Healthcare Delivery in Developing Countries: Challenges and Potential Solutions

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Bringing intelligent healthcare informatics to bear on the dual problems of reducing healthcare costs and improving quality and outcomes is a challenge even in countries with a reasonably developed technology infrastructure. Much of medical knowledge and information remains in paper form, and even where it is digitized, it often resides in disparate datasets and repositories and in diverse formats. Data sharing is uncommon and frequently hampered by the lack of foolproof de-identification for patient privacy. All of these issues impede opportunities for data mining and analysis that would enable better predictive and preventive medicine.

Developing countries face these same issues, along with the compounding effects of economic and geopolitical constraints, transportation and geographic barriers, a much more limited clinical workforce, and infrastructural challenges to delivery. Simple, high-impact deliverable interventions such as universal childhood immunization and maternal childcare are hampered by poor monitoring and reporting systems. A recent *Lancet* article by Christopher Murray's group concluded that "immunization coverage has improved more gradually and not to the level suggested by countries' official reports of WHO and UNICEF estimates. There is an urgent need for independent and contestable monitoring of health indicators in an era of global initiatives that are target-

The NxOpinion health platform being used by Indian health extension workers.

oriented and disburse funds based on performance." [1]

Additionally, the most recent report on the United Nations Millennium Development Goals notes that "pneumonia kills more children than any other disease, yet in developing countries, the proportion of children under five with suspected pneumonia who are taken to appropriate health-care providers remains low." [2] Providing reliable data gathering and diagnostic decision support at the point of need by the best-trained individual available for care is the goal of public health efforts, but tools to accomplish this have been expensive, unsupportable, and inaccessible.

Below, we elaborate on the challenges facing healthcare delivery in developing countries and describe computer- and cell phone–based technology we have created to help address these challenges. At the core of this technology is the NxOpinion Knowledge Manager[1] (NxKM), which has been under development at the Robertson Research Institute since 2002. This health platform includes a medical knowledge base assembled from the expertise of a large team of experts in the U.S. and developing countries, a diagnostic engine based on Bayesian networks, and cell phones for end-user interaction.

SCALE UP, SCALE OUT, AND SCALE IN

One of the biggest barriers to deployment of a decision support or electronic health record system is the ability to scale. The term "scale up" refers to a system's ability to support a large user base—typically hundreds of thousands or millions. Most systems are evaluated within a narrower scope of users. "Scale out" refers to a system's ability to work in multiple countries and regions as well as the ability to work across disease types. Many systems work only for one particular disease and are not easily regionalized—for example, for local languages, regulations, and processes. "Scale in" refers to the ability of a system to capture and benchmark against a single

[1] www.nxopinion.com/product/knowledgemng

individual. Most systems assume a generic patient and fail to capture unique characteristics that can be effective in individualized treatment.

With respect to scaling up, NxKM has been tested in India, Congo, Dominican Republic, Ghana, and Iraq. It has also been tested in an under-served inner-city community in the United States. In consultation with experts in database scaling, the architecture has been designed to combine multiple individual databases with a central de-identified database, thus allowing, in principle, unlimited scaling options.

As for scaling out to work across many disease types and scaling in to provide accurate individual diagnoses, the amount of knowledge required is huge. For example, INTERNIST-1, an expert system for diagnosis in internal medicine, contains approximately 250,000 relationships among roughly 600 diseases and 4,000 findings [3]. Building on the earlier work of one of us (Heckerman), who developed efficient methods for assessing and representing expert medical knowledge via a Bayesian network [4], we have brought together medical literature, textbook information, and expert panel recommendations to construct a growing knowledge base for NxKM, currently including over 1,000 diseases and over 6,000 discrete findings. The system also scales in by allowing very fine-grained data capture. Each finding within an individual health record or diagnostic case can be tracked and monitored. This level of granularity allows for tremendous flexibility in determining factors relating to outcome and diagnostic accuracy.

With regard to scaling out across a region, a challenge common to developing countries is the exceptionally diverse and region-specific nature of medical conditions. For example, a disease that is common in one country or region might be rare in another. Whereas rule-based expert systems must be completely reengineered in each region, the modular nature of the NxKM knowledge base, which is based on probabilistic similarity networks [4], allows for rapid customization to each region. The current incarnation of NxKM uses region-specific prevalence from expert estimates. It can also update prevalence in each region as it is used in the field. NxKM also incorporates a modular system that facilitates customization to terms, treatments, and language specific to each region. When region-specific information is unknown or unavailable, a default module is used until such data can be collected or identified.

DIAGNOSTIC ACCURACY AND EFFICIENCY

Studies indicate that even highly trained physicians overestimate their diagnostic accuracy. The Institute of Medicine recently estimated that 44,000 to 98,000

preventable deaths occur each year due to medical error, many due to misdiagnosis [5]. In developing countries, the combined challenges of misdiagnoses and missing data not only reduce the quality of medical care for individuals but lead to missed outbreak recognition and flawed population health assessment and planning.

Again, building on the diagnostic methodology from probabilistic similarity networks [4], NxKM employs a Bayesian reasoning engine that yields accurate diagnoses. An important component of the system that leads to improved accuracy is the ability to ask the user additional questions that are likely to narrow the range of possible diagnoses. NxKM has the ability to ask the user for additional findings based on value-of-information computations (such as a cost function) [4]. Also important for clinical use is the ability to identify the confidence in the diagnosis (i.e., the probability of the most likely diagnosis). This determination is especially useful for less-expert users of the system, which is important for improving and supervising the care delivered by health extension workers (HEWs) in developing regions where deep medical knowledge is rare.

GETTING HEALTHCARE TO WHERE IT IS NEEDED: THE LAST MILE

Another key challenge is getting diagnostics to where they are most needed. Because of their prevalence in developing countries, cell phones are a natural choice for a delivery vehicle. Indeed, it is believed that, in many such areas, access to cell phones is better than access to clean water. For example, according to the market database Wireless Intelligence,[2] 80 percent of the world's population was within range of a cellular network in 2008. And figures from the International Telecommunication Union[3] show that by the end of 2006, 68 percent of the world's mobile subscriptions were in developing countries. More recent data from the International Telecommunications Union shows that between 2002 and 2007, cellular subscription was the most rapid growth area for telecommunication in the world, and that the per capita increase was greatest in the developing world.[4]

Consequently, we have developed a system wherein cell phones are used to access a centrally placed NxKM knowledge base and diagnostic engine implemented on a PC. We are now testing the use of this system with HEWs in rural India. In addition to providing recommendations for medical care to the HEWs, the phone/

[2] www.wirelessintelligence.com
[3] www.itu.int
[4] www.itu.int/ITU-D/ict/papers/2009/7.1%20teltscher_IDI%20India%202009.pdf

central-PC solution can be used to create portable personal health records. One of our partner organizations, School Health Annual Report Programme (SHARP), will use it to screen more than 10 million Indian schoolchildren in 2009, creating a unique virtual personal health record for each child.

Another advantage of this approach is that the data collected by this system can be used to improve the NxKM knowledge base. For example, as mentioned above, information about region-specific disease prevalence is important for accurate medical diagnosis. Especially important is time-critical information about the outbreak of a disease in a particular location. As the clinical application is used, validated disease cases, including those corresponding to a new outbreak, are immediately available to NxKM. In addition, individual diagnoses can be monitored centrally. If the uploaded findings of an individual patient are found to yield a low-confidence diagnosis, the patient can be identified for follow-up.

THE USER INTERFACE

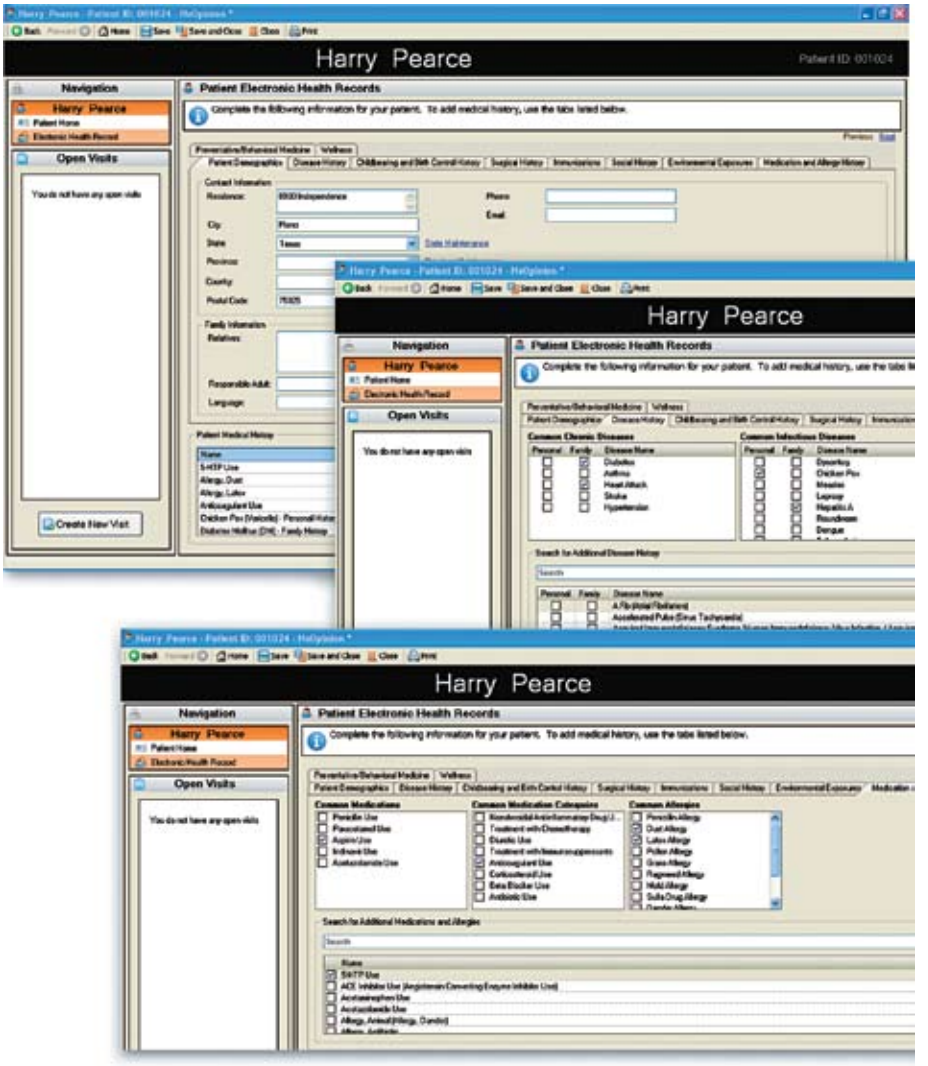
A challenge with cellular technology is the highly constrained user interface and the difficulty of entering data using a relatively small screen and keypad. Our system simplifies the process in a number of ways. First, findings that are common for a single location (e.g., facts about a given village) are prepopulated into the system. Also, as mentioned above, the system is capable of generating questions—specifically, simple multiple-choice questions—after only basic information such as the chief complaint has been entered. In addition, questions can be tailored to the organization, location, or skill level of the HEW user.

It is also important that the user interface be independent of the specific device hardware because users often switch between phones of different designs. Our interface application sits on top of a middle-layer platform that we have implemented for multiple devices.

In addition to simple input, the interface allows easy access to important bits of information. For example, it provides a daily summary of patients needing care, including their diagnosis, village location, and previous caregivers.

DATA-SHARING SOLUTIONS

Even beyond traditional legacy data silos (such as EPIC and CERNER) [5], barriers to sharing critical public health data still exist—including concerns about privacy and sovereignty. Data availability can also be limited regionally (e.g., in India and South Africa), by organizations (e.g., the World Health Organization,



NxOpinion's innovative approach, which shows data when you want it, how you want it, and where you want it, using artificial intelligence.

World Vision, or pharmaceutical companies), or by providers (e.g., insurance companies and medical provider groups). Significant public health value resides in each of these datasets, and efforts should be made to overcome the barriers to gathering data into shared, de-identified global databases. Such public datasets, while useful on their own, also add significant value to proprietary datasets, providing valuable generic context to proprietary information.

NxKM imports, manages, and exports data via *publish sets*. These processes allow various interest groups (governments, public health organizations, primary care providers, small hospitals, laboratory and specialty services, and insurance providers) to share the same interactive de-identified (privacy-preserving) global database while maintaining control of proprietary and protected data.

LOOKING FORWARD

Several challenges remain. While better educated HEWs are able to use these data collection and diagnostic decision support tools readily, other HEWs, such as Accredited Social Health Activists (ASHAs) and other front-line village workers, are often illiterate or speak only a local dialect. We are exploring two potential solutions—one that uses voice recognition technology and another that allows a user to answer multiple-choice questions via the cell phone's numeric keypad. Voice recognition technology provides added flexibility in input, but—at least so far—it requires the voice recognizer to be trained by each user.

Another challenge is unique and reproducible patient identification—verification that the subject receiving treatment is actually the correct patient—when there is no standard identification system for most under-served populations. Voice recognition combined with face recognition and newer methods of biometrics, along with a corroborating GPS location, can help ensure that the patient who needs the care is the one actually receiving treatment.

Another barrier is data integrity. For example, most rural individuals will report diagnoses that have not been substantiated by qualified medical personnel and could be erroneous. We have attempted to mitigate this issue by using an inference engine that allows for down-weighting of unsubstantiated evidence.

Deploying systems that work anywhere in the world can lead to the creation of a massive amount of patient information. Storing, reconciling, and then accessing that information in the field, all while maintaining appropriate privacy and security, are exceptionally challenging when patient numbers are in the millions (instead of tens of thousands, as with most current electronic health record

systems). Further, feeding verified data on this scale back into the system to improve its predictive capability while maintaining the ability to analyze and retrieve specific segments (data mine) remains difficult.

A final, and perhaps the greatest, obstacle is that of cooperation. If organizations, governments, and companies are willing to share a de-identified global database while protecting and owning their own database, medical science and healthcare can benefit tremendously. A unified database that allows integration across many monitoring and evaluation systems and databases should help in quickly and efficiently identifying drug resistance or outbreaks of disease and in monitoring the effectiveness of treatments and healthcare interventions. The global database should support data queries that guard against the identification of individuals and yet provide sufficient information for statistical analyses and validation. Such technology is beginning to emerge (e.g., [6]), but the daunting challenge of finding a system of rewards that encourages such cooperation remains.

SUMMARY

We have developed and are beginning to deploy a system for the acquisition, analysis, and transmission of medical knowledge and data in developing countries. The system includes a centralized component based on PC technology that houses medical knowledge and data and has real-time diagnostic capabilities, complemented by a cell phone–based interface for medical workers in the field. We believe that such a system will lead to improved medical care in developing countries through improved diagnoses, the collection of more accurate and timely data across more individuals, and the improved dissemination of accurate and timely medical knowledge and information.

When we stop and think about how a world of connected personal health records can be used to improve medicine, we can see that the potential impact is staggering. By knowing virtually every individual who exists, the diseases affecting that person, and where he or she is located; by improving data integrity; and by collecting the data in a central location, we can revolutionize medicine and perhaps even eradicate more diseases. This global system can monitor the effects of various humanitarian efforts and thereby justify and tailor efforts, medications, and resources to specific areas. It is our hope that a system that can offer high-quality diagnoses as well as collect and rapidly disseminate valid data will save millions of lives. Alerts and responses can become virtually instantaneous and can thus lead to the identification of drug resistance, outbreaks, and effective treatments in a fraction of the

time it takes now. The potential for empowering caregivers in developing countries though a global diagnostic and database system is enormous.

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