Standardization of Full-process Information Elements for Neonatal Congenital Heart Disease Screening in Cold Regions and Construction of Referral Information Linkage Chain

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ABSTRACT
There are some problems in neonatal congenital heart disease screening in cold areas, such as different data caliber, cross-institutional information barrier and delayed referral. In this study, a standardized information element system adapted to the local medical environment was constructed, and the referral information path among community, county and tertiary hospitals was designed. The core data elements are clarified, unified specifications are formulated, and a multi-source data mapping method is proposed to solve the data difference problem of heterogeneous systems. On this basis, a multi-level referral network is constructed, the state machine model is introduced to realize the tracking of screening diagnosis and treatment process, and the offline message queue is used to ensure the reliable data transmission in the weak network environment. The results showed that the missing rate of screening data in the pilot area decreased from 14.2% to 2.1%, the success rate of uploading data from weak network reached 98.5%, and the waiting time for diagnosis of suspected children was shortened from 48.5 hours to 16.2 hours. To some extent, this scheme improves the information collaboration ability of screening and grading diagnosis and treatment of congenital heart disease in cold areas, and provides technical support for early screening in resource-limited areas.

Keywords: *Neonatal congenital heart disease, Standardization of information elements, Referral information link, State machine model, Weak network environment.*

1. INTRODUCTION

Early screening and timely intervention of neonatal congenital heart disease play an important role in reducing infant mortality and improving the long-term prognosis of children [1]. Due to the severe cold climate, complex geographical environment and scattered population in some high-latitude cold regions of China, primary medical resources are relatively limited. Screening for neonatal congenital heart disease in these areas may be limited by the shortage of medical equipment and professionals, and also by extreme weather [2]. Screening of congenital heart disease in cold regions mostly depends on primary medical institutions for preliminary evaluation [3]. In the actual operation of this graded diagnosis and treatment model, the smoothness of information flow directly affects the efficiency of screening and treatment.

At present, there are some problems in information management and circulation in the process of neonatal congenital heart disease screening and referral in cold areas [4]. Medical institutions at all levels lack uniform standards when collecting screening information, and there

are differences in data recording formats and index definitions. This information barrier increases the difficulty of data integration and easily leads to statistical errors [5]. In the process of referral of children from grassroots to high-level hospitals, information transmission often lags behind. It is difficult to share scattered electronic records in real time, and higher-level hospitals cannot obtain complete screening data before the arrival of children [6]. In remote areas in cold regions, the network signal coverage is unstable, and the weak network or disconnected network environment is frequent. The traditional real-time online data transmission mode is difficult to guarantee the integrity of information. This study hopes to reduce the omission rate of screening data and shorten the waiting time for diagnosis of suspected children by standardizing data standards and optimizing information flow mechanism.

2. CONSTRUCTION OF STANDARDIZATION SYSTEM OF INFORMATION ELEMENTS

2.1 Core Data Elements

On the basis of sorting out the existing screening records in cold regions, this study divides the whole process information of neonatal congenital heart disease screening into four elements: basic demography, clinical screening indicators, cold environment adaptation and referral status tracking. Basic demographic factors mainly include basic information of newborns and risk factors related to congenital heart disease; Clinical screening index elements include key indicators such as oxygen saturation, cardiac auscultation, pulse waveform characteristics and screening time; the cold environment adaptation factors include environmental parameters, equipment calibration, rewarming and other related information for the impact of low temperature environment. Referral status tracking elements are used to record time nodes, institutional circulation status and diagnostic feedback information in the referral process. The hierarchical relationship is shown in “Figure 1”.

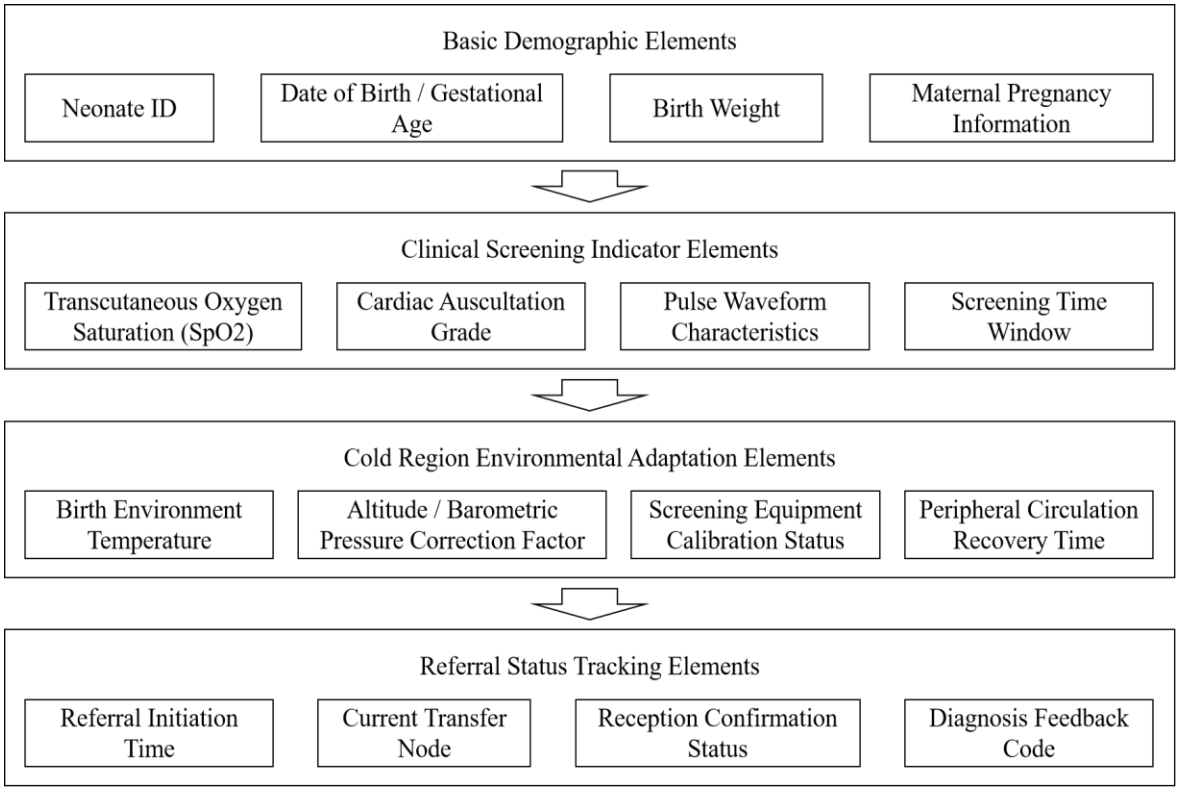


Figure 1 Information standard framework of neonatal congenital heart disease screening.

2.2 Attribute Specification Design

In this study, a unified attribute specification is formulated for all kinds of data elements. It mainly includes field identification, data type, value range, unit of measurement and verification rules. Taking clinical screening indicators as an example, the key data such as blood oxygen saturation are standardized. According to the characteristics of cold environment, the corresponding correction rules are set up to reduce the influence of abnormal data on screening results under low temperature conditions. All attribute specifications are published in the form of structured data dictionary, which provides a unified basis for data entry, field alignment and quality verification of medical institutions at all levels.

2.3 Multi-source Data Mapping Conversion

There are differences in data format and coding system in information systems of different medical institutions in cold regions [7]. In this study, a data mapping transformation method based on intermediate semantic layer is designed. This method realizes field mapping of data from different sources through unified data model, and completes data type conversion, unit unification and logical verification according to attribute specification. In order to solve the problem of inconsistent description of indicators among different institutions, the system unified conversion through standardized rules. For the data temporarily stored in weak network environment, the system completes incremental synchronization and anomaly check after network recovery. With the help of this mechanism, the standardized exchange of screening data between primary, county and tertiary hospitals is realized, and manual repeated entry is reduced.

3. DESIGN OF REFERRAL INFORMATION LINK

3.1 Multi-level Referral Network Architecture

The screening and treatment of neonatal congenital heart disease in cold areas involves three levels: community hospitals, county-level maternal and child health care institutions and tertiary general hospitals. The multi-level referral network architecture constructed in this study takes county-level maternal and child health care institutions as regional information hubs. It connects the cardiovascular specialty of tertiary hospitals upwards and radiates to communities and township hospitals downwards. In this framework, the information flow path is independent of the physical transport path of children. When the community screening personnel find suspected positive children, the system will immediately push the standardized screening data to the county-level hub node. After the initial quality control and triage evaluation of the data, if it is determined that urgent intervention is needed, the county node will directly forward the complete electronic medical record summary to the green channel of congenital heart disease in the tertiary hospital. The data interaction between nodes at all levels adopts a lightweight communication protocol based on RESTful API to adapt to the relatively limited server computing resources of primary medical institutions. The overall topology and information flow of the referral network are shown in “Figure 2”.

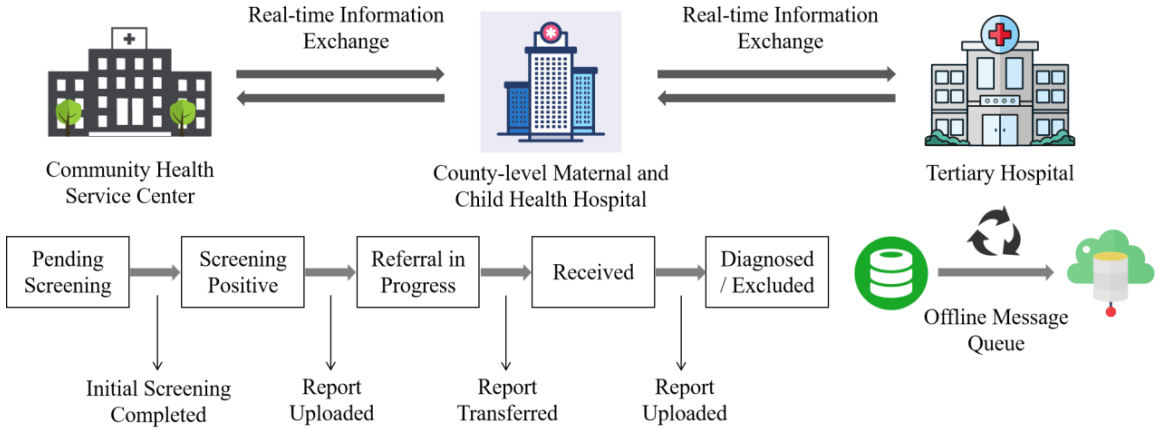


Figure 2 Multi-level referral process of neonatal congenital heart disease in cold region

3.2 Application of State Machine Model

In order to ensure the continuity of children's information in the process of inter-agency circulation, a finite state machine model is introduced to track the state of the whole referral process. The state machine abstracts the process of screening and diagnosis and treatment of children into five core states: to be screened, screening positive, being referred, being admitted, and being diagnosed or excluded. Each state is bound with strict state transition conditions and trigger events. When the community node uploads the record that the oxygen saturation is lower than 90%, the state machine will automatically transfer the state of the child from "to be screened" to "screening positive". When the county hospital confirms to receive the referral work order, the status is updated to "Referral"; after the third-level hospital completed the echocardiogram examination and entered the diagnosis conclusion, the status finally transferred to "confirmed or ruled out". The state machine model records the time stamp of each state transition, the operation subject and the associated data snapshot, and forms an unbreakable whole-process audit trajectory.

3.3 Transmission Guarantee in Weak Network Environment

In winter, remote areas in cold regions often encounter extreme weather such as snowstorms, which leads to the damage of communication base stations or serious attenuation of network signals [8]. In view of this weak or even disconnected network environment, a data transmission guarantee mechanism based on offline message queue is designed in the referral information link. When the primary screening equipment detects that the network connection is unavailable, the system automatically encapsulates the newly generated screening records and state transition events into encrypted messages and writes them into the local lightweight message queue. The message queue adopts the first-in-first-out scheduling strategy, and assigns a globally unique sequence number and timestamp to each message. Once the network is restored, the background synchronization service is started immediately, and the backlog messages are uploaded to the county-level hub nodes in batches according to the sequence number. In the process of uploading, the system introduces breakpoint continuation and data verification mechanism. If a message transmission fails, the synchronization service will automatically retry in the next cycle until it receives a confirmation from the server.

4. APPLICATION EFFECT ANALYSIS

4.1 Data Quality and Integrity Assessment

In this study, three county-level administrative districts under the jurisdiction of a city in cold regions were selected as the pilot, and the data of neonatal congenital heart disease screening before and after the system went online were compared. Before the system went online, there was a high loss rate of screening records because the data standards of various institutions were not uniform and relied on manual summary. Adaptation information such as ambient temperature and equipment calibration status is easy to be omitted. After the system goes online, the data integrity is obviously improved through attribute specification verification and multi-source data mapping conversion. As shown in "Table 1", the missing rate of screening data in the pilot area decreased from 14.2% to 2.1%, and the statistical error rate decreased from 5.8% to 0.9%. The offline message queue mechanism makes the success rate of data uploading in weak network environment reach 98.5%, which reduces the risk of data loss caused by network fluctuation.

Table 1. Comparison of Screening Data Quality in Pilot Areas Before and After System Deployment

Evaluation Indicator	Before System Deployment	After System Deployment	Improvement
Core Element Deficiency Rate	14.2%	2.1%	Decreased by 12.1 percentage points
Statistical Error Rate	5.8%	0.9%	Decreased by 4.9 percentage points
Data Upload Success Rate Under Weak Network Conditions	76.4%	98.5%	Increased by 22.1 percentage points
Manual Secondary Data Entry Rate	35.0%	0.0%	Decreased by 35.0 percentage points

4.2 Evaluation of Diagnosis and Treatment Efficiency and Synergistic Effect

The establishment of referral information link significantly optimizes the diagnosis and treatment process of suspected children. Before the application of the system, the grass-roots institutions need to contact the higher-level hospitals by telephone or paper documents after finding the positive children, and there is an obvious delay in information transmission. Third-level hospitals often can't start to prepare the inspection equipment until the children arrive. After the application of the system, the standardized screening data was pushed to the receiving hospital at the time of referral initiation, and the information was transferred in advance. The average waiting time for suspected children from the initial screening positive in the community to the completion of echocardiography diagnosis in tertiary hospitals has been greatly shortened. The workload of referral coordination in county-level maternal and child health hospitals has been reduced, and the collaborative efficiency of regional graded diagnosis and treatment has been substantially improved.

5. CONCLUSION

Restricted by the harsh natural environment in high-latitude cold regions and the geographical features of vast territory and sparsely populated areas, the basic medical service capacity in some areas of China is relatively weak. This makes the screening of neonatal congenital heart disease face challenges such as lack of hardware facilities, lack of professionals and bad weather obstacles. Aiming at the problems existing in the process of neonatal congenital heart disease screening and referral in cold regions, this study constructed a standardized information element system. By unifying data elements and attribute specifications, combined with multi-source data mapping conversion method, the standardization and interoperability of screening information are improved. The status tracking mechanism is introduced to manage the screening and referral process, and the information transmission strategy in the weak network environment is combined to enhance the stability of data flow. The application results show that the scheme can improve the quality of screening data management and enhance the information synergy in the referral process.

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