

An ECG network system for health promotion: Application in a regional medical association in China

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Research article

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Abstract

Background: China has made good progress in its medical reform but challenges remain. In this paper, we proposed a multi-tiered electrocardiogram (ECG) network system to solve the problems of traditional ECG monitoring.

Methods: We discussed the current situation and insufficiencies of ECG examination and constructed an ECG network system. The proposed ECG network system consisted of nosocomial ECG system combined with hospital information system and electronic medical record system, WEB-based ECG network system for the regional medical association system, and 120 pre-hospital first-aid ECG system based on 4G mobile network. The ECG network system has initially applied for clinical monitoring and diagnosis for 5 years.

Results: Our application results showed that the ECG network system had high efficiency and practicability under the current medical environment, which provided a reliable basis for clinical rapid and definite diagnosis, and partially solved the imbalance of the medical resources among regional medical institutions.

Conclusion: It has great significance for the management and remote consultation of heart disease and provides a reference for exploring the reform of clinical data sharing and improving the efficiency of medical resource integration.

1 Introduction

Chinese health care reform has been heatedly promoted around the whole nation in the past decade and has made laudable achievements, such as strengthened primary health care system, increased public funding, and expanded insurance coverage (1, 2). However, Chinese government still faces challenges in improving the quality and equity of healthcare service delivery, partially due to the large population and regional diversity (3). Evident urban-rural disparity in health care resources and utilization is a critical concern for Chinese health system planners (4). Moreover, current low capacity of primary healthcare leads to unreasonable distribution of the patients and inefficient use of healthcare resources. To improve the quality of primary healthcare service and achieve maximum use of healthcare recourse, it is imperative to implement more effective intersectoral coordination and cooperation.

In response to the concerns about current health system, the government piloted regional medical association plan, which urges the cooperation between public hospitals and primary healthcare institutions to achieve continuous and comprehensive medical assistance. Regional medical association is an integrated medical service system, which provides a new way to solve the difficulties of inadequate utilization of medical resources and unreasonable distribution of the patients by associating different level hospitals (5). Under the framework of regional medical association, telemedicine service system has also been constructed on the basis of regional resource sharing center, allowing clinicians in the major public hospitals to provide remote diagnosis and consultation to patients in primary hospitals. Under

current medical environment, it is of great importance to launch the synergistic service of regional medical association.

Heart disease is one of leading causes of death worldwide (6). Electrocardiogram (ECG), as one of the most important methods for clinician to measure heart disease, plays a significant role in the prevention, diagnosis and treatment of heart disease (7). ECG has become an indispensable choice for patients with chest pain and arrhythmia, and it also plays an important role in the diagnosis of acute coronary syndrome. Moreover, the rapid development of internet technology has vastly accelerated the process of telemedicine on the basis of the ECG network system in China (8). Currently, great progress has been made in the construction of regional medical association centers. The application of ECG network system in regional medical association will address the inefficient healthcare at rural hospital and overcrowding at city hospitals, and improve the out-come of heart disease. In the present study, we summarize the experience in implementing telecommunicating ECG network system for the management and remote consultation of heart disease in our regional medical association, which might provide a reference for exploring the reform of clinical data sharing and improving the efficiency of medical resource integration.

2 Materials And Methods

2.1 Current situation and insufficiencies of ECG examination

The traditional ECG examination model that utilizes clinical printed or handwritten report is still carried out in the majority of primary hospitals in China. With the traditional ECG system, cardiologists have been limited to obtain the ECG report integrally and timely, thus it is difficult to make the consultation and accurate rescue for patients, especially for critically ill patients. Meanwhile, the informationalized level of most primary hospitals remains in its primary stage in China. The laggard informationalized level causes the formation of information islet or resource islet, which severely limits the cooperation and communication among regional medical association institutions and restricts the development of telemedicine services. Furthermore, due to primary hospitals lacking of practice opportunities for medical staff and its low medical capacity, the diagnosis accuracy through ECG is relatively low, which might lead to delayed and inappropriate treatment for patients with myocardial infarction and severe arrhythmias. Additionally, the standardization of telemedicine services is still imperfect in China. Nonuniform standards make the information system of medical institutions incompatible with each other, leading to difficulty in promoting medical resource sharing and information exchange among regional medical association institutions. Therefore, the ECG network system has become an important task in the informationalized construction of our hospital.

2.2 Construction and optimization of ECG network system

In 2015, ECG network system has achieved full coverage within our hospital. The ECG network system is based on the construction of the information technology system, such as hospital information system (HIS), picture archiving and communication system (PACS) and laboratory information system (LIS). Using the MEEG-200 12-lead synchronous ECG analysis system, the digital ECG network system is

established with Department of Cardiac Function as the center, and makes remote wireless ECG cover all wards. Figure 1 illustrates the proposed ECG network system. The ECG network system consists of three parts, including nosocomial ECG system based on HIS and electronic medical record (EMR) system, WEB-based ECG network system for the regional medical association system, and 120 pre-hospital first-aid ECG system based on 4G mobile network.

The system realizes the information collection, storage and management of ECG, and provides an intelligent report generation system. In our hospital, we have completed the installation of ECG data server and storage server, which have been perfectly integrated with the existing information systems, such as HIS, EMR, and PACS. Through the HIS system, the system can receive the electronic application forms of ECG examination from the clinic, and the ECG reports can be accessed by the clinician station can at any time through the electronic medical record system. The ECG data acquired from the primary hospitals in our regional medical association system can be transferred to the network center of ECG diagnosis in our hospital through dedicated network. The ECG data will be examined by professional cardiologists and patients in primary hospitals will get a professional diagnosis, which is conducive to the comprehensive application of medical resources. In case of emergency, the ECG data of patients can be transmitted to our diagnostic center using 120 first-aid vehicle-mounted equipment through the 4G mobile network to achieve a pre-hospital diagnosis for critical patients. Importantly, the ECG network system files the examination data and patient information generated by various ECG devices in accordance with the unified data format, which is convenient for the provision of unified digital ECG waveform and measurement tools, and facilitates doctors to analyze and report the ECG waveform and to mine and share electrophysiological data.

This proposed ECG network system utilizes 12-lead synchronous ECG analysis system, and achieves the real-time display, record, and playback of ECG data at any time, which greatly improves the inspection speed, diagnostic accuracy and storage capacity of ECG. The system realizes not only the full sharing of patient data and ECG data, but also the full sharing of ECG equipment and professional resources among regional medical association institutions, which might ameliorate the imbalance of the medical resource allocation in the reform process. On the basis of the ECG network system, professional cardiologists from the major public hospital can provide professional consultations for intractable cases in primary hospitals, that significantly improves the quality and service of ECG diagnosis in our regional medical association institutions. In addition, the ECG network system also includes a remote diagnosis platform for 120 pre-hospital ECG examination, enabling patients to be prepared for cardiac rescue as early as possible. Figure 2 shows the distribution map of the ECG network diagnosis center.

2.3 Composition of ECG network system

2.3.1 Department of Cardiac Function

ECG examination workstation

The ECG examination workstation is located in the outpatient department, and is mainly used to perform ECG examination for outpatient patients. Based on the digital design, ECG examination workstation has powerful ECG analysis and measurement functions, which can obtain the list of patients booked for examination, and carry out the collection, recording, and reporting of ECG data. The ECG examination reports of patients can be directly uploaded to the server for centralized storage, and the workstation supports the retrieval of ECG data of all patients on the server.

ECG Reporting Workstation

The ECG reporting workstation is placed in the Department of Cardiac Function, which can gather the ECG data transmitted from the mobile ECG instrument in the ward. The ECG reporting workstation has the functions of automatic analysis of ECG and the generation of graphic diagnosis report. It is equipped with a printer to print the report at any time. The ECG reporting workstation can centrally process the medical records sent by multiple handheld ECGs to achieve centralized reporting.

2.3.2 Wireless ECG system in the ward

Wireless ECG system in the ward is an important part in the construction of ECG network system. In our hospital, MECG-200 mobile ECG equipment is adopted, which is a portable 12-lead ECG inspection tool. It allows for initial bedside examination of patients in the ward with due regard to its portability. The patients' ECG waveform could be transmitted to the ECG workstation in the Department of Cardiac Function.

2.3.3 ECG access based on EMR system

Using web technology, our ECG network system can achieve the quick access of ECG reports on the basis of EMR system. Once the ECG report is uploaded, the clinician can retrieve the ECG result in the doctor's workstation in the real time. Without installing special software, the clinician can directly view the report by clicking the link online, and the system also supports online ECG waveform analysis, processing, and reporting functions.

2.3.4 Chest pain center

The chest pain center is an important indicator to measure the clinic level of medical institutions in the treatment of acute myocardial infarction. The chest pain center of our hospital has obtained the national certification, which is the first chest pain center in Qingdao city. Through the on-board information system mounted in the ambulance of the municipal emergency center, the chest pain center can receive the pre-hospital ECG monitoring information and ECG report, which wins precious "golden time" for many patients with myocardial infarction, and makes it possible to seamlessly connect the hospital treatment and pre-hospital emergency treatment. Since the establishment of chest pain center on January 20, 2015, it has treated thousands of patients with acute myocardial infarction. The Door to Balloon (DB) time has reached 47 min, ranking among the top 20 in China. Our efforts have achieved increase survival rate, improved prognosis, and reduced complications of patients, which reduces the social and economic burden.

2.3.5 Regional medical association

One of the most important applications of the ECG network system is to improve the diagnosis level of heart diseases in the regional medical association system. A regional medical association system consists of a tertiary public hospital as medical center and some secondary hospitals and primary healthcare institutions as members. Our hospital is the medical center in this regional medical association system. Using the ECG network system, the ECG data of patients in primary healthcare institutions can be transmitted to the diagnostic center, where a remote diagnosis can be made within minutes by a cardiac specialist. The application of ECG network system in the regional medical association system realizes the remote consultation and online diagnosis, which significantly enhances the survival rate of the severe cases in primary healthcare institutions. We have completed 725 cases of remote ECG diagnosis. Recently, the ECG network system is gradually expanding, and another 11 medical members in the regional medical association system are undergoing equipment debugging to join the ECG network system, achieving the resource sharing within the regional medical association system. In addition, the patients' ECG data could be transmitted to WeChat group in the form of pictures in time using mobile phones, and the cardiac specialists could be reminded of timely consultation. In case of emergency, we can communicate timely by telephone to ensure that patients can receive effective treatment in the prime time.

3 Results

ECG network technology has been widely used in clinic (9, 10). Nearly 5 years of application of ECG network system, our hospital has gradually summed up some practical experience. The clinical application of ECG network system makes ECG examination more effective and applicable, achieves timely monitoring of acute myocardial infarction, malignant arrhythmia, and variant angina, and makes more convenient and rapid consultation, which provides a reliable basis for clinical rapid and definite diagnosis. Figure 3 shows the quantity of ECG inspection in our hospital before and after the application of ECG network system. It was displayed that the number of cases examined after the application of ECG network system was significantly increased relative to that before the application of ECG network system, with a statistic difference. Meanwhile, the application of ECG network system realized the real-time monitoring of critical values in cardiology. Table 1 shows the result of the real-time monitoring of critical values between January 2018 and June 2018.

Table 1
Monitoring of critical values using ECG network system

Critical value item	Outpatient cases	Hospitalized cases	Total cases	Necessity and rationality	Notes
Acute myocardial infarction	15	19	34	Necessary and reasonable	The diagnosis should be confirmed by combining with other clinical examinations if no Q wave and non-ST segment elevation in the ECG.
Myocardial ischemia	1	2	3	Necessary and reasonable	It should be distinguished from acute cases with similar pattern changes, such as acute pulmonary embolism.
Ventricular tachycardia	2	2	4	Necessary and reasonable	/
Ventricular flutter	0	0	0	Rare, can be combined with ventricular fibrillation	/
Ventricular fibrillation	0	0	0	Rare, can be combined with ventricular flutter	/
sinus arrest	3	7	10	Necessary and reasonable	/
Third degree atrioventricular block	0	5	5	Necessary and reasonable	/
Atrial fibrillation with high atrioventricular block	0	1	1	Necessary and reasonable	/
Atrial fibrillation with preexcitation	0	2	2	Necessary and reasonable	More common in rapid ventricular rate, such as supraventricular tachycardia

Critical value item	Outpatient cases	Hospitalized cases	Total cases	Necessity and rationality	Notes
Severe hyperkalemia or hypokalaemia	0	0	0	Necessary and reasonable	ECG changes may not correspond exactly to ion disturbances.

Combined with the existing basic conditions and the current development trend of the ECG network in our hospital, the first rural ECG database of physical examination was initially established in Qingdao under the national chronic disease prevention and treatment strategy. ECG data system was incorporated into the prevention and treatment strategies of chronic diseases, such as hypertension and diabetes. The establishment of the entire database will drive the rapid development of information construction in our hospital.

Referring to the network information security institution of our hospital, we formulated and improved the corresponding institution suitable for ECG network management under the requirement of quality control security.

In addition to the construction of ECG network diagnosis center, we actively participated in the construction of other clinical centers, such as chest pain center, sleep center, atrial fibrillation and arrhythmia center, and stroke center, actively undertook corresponding tasks, and deeply participated in scientific research. These efforts make us accumulate the experience of diagnosis and prevention of ECG and other cardiac function-related diseases, which forms an effective complement to clinical disciplines. We have gradually established a sound dynamic adjustment mechanism and achieved regular assessment of ECG network.

4 Discussion

The ECG network system subverts the traditional ECG examination process, which can provide more efficient and convenient services for the clinic. In the present study, we described the construction of the ECG network system in our hospital, which consisted of nosocomial ECG system, ECG network system for the regional medical association system, and 120 pre-hospital ECG system.

Here, we emphasized the application of ECG network system in the regional medical association system, which partially solved the imbalance of the medical resources in the reform process. For patients with cardiopathy in primary hospitals, they often receive suboptimal treatment due to the shortages of professional doctors and low ECG diagnostic level in primary hospitals. The application of ECG network system in the regional medical association system has greatly improved the situation. It not only contributes to correct diagnosis timely for patients in rural areas by remote consultations, but also provides treatment guidelines for patients with severe symptoms under the assistance of professional

cardiologists. Moreover, the application of ECG network system can improve the efficiency of medical staffs and increase the remedy rate of severe heart diseases. In addition, the application of ECG network system in the regional medical association system will strengthen the cooperation among hospitals, and the collection of ECG data will create a databank to facilitate the data analysis and promote the development of studies on cardiology.

In order to comply with the regulations on the prevention and control of chronic diseases in community and timely detection and treatment of critical cases, the ECG network system has been applied in each member unit of the regional medical association system, which makes patients enjoy the telemedicine service in the nearest hospital, and minimizes the irreversible damage of patients.

It is an imperative project to benefit the people, and is also an important embodiment of the extension of public welfare in our hospital. In the future, we will provide the online remote ECG diagnosis and guidance services, strengthen the communication among the medical units in the regional medical association system, and provide personalized solutions based on the characteristics of each individual to reach the best diagnostic effect. Using this information platform, our hospital will provide authoritative, effective, and homogeneous ECG technical service support for the regional medical association system.

The ECG network system brings great convenience and efficiency for patients and medical staffs. While there are some problems inevitably, such as network instability, irregular operation, and improper use of instruments. Therefore, with the gradual establishment and improvement of ECG network system, a lot of maintenance work needs to be done to ensure the normal operation of the system. The supplier should provide appropriate after-sales service for the ECG network system. The technology department of our hospital should maintain and repair the equipment regularly, and provide spare instruments to ensure the normal operation of the system. The information department should ensure the safe operation of the ECG network, and develop an early warning plan to ensure that the ECG examination is not interrupted due to network failure. The clinical departments should use the ECG equipment correctly, and examine the patients in strict accordance with the operating standards and procedures to minimize and avoid the generation of invalid ECG. The cardiac function department, as the center of the system, should not only guarantee the normal operation of daily work, but also coordinate the work of relevant departments to ensure the safe operation of the system. Importantly, the Chinese government should establish the relevant legal system as soon as possible to normalize the telemedicine behavior.

The ECG network system proposed in this study provides a multi-tiered diagnosis and treatment system. Our 5 year of initial implementation displays the practicability of this system. Under the current medical environment, it has great implications to improve the ECG diagnostic level and establish the synergistic service in the regional medical association system.

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Availability of data and materials: All data generated or analysed during this study are included in this published article.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: ZG and MZ performed the construction of the system, interpreted the data, and contributed to writing the manuscript. YQ and QX interpreted the data, and contributed to critical revisions of the manuscript. All authors read and approved the final manuscript.

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Figures

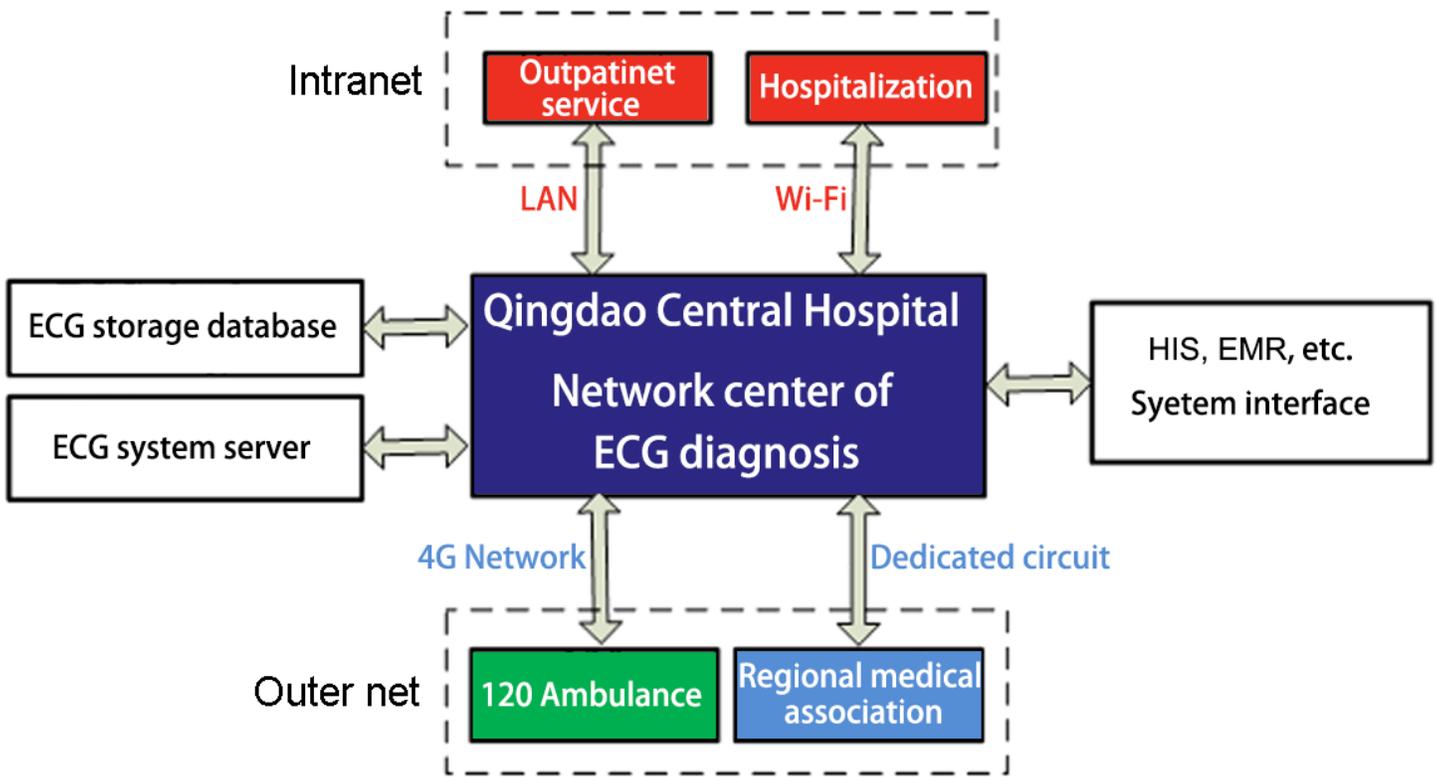


Figure 1

Diagram of the proposed ECG network system structure.

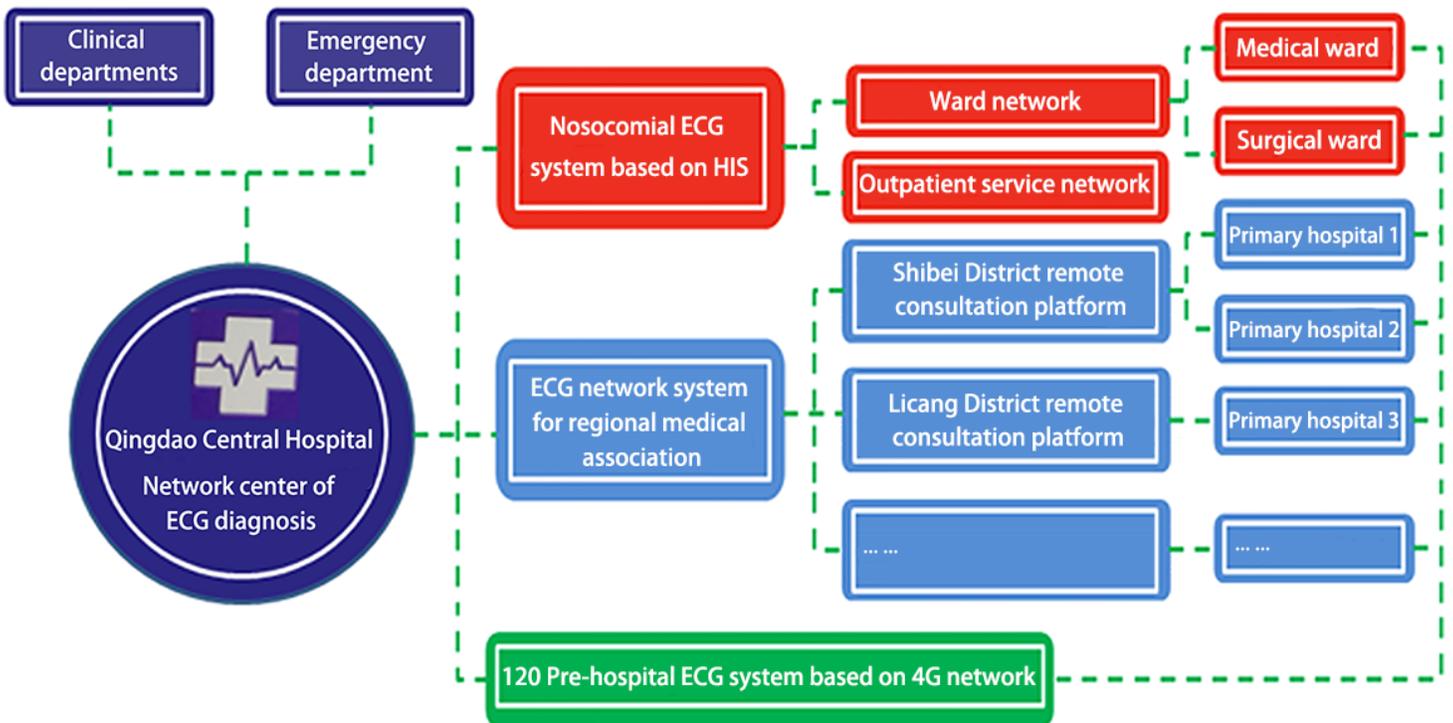


Figure 2

Distribution map of the proposed ECG network diagnosis centers.

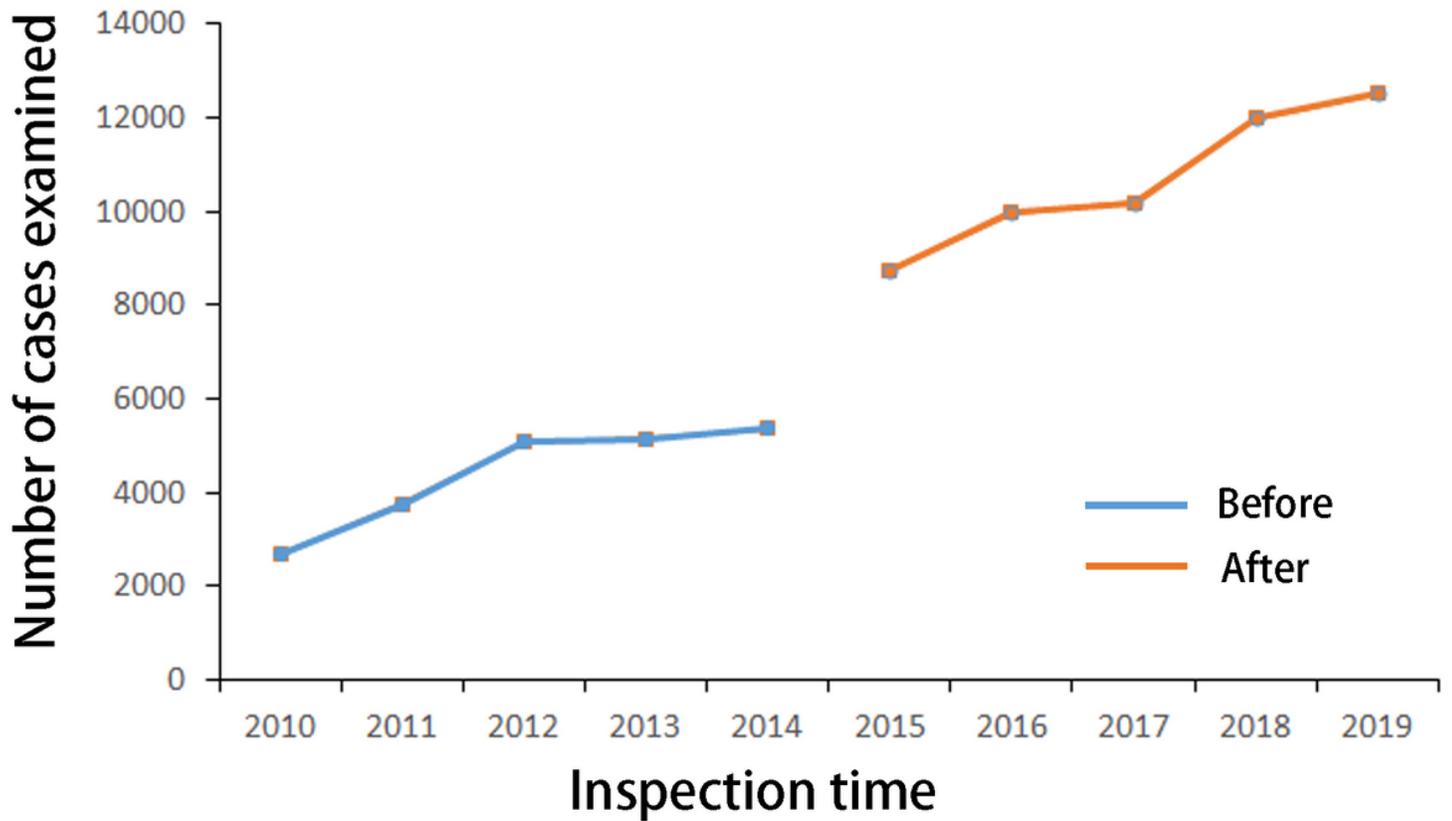


Figure 3

Quantity of ECG inspection in our hospital before and after the application of ECG network system.