master health status, disease prevention, rehabilitation care and other relevant information. The continuous improvement of people's living standards and the strengthening of health awareness have promoted the increase of consumption of medical and health care products and services. Compared with the past, ordinary people also pay more attention to medical care, monitoring instruments and disease prevention related to their own health status. With the strong support of national policies and the improvement of family medical consumption capacity, people put forward higher requirements for the function, use, operation convenience and price of family medical monitoring instruments, which also promoted the further improvement of family medical testing technology and instrument research and development level.

Home medical monitoring of cardiovascular diseases is of great significance to the early diagnosis and treatment of diseases and even to saving lives. More and more attention has been paid to it. More funds and technical forces have been invested in the development of home monitoring technology and instruments of cardiovascular system. It is expected that more in-depth research will be carried out in the following aspects.

1) Realize unconscious, unrestrained and non-invasive measurement to a greater extent. Considering the objects of family medical

monitoring and the effectiveness of monitoring data, the monitoring methods should be combined with the furniture and appliances used by people in the family as far as possible, so that people can inadvertently complete the detection and collection of relevant physiological information. For example, pillows and mattresses with sensing devices can detect and record the number of heart beats, breathing, snoring, body movements, etc. During sleep; the multifunctional toilet seat with sensor detection device inside can detect and record the blood pressure, heart beats, body weight, excretion volume and excretion speed when people use the toilet; there are also watches and mobile phones that can detect the number of heart beats and walking steps. In addition, the non-invasive measurement of home monitoring is also advancing. For example, non-invasive blood glucose detection is developed by using spectral methods to replace the currently widely used minimally invasive blood glucose detection methods.

2) Reduce the number of sensors or electrodes bound or pasted on the human body, and improve the monitoring comfort. Home medical monitoring often needs to monitor multiple physiological parameters. The use of too many sensing devices is bound to cause problems such as cumbersome use and complex operation. Users will give up using it because of cumbersome use. Therefore, the development and application of composite sensor devices is imperative, for example, using a group of sensors to monitor blood pressure, cardiac beats, arterial and venous oxygen saturation at the same time.

3) Improve monitoring accuracy. Different from the medical detection instruments used in hospitals and other medical institutions, home medical monitoring instruments should have the requirements of small volume, easy to carry, simple operation, low power consumption, but at the same time, the monitoring accuracy of monitoring instruments is not high. For example, at present, the electronic sphygmomanometer with high household popularity has certain problems in both its detection principle and detection method, so its detection results can not be used as the basis for doctors' diagnosis. In the future, home medical monitoring instruments, especially cardiovascular monitoring instruments, should improve the monitoring accuracy: A. Study effective methods suitable for home cardiovascular system monitoring; b. Develop high-precision monitoring instruments to provide reliable basis for early detection and early treatment of cardiovascular diseases.

4) Application of Internet of things technology. Optimize the configuration of cardiovascular system home monitoring sensor devices, form or fix, or move, or place, or wear a home monitoring system, and through long-term daily continuous monitoring, timely master the cardiovascular system work and system health status of normal people, as well as the treatment and recovery of cardiovascular patients, so as to achieve all-round and whole process health monitoring and disease prevention, Moreover, the monitoring results can be shared with medical institutions or centers for Disease Control and prevention. When normal people have abnormal monitoring information, the system will alarm and remind them to go to the hospital for diagnosis and treatment; in case of special circumstances, patients with heart disease can be treated in time.

5) Intelligent monitoring instruments. From the future medical monitoring trend of home cardiovascular system, it will be an inevitable trend to carry out intelligent remote patient monitoring based on the connection between home medical devices and medical institutions. As intelligent medical robots, nursing robots and other intelligent monitoring instruments gradually enter the home, it can be predicted that home medical monitoring will

bring changes from scattered to system, from manual to intelligent.

Conflict of interest

The authors declare no conflict of interest.

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