MULTI-TIERED ELECTROCARDIOGRAM NETWORK SYSTEM: APPLICATION IN A REGIONAL MEDICAL ASSOCIATION IN PR CHINA

Zhi-Hua Gong[1], Ming-Ming Zhang[2], Yao Qu[3] and Qing Xia[3]

[1]Department of Cardiac Function, [2]Department of Information, [3]Department of Cardiac Ultrasound, Qingdao Central Hospital, Qingdao, PR China

Abstract. People's Republic of China has made good progress in its medical reform but challenges remain. A multi-tiered electrocardiogram (ECG) network system was developed to solve problems of traditional ECG monitoring, comprising a hospital ECG, information and electronic medical record systems, a web-based ECG network system of the regional medical association and 120 pre-hospital first-aid ECG systems linked by a4G mobile network. Initial implementation of the ECG network system demonstrated efficiency and practicability under current medical environment. This network should be of significant benefit for management and remote consultation of heart disease and provides a reference for exploring reforms in clinical data sharing and improvement in efficiency of medical resource integration.

Keywords: PR China, electrocardiogram, heart disease, medical resource sharing, regional medical association

INTRODUCTION

Health care reform in People's Republic of China has been strongly promoted across 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 (Li and Fu, 2017; Xu and Mills, 2019). However, the government still faces challenges in improving quality and equity of healthcare service delivery, due in part to the large population and regional diversity (Meng *et al*, 2019). Urban-rural disparity in healthcare resources and utilization is a critical concern for PR China health system planners (Li *et al*, 2018). In addition, current low capacity of primary healthcare leads to unequal distribution of patients and inefficient use of healthcare resources. In order to improve the quality of primary healthcare services and achieve optimal use of healthcare resources, it is imperative to implement a more effective intersectoral coordination and cooperation.

In response to concerns of the current health system, the government recently launched the establishment of regional medical associations, role of which is to foster cooperation between public hospitals and primary healthcare

Correspondence: Qing Xia, Department of Cardiac Ultrasound, Qingdao Central Hospital, No. 127 Siliunan Road, Shibei District, Qingdao 266042, People's Republic of China.
Tel: +86 18669710089
E-mail: ayue112266@163.com

institutions to achieve a continuous and comprehensive medical assistance (Zhai, 2016). The regional medical association is an integrated medical service system, which provides a new path towards solving difficulties of inadequate utilization of medical resources and unequal distribution of patients by associating hospitals of different sizes and facilities into a regional medical association. Telemedicine service system was constructed to allow sharing of regional resources and enable clinicians in the major public hospitals to provide remote diagnosis of patients and consultations to fellow physicians in primary hospitals. In order to achieve the goal of an equitable healthcare for all patients in the country it is of great importance to encourage an active and synergistic utilization of services provided through a regional medical association.

Heart disease is one of leading causes of death worldwide (GBD 2017 Causes of Death Collaborators, 2018). Electrocardiogram (ECG) is one of the most important methods for clinicians in cardiology as it plays a significant role in diagnosis, treatment and prevention of heart diseases (Woodrow, 2010). ECG has become an indispensable method in examining patients with chest pain and arrhythmia, and in particular in diagnosing acute coronary syndrome. The rapid development of internet technology has vastly accelerated the process of telemedicine in creating an ECG network system in PR China (Zhang *et al*, 2015). Application of an ECG network system in a regional medical association will be able to address the problems of poor healthcare at rural hospitals, which has led to overcrowding at city hospitals, and to improve outcomes of heart disease.

The traditional ECG examination method utilizing a handwritten or printed clinical report is still carried out in the majority of primary hospitals in PR China. With this system, cardiologists have been constrained in obtaining ECG reports integrally and in a timely fashion, making it difficult to make accurate diagnosis and appropriate treatment for patients, especially the critically ill patients. Meanwhile, the collection and integration of information in primary hospitals remains at an elementary stage in PR China (Li *et al*, 2017). This causes formation of information or resource islets, which severely limits communication and cooperation among regional medical institutions and thereby retards the development of telemedicine services. Furthermore, due to a lack of practice opportunities for medical staff and low medical capacity in primary hospitals, accuracy of diagnosis by ECG in these institutions is relatively poor, which might lead to delayed and inappropriate treatment for patients with myocardial infarction and severe arrhythmias.

In addition, standardization of telemedicine services is still imperfect in PR China. Nonuniform standards make information systems of medical institutions incompatible with each other, leading to difficulty in promoting sharing of medical resources and exchange of information among institutions in a regional medical association. Here, the experience in implementing a telecommunicating ECG network system for management and remote consultation of heart diseases in a regional medical association is described, which should provide baseline data for exploring reforms in sharing of clinical data and improving the efficiency of integrating medical resources.

MATERIALS AND METHODS

Construction and optimization of an ECG network system

In 2015, an ECG network system achieved full coverage within, Qingdao, PR China. The ECG network system is based on an information technology system, comprising such features as a hospital information (HIS), picture archiving and communication (PACS) and laboratory information (LIS) systems. Using an MECG-200 12-lead synchronous ECG analysis system, a digital ECG network system was established with the Department of Cardiac Function as the hub that provides remote wireless ECG coverage of all wards (Fig 1).

The ECG network system consists of three components, namely, an in-hospital ECG system based on HIS and an electronic medical record (EMR) system, a web-based ECG network system for the regional medical association system, and 120 external hospital first-aid ECG systems based on a 4G mobile network. The system collects all ECG information, stores and manage the data, and provides an intelligent report generation system. At Qingdao Central Hospital, installation of ECG data server and storage server, which have been smoothly integrated with the existing information systems, *eg* HIS, EMR, and PACS, has been completed. Through the HIS system, the system receives electronic application forms of ECG examination from the clinic and the ECG reports can be accessed at any clinical station at any time through the EMR system.

ECG data acquired from primary hospitals of the regional medical association are transferred to Qingdao Central Hospital ECG network center through the dedicated

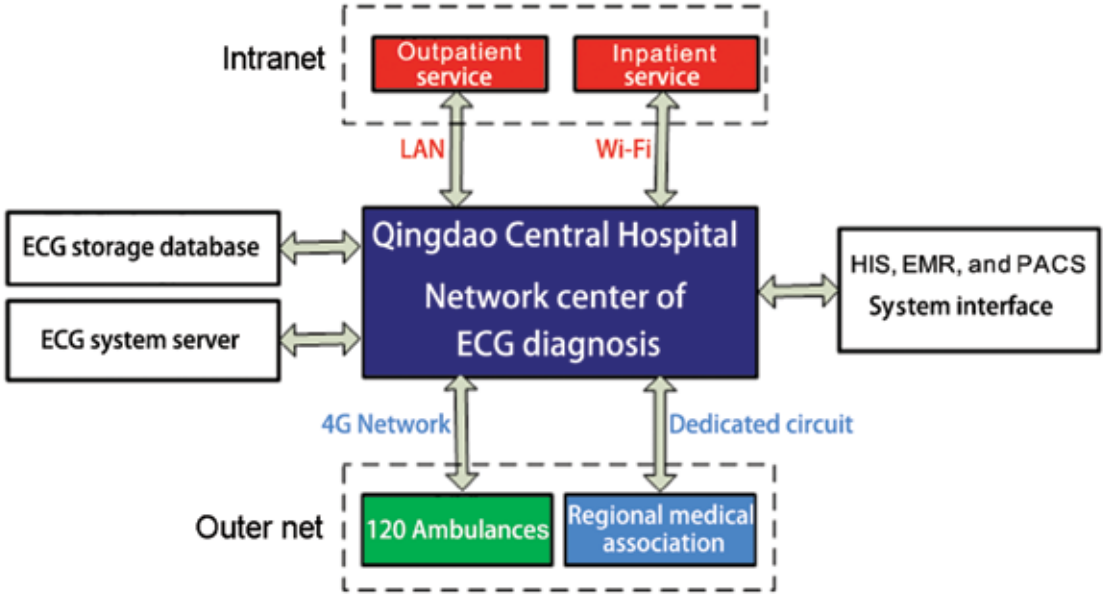

Fig 1-Diagram of the structure of an electrocardiogram (ECG) network system,Qingdao, PR China.
EMR: electronic medical record; HIS: hospital information system.

network. The ECG data are examined by professional cardiologists and physicians in the primary hospitals receive professional opinions, conducive to a comprehensive application of medical resources. In case of an emergency, ECG data of patients are transmitted to the diagnostic center using 120 first-aid vehicle-mounted 4G mobile equipment to obtain a pre-hospital diagnosis. Importantly, the ECG network system files examination data and patient information generated by various ECG devices in accordance with a uniform data format, which is convenient for the provision of common digital ECG waveforms and measurements, facilitating reporting and analysis of ECG waveforms and the sharing of electrophysiological data.

This ECG network system utilizes a 12-lead synchronous ECG analysis system and achieves real-time display, record and playback of ECG data at any time, which greatly improves inspection speed, diagnostic accuracy and storage capacity of ECG. The system realizes not only sharing of patients' and ECG data but also full sharing of ECG equipment and professional resources among institutions of the regional medical association, which should ameliorate the existing imbalance of medical resource allocation. In the ECG network system, professional cardiologists from major public hospitals can provide professional consultations on intractable cases in primary hospitals, thereby significantly improving the quality and service of ECG diagnosis in the regional medical association institutions. In addition, the ECG network system includes a remote diagnosis platform for 120 pre-hospital ECG examination locations (Fig 2), enabling hospitals to be prepared for cardiac rescue ahead of

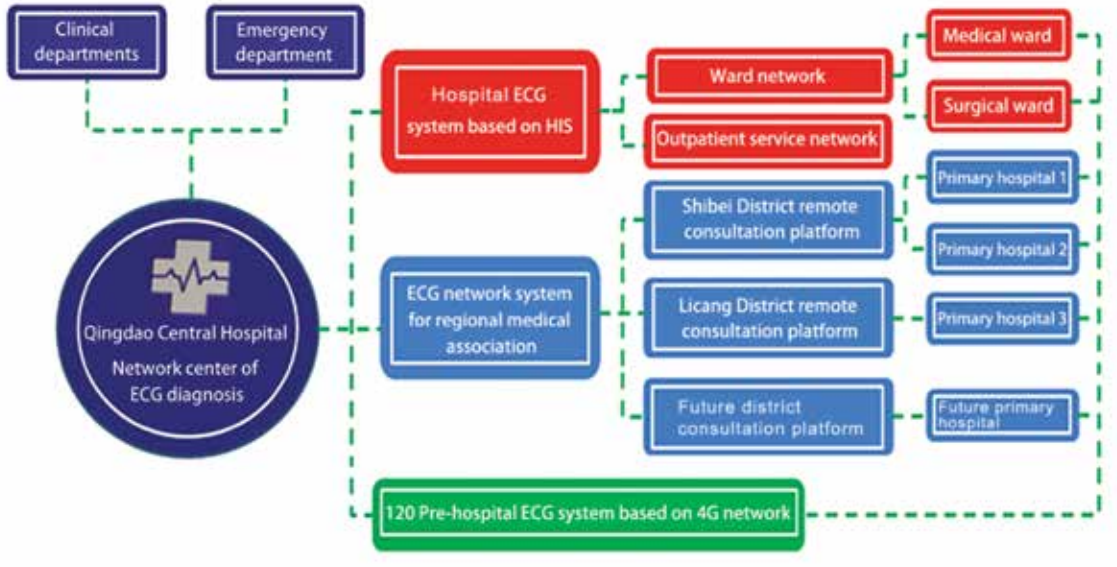

Fig 2-Diagram of the links among electrocardiogram (ECG) network diagnosis centers, Qingdao, PR China.

HIS: hospital information system.

patients' arrivals.

Composition of ECG network system

Workstations

The central hospital has two workstations, namely, ECG examination workstation and ECG reporting workstation. The former workstation is located in the Outpatient Department and is used to perform ECG examinations of outpatient patients. Due to its digital design, ECG examination workstation has a powerful ECG analysis and measurement function, which stores names of patients booked for examination and recordings and reports of ECG data, which are directly uploaded to the server for centralized storage and can subsequently be retrieved at the same workstation. The ECG reporting workstation is located in the Department of Cardiac Function and gathers ECG data transmitted from mobile ECG instruments in the ward, conducts automatic analysis of ECG data and generates graphic diagnosis reports that can be printed out upon request.

Ward wireless ECG system

Wireless ECG system in the ward is an important component of the ECG network system. The Qingdao Central Hospital employs a MECG-200 mobile ECG equipment, a portable 12-lead ECG inspection tool that allows initial bedside examination of patients in the ward. The patients' ECG waveforms are transmitted to the ECG workstation in the Department of Cardiac Function. In addition, patients' ECG data can be transmitted to a WeChat group in the form of pictures in real time via mobile phones, and the cardiac specialists can be reminded of timely consultation. In case of emergency, communication by telephone ensures patients will receive timely effective treatment.

ECG access based on EMR system

Using web technology, the ECG network system allows rapid access of ECG reports using an EMR system. Once an ECG report is uploaded, the clinician can retrieve the ECG results at the doctor's workstation in real time. Without installing any special software, the clinician can directly view the report by clicking the online link. The system also supports online ECG waveform analysis, processing and reporting.

Chest Pain Center

The Chest Pain Center plays an important role in improving clinical levels of medical institutions in the treatment of acute myocardial infarction. The Chest Pain Center of Qingdao Central Hospital the first chest pain center in Qingdao city to obtain national certification. By means of the on-board information system mounted in ambulances of the municipal emergency center, the Chest Pain Center receives pre-hospital ECG monitoring information and ECG report, which enables precious "golden time" for many patients with myocardial infarction and makes it possible to seamlessly connect pre-hospital emergency treatment with hospital treatment upon arrival. Since the establishment of the Chest Pain Center on 20 January 2015, thousands of patients with acute myocardial infarction have been treated. The "door-to-balloon" time has been reduced to 47 minutes, ranking among the top 20 in PR China and the Center has achieved increase in survival rate, improvement in prognosis and reduction in complications in patients, thereby contributing to lessening social and economic burdens.

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 a medical center and secondary hospitals and primary healthcare institutions as members. Qingdao Central Hospital is the medical center in the Qingdao regional medical association system. Using the ECG network system, ECG data of patients in primary healthcare institutions are 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 enables remote consultation and online diagnosis, which significantly enhance survival rate of severe cases in primary healthcare institutions. The ECG network system has recorded 725 cases of remote ECG diagnosis. Currently, the system is gradually expanding, with an additional 11 medical institutions undergoing equipment renovations to enable joining the network.

RESULTS

Clinical application of the ECG network system made ECG examination more effective and applicable, achieved timely monitoring of acute myocardial infarction, malignant arrhythmia, and variant angina, and resulted in more convenient and rapid consultations, providing a reliable basis for rapid and definitive diagnosis. This was reflected, following the installation of an ECG network system in 1995, in a jump in the number of cases of heart disease examined in Qingdao, PR China with a higher rate in case numbers in the following five years compared to the previous five years (Fig 3). Application of ECG network system enabled real-time monitoring of critical conditions in cardiology (Table 1).

As regards security of the network information system of Qingdao Central Hospital, a program was formulated to improve the security system suitable for an ECG network, with a management to supervise quality control of the installed

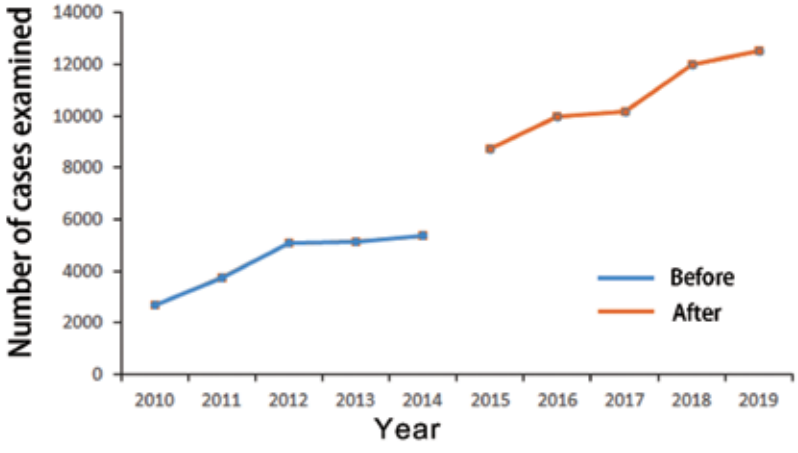

Fig 3-Number of electrocardiogram (ECG) cases examined in Qingdao, PR China before and after installation of ECG network system in 2015.

Table 1
Critical cardiac conditions monitored using the electrocardiogram (ECG) network system at Qingdao central Hospital, Qingdao, PR China (January - June 2018).

Condition	Number of outpatient cases	Number of inpatient cases	Total number of cases	Need and rationale	Note
Acute myocardial infarction	15	19	34	Necessary and reasonable	The diagnosis should be confirmed by combining with other clinical examinations if there are no Q wave and non-ST segment elevation in ECG.
Myocardial ischemia	1	2	3	Necessary and reasonable	Diagnosis should be distinguished from acute cases with similar pattern changes, such as acute pulmonary embolism.
Ventricular tachycardia	2	2	4	Necessary and reasonable	-
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.

security procedures (data not shown).

In addition to the construction of ECG network diagnosis center, installation of other clinical centers, such as chest pain, sleep, atrial fibrillation and arrhythmia, and stroke centers, were actively undertaken, as well as scientific research. These efforts allowed accumulation of experience in diagnosis and prevention of other cardiac function-related diseases, which form an effective complement to other clinical disciplines. Clinicians at Qingdao Central Hospital have gradually established a sound dynamic adjustment mechanism and achieved regular positive assessment of the ECG network.

DISCUSSION

ECG network technology has been widely used in clinical settings in PR China (Cho *et al*, 2015; Lu and Chen, 2015). Combined with existing basic conditions and current trend in the development of ECG networks, the first rural database of ECG examinations was initially established in Qingdao in 2015 under the national chronic disease prevention and treatment strategy (Kong, 2017). The ECG data system was also incorporated into the prevention and treatment strategies of chronic diseases, such as hypertension and diabetes.

The ECG network system enhances the traditional ECG examination process and can provide more efficient and convenient services for the clinic. Application of the ECG network system to the regional medical association system solved, in part, the imbalance of medical resources. Patients with cardiopathy in primary hospitals often receive suboptimal treatment due to shortages of professional doctors and low ECG diagnostic level in primary hospitals. Introduction of the ECG network system not only contributes to timely correct diagnosis for patients in rural areas through remote consultation 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 cure rate of severe heart diseases. In addition, the ECG network system in a regional medical association system will help to strengthen cooperation among hospitals, and the collection of ECG data will create a databank to facilitate data analysis and promote research studies in cardiology.

In order to comply with regulations on the prevention and control of chronic diseases in the community (Chen and Li, 2011) and to provide rapid detection and treatment of critical cases, an ECG network system should be connected to each member unit of a regional medical association system, enabling patients to benefit from telemedicine service of the nearest hospital thereby minimizing potential irreversible damage stemming from delayed diagnosis and treatment. Online remote ECG diagnosis and guidance services will strengthen communications among medical units in regional medical associations and provide personalized solutions according to the symptoms of each individual to reach the best diagnosis. Using this information platform, hospitals will be able to provide authoritative, effective and equitable ECG technical service support for the regional medical association system. It is an imperative that introduction of a project to benefit the people's health should embody an extension of hospital expertise and services to the public at large.

While the ECG network system brings great convenience for patients and

enhances efficiency of medical staff, some problems are inevitably, such as network instability, irregular operation and improper use of instruments. Therefore, with the gradual establishment and improvement of ECG network system, the following procedures should be installed: continuous maintenance work to ensure normal operation of the system; suppliers providing appropriate after-sales service for the ECG network system; technology department of the hospital maintaining and repairing of equipment on a regular basis and having on hand adequate spare instruments for instant replacement of defective devices without waiting for repairs to be undertaken; information department ensuring the safe operation of the ECG network and developing an early warning plan to ensure that the ECG examination is not interrupted due to network failure; training in proper use the ECG equipment and in the examination patients in strict accordance with the operating standards and procedures to minimize and avoid generation of invalid ECG data; cardiac function department, as the center of the system, not only guaranteeing normal operation of daily work but also coordinating with relevant departments to ensure the safe operation of the system; and importantly, the Chinese government establishing a relevant legal system as soon as possible to ensure appropriate codes of conduct of telemedicine.

In conclusion, installation of the multi-tiered ECG network system in Qingdao, with Qingdao Central Hospital acting as the central reference center study provides improved diagnosis and treatment system of cardiac diseases among member of the regional medical association. In the five years following the initial implementation of this system, there were a marked increase in number of cases of cardiac diseases and real-time remote diagnosis and appropriate pre-treatment and consultation of serious conditions prior to admission to a hospital. Under the current medical environment to improve medical services across the country, the multi-tiered ECG network system should improve ECG diagnosis in rural settings and establish synergistic services in the regional medical association system.

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