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Implementing electronic medical record systems in developing countries

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ABSTRACT

The developing world faces a series of health crises including HIV/AIDS and tuberculosis that threaten the lives of millions of people. Lack of infrastructure and trained, experienced staff are considered important barriers to scaling up treatment for these diseases. In this paper we explain why information systems are important in many healthcare projects in the developing world. We discuss pilot projects demonstrating that such systems are possible and can expand to manage hundreds of thousands of patients. We also pass on the most important practical lessons in design and implementation from our experience in doing this work. Finally, we discuss the importance of collaboration between projects in the development of electronic medical record systems rather than reinventing systems in isolation, and the use of open standards and open source software.

Keywords: databases, developing countries, electronic medical records, HIV

Introduction

The developing world currently faces a series of health crises that threaten the lives of millions of people. Many of the worst-affected developing countries lack resources and robust healthcare infrastructures.[1] Recent statistics suggest that treating the rising tide of human immunodeficiency virus (HIV) in developing countries requires that large-scale interventions are immediately put into place, and ambitious worldwide initiatives such as the Global Fund and the World Health Organization (WHO) 3 by 5 Initiative have begun to mobilise resources and manpower in response.[2,3] Early lessons from treatment programmes indicate that new systems of care are required to allow these efforts to scale rapidly to thousands or even hundreds of thousands of patients.[4] Programmes must also support healthcare providers, many of whom have limited training. To achieve these ends requires the ability to manage large and often complex projects, including the initiation of new treatments, the follow-up and monitoring of chronic diseases, medication procurement, and reporting to governments and funders.[5,6] Research must also occur concurrently with these efforts, as the pathophysiology of these diseases is not fully understood in these environments, and continues to change in response to our interventions. Many of these goals require excellent information management in order to be successful. Concerns have been expressed that the lack of infrastructure and skills in developing countries will prevent large-scale treatment of such diseases as HIV and multi-drug-resistant tuberculosis (MDR-TB).[7] While HIV, TB and malaria are the best known, other important problems must be addressed, including maternal and infant mortality, other infectious diseases, trauma, and rising levels of hypertension, diabetes and cardiovascular disease in developing countries.[8]

Growing use of electronic medical record (EMR) systems in Europe and the United States (US) has been driven by the belief that these systems can help to improve the quality of health care. Decision support systems, particularly for drug order entry, are becoming important tools in reducing medical errors.[9] Email is important and widely used in healthcare systems, and access to medical data including online journals is expanding.[10]

Even in resource-rich nations, the development of EMR systems is still an uncertain and challenging task, calling for a sensitive matching of local needs to available technologies and resources.[11] Experience with creating EMR systems for the developing world is much more scarce; requirements, priorities and local constraints are less well understood and probably more heterogeneous. Some settings in the developing world are similar to a European or US healthcare environment and can use similar software; other environments have very limited resources. It is impossible, therefore, to suggest a single EMR architecture and implementation that will fit all environments and needs. In this paper we focus on systems that can support health care in the very challenging impoverished environments where the vast majority of the world's population live. A handful of projects in developing countries have now met the test of actual implementation in such settings and are in day-to-day use.

We first discuss the potential benefits of EMR systems in developing countries and then present short descriptions of several systems with which we are familiar that are in regular use. We then provide a taxonomy of system architectures and technology choices and comment on their applicability in particular kinds of environments, drawing on our practical experiences and the examples of deployed systems. We also present a number of challenging issues including reliable patient identification, data quality management, and data confidentiality and security. Finally, we conclude with mostly non-technical lessons learned from experience in successfully deploying systems.

This is intended as a practical guide for deploying and using EMR systems in developing countries rather than a review of all existing projects. Unfortunately few systems have been described in the literature and fewer evaluated, but a systematic review of such systems was published in 2002.[12]

Potential benefits of EMR systems in developing countries

Although EMR systems have been shown to be feasible in developing countries, the problem of limited resources begs several questions.[13–15] Do EMRs contribute important benefits to healthcare projects? Is this use of information technology (IT) practical beyond a few well-funded pilot sites? Does it have a beneficial impact on patient care or the management of such healthcare organisations? What lessons can we pass on to other healthcare organisations to help them identify the most effective and sustainable technologies for EMR systems in these environments?

Rapid developments in IT have greatly reduced the costs of setting up information systems. Plans have recently been announced to develop a laptop PC for $100.[16] Internet access is now relatively widely available in many developing countries (Peru, Ghana, etc.) and there exists a broad range of robust and flexible devices to manage data, including personal digital assistants (PDAs) and mobile phones.

In developing countries, healthcare information systems have been driven mainly by the need to report aggregate statistics for government or funding agencies.[17] Such data collection can be performed with simple paper forms at the clinic level, with all electronic data entry done centrally, but that approach tends to be difficult and time-consuming and may provide little or no feedback to the staff collecting data.[18]

Individual patient data that are collected and accessible at the point of care can support clinical management. Clinicians can easily access previous records, and simple tools can be incorporated to warn of potential problems such as incompatible drugs. Physicians or nurses can check on the outcomes of individuals or groups of patients and perform research studies. Many of these functions will work well on paper or with simple spreadsheets for up to 100 patients but become very time-consuming and potentially unreliable with more than 1000 records, and virtually impossible with 10 000 or more. Networked EMR systems allow laboratory data to be entered from distant sites, assisting prompt and effective patient management. Access to email or web communications allows staff to seek specialist advice from remote physicians.[19,20] Assessing resource requirements and preventing drug stock shortages, while not normally a consideration for medical staff in developed countries, can be a critical issue in the developing world.[18] It requires an accurate knowledge of numbers of patients with particular regimens or types of disease and knowledge of drug stocks and supply.[21,22] EMR systems can also be used to track patient outcomes, compliance with therapy and to record surgical procedures.

Finally, point-of-care data can be used to rapidly generate aggregate reports, which should be more complete and accurate because users will more likely recognise errors regarding their own patients.[15] Incorporating multiple functions into the same information system allows reuse of data and should help to justify the basic costs of set-up and technical support. For example, in sites with no modern communications, a satellite internet connection might be justified purely to allow regular communication by email and possibly internet telephony.[14] The benefits of web access for data management and medical education are additional.[23] Box 1 summarises the benefits of EMR systems.

Box 1 Benefits of EMR systems

- Improvement in legibility of clinical notes[13]
- Decision support for drug ordering, including allergy warnings and drug incompatibilities[24]
- Reminders to prescribe drugs and administer vaccines[24,25]
- Warnings for abnormal laboratory results[25]
- Support for programme monitoring, including reporting outcomes, budgets and supplies[26,27]
- Support for clinical research
- Management of chronic diseases such as diabetes, hypertension and heart failure[2,28]

Case summaries of existing systems

Despite the difficulties in deploying information systems in developing countries, several have successfully integrated into clinical workflows. While none represent a complete or ideal solution, their successful use over several years, with combined patient records numbering in the hundreds of thousands, offers valuable insights into successful future deployments. This is not intended to be an exhaustive list; other systems might contain important ideas and designs but need to be validated in appropriate environments. Box 2 includes brief descriptions of other known systems deployed in developing countries. A recent report includes an assessment of medical information needs in African clinics and some additional systems.[18]

(1) AMRS, Kenya

Background: Indiana University School of Medicine and Moi University School of Medicine (Eldoret, Kenya) have been collaborating for over 15 years. In February 2001, this collaboration led to the Mosoriot Medical Record System (MMRS). The MMRS was installed in a primary care healthcare centre in rural Kenya. In November 2001, the MMRS software was adapted to support the AMPATH (Academic Model for the Prevention and Treatment of HIV/AIDS) project and renamed to AMRS.[29,30]

Design: Two networked computers running Microsoft (MS) Access™, powered by a UPS with solar battery back-up. For the AMPATH project, the network has expanded to seven networked computers linked to a single MS Access database.

Number of patients entered: 60 000 patients and over 150 000 visits in four years. For HIV care, 8000 patients, 3300 of whom are currently receiving anti-retroviral drugs (ARVs).

Sites: Two, with the AMPATH site serving as a central repository for eight remote clinics.

Data entry: In the MMRS, patients are registered in the system upon arrival, travel through the clinic with a paper visit form, and present the visit form as they depart. Clerks perform the registration and transcribe visit data. AMRS data are collected on paper forms at each visit, delivered to a central location for data entry, and then returned to the patient's paper chart.

Functions: MMRS provides both patient registration and visit data collection functions. Data are collected on all patients seen in the medical clinic, including their laboratory results and medications. AMRS supports comprehensive HIV care as well as mother-to-child-transmission prevention, while serving as a rich database for quality improvement and answering research questions.

Pharmacy management: Based on drug regimens analysis available.

Evaluation: A comparison of the clinic before and after adoption of the MMRS showed patient visits were 22% shorter, provider time per patient was reduced by 58% ($P < 0.001$), and patients spent 38% less time waiting in the clinic ($P < 0.06$); clinic personnel spent 50% less time interacting with patients, two-thirds less time interacting with each other, and more time in personal activities.[14] The MMRS has also vastly simplified the generation of mandatory reports to the Ministry of Health.

Significance: The growing AMRS and MMRS databases serve both clinical and research needs, gen-erating clinical summary reports for providers and providing a centralised source of data for epidemiological research. The next generation of the database, called AMRS, has a completely revamped data model, and uses new technology (MySQL, Python-based Zope and Plone, and MS InfoPath to allow web-based data entry).[30] See http://amrs.iukenya.org for more information.

(2) PIH-EMR, Peru

Background: In 1996 Partners In Health (PIH) started a treatment programme for drug-resistant tuberculosis in the slums of Lima, Peru. (A patient that is multi-drug resistant is infected with bacteria resistant to isoniazid and rifampin, the two most efficacious anti-tuberculous drugs.) The PIH-EMR is a web-based EMR developed to support the two-year treatment regimen for these patients. It was implemented in 2001.
Number of sites: Peru: three; The Philippines: one.
Number of patients: 4300; 2900 have received treatment to date.
Design: Open source web system backed by an Oracle database. Bilingual English and Spanish.
Data entry: Forms filled out by the chest physicians, as well as laboratory result forms. Medication data is entered by the nurses and their assistants who manage the patients in each district on advice from the chest physicians.
Functions: The PIH-EMR includes a clinical record with initial history, physical examination, laboratory results and medications on all patients receiving individualised treatment for MDR-TB. The custom medication order entry system provides advice on potential problems and feedback to the nurses, who can consult the physicians if, for example, a patient has new evidence of resistance to the drug they have been prescribed. Laboratory tests for second-line drug resistance are entered in Boston and Peru and accessible by staff in both sites.

The PIH-EMR is also used to create monthly reports for the Global Fund and the Health Ministry. There is an extensive suite of web-based analysis tools for reporting and outcome monitoring.[27] These include graphs of culture conversion rates (time until sputum culture becomes negative) and search tools for patients with particular resistance patterns and drug regimens. Analysis tools are used to assess drug requirements based on the medications prescribed. The system is being extended to include all MDR-TB patients in Peru and linked to the main tuberculosis laboratories there.
Pharmacy management: Full inventory system and drug regimen analysis.
Evaluation: The medication order entry system was shown to produce significantly fewer errors than the previous paper and spreadsheet approach (17.4% to 3.3%, $P < 0.0075$).[31] Drug requirements analysis tools are based on the medications prescribed, and have been shown to match the usage data in the pharmacy to within 3%.[21]
Significance: The PIH-EMR demonstrates the strength and flexibility of a web-based approach when internet connectivity is available.

(3) The HIV-EMR system, Haiti[14]

Background: Since 1999, PIH has run a community-based HIV treatment programme in Haiti with its sister organisation Zanmi Lasante, expanding to seven public health clinics in an area with virtually no roads, electricity or telephone service.
Design: Based on the PIH-EMR. Satellite-based internet access at each site supports email and web communication.
Sites: Seven in rural Haiti.
Number of patients: 4000; 2000 full patient records.
Data entry: Doctors enter case histories and medications directly, whereas technicians enter laboratory results and pharmacists enter stock records. The data entry staff is being expanded.
Design: Open source web system backed by an Oracle database (the same as the PIH-EMR) with an additional offline client for data entry and review. Bilingual English and French.
Functions: History, physical examination, social circumstances and treatment recorded. Decision support tools provide allergy and drug interaction warnings, and generate warning emails about low CD4 counts. An offline component of the EMR was developed to overcome unreliable internet communications in some sites. This allows data entry and case viewing when the network is down, and has proven to be reliable and popular with clinical staff.
Pharmacy management: Full inventory system and drug regimen analysis.
Significance: The HIV-EMR shows the feasibility of implementing a medical record system in remote clinics in a remote area with virtually no infrastructure and limited technical expertise.

(4) Careware, Uganda[32]

Background: A team at the US Department of Health and Human Services has developed a medical record system to support HIV treatment via the Careware system.
Design: Stand-alone database built with MS Access.
Sites: US: 350; Africa: Two.
Number of patients: Several hundred in Africa, many thousands in the USA.

Data entry: Both direct by users, and on paper forms.
Functions: Provides comprehensive tools for tracking HIV patients and their treatment, including clinical assessment, medications and billing data. It is widely used in health centres and hospitals in the US, and has recently been internationalised and deployed in Uganda in October 2003.
Pharmacy management: Drug inventory support in international version.
Significance: Careware is an example of a US-based stand-alone EMR that is being adapted to developing country environments. An internet-accessible version that is under development will allow local data entry offline but provide networked communications and back-up.

(5) Lilongwe EMR, Malawi[13]

Background: Kamuzu Central Hospital located in Lilongwe, Malawi has made extensive use of a touch-screen patient management information system for a wide range of clinical problems in the 216-bed paediatric department since 2001.
Design: Runs over a local area network built on Linux/MySQL with Visual Basic™ for the client programs.
Sites: One.
Number of patients: 160 000 total; 6000 with HIV.
Data entry: Physicians, nurses and pharmacists perform all data entry using touch screens, including medication orders.
Functions: Data are collected on patient demographics, medication, laboratory tests and X-rays. A potential limitation of the touch screen approach is that it is difficult to enter free text, though an 'on-screen' keyboard is available and has been used by local staff to enter all the patients' names.
Pharmacy management: Recording of regimens only.
Significance: The extensive use of this system directly by healthcare workers in a poor country with limited IT skills is a convincing demonstration of the potential of EMRs with user-friendly data entry mechanisms.

(6) SICLOM, Brazil

Background: The Brazilian public health system uses the 'Computerized System for the Control of Drug Logistics (SICLOM)' to deliver ARV treatment to over 100 000 patients – by far the largest group in the developing world.[33,34]
Design: Separate EMR databases on each physician's desktop periodically connect to the central server by dial-up to update records. Language: Portuguese.
Number of sites: Widespread throughout Brazil.
Number of patients: More than 100 000.
Function: Used to support prescribing and track medication supplies (limited information available).
Significance: It is considered a 'key factor(s) helping to overcome logistical challenges to delivery of anti-retroviral treatment in Brazil'.[33]

Box 2 Other EMR systems in developing countries

FUCHIA was developed by Epicentre, the epidemiology group of Médecins Sans Frontières, to support their HIV treatment projects.[35] It supports clinical care and long-term follow-up of patients, including scheduling of visits; it includes data on medications and investigations and generates reports. It was developed as a stand-alone system using MS Access and the Delphi programming language.

An information system was developed in Botswana to support the TB programme and is built using EpiInfo (a free stand-alone program from the US Centers for Disease Control [CDC] designed for data collection and analysis in developing countries).[26,36] It includes reporting and analysis tools and has been successfully deployed to multiple sites in several countries.

PDA/Palm systems
A variety of PDA-based medical information systems have been proposed or implemented for projects in developing countries on the basis that handheld devices will be easier to use and support in remote sites. Such devices would seem to provide particular benefits for community health care, being simple and relatively unobtrusive to carry around. Palm-based devices tend to be favoured due to their excellent battery life and generally lower cost. In KwaZulu Natal, South Africa, a Palm-based system allows secure access to HIV results in remote clinics.[37] In rural India, a Pocket PC-based system has been used to store health records for community nurses visiting remote villages.[38] Palm or Pocket PC systems can be easily set up to view pages offline from a web-based EMR, though care is required to maintain data security.[39] Satellife is using the mobile phone network in Uganda to link PDA-based medical records to a central site. Local healthcare workers collect data on Palm Pilots™ and then connect to a local battery-powered server that connects to a central database via a mobile phone modem.[40]

continued

Web-based collaboration and telemedicine systems
The web allows data sharing for remote consultation, and several projects have established systems that can be used to support diagnosis and treatment decisions in remote sites with limited bandwidth. The RAFT project permits remote collaboration, case discussion and data sharing over low-bandwidth networks between Geneva University Hospitals and Bamako, Mali.[41] The IPATH server is a web-based tool for image sharing in pathology and radiology being used in South Africa and the Pacific as well as Switzerland.[42] Telemedmail is a secure email and web-based telemedicine system under evaluation in South Africa and Peru.[20]

System architectures

Data model

The design of the database tables and their relationships, the *data model*, is the core of any EMR system, but unfortunately its design and implementation do not always receive enough attention. Pressures to develop an EMR system quickly and according to a set of initial project requirements often contribute to this. The strength of the data model will dictate the scalability and flexibility of a system. The design of the database schema is usually driven by the functional requirements of the EMR system; if the system is primarily for reporting and health statistics, there is a tendency to represent all data items as columns, similar to a spreadsheet. This approach is suitable for simple single functional function systems, such as for clinical trials, but tends to be inflexible, especially for chronic care.

For more multi-functional systems a data model is required that:

- can support a variety of functions within clinical care, programme monitoring and reporting, supplies and logistics, and research; these more complex systems need to be able to handle different types of data;
- can accommodate new data such as drugs, clinical conditions and outcomes without modifying the data model; future data requirements are often not known at the start of the project and evolve during the lifetime of the system;
- allows for temporal data; data for clinical diagnoses, laboratory tests, treatments and outcomes are often temporal in nature, particularly for chronic disease management;
- allows for data to be exported in standard formats for analytic and statistical packages, third party software, etc.;
- allows for, or can gracefully expand to, support different spoken languages and variations in medical terminology.

Most EMR systems in developing countries use commercial relational databases such as MS Access (MMRS, Careware) and SQL Server and Oracle (HIV-EMR, PIH-EMR), or open source alternatives such as MySQL (Malawi) and Postgres. Maintaining and using relational databases is simplified by the widespread availability of expertise, tools and software for these systems.

One approach in designing a data model for more complex EMR systems is the use of a concept dictionary. For example, hard-coding types of clinical conditions and outcomes into the database schema often results in making frequent changes to the data model as the system is expanded to allow for more types of clinical conditions. This expansion is not always possible or easily made and the data model can end up restricting certain extensions to the system. Instead codes from a central concept dictionary can be created that map to the clinical conditions and allow the database schema to store these concepts as data (see Box 3). The meaning of these codes will not be a fixed part of the database schema. When the system expands to allow for new clinical conditions, all that is required is to insert new concept codes without changes to the database schema. These codes can include fields in a second language, allowing straightforward translation in bilingual environments. This approach can also deal with variations and nuances in terminology between projects and sites. It is possible to map a single code to many natural language phrases. Each coded concept must be well described and non-ambiguous. Where possible, the concept codes should be mapped to standard coding systems such as ICD10, SNOMED, LOINC or HL7, though none provide complete coverage.[43] These standards could also assist in exchanging data with other EMR systems in the future.

The data model can even be extended to assist in the automatic generation of user interfaces and to support validation rules for correct data entry. To move beyond successful prototypes to widespread use, it is essential that EMR systems are developed with open standards and sharable components. A common data model can efficiently link the wide range of technology platforms discussed earlier and ease collaboration between projects.

Network architectures

Stand-alone systems

In these systems, a database and user interface is deployed on a single machine. Examples of stand-alone systems

Box 3 Flat file versus coded database design

Traditional 'flat file' database design

- Each patient has one row in a database table
- Each data item has its own column in a table, similar to a spreadsheet
- Multiple results over time (such as laboratory tests) each need a separate column
- Adding new data items requires changing the structure of tables in the database
- Scaling to hundreds or thousands of observations is nearly impossible
- Quick and simple to create for small systems

Coded database structure

- Each observation has one row in a database table
- Observation names and descriptions are stored in a separate table
- Adding a new data item just requires typing in a new type of observation
- Each observation is time-stamped so temporal data are easy to analyse
- Data have to be converted for easy analysis in statistical tools and spreadsheets
- Straightforward to link to standard medical coding systems
- Simplifies support for multiple languages
- This design is used in large EMR systems as it scales well

reviewed here are (1) AMRS, (5) Careware, and Fuchia (see Box 2). The EMR system has no explicit functionality to communicate with other machines over a network. These systems range from a simple spreadsheet for storing patient data to a simple database. Stand-alone systems are the easiest type of EMR to design and implement and are suitable for isolated applications such as a small EMR, patient registry or a clinical trial database.

Local area network (LAN) systems

A LAN EMR system is deployed at a single site and machines have a relatively fast connection to each other (= 10mb/s). Typically these systems revolve around a database (Oracle, MySQL, MS SQL Server) deployed on a central server. Users have local client application interfaces in which they enter, query and modify data directly on the central database. An example of this system is (4) Lilongwe.

Wide area network (WAN) systems

These consist of a networked system that operates across multiple geographical sites. Sites could be spread across a single city, state, country or could even span multiple countries. There are many approaches to WAN EMR systems. These can be classified into three categories: a thin client approach, such as centralised web-based systems like PIH-EMR and HIV-EMR; a thick client approach, such as (6) SICLOM in Brazil and a system used in Israel; and a hybrid approach, such as the (3) HIV-EMR in Haiti.[9,33,44] These approaches are described in Box 4.

Box 4 Types of client architectures

Thin client

Thin client architecture revolves around a single, central high-powered server with a single database. In these types of systems, no client application is required at remote machines. Web browsers connect to a central web server over a WAN, and provide a user interface to interact with data stored at a centralised database. However, web-based interfaces have some limits in the functionality for user interaction that they can offer. Richer application functionality is possible by using products such as Citrix Winframe, Microsoft Infopath and Windows Terminal Server, but at a price. Thin client systems require no proprietary software to be installed and maintained at remote sites; however, a reliable network connection to the central server is required and the central server forms a critical failure point of the system.

Thick client

As opposed to thin client architectures, where the central database maintains and stores all data in the system, thick client architectures allow remote nodes to store and maintain local data by hosting a database locally. The system must provide a mechanism for synchronisation with the central database. Examples of these systems are SICLOM in Brazil, and a similar approach being used in some small practices in Israel.[30,38] In some approaches a large multi-user database system can be installed in each site. Such systems can provide faster and more comprehensive services than a basic web-based system and continue to provide good functionality if the internet is unavailable. Communication between sites can be via web protocols, direct database synchronisation or various proprietary protocols. The trade-off is that complex database systems are difficult to maintain in remote sites.

continued

Hybrid approaches
The thin client approach hinges around 24/7 connectivity and availability of a centralised server, probably located in a different site. Often this is not possible in developing countries. A thick client approach could be used, but software and database installation at remote nodes and data synchronisation are major hurdles. An alternative is the HIV-EMR in Haiti, where a program installed on a remote machine uses a local web-based interface to store data locally and uploads these data to a central server when the network is available.[9] This is a hybrid approach as a client program is installed, and local storage is used when the network is unavailable, but it is not a full 'thick client' system. Only recent transactions/modifications are stored locally and remote nodes do not contain a proper local database. Data synchronisation becomes an issue if two users modify and upload the same record. In this system the central server still has the definitive copy of all data.

The above systems vary in the degree to which they are networked, in location and in the type of databases deployed. Simple systems based on a database on one PC are common as they are easy to develop and deploy for many basic tasks. Networked systems require more expertise and technical ability to set up, but provide a number of benefits as given in Box 5.

Box 5 Benefits of using a networked EMR

- Data are accessible and shared at multiple sites
- Multiple users can enter data simultaneously
- Data can be backed up automatically at more than one site
- Information can be communicated between multiple locations such as from laboratory to physician
- Wide area networks can link up remote locations
- Web-based systems and some other client programs can often be debugged and upgraded over the internet without visiting remote sites[19]

The approach chosen largely depends not only on the infrastructure and expertise available at individual sites, but also on the availability and reliability of communication infrastructure between sites.

User interfaces

A wide range of user interfaces are available to allow staff to interact with systems.[45] The interface choice might make a significant difference to the user experience but should not tie the system to a particular data model or architecture. Ideally any interface should be usable with any data model, and most network architectures.

The choice of user interface (see Box 6) will depend on the system and user requirements (see next section). In larger EMR systems, it is important to design and implement the user interface as a separate component. The system should provide a structured programmatic interface to transfer data to and from

Box 6 Different user interfaces that can be used in EMR systems

- Local Windows forms such as MS Access forms or Java forms. Generally rapid to develop and provide a very wide range of functions and flexibility.
- Web pages are more widely understood and used than other interfaces and simple to deploy at a distance. They are flexible but can be more limited in functions and interactions than other forms.
- Personal digital assistants (PDAs) such as Palm Pilot or Pocket PC devices. Portable, low cost, long battery life (Palm) and generally easy to use.[46] Either use custom software, form generation tools or a web browser that stores local copies of web pages for review or upload.[39] Small screen size limits ease of data entry for large forms.
- Phone. Can be used to access and enter data through a voice interface such as the Voxiva disease surveillance system in Peru.[47] Mobile phones can also permit limited data entry on screen.[48,49]
- Scanned paper forms with optical character recognition. Allow data recorded in a structured way to be entered automatically into the computer system, for example Teleforms™.[50,51] Some systems allow the forms to be faxed to a remote site for processing. These systems generally need data to be checked by an operator and tend not to handle free text well.
- Email can be generated to send warnings or reminders even when the user does not have direct access to the EMR. Some systems allow data to be entered and uploaded by email, which can be helpful when bandwidth is limited.[20,42]

the user interface. Thus it should be possible initially to build a forms-based interface, and with minimal effort introduce a PDA interface at a later stage without having to redesign the entire system. The user interface is also the component of the system that changes the most. User interfaces should contain minimal functionality and should be easy to change; modifying and creating new forms should be a rapid and painless process that may be delegated to junior IT staff.

Order entry systems

One specific type of interface that requires particular care and expertise is that used in order entry systems. These allow physicians or nurses to request medications and investigations directly online, using rules to guide documentation and clinical decision making and assist in preventing some types of medical errors.[9] However, these benefits come at a price. Order entry systems require considerable care and expertise to build, evaluate and maintain. Failure can be costly in time and money, can slow clinical care, and most importantly could cause medical errors, thus putting patients at risk.[11,52]

Organisational and user issues

Data quality and completeness

Data quality and completeness are critical to the success of any information system. Achieving high standards is a particular challenge in sites with limited computer literacy and experience. It is important to design systems that are easy to use and have good instructions and training. The system should collect the minimum data necessary for the task, and data items should be structured and coded where possible to simplify data checking and optimise reuse. This does not mean that free text must be excluded; doing so prevents the system from capturing any data that do not fit the normal pattern. Such data will either be lost or recorded in hard-to-locate paper records. Structured data such as laboratory test results might benefit from double entry. In some projects physicians and other staff enter data directly.[13,14] This has the advantage of avoiding transcription errors, and also allows order entry systems to be deployed to check for potential medical errors.

A well-trained local data manager is fundamental in maintaining data quality. They need good communication skills as well as technical training. In addition to training and supervision they should perform regular surveys of data quality and investigate problems. Maintaining regular communication with users through a data manager and meetings is also important. While some users will offer unsolicited information about data issues, many do not. Developers can discover valuable information by keeping in close contact with users. A web-based system can be helpful in this respect as user problems and data quality can often be monitored centrally. Regular conference calls to discuss technical problems and new requirements with users keep the development team in close touch. Email, instant messaging, internet video conferencing and application sharing can all be valuable in supporting users and can usually be made to work well over limited internet connections.[41] Prompt and effective help to users is a vital factor in generating support and ensuring widespread use of an EMR system.

Low literacy contributes to inconsistent spelling of patients' names and addresses. Search tools can be used to match similar names and age, gender and address, and either merge the two records or email the details to the users for advice. Use of patient ID cards has also been helpful in several projects in Africa.[13] A WAN system can be valuable in enforcing a single unique identifier across sites.

Data security and confidentiality

Views of medical data security and confidentiality vary in different developing countries. In some sites, the use of electronic databases is treated with great suspicion; in other sites staff think nothing of emailing sensitive medical data. Patients can face serious risk if their communities discover their HIV status or other sensitive medical information. It is imperative that healthcare providers protect this information. However, it has been suggested that the very limited access to health care makes it critical to avoid barriers that might be created by excessive adherence to principles of confidentiality. Well-run projects should use a combination of technical and human protocols as described here:

- Users are required to have complex passwords and can only access the parts of the system they need.
- All log-ins and viewed data are recorded and reviewed to minimise the occurrence of unauthorised access.
- Using a centralised database allows the computer and data to be physically secure and backed up on a regular basis.
- Encryption of data transfers is performed using the Secure Socket Layer (SSL) protocol.
- Sensitive print-outs with identifiable patient data are shredded.

The capability to look up patient details securely in a web-based EMR removes the need to send patient information by non-secure email, a potential problem in many countries. Users can simply click on a link to open the web page and log in. Nevertheless, as it is difficult to abolish completely the use of non-secure clinical email (even if a better, more secure alternative system is available), organisations should consider setting up their own secure web-based email systems.[20]

Choosing appropriate system architecture and design

The choice of system or technology to be implemented will be influenced by medical, staffing and environmental factors. Reference should be made to the design issues discussed earlier. Table 1 gives example costs for satellite internet access, and Box 7 lists pitfalls and problems that can occur.

Table 1 Typical non-personnel costs of internet access in remote sites such as rural Haiti (US$); assumes electrical supply/generator and limited technical support

Satellite dish and modem	$6000
2 desktop PCs	$1500
1 laptop PC	$1000
Network cables, power supply, etc.	$500
Total	$9000
Annual internet charges	$2000
Approximate cost per year over 4 years	$4250

Number and size of sites

A single large hospital will probably need to have multiple terminals for data entry and viewing: this makes a networked system the logical design. With good local technical support and stable power the server could be located in the facility (for example, (4) Malawi case study). If the site has limited infrastructure, a web-based system is an alternative with the server off-site (see (2) Peru case study). A small clinic could set up a stand-alone database system (as in (1) Kenya case study). Alternatively an internet-based system could be deployed with local data storage to help with network outages (see (3) Haiti and (6) Brazil case studies). This design also makes sense if there are multiple sites that need to be covered, particularly if certain resources are located at a distance, such as laboratories or a common drug warehouse.

Box 7 Important pitfalls in implementing EMR systems

User problems

- Lack of user training
- Poor initial design limiting capabilities and expansion potential
- Systems difficult to use or too complex
- Lack of involvement of local staff in design and testing of systems
- Lack of systems and staff training to ensure data quality and completeness
- Lack of perceived benefit for users who collect the data
- Dependence on one individual 'champion'

Technical problems

- Lack of back-up systems in event of computer loss
- Poor system security leading to viruses and spyware
- Unstable power supplies and lack of battery back-up
- Poor or inadequate data back-ups
- Lack of technical support staff and/or system hard to maintain

Available infrastructure in sites

Servers need stable power and physical security in a relatively dry, dust-free and temperature-regulated area. Off-site data back-up as well as a second back-up server in a different location is strongly advised.

Access to networks

Internet access allows more flexible designs with external communication of data and off-site back-up. Pure web-based systems need reliable networks, but dial-up connections can work if the pages are designed carefully and the system is not required all the time.[27]

Local expertise in development and technical support

A major factor in any design will be the availability and skills of local technical support staff. Managing client PCs or single Windows machines running a database is within the expertise of many countries (though viruses and security issues are very important challenges). Servers need more expertise for setting up and backing up data; MS Windows tends to be easier for small sites to manage. For larger installations open source software can be cheaper and more 'future proof', also Linux is very easy to manage and support over the internet. Good documentation and easy-to-configure systems are important.

Discussion

The deployment of significant numbers of EMR systems in developing countries has blunted some of the scepticism about such approaches, but real concerns and much resistance remain. The potential diversion of resources from other healthcare needs to support information systems has to be weighed against the potential to improve quality of care and efficiency of care delivery. Successful new IT applications tend to have certain beneficial capabilities that overcome uncertainties and drive forward their deployment. At present, two examples have emerged as primary benefits for EMR systems in developing countries: the ability to get laboratory results to remote clinics in a timely fashion, and the ability to track drug supplies and expected drug usage, particularly for HIV and MDR-TB. The use of EMR systems to reduce medical errors and improve quality of care is still in its infancy, but initial evaluations are promising despite the challenges.[31] Improvement of clinical management by physicians and other healthcare workers has the greatest potential to benefit patients. It also requires more sophisticated tools than just simple patient registries and could therefore take longer to demonstrate.

The development of EMR systems in the US over the last two decades has been dogged by problems of closed, proprietary and incompatible systems; a recent survey of US primary care physicians identified 264 different EMRs in use![53] Unfortunately, developing countries are beginning to experience similar problems, with many projects building their own basic EMR systems. This stems from a lack of good customisable systems, lack of appropriate foreign language options in some cases, and a feeling that each project is unique.[18] There are clear advantages in developing custom software but the cost in time and money can be high. Once the system is operational, it needs to be supported and upgraded. Many of the core tasks in building a good EMR are common to most projects and benefit from the feedback of multiple users and developers. Because software development has a significant component of trial and error, reuse of well-tested components helps reduce technical problems, especially for complex functions like order entry.[52] This is particularly important in remote sites with limited access to technical support. The software should also be open-source if possible.[54] Small projects are vulnerable to the loss of a key programmer or IT company and are likely to fail if source code is not available to other programmers.

Conclusions

In deciding what EMR systems to develop and deploy in developing countries, promising ideas are not enough: they need to be validated in the field. It is important to look closely at systems that have been successfully deployed in challenging environments, and any available evaluation data. The introduction of IT systems to remote sites with no communication should provide good opportunities to evaluate the impact of data management and/or communications tools. Specific outcomes should be measured, such as time to change patient management in response to new laboratory results, or better monitoring of patient compliance.[15,25] There is some evidence of benefit to patient care from access to communication, including the use of telemedicine consultations to improve diagnostic accuracy and reduce unnecessary patient transfers.[55,56] Improvements in drug supply management using medication data from EMR systems could offer the most measurable cost benefits at present; a well-managed drug supply also improves availability and quality of patient care.[21]

In creating or choosing a new EMR, it is essential that the underlying data model is designed with a long-term vision of the functions that will need to be supported: it can be very difficult to scale from a simple flat file data model to a larger clinical system or one that can be deployed in other sites. Furthermore it makes little sense to recreate the same functions and tools at each site. Collaborative development between projects using an open source model (even if the underlying operating system is not open) has great potential to improve quality of software and reduce costs.

We are now in the fortunate situation of falling IT costs, improving computer literacy and increasing resources, combined with preliminary evidence of EMR successes in resource-poor areas. The critical challenge is to create well-designed, effective, low-cost systems by sharing resources, learning from each other's experience and evaluating our work.

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CONFLICTS OF INTEREST

None.

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