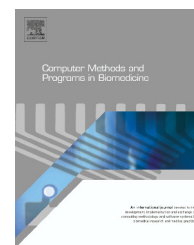




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Empowering village doctors and enhancing rural healthcare using cloud computing in a rural area of mainland China

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ABSTRACT

Background: China's healthcare system often struggles to meet the needs of its 900 million people living in rural areas due to major challenges in preventive medicine and management of chronic diseases. Here we address some of these challenges by equipping village doctors (ViDs) with Health Information Technology and developing an electronic health record (EHR) system which collects individual patient information electronically to aid with implementation of chronic disease management programs.

Methods: An EHR system based on a cloud-computing architecture was developed and deployed in Xilingol county of Inner Mongolia using various computing resources (hardware and software) to deliver services over the health network using Internet when available. The system supports the work at all levels of the healthcare system, including the work of ViDs in rural areas. An analysis done on 291,087 EHRs created from November 2008 to June 2011 evaluated the impact the EHR system has on preventive medicine and chronic disease management programs in rural China.

Results: From 2008 to 2011 health records were created for 291,087 (26.25%) from 1,108,951 total Xilingol residents with 10,240 cases of hypertension and 1152 cases of diabetes diagnosed and registered. Furthermore, 2945 hypertensive and 305 diabetic patients enrolled in

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follow-up. Implementing the EHR system revealed a high rate of cholecystectomies leading to investigations and findings of drinking water contaminated with metals. Measures were taken to inform the population and clean drinking water was supplied.

Conclusions: The cloud-based EHR approach improved the care provision for ViDs in rural China and increased the efficiency of the healthcare system to monitor the health status of the population and to manage preventive care efforts. It also helped discover contaminated water in one of the project areas revealing further benefits if the system is expanded and improved.

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1. Introduction

Over 68% of the population (900 million people) of China live in rural areas and its healthcare system often struggles to meet their needs [1–3]. Providing equitable access and timely care for rural populations is an important issue for healthcare reform [1,2] with long term management of chronic diseases being one of the major healthcare challenges in China [4]. Only 8.1% of the hypertensive population is aware of their condition and manage their blood pressure correctly [5].

One strategy that might help support these health reforms is to implement Health Information Technology (HIT) systems [6], such as an Electronic Health Record (EHR) system to systematically collect patient health data electronically through cloud computing. Cloud computing is the use of various computing resources (hardware and software) to deliver health services and patient data over the health network using Internet when available. Various studies have been conducted regarding the potential benefits for HIT to healthcare systems in developing countries [6–8].

However, Internet access in rural areas is often unavailable and further deprived by lack of local knowledge of keeping IT systems operational [9,10]. One solution is to set up a local vendor with knowledge and experience necessary to maintain the system on behalf of the healthcare organization [10].

In this study we present an alternative strategy based on implementing a system supplied by a cloud-computing vendor. A cloud-based Electronic Health Record (EHR) system was implemented in Xilingol county of Inner Mongolia to support work at all levels of the healthcare system, including work conducted in rural areas with a low level of infrastructure. The system's two goals for health reform are to (1) aid rural health workers with preventive medicine and public health efforts, and (2) to improve integration of care between different levels of the healthcare system. Thus, we address the following questions:

1. How can HIT improve the ability of ViDs to support preventive care and long term management of chronic diseases in rural areas?
2. What benefits has an EHR system in enhancing healthcare delivery to the rural population?
3. What strategic lessons does this system provide to improve the adoption of HIT systems in rural areas of developing countries?

2. Methods

2.1. Setting

The cloud-based EHR system was deployed in Xilingol county (population: 1,108,951; area: 211,866 km²) of Inner Mongolia province in 2008.

2.1.1. Rural healthcare in China

The Chinese healthcare system is comprised of three levels of healthcare providers; city hospitals, county/town hospitals, and village health stations. All levels of the healthcare system are important for populations in rural areas since a patient may visit a city hospital to see a specialist for a complex health problem. However, the majority of primary healthcare work in rural areas is conducted at village health stations by certified health workers that have less training than medical doctors referred to as “barefoot doctors” [11,12]. They focus primarily on preventive issues such as health education, maternal and child healthcare, immunization and collection of disease information [12]. Over the years as the system has evolved, there are now different types of certified rural health workers with varying amounts of formal training and responsibilities.

Village doctors (ViDs) that have received 18 months of training and use a pay-for-service business model currently perform the majority of work related to delivering primary healthcare in rural areas.

2.1.2. Challenges with the village doctor system

Although the ViD system is considered a success on a cost-benefit basis, there are some challenges with the system. One challenge is the pay-for-service business model resulted in preventive medicine and public health work becoming a lower priority [11]. Recent reforms have changed the economic incentives for ViDs, providing them with a salary and bonus for performance instead of a pay-for-service model, resulting in a reduction of drug costs and unnecessary drug prescriptions [13,14].

Another challenge is related to health records. Because the ViDs live in the community in which they work and know all of their patients personally, they generally have not kept formal health records [14]. This creates challenges in integrating different levels of the healthcare system and makes it difficult for officials in obtaining the information needed to implement public health efforts and to manage chronic diseases, all important aspects of current health reform efforts in China [2,15].

2.1.3. The implementation of the cloud-based EHR system

In order to deal with these challenges a cloud-based EHR system was implemented. A study of 20 different definitions by Vaquero et al. [16] define a cloud as "...a large pool of easily usable and accessible virtual resources..." associated with a pay-for-use model by the infrastructure provider. This business model can have different characteristics like software as a service (SaaS), platform as a service (PaaS) and infrastructure as a service (IaaS) [17]. In this project a private cloud was set up within the hospital system based on the IaaS model.

The usage of a private cloud provides advantages in healthcare through increased stability, security, and patient privacy, as the healthcare organization maintains control and ownership of all the patient data. The IaaS model is advantageous in this case, since the hospital system does not need to investigate the hardware and software requirements for the system separately. It also guarantees that the hardware and software are optimized for usage together, and that maintenance of these systems is very straightforward.

The cloud-based EHR comes from Healthgrid Technology Inc. (ref) and its hardware architecture based on Blade server [18] is very flexible and scalable with only one server needing to be deployed at each city hospital (see Fig. 1). Additional client machines can be deployed at other locations and client data can be inputted and used throughout the healthcare system. This allows the system to support health work at all levels of the Chinese healthcare system at different types of facilities over a large geographical area. Fig. 1 shows the overall schema of hierarchy of different level of health providers that are connected. City hospital is connected with County and Town hospitals and Town hospital will enroll and receive information from village doctors. Fig. 2 depicts the working station of village doctor.

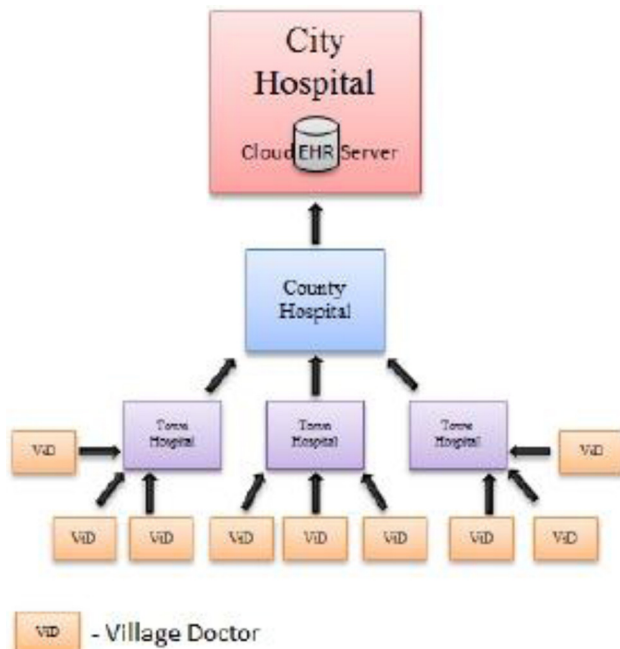


Fig. 1 – Hierarchical representation of the healthcare model in China.



Fig. 2 – A ViD office with a notebook computer that can access the cloud-based EHR system.

The planned system is designated for rural areas usage including ViDs traveling to areas without Internet access, and contains features that help remove various operational barriers. These features include:

- Work in remote areas is supported by notebook computers enabling access to the EHR system via a web interface. Fig. 2 shows a ViD at his office with a laptop accessing the EHR system.
- The laptops used by the ViDs are standard and easy to replace, avoiding data loss when used in remote areas, become damaged or are lost.
- All data stored in the cloud and servers are located only at city hospitals. Therefore, no work is needed for maintaining servers in remote areas.
- Support for offline usage. In addition to web interface access ViDs have a locally installed desktop version of the software. Using the offline mode, the ViDs can enter information into the system and view the health data for their local patients. New data are integrated into the EHR system when connectivity is established. This happens during regularly scheduled visits (usually every other week) in order to obtain supplies, and is done either by USB stick or directly from their laptop.
- Around 70% of the ViDs have Internet access from their clinics.
- Remote monitoring and auditing of the system is also supported which allows administrators to address different issues remotely.

2.2. Security

The ViDs are required to log into the system using a locally verified username and password. The computing environment is very stable; antivirus and anti-spyware software were installed and the operating system receives regular updates. Network security requires strong user authentication (user name and password) whenever someone accesses the EHR system via the web interface. The identity of the browser



Fig. 3 – An image showing patient health information present in EHR (patient ID has been removed from the figure as privacy protection protocol).

is also verified for keeping unauthorized machines from accessing the system. The connection is secured with TLS1.0 encryption and software was checked for vulnerabilities to avoid problems such as SQL injection.

2.2.1. Usability features: system design

The interface was designed for easy usage and contains templates for data input of patient's medical history and current status. Figs. 3-5 show images of the user interface for various components used by the ViD.

Fig. 3 shows an overview of the patient records collected by the ViDs. The horizontal bars on the left reveal the complete record for each patient: demographic information, photo of the patient, examination results, and past medical history. This interface helps the ViDs and public health officials to evaluate the completeness of the information collected.

Fig. 4 shows an overview of health information for hypertensive patients used by ViD to obtain information used in management of hypertension. The first column shows the follow up records for blood pressure as they change over time. The other columns contain additional patient information such as age, sex, ID, systolic and diastolic blood pressure values, village name and the ViD entering the data. The blood pressure values are shown in green font for normal readings, whereas abnormal values are shown in red (Fig. 5).

This overview allows the ViDs to easily identify the patients with poor management so that they can focus on the medications and life style of these patients.

2.2.2. Usage in rural areas: system utilization

In order to initiate preventive medicine efforts the ViDs were instructed to visit all patients in their area, and create electronic records containing the relevant public health



Fig. 4 – Screen showing follow-up information of patients enrolled in hypertension management.



Fig. 5 – The PC screen highlighting abnormal blood pressure (red) of the hypertensive patients. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

information. The data collection efforts included visits to nomadic herdsmen, as this is a significant portion of the population. The preventive care measure specifically targeted high blood pressure and diabetes.

The ViDs were provided with the necessary medical equipment including a sphygmomanometer and glucometer to identify patients that would qualify for a follow up program in order to help them manage their condition. The follow-up program includes regular visits by the ViDs to nomadic herdsmen to measure blood pressure and blood sugar levels, and to check the compliance of medication. The preventive medicine efforts were also supported by patients visiting a hospital for hypertension or diabetes checkups with all information inputted in the EHR system. Efforts were also made to enroll patients in a follow-up program conducted by the ViDs.

2.2.3. Additional organizational issues

Since HIT systems should be viewed as socio-technical systems, it is important to consider the organizational design going into the development of the overall system usage [19,20]. Each ViD receives training on how to use the system for 100 h during standard training every other year as part of renewing their license at a town hospital. Caution was taken to assure that proper incentives were in place [17]. During a pilot phase of the project, challenges encountered in convincing the ViDs to take on new responsibilities were solved by offering them additional 2500 RMB annually (approximately 600 USD) to complete the data collection task, and support future preventive medicine efforts.

The study was exempt from ethical approval by both China and Taiwan Ethical Review Boards due to its nature (no interventions or trials were performed).

3. Results

The EHR system has been utilized since 2008. Currently about 44 ViDs are using the EHR system for creating EHR records

Table 1 – Characteristics of Xilingol province; patients in the EHR system, and HTN and DM patients.

| Characteristics | Value |
|--------------------------------|-------------------------|
| Area | 211,866 km ² |
| Population | 1,108,951 |
| Total patients in the EHR | 291,087 |
| Patients with HTN | 10,240 |
| Patients with DM | 1152 |
| Patients with HTN in follow-up | 2945 |
| Patients with DM in follow-up | 305 |

in the Xilingol. From November 2008 to June 2011 there were 291,087 EHRs (26.25% of the total population) created by ViDs and doctors from higher level healthcare institutions.

The use of the system to date has resulted in two notable health improvements. The first is the system was used in implementation of chronic disease management related to hypertension and diabetes. Table 1 shows the total number of patients in the EHR system in Xilingol diagnosed with diabetes mellitus (DM) and hypertension (HTN), as well as the number of patients enrolled in a follow-up program (long term management) after being diagnosed. Table 2 shows the distribution and prevalence by age for HTN and DM as recorded in the EHR.

In the EHR system the number of persons with hypertension corresponds to only 3.5% of the total population (10,240 of 291,087) and 5.2% are 30 years old (10,190 of 195,790). Enrollment in the follow-up programs was below 50%.

The second improvement is related to an unexpected discovery by a director of a town hospital in Xilingol county. While reviewing the records of patients in his region he noticed 1038 cholecystectomies; one town in the east of Xilingol had a particularly high prevalence. At 0.65% (163/25,017), it is two times higher than the entire Xilingol statistics at 0.32% (931/291,106).

Cholecystectomy is often performed because of gall stones formation induced by heavy metal consumption [21]. After a thorough environmental investigation reports revealed contaminated drinking water with a metal concentration higher

Table 2 – Age distribution for the adult population in the EHR system with HTN and DM Age.

| Age | Population in EHR | HTN patients | HTN% | DM patients | DM% |
|-------|-------------------|--------------|-------|-------------|-------|
| 0–10 | 21,173 | 0 | 0 | 0 | 0 |
| 11–20 | 28,445 | 8 | 0.03 | 1 | 0.004 |
| 21–30 | 45,679 | 42 | 0.09 | 7 | 0.015 |
| 31–40 | 57,869 | 371 | 0.64 | 44 | 0.07 |
| 41–50 | 60,383 | 1731 | 2.8 | 164 | 0.27 |
| 51–60 | 41,239 | 3005 | 7.28 | 343 | 0.83 |
| 61–70 | 21,556 | 2878 | 13.35 | 380 | 1.76 |
| 71–80 | 11,938 | 1821 | 15.25 | 194 | 1.63 |
| 81–90 | 2568 | 370 | 14.40 | 19 | 0.73 |
| 91– | 237 | 14 | 5.9 | 0 | 0 |

than acceptable limits. The population has been informed not to drink water from the contaminated wells and measures have been taken to provide clean drinking water.

4. Discussion

4.1. Utilizing HIT to aid ViDs in supporting preventive care and long term management of chronic diseases

This project demonstrates how empowering ViDs with technology and using an improved record keeping system can enhance preventive care and long term management of chronic diseases and also connecting with higher levels the healthcare system. To date the implementation of large-scale HIT systems in rural areas of developing countries is still limited by many challenges especially finances. More studies are needed on how HIT systems can increase benefits of use.

Since socio-technical development of healthcare systems using HIT is considered “reinvention of healthcare” [19] additional benefits are expected from development of this system. EHR systems often serve as a backbone for supporting other HIT systems. As the system matures it should extend its capabilities to support tele-consultation and decision support functionalities, improving the quality of care provided by the ViDs.

The increased contact between the ViDs and community in supporting public health and preventive medicine programs may also help to overcome some noted cultural challenges related to healthcare in rural China. Today a large percentage of the population in China often uses western medicine as a last resort, and when efforts fail, it can lead to mistrust among patients in the healthcare system [22]. This not only makes it difficult to treat the population, but also leads to other problems, including health personnel in China experiencing violent attacks from dissatisfied patients and their families [22–24]. If the visits by ViDs to the rural population help establish a positive relationship with patients during a less complicated situation as opposed to a critical procedure and the system also improves the overall quality of care available to patients from the ViDs, it can help increase the trust of the population towards the healthcare system.

4.2. Current benefits of the cloud-based EHR system to rural healthcare delivery

To date the project has enabled the collection of health information on over 290,000 people leading to 2945 people being

enrolled in follow-up programs for management of HTN and 305 people being enrolled in follow-up programs for DM. It also has led to the identification of a previously unknown environmental problem related to metals present in water wells that affected the population’s health, resulting in policies for improving clean water supply to the affected population.

The study also reveals that the implemented system cannot solve all problems related to chronic disease management in the region. It is estimated that 27.2% of the adult population in China has hypertension [5]. This is a higher rate than found from the database analysis indicating there are some challenges identifying all people with hypertension qualifying for the disease management program. However, the system has enabled thousands of people from a remote county to benefit from chronic disease management, previously not possible. This is an achievement when considering that only 8.1% of the hypertensive population in China is aware of their condition and make efforts to manage their blood pressure [5]. In the future the benefits are expected to grow as awareness about chronic disease management is increased and more experience is gained within the healthcare system on how to utilize this model.

4.3. Strategic perspectives to improve the adoption of HIT systems in rural areas of developing countries

In addition to demonstrating the possibility for HIT to support health reforms in rural China, the project also provides some strategic perspectives on how to implement similar systems, both in China and in other countries. From a user experience perspective, the system supported rural healthcare workers by providing the following features:

- Ease of use
- Security
- Support for off-line use so patients can be served without using the Internet
- Minimal system administration and maintenance requirements
- Low cost and easily replaceable hardware
- Ability to input data anywhere to be used throughout the healthcare system

The system supports usage in peripheral areas reflecting on the cloud-computing concept of supplying users with “...a large pool of easily usable and accessible virtual resources...” [17] which requires a scalable and flexible architecture. We

have not conducted a complete cost–benefit analysis on the decision to use an external vendor instead of developing the system internally; therefore, it is not definite if the usage of a cloud-computing is the most cost-effective.

Cloud-computing firms are quite experienced in developing such architectures; thus, in many cases it should be advantageous for organizations looking to implement EHR systems to utilize the cloud-computing model.

An additional perspective from this project is how the computing architecture utilized can make possible to implement a wide scale HIT system despite Internet access being unavailable in many situations. Previous projects have shown that it is possible to overcome lack of Internet access for HIT projects by developing point-to-point WiFi networks connecting peripheral clinics to hospitals [10]. For this project such solution would not support the mobile work of ViDs since point-to-point WiFi stations are generally static. Instead this project utilizes architecture that supports the work of ViDs while offline, and also supports the synchronization and backup of health records using Delay Tolerant Networking (DTN) via USB stick or laptop data transport.

Although health workers working in developing countries seem highly positive to the possibilities for DTN to support HIT in rural areas, to date few projects have reported its utilization [25]. The implementation of DTN on this project and successful use of point-to-point WiFi when available demonstrates that with proper architectural design it is possible for projects to establish enough connectivity to support HIT projects on their own even if connectivity to Internet, mobile phone networks, and satellite are unavailable or too expensive.

From an organizational perspective the inclusion of a new payment structure to support the public health and preventive medicine efforts is also an important aspect of such project. Various financial incentives are also useful when implementing EHR systems in developing countries [7], consistent with recent attempts to improve ViD programs by the introduction of income other than just pay-for-service payments [13,14]. This emphasizes the socio-technical nature of healthcare transformation with HIT and projects, in order to be successful may require larger changes to the healthcare model than basic requirements to support the technical system and training of users.

4.4. Additional implications

The project also provides some perspectives useful for developed countries. Studies in the United States reveal benefits for small rural hospitals when they outsource IT systems from larger urban hospitals [26]. The cloud-based EHR approach can be viewed as a further development of a model that enables urban hospitals to also support primary care workers in rural areas with systems that will more easily fulfill the meaningful use criteria [27].

This project reflects the overall potential for Information Technology (IT) to enable healthcare reform. Recently this occurred in Taiwan when emergency medical workers and the Ministry of Health utilized Facebook to move health reforms forward quicker than previously [28]. Although the context and results in this project are different from Taiwan, both

cases illustrate how IT can enable healthcare workers to improve awareness among higher officials regarding issues impacting the health of the population and how this awareness can lead to health reform. In this study, the high level officials were able to make decisions based on information obtained from the EHR system.

5. Conclusions

A cloud-based EHR system was implemented in a rural region of China with 1.1 million people, allowing health information to be compiled on over 290,000 people. This enabled ViDs to begin chronic disease management programs and also lead to the discovery of previously unknown environmental problems. The project demonstrates the use of HIT in improving record keeping, enabling the ViD system in China to improve preventive medicine efforts and chronic disease management, and to better connect with higher levels of the healthcare system. The strategy is expected to provide further benefits to the rural population of China if implemented on a larger scale, with additional functionalities such as decision support added to the systems used by the ViDs.

The project also provides strategic perspectives on how to approach the implementation of large-scale HIT systems in rural areas of developing countries.

In particular it offers two key perspectives:

- (1) The cloud-computing model holds great potential for supporting rural health workers in developing countries.
- (2) HIT computing architectures supporting offline work with easy data back-up and synchronization through the use of DTN data delivery make possible for overcoming challenges related to limited Internet connectivity.

The project also suggests that the cloud-computing model is worth exploring in other contexts for both developed and developing countries which enables large hospitals or larger scale hospital systems to support primary healthcare providers in rural areas where it may be difficult for them to independently develop systems that fulfill meaningful use criteria.

Competing interests

The authors declare no competing interests.

Authors' contributions

All authors made significant contributions to this study. CWL designed the study and participated in data interpretation and analysis. SSA collected the data and participated in drafting the manuscript and in data interpretation and analysis. JS and YCL participated in drafting and revising the manuscript and data interpretation and analysis. DLC drafted and revised the final manuscript and participated in data interpretation and analysis. XJ, HL and SSC participated in obtaining data and the study implementation. All authors read and approved the final manuscript.

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