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Review

The Latest Progress and Development Trend in the Research of *Ballistocardiography* (BCG) and *Seismocardiogram* (SCG) in the Field of Health Care

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Featured Application: Our team currently works on the IPBS (IPBS for the "Internet + Smart bed") system based on the BCG, using AI and Big Data algorithm to perform health management. After testing our system for a while, we found out that the IPBS system is feasible and effective in elder chronic diseases management. We believe it will bring a solution to the ageing population and create economic benefits.

Abstract: The current status of the research of *Ballistocardiography* (BCG) and *Seismocardiogram* (SCG) in the field of medical treatment, health care and nursing was analyzed systematically, and the important direction in the research was explored, to provide reference for the relevant researches. This study, based on two large databases, CNKI and PubMed, used the bibliometric analysis method to review the existing documents in the past 20 years, and made analyses on the literature of BCG and SCG for their annual changes, main countries/regions, types of research, frequently-used subject words, and important research subjects. The results show that the developed countries have taken a leading position in the researches in this field, and have made breakthroughs in some subjects, but their research results have been mainly gained in the area of research and development of the technologies, and very few have been actually industrialized into commodities. This means that in the future the researchers should focus on the transformation of BCG and SCG technologies into commercialized products, and set up quantitative health assessment models, so as to become the daily tools for people to monitor their health status and manage their own health, and as the main approaches of improving the quality of life and preventing diseases for individuals.

Keywords: *Ballistocardiography*; *Seismocardiogram*; medical care and nursing; health management and nursing; technical practice

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1. Introduction

For the past 20 years, with the innovation of sensing technology [1], many new technologies have emerged in the academic circles, enabling scholars to expand their research fields extensively, and have the opportunities to make use of the technologies that were unable to get in-depth research due to technical limitations in the past. At this time, *Ballistocardiography* (BCG) and *Seismocardiogram* (SCG) technologies see their revival.

1.1. Ballistocardiogram

The BCG signal records the movement of the heart as it pumps blood to shift the body's center of gravity during the heart beating cycle. It is the indirect medium for interpretation

of heart activities [2,3]. Its earliest discovery dated back to 1877, when Gordon et al. [4] observed the phenomenon of BCG signals, i.e., when a human body stood on a scale, the scale pointer swung regularly in synchronization with the heartbeat. This was the earliest BCG record. Then, in 1939, Starr et al. [5] were the first to systematically study body trembling caused by heart contraction. They also designed and made a platform capable of recording body movement, and systematically studied the relationship between the formation mechanism of various waveforms in BCG signals and the heart dynamics, thus laid the foundation for researching the subject of BCG [3,6]. Thereafter, during the period of 1940 to 1980, the academic circles proposed various methods for detection of BCG signals, to apply BCG technology to clinical medicine for research of various physiological parameter detection [6–8]. The expression of its typical waveforms is shown in Figure 1. The significant morphological features of its output can be used to analyze human health information [9,10]. For example, the amplitude of IJ segment reflects fluctuation of cardiac output (CO), associated with difference in aortic blood pressure [11]; and peak J, the highest peak, corresponds to the movement of ventricular valves and can be used for monitoring to predict cardiac function [12].

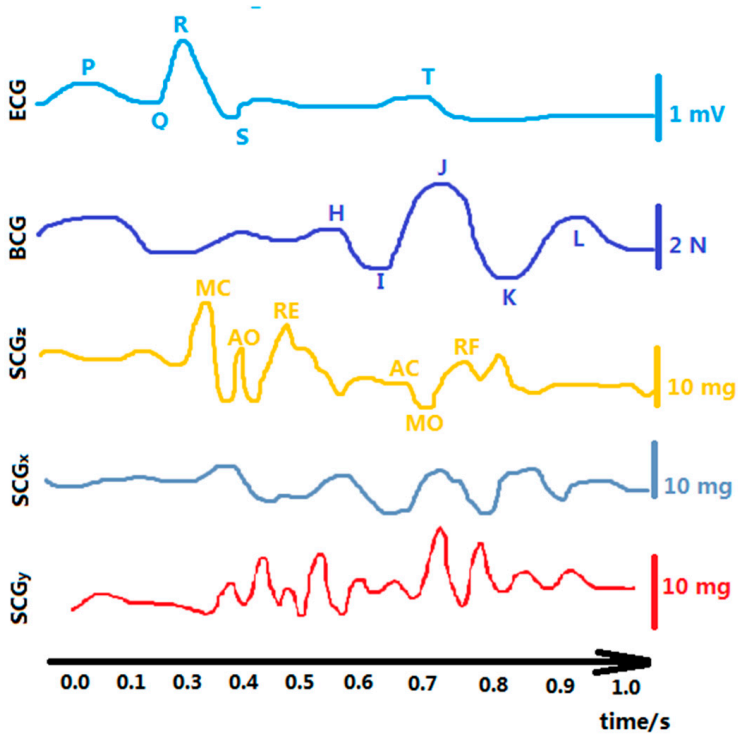


Figure 1. ECG/BCG/SCG signals.

Figure 1 shows *Electrocardiogram* (ECG), *Ballistocardiogram* (BCG), and tri-axial *Seismocardiogram* (SCG) in a human volunteer [13]. For the SCG, the x, y, and z subscripts correspond to the medial-lateral, the cranialcaudal, and the posterior-anterior axes respectively. The S1 and S2 components, and their respective fiducial markers are shown labelled: MC = mitral valve closure, AO = aortic valve opening, RE = rapid ejection, AC = Aortic valve closing, MO = mitral valve opening and RF = rapid filling.

But after the 1980s, the research of BCG was gradually stopped [6,14] for the reasons of its bulky equipment and complicated signal analysis, which caused the researchers to turn their sight to electrocardiograph (ECG) shows as Figure 1. ECG is a graphical representation of heart voltage over time measured by electrodes placed on the skin. It is a standard non-invasive diagnostic and monitoring technique used to record far-field cardiac electrophysiological signals. During normal sinus rhythm (NSR), the ECG will produce a stable and reproducible waveform of healthy subjects. This waveform is used here to

illustrate the heart cycle [13]. The ECG has some limitations, it needs to be performed by trained physicians or sonographers. Their acquisition and interpretation are operator-dependent and show non-negligible intra-operator and inter-operator variability, raising questions about their reproducibility while the acquisition and interpretation should be fully automated and quantitatively reproducible. Thus, since 2000, BCG has been popular again in research around the world for its medical potential [6].

1.2. Seismocardiogram

The SCG signal presents the vibration due to the pressure within the body and the acceleration of the blood during the diastole and systole of the cardiac cycle [15,16]. Compared with BCG and ECG signals, SCG waveform is more responsive to the changes in heart function, because its signal is directly caused by heart vibration [17,18]. The SCG monitoring position is usually set near the sternum of the human body, as shown in Figure 2. The signal is measured from the dorsal ventral direction, from the front of the subject's chest to the back [19–22]. Figure 1 shows a typical ECG, head-to-foot BCG, and tri-axial SCG. The SCG records the accelerations of the chest wall and is thus presented in units of milligram. In the SCG signal from AO to AC, the heart is in systole, while in the rest periods, the heart is in diastolic [23]. Choudhary's team [15,24,25] carried out research on the physiological waveform of SCG signal and the opening and closing of the corresponding heart aortic valve, to mark the start and end time of cardiac systolic and diastolic periods, reflect the strength of myocardial contraction, and accurately mark abnormal information in cardiac activities [19].

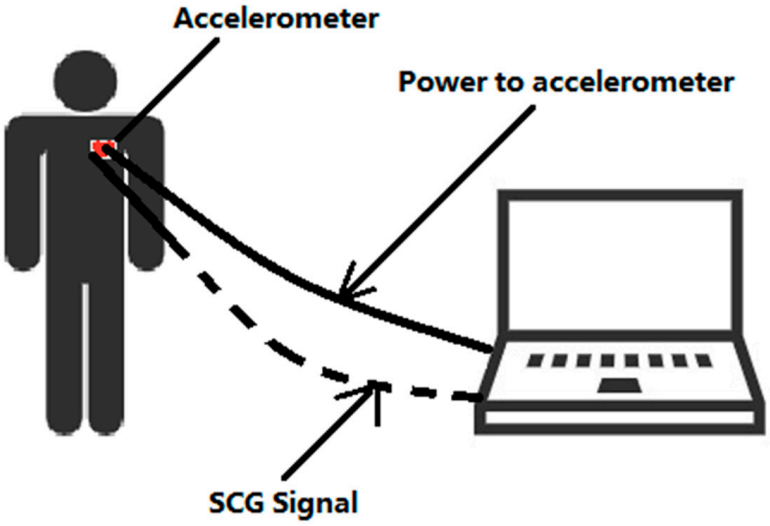


Figure 2. A schematic of SCG measurement device.

The research of SCG started from the 1960s [26]. This technology was initially used in space programs to monitor health of astronauts, and then gradually applied to clinical medicine [14]. The development of SCG was very similar to that of BCG, both declined due to limitations of technology development, and have risen again for their technical potential [26].

1.3. Revival of BCG/SCG

Since 2003, researches related to SCG/BCG technology have sprung up like mushrooms after a spring rain, with the publications of research in large quantities and high frequency, as Jähne-Raden [27] put it, the year 2003 was "the starting point for the revival of the BCG/SCG research".

One of the highlights of BCG/SCG technology that attracts researchers is its non-invasive characteristics, i.e., the measurement can be done without direct contact with the human body [28,29]. It can be seen from Figure 3 that this non-invasive sensing

technology can be mounted on a variety of carriers for measurement. Part a shows a BCG-based chair that using cuffless blood pressure measurement methods that detect the peak pressure via signals measured using photoplethysmogram (PPG) and electrocardiogram (ECG) sensors the pulse transit time (PTT) or pulse wave velocity (PWV) have been studied [30]. Part b shows a BCG-based mattress which had three accelerometers to measure the *ballistocardiogram* (BCG) [31]. Part c shows an ECG-based weighing scale which measures using dry electrodes R-J intervals were extracted as a BP correlated parameter at every cardiac cycle [32]. Part d shows a BCG-based camera A robust HR measurement method was proposed and, a bidirectional optical flow algorithm is designed to select and track valid features in the video captured by the camera [33]. Part e shows a PPG-based wearable device using a multi-location wireless vital signs monitor and head movement PPG signal [34]. Part f shows portable device placed on sternum reading simultaneously ECG and BCG signals during the flight [35]. BCG/SCG can be used in different application scenarios, such as a ward [36], a hospital waiting room [37], a MRI room [38], or at home [39], for monitoring physical health status.

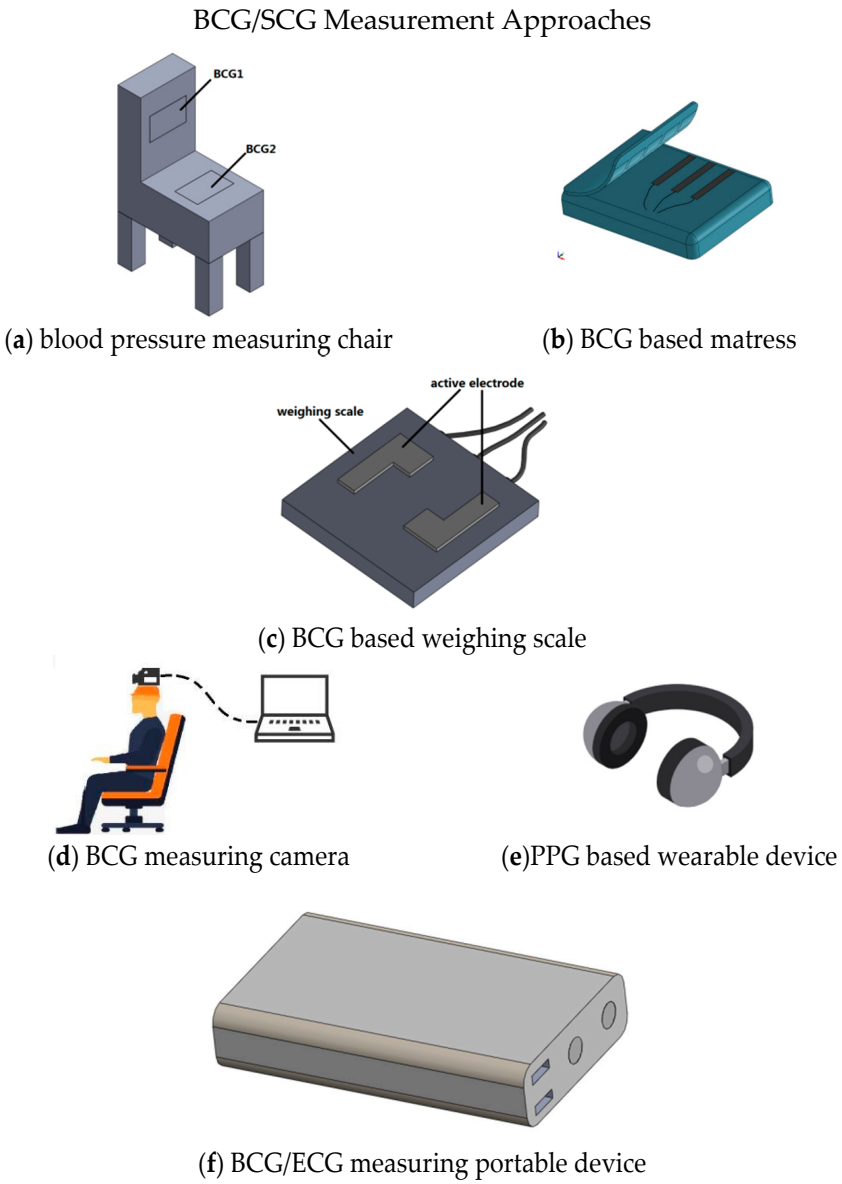


Figure 3. Various devices for BCG/SCG measurement.

Wearable devices can be carried easily in daily life realizing zero load measurement on human body [40]. With the gradual maturity of the technology related to measurement of BCG/SCG signals, the development and production costs have been gradually reduced [41], so as to meet the market demands, and be applied in wider fields such as medical treatment, health, and military applications [42]. The purpose of this study was to review the existing literature by means of bibliometrics, systematically discuss the development and trends of BCG/SCG technology since 2003 worldly, with the emphasis on the progress of the research of application of the technology, and exploration of the realization of the future technology, by analyzing the important research directions, to provide references for the research of BCG/SCG technology in the field of medical, health care and nursing.

2. Materials and Methods

2.1. Data Collection

Because BCG/SCG technology research involves multiple systems and disciplines, it is an interdisciplinary and crossover field. In order to include as many and accurate as possible the relevant documents in the field of medical treatment, health care and nursing, this study used two large databases, the compressive literature database China National Knowledge Infrastructure (CNKI) and PubMed for the publications in the recent 20 years, as the source of data retrieval for research of BCG/SCG technology. The main retrieval strategy was the papers containing "BCG/SCG technology" in the title, key words, or abstract. The supplementary retrieval strategies were: ① the papers containing "BCG/SCG technology" in the title, key words, or abstract. In PubMed and CHKI, "*Ballistocardiography*", "*Ballistocardiogram*", "*Seismocardiography*" and "*Seismocardiogram*" were used as the key words for retrieval; ② the focus of discussion in this study was the progress of the research in application, with the emphasis on the analysis of the field of medical treatment and health management. The relevant topics included detection/monitoring of basic vital signs, analysis of sleep phase, testing of cardiovascular function parameters, etc. The document types: to include literature that reflected the original research and innovation in theoretical perspectives. The retrieval period started from January 2003 and ended in December 2020, with the results of 368 related articles obtained.

2.2. Data Processing

The documents retrieved from CNKI and PubMed were used for analyzing functional analysis data, and the basic laws of bibliometrics were used as the method of data analysis, to make compressive analyses of the annual changes, main countries/regions, types of research, frequently-used subject words, and important research subjects of application of BCG/SCG technology in the field of medical treatment and health.

2.3. Standards of Classification

In order to have a compressive analysis of the direction and focus of BCG/SGC research on a global scale, the relevant documents were classified for their research fields, research environments, and research samples. Classification was done in accordance with the standards listed in Table 1 (In this study, the literature was classified according to the mutually compatible standards). For the study, analysis would be made on the representative articles selected from the classified documents.

Table 1. Standards for Classification of Documents.

Classification Standards		Description of Classification
Fields of the study	Research of technologies	The papers contain research on development of BCG/SCG technology, such as exploration of the principle of signal generation, design of signal detection devices, optimization of signal processing methods, establishment of the models for monitoring body status.
	Research of applications	Exploration and attempt aimed at practical applications of BCG/SCG.
	Field of medical treatment (application)	A branch of the category of "application". The documents intuitively indicated the assessment of BCG/SCG technology in clinic medicine for such aspects as disease diagnosis, patient health status monitoring, and postoperative recovery status.
	Field of health management (application)	A branch of the category of "application". The research of evaluation of human body health level by means of BCG/ SCG technology, especially the important role in improving health level and preventing diseases.
	Field of respiratory monitoring (medical)	A branch of the category of "medical treatment". BCG/SCG technology is used for monitoring abnormal breathing information, mainly applied in apnea and asthma.
	Field of cardiovascular health (medical)	A branch of the category of "medical treatment". This technology is mainly used for evaluation of cardiovascular status, assisting in the detection of cardiovascular diseases, such as hypertension, coronary heart disease, coronary atherosclerosis, and atrial fibrillation, etc.
	Field of sleep monitoring (medical)	A branch of the category of "medical treatment". The study explored application of BCG/SCG technology in sleep monitoring, and laid emphasis on monitoring sleep-related diseases.
	Field of sleep monitoring (health)	A branch of the category of "health". The study mainly explored application of BCG/SCG technology in sleep monitoring, and laid emphasis on evaluation of the overall level of health during sleeping.
Environment for the study	Laboratory environment	The experiment was conducted in a laboratory, and the experiment environment was strictly controlled.
	Non-laboratory environment	The experiment was conducted out of a laboratory, and the real site was affected by certain environmental variables, including the experimental tests conducted in a hospital, clinic or at home.
	Both of the above	The experiments were conducted in both the laboratory and non-laboratory environments.
	Not mentioned	What environment the experiment was conducted in was not mentioned in the article.
Samples in the study	Complete experimental samples	The experimental samples included male/female/healthy/diseased subjects.
	Sufficient experimental samples	The experimental samples did not cover the subjects of all types, but the candidates included in the samples were enough to provide the basis for experimental analysis. For example, in a study, which used BCG to monitor patients with heart failure, a group of samples, who were all patients with heart failure, were used.
	Limited experimental samples	The experimental samples were not universal, and some types of experimental subjects were ignored.
	Not mentioned	The composition of the experimental samples was not mentioned in the article.

3. Results

3.1. Annual Changes

In accordance with the above standards for classification, a total of 368 relevant documents were finally screened out from the two databases. The hot terms of BCG/SCG technology and the year-by-year changes of the number of documents in the field of medical treatment and health management, and the proportion of research focus in different fields

can be obtained from Figures 4–6. It can be seen that the scope of research and practice of this technology has been expanded, and the number of documents showed a trend of sharp increase. The developed countries headed by the US have made remarkable achievements in the research in this field, with the hot terms of their researches mainly focused on detection/monitoring of basic vital signs of human body (such as the indicators of heart rate and blood pressure), analysis of sleep phase, testing of cardiovascular function parameters, diagnosis of cardiovascular diseases, home care for the aged, and the evaluation tools for intelligent health management, etc.

Figure 4. Hot keywords in the literature.

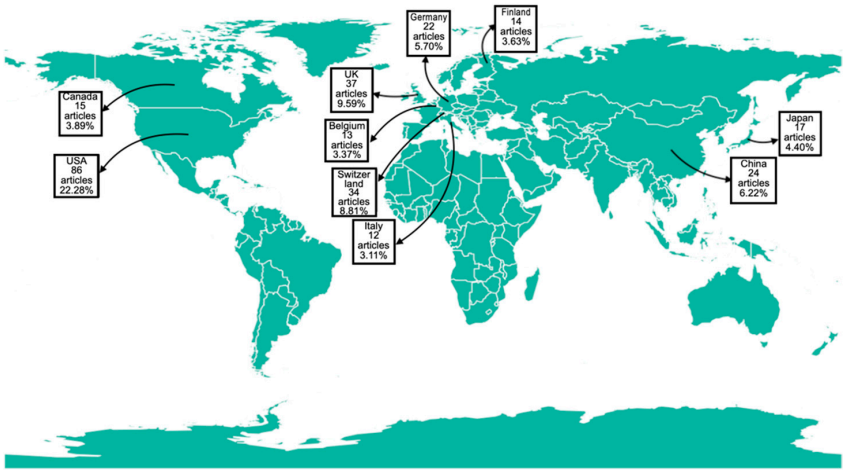


Figure 5. Distribution in countries/regions for contribution of the literature on BCG/SCG.

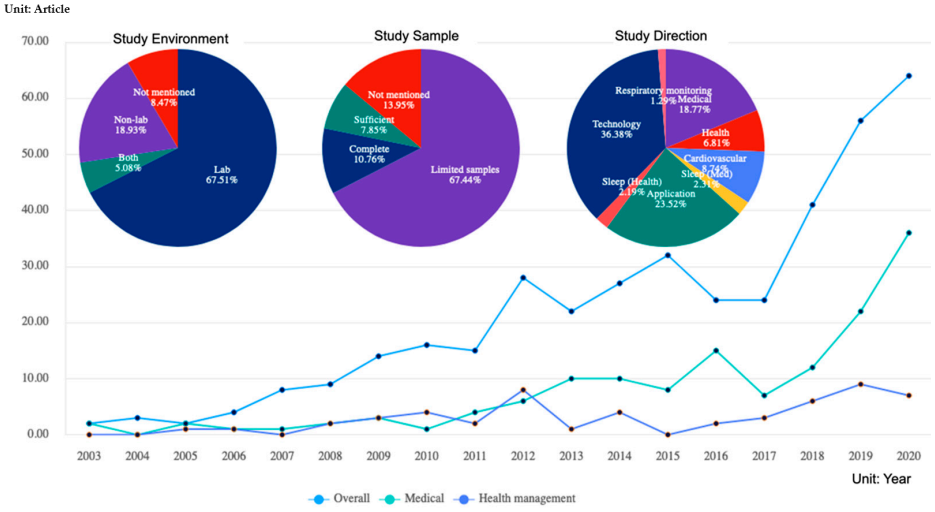


Figure 6. Annual statistics of publications and results of classification (top 10).

3.2. Areas of Research Focus

It was discovered in literature study that the main concern of academia was how to promote the application practice of BCG/SCG technology, with the focuses on such aspects as signal model establishment [43–45], signal acquisition and measurement methods [46–48], signal processing approaches [49–53], and signal standardization [54]. At the same time, the limitations were also exposed in the study, which included great variability in the waveform itself [55–58], difficulty in signal standardization system [6–24], and complexity of independent measurement and analysis of signals [59,60].

3.3. Medicine

Application of BCG/SCG in the field of medical treatment is focused on cardiac activity analysis, respiratory monitoring, and sleep screening.

3.3.1. Cardiac Activity Analysis

There are many applications of BCG/SCG in cardiac activity analysis, such as diagnosis of cardiovascular diseases [61–64], monitoring of cardiovascular status of a patient [37,65–69], and assisting in evaluation of human cardiovascular health level [70–72]. It should be noted that ECG, as the golden standard for the means of cardiovascular monitoring, always takes the leading position [73,74], therefore, BCG/SCG research, often with reference of ECG measurement results, assists waveform reference point in signal analysis [75,76].

3.3.2. Respiratory Monitoring

BCG/SCG signals can accurately detect human respiratory status [77,78], evaluate the corresponding respiratory status of human body [79–81], and diagnose respiratory diseases [82–84]. See Table 2 for the typical research.

Table 2. Typical Research of Application of BCG/SCG in Clinic Medicine in the Tears 2015–2020.

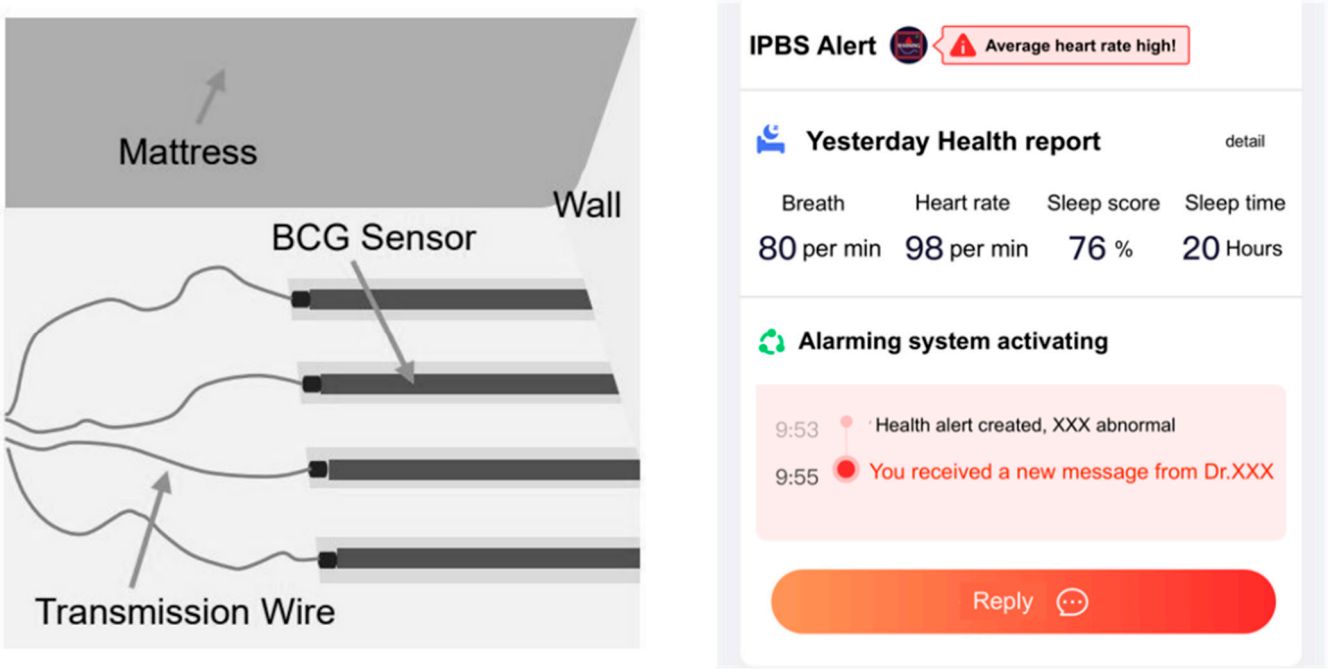
Research Contents	Researcher [Representative Article] (Year)	Conclusion
The relationship between BCG waveform and blood pressure	Shan He (2019) [61]	By comparing BCG and ECG synchronous signals, the relationship between peak R and peak J in the waveforms of these two signals was analyzed, to obtain more accurate estimation of blood pressure, for diagnosis of hypertension.
Evaluation of cardiopulmonary function with SGC	K. Sorensen (2020) [71]	The relationship between SCG signal and VO2 max was used for in-depth exploration, to analyze the reference point of waveform, and cardiorespiratory fitness (CRF) grades could thus be accurately assessed.
Application of SCG in diagnosis and rehabilitation of coronary artery disease	E. M. I. Johnson (2020) [67]	A case study of a patient after cardiac valve replacement was conducted using SCG and MRI technologies, and it was found that the morphologic changes of SCG signal during cardiac diastolic period accurately reflected the status of cardiovascular functional recovery of the patient.
SCG/BCG for patients with aortic stenosis (AS) in home settings	C. Yang (2020) [68]	A system was developed using SCG/BCG technology to monitor the health of patients with aortic stenosis (AS) in home settings to determine the severity of disease progression.
Application of BCG signal in diagnosis of cardiovascular diseases	B. Yu (2019) [65]	Detection of atrial fibrillation by means of bed-type BCG signal measurement.
BCG signal for sleep phase analysis	A. M. Yebra (2017) [79]	The dynamic time warping (DTW) method was used to obtain the morphologic changes of BCG signal waveform corresponding to different postures/breathing phases to judge the phase of sleep.
SCG for sleep phase analysis	V. Zakeri (2017) [80]	A machine learning algorithm was developed using SCG signal to independently extract the information from different breathing phases in the signal.
BCG signal for diagnosis of respiratory diseases	Zhao (2015) [82]	The heart rate variation index was calculated, and the data of sleep phase was analyzed by means of BCG signal, these can be used for diagnosis of apnea syndrome and evaluation of the status of stress of the user.

BCG/SCG technology, with its characteristics of non-invasive measurement, can realize the long-term collection of the signals of human vital signs with no interference or low interference, thus very suitable for sleep screening [85,86]. The research conducted by Zhao et al. [82] proposed to use BCG information to calculate heart rate variation index and determine sleep apnea syndrome. In addition, BCG/SCG technology can also produce a positive guiding effect on the patients with depression, for example, Alivar's [87] team used a smart bed to monitor the sleep quality of a group of children suffering from depression, analyze their sleep quality, timely intervene in their abnormal physical status, and alleviate the risk of disease deterioration.

3.4. Health Management in Elderly Care (Wellness)

With aggravated aging of the population, the issue of health management for the elderly, a special group, has attracted academic attention, and BCG/SCG technology has thus received wide attention [88,89].

In fact, as early as in 2012, Paalasma's [90] team established a self-service online sleep monitoring platform based on BCG measurement, as shown in Figure 7. Through this platform, users can access their personal sleep data to achieve intelligent health management of sleep quality. Since then, BCG/SCG measurements of sleep data have been further studied. Jaworski's [91] research team combined the measurement results of the sleep monitoring analyzer with BCG signal to realize the assessment of the body state corresponding to different sleep phases. Park's [92] team used BCG signal to study the sleep phases, and determined the state of human body in the sleep phase with the heart rate variability characteristics in BCG waveform.



(**a**) (**b**)

Figure 7. Online sleep monitoring platform: (**a**) sensor, (**b**) interface.

After the effective integration of BCG/SCG signals with other physiological information, a more comprehensive health detection system was presented. Armanfard's [93] team, for example, established a complete smart home health monitoring system, as shown in Figure 8, with the combination of such signals as ECG, PPG, EMG, BCG and IPPG. This system has achieved accurate collection of human body physiological information, and provided a powerful basic support to the realization of home health management.

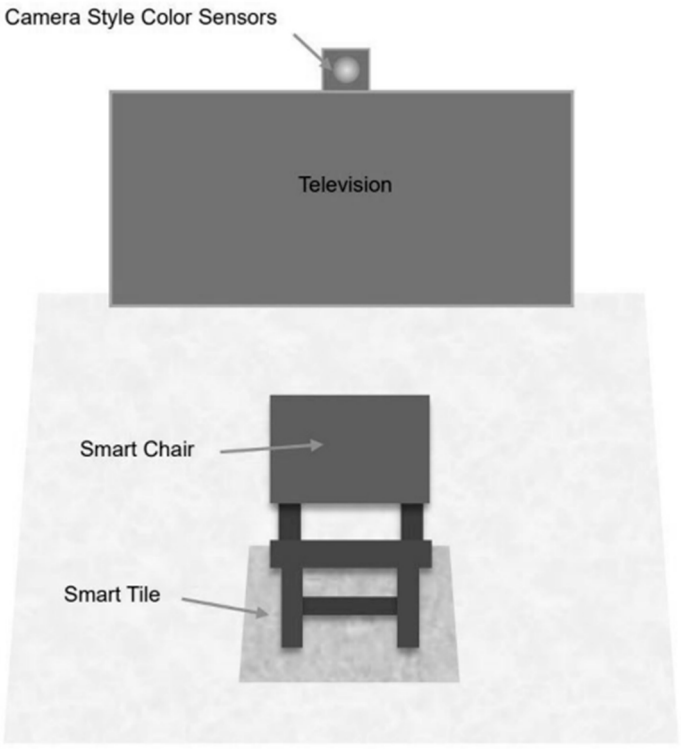


Figure 8. A schematic of smart home construction.

4. Discussion

4.1. Increasing Attention on BCG/SCG Technology

The number of papers published in a certain research field reflects, to some extent, the degree of development and the level of research of the subject. The result of this study manifests the increasing number of the literature related to BCG/SCG technology in the field of medical treatment and health. This indicates that since the revival of BCG/SCG technology in 2003, the number of literature in this field included in CNKI and PubMed databases has been on the rise, revealing that BCG/SCG technology has received more and more attention from the health care circles. Deduced according to the law of literature growth, and the Price curve theory, the current research in this field is still in a period of rapid development. Thus, it can be seen that the attention to BCG/SCG technology research has increased year by year, and has gained certain growth in the recent years.

4.2. Future Development Direction of BCG/SCG Technology

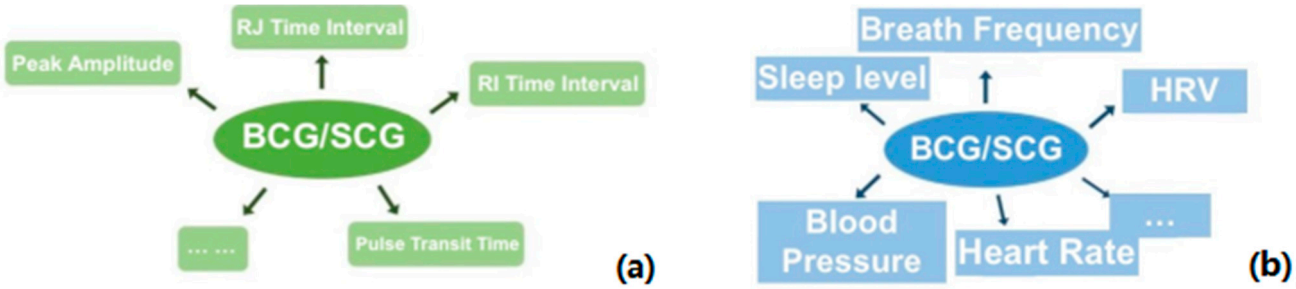
Search of literature of BCG/SCG technology in the past 20 years in the field of medicine is synthesized and presented in Figure 6, in which, 37.16% of the researches were related to cardiovascular health, 9.84% were related to application of sleep monitoring; compared with this, it accounted for 28.96% in health management research, in which, 9.29% were related to the research of sleep health management. The directions of future development of BCG and SCG are the application of sleep health management, cardiovascular monitoring and diagnosis, and respiratory testing.

4.3. Application of BCG/SCG in Medical Treatment and Health Care

4.3.1. Specificity and Comprehensiveness

The application of BCG/SCG in medical field is very specific. The researchers applied this technology to the measurement and diagnosis of cardiovascular parameters, as shown in Figure 9a. The measurement of a specific cardiovascular parameter was achieved by analyzing a characteristic value in the signal waveform, and the corresponding diseases

(heart failure, sleep apnea, atrial fibrillation, etc.) were studied. Diagnoses using BCG/SCG technology on specific diseases mentioned before have high medical reference value.



Application of BCG/SCG in measurement and diagnosis of cardiovascular parameters

Application of BCG/SCG in health management

Figure 9. The types of data under the concern.

The application of BCG/SCG in the field of health management is comprehensive. By macroscopically detecting various physiological parameters of the human body, as shown in Figure 9b, the physiological changes of the human body in a certain period of time can be calculated, and the body functions can be evaluated. Based on these functions, BCG/SCG, for its features of easy design and operation, low measurement threshold, comprehensive data analysis, etc., will have a great potential for development in the field of health care.

4.3.2. Subjectivity and Objectivity

The main part of BCG/SCG in the diagnostic monitoring in medical treatment is the signal itself, which has certain subjectivity. The research of its application in the medical field mainly focuses on the correlation between waveform characteristics and heart activities to draw monitoring conclusions. The signal itself and the analysis results are strongly causal. Therefore, BCG/SCG signal can be used to monitor and feedback human heart functional status in real time, and make decisions on the outcome of changes in the body when signal abnormalities occur. In Kim et al. [44]'s work, features of BCG signal were related to cardiovascular activities by mathematical modelling. In a normal BCG signal (see Figure 1), the time interval between the beginning of the I wave and peak of the J wave may represent the aortic pulse transit time while the ratio of the amplitude of the J-K down-stroke to the amplitude of the J wave may indicate PP (aortic pulse pressure, PP = systolic BP − diastolic BP) amplification. Both of them are powerful predictor of cardiovascular risk [94].

The application of BCG/SCG in health management is more objective, requiring long-term monitoring and evaluation of human macroscopic conditions, so as to make timely prediction when the health level declines. Although the basis of data analysis in the field of health management is still signal, with the accumulation of a large number of data, the judgment indicators of human health functions will gradually become regular and identical, because of high comprehensiveness of the data analysis results, even if one of the parameters has an error, the overall judgment will not be affected. Through multi-parameter and comprehensive analysis, balance or imbalance of human health status can be judged, and the occurrence of diseases can be predicted prospectively, thus timely intervention, prevention and control of diseases can be achieved in the early stage.

4.3.3. BCG/SCG's Field Implementation

Despite the rapid development of the research of BCG/SCG technology, the applications of this technology in real life have been still very few. This is mainly because this technology is still on the rise and has not reached full maturity, with the main manifestations:

Standardization and Reference

The lack of physiological standards of BCG/SCG waveforms and the existence of many variabilities, resulting in the difficulty to guarantee the signal quality so that it is often applied to a specific scene. In Inan Omer's review [6], he mentioned that there is a naming issue between BCG and SCG and a confused terminology when it comes to the description of specific features (peaks and valleys). Finally he proposed standardization on indication of the site of measurements, specs and orientation of sensors which will facilitate works based on BCG/SCG literature.

Noise and Interference

According to Inan et al. [6], sensor and circuit noise, motion artifacts and floor vibration can potentially corrupt BCG and SCG measurements. The sensor and circuit noise were characterized and reduced for weighing-scale-based BCG systems using an ac-bridge amplifier approach. This approach led to a SNR improvement of 6 dB. Motion artifact detection for standing BCG measurements was accomplished using auxiliary sensors as noise references; then, gating the BCG signal based on the detection of excessive noise. Floor vibration poses challenges for measurements taken on vehicles and planes. Inan Omer [95] gave an successful example of BCG measurement by using an auxiliary sensor for vibration detection and adaptive noise cancelling to cancel floor vibration artifacts.

Effect of Respiration, Posture, Sensor Adherence

In recent research of SCG signals, the authors presented some limitations concerning this relatively new measurement and their proposition of solutions regarding those points [96]. SCG has variability on its morphology decided by respiration, sensor location, subject posture etc. conforming with the conclusion of Inan Omer [6,8] where BCG had similar variability due to their nature of measurements. It needs further research to ameliorate SCG's utility. Amirtahà Taebi et al. [96] proposed to make a comprehensive SCG signal database which will play an important role in stimulating basic research and medical device development. The combination of ECG, BCG, SCG and other electro-mechanical signals was equally mentioned for more efficient diagnostics.

Modern *ballistocardiography* and seismocardiography systems may be capable of monitoring slow, longitudinal changes in cardiac function associated with a number of cardiovascular diseases. Timely noninvasive detection of subtle changes in cardiac pathophysiology may one day enable daily drug dosage adjustments, thus reducing costly and morbid rehospitalizations [97]. Recent study has shown BCG and SCG potentiality in sleep quality assessment in terms of detecting obstructive sleep apnea [98].

But BCG/SCG's the poor universality, which leads to high dependence on other reference signals, and makes it difficult to give full play to its advantages in practical applications. Despite the large number of published studies, as shown in Figure 6, the analysis found that 68% of BCG/SCG technology was implemented in a strictly controlled laboratory environment and still some way from being put in market applications.

5. Conclusions

In order to give consideration to the comprehensibility and effective authority of the inclusion of the literature, this study selected two comprehensive literature databases, CNKI and PubMed, which are authoritative databases in the medical and health field both at home and abroad, to conduct a comprehensive analysis of the representative high-quality literature of BCG/SCG in this field, able to better reflect the research characteristics of the application of this technology. The countries that contributed high quality papers were also those with high level of application. Moreover, in analysis, the subject words in different time periods could truly reflect the changes of the research topics of BCG/SCG technology. However, this study did not cover all the relevant domestic and foreign literatures for analysis, and there might be some deviations in the analysis of the development trend of BCG/SCG technology. In the future study, combination of multiple literature databases

for comparative analysis can be tried so as to present a more comprehensive and overall disclosure of the distribution, development trend and research topics of the research of BCG/SCG technology.

In general, BCG/SCG has received extensive attention and in-depth research in the recent years. Academics are actively exploring the principles and physiological values of BCG/SCG, and the ways of applying them to life. In addition to its amazing development speed, BCG/SCG also faces many issues, including the obstacles at the technical improvement level and the difficulties in the technical implementation process. Only by commercializing BCG/SCG technology products, those difficulties in technical implementation process could be overcome.

To sum up, the application of BCG/SCG technology has been presenting broad-prospects getting attentions from researchers and in-depth studies were conducted. With the continuous improvement of signal monitoring methods, products based on BCG/SCG will get a more precise approach to clinical diagnosis. Hopefully we shall see their commoditization in the future and a wider range of applications.

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