Evaluations of the Impact of eHealth Technologies in Developing Countries: A Systematic Review

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Abstract

Context: The number of eHealth implementations in developing countries has increased dramatically over the last few years with the promise of improved patient care and scalability of health care systems. These claims, however, require confirmation by rigorous scientific evaluations.
Objective: To review evaluations performed on eHealth implementations in developing countries and provide recommendations for future evaluations.
Data sources: Searches of MEDLINE, EMBASE, Science Citation Index (Web of Science), Social Sciences Citation Index, The Cochrane Library, the Latin American and Caribbean Health Science Literature Database (LILACS), the RHINO Literature Database,[1] and Google Scholar. We consulted other researchers and implementers in the field and performed a manual search of the reference lists of review articles.
Studies selected: 56 articles or abstracts were selected according to inclusion criteria from a total of 1947 identified.
Results: Of the 56 articles found, 15 performed qualitative evaluations and 48 performed quantitative evaluations. If an evaluation performed both types it was counted in both categories. Two qualitative and 16 quantitative evaluations had statistical analysis and two qualitative and eight quantitative evaluations were performed by an outside evaluator. The number of evaluations has increased in the last few years, though most of the available literature referred only to pilot projects and short-term outcomes with evaluations of low quality. Evaluations were then grouped and analyzed according to the system type.
Conclusion: There is clearly an urgent need for solid evidence of the impact of medical information systems in developing countries since most evaluations to date are limited. We would recommend that funders include resources for evaluation of information systems developed and deployed in developing countries and perhaps make them a requirement for continued funding.

Introduction

eHealth systems, also referred to as health information technology (HIT), have the potential to greatly impact health service efficiency, the scalability of treatment delivery in developing countries, and patient outcomes.[2] They could provide clinical decision support where there are no doctors, clinical data on chronic diseases where acute or no treatment are the norm, help prevent loss to follow-up of HIV and TB patients, and ensure medicines and supplies arrive before stock runs out. In acknowledgement of this potential, the World Health Organization (WHO) has published and updated a manual on how to implement electronic health records

(EHR) for developing countries for several years.[3 4] Funding agencies worldwide have similarly begun to realize that the monitoring and evaluation of any large health care investment requires electronic systems. Many are doing research and publishing reports for organizations receiving funding to accelerate the process of using eHealth systems[5 6] and to perform formative measuring process variables during an implementation,[7] or summative evaluations after full implementation demonstrating project impacts.[8]

There are few evaluations, however, of the impact of eHealth systems on the care provided to patients particularly of systems currently being used in developing countries.[9 10] These evaluations are essential in ensuring that the systems being implemented are safe, have a significant impact, and are not a waste of already scant resources.[9 11] A systematic review performed in 2004 of the use of IT in primary health care worldwide[12] found that most articles in the realm of eHealth "lacked any evaluation of their concrete application to health care." This echoes the conclusions of a 2001 review of the impact of computers on primary care titled "A descriptive feast but an evaluative famine,[13]" as well as separate systematic reviews of telemedicine applications' effect on patient care[14] and cost-effectiveness.[15]

In developed countries, the relatively few rigorous evaluations of EHRs that exist are beginning to define the requirements of a well-implemented EHR and the benefits it can provide. Evaluations have shown that EHRs can improve patient outcomes in the management of renal disease.[16 17] Another study found that two years after an EHR was fully implemented age adjusted rates of office visits and specialty care visits decreased by 9% and 5-6%, respectively. [18] Wang *et al*. [19] have estimated that the net benefit from using an electronic health record for a 5-year period was US$86,400 per provider. The US Veterans Health Administration recently demonstrated that their EHR improved efficiency by an estimated 6% per year. [20] In the case of Computerized Clinical Decision Support Systems (CDSS), a review found that they improved practitioner performance in 62 (64%) of the 97 studies assessing this outcome and 7 (13%) improved patient outcomes in the 52 who reported that outcome.[21] Computerized physician medication order entry systems have some of the greatest promise for reducing medical errors,[22] however, it has been shown that they can also increase error rates if not well designed.[23] Finally, a systematic review of telemedicine applications found that three of five randomized controlled trials (RCTs) for patient monitoring and counseling improved patient outcomes.[14]

Although large differences exist between infrastructure and resources for health care in developing countries, [24-26] it is possible that eHealth systems may lead to much larger impacts on patient outcomes, health service efficiency and treatment delivery in these sites. The goal of this review was to survey the evaluations that have been performed on eHealth systems in developing countries to find their potential impact and to guide future implementations and evaluations of these systems.

Methods

Studies Eligible for Review

We included any qualitative or quantitative evaluation of IT affecting health care in developing countries. Our definition of eHealth encompassed any information technology or software system that could be used to improve the care provided to a patient. Developing countries were

defined as those in the Emerging and Developing Economies List in the International Monetary Fund's World Economic Outlook Report[27]. Evaluations were excluded if (1) data completeness of the system was the only outcome, (2) the evaluation method was not described in the article, (3) the article was limited to describing the feasibility or technical evaluation of a system, (4) the evaluation was on attitudes towards or knowledge of eHealth (not an implemented system), or (5) it was only an educational tool[28 29]. In the cases of Uganda Health Information Network[30 31] and EHAS[32 33] where both systems were a health education and an eHealth system, we only report on the eHealth system.

Finding Relevant Studies

We conducted a worldwide review of the literature and requested submissions from researchers and implementers of eHealth systems in developing countries. Literature searches were completed through May 2008 without language restrictions through MEDLINE, EMBASE, Science Citation Index (Web of Science), Social Sciences Citation Index, The Cochrane Library, and the Latin American and Caribbean Health Science Literature Database (LILACS). To find reports not in scientific journals or conferences, we also used Google Scholar. All citations were downloaded into EndNote X (Thomson ISI Research-Soft, Philadelphia, PA). For MEDLINE and EMBASE, terms were derived from the MeSH database and EMTREE tool, respectively. Among the terms used in the final strategies were *medical informatics applications, management information systems, telemedicine, telehealth, reminder system, geographic information system, hospital information systems, outcome and process assessment (Health Care), program evaluation, evaluation studies, attitude, costs and cost analysis, developing countries, poverty, Africa, Latin America, eastern Europe, central or southeastern Asia* (complete strategies available from the authors). An initial reviewer evaluated the eligibility of all studies identified in our search. A second reviewer confirmed all relevant articles and retrieved full text article. Supplementary methods of finding evaluations included a review of article reference lists, informatics conference proceedings, information provided by primary study authors, requesting submissions from other researchers and implementers and searching the RHINO Literature Database[1] and other recent reviews.[12 34-36]

Data Abstraction and Synthesis

We extracted data according to recurring themes. We summarized these findings using tabular techniques and descriptive statistics. Reported analyses were too disparate to be pooled in a meta-analysis.

The systems described in the articles were placed into one of nine categories:

1. Electronic Health Record (EHR): an electronic record of health-related information on an individual that can be created, managed, or consulted by clinicians or staff. We have found that in the literature the term electronic medical record (EMR) is used interchangeably and therefore will be used as a synonym for the purposes of this paper.
2. Laboratory Information Management System (LIMS): a system for laboratory specific activities or for reporting results to administrators and health care personnel.
3. Pharmacy Information System: any electronic system used to order, dispense, or track medications or medication orders including computerized order entry (COE) systems.

4. Patient Registration or Scheduling System: any system used to monitor and manage the movement of patients through multistep processes or maintain a census.[37] An example is admissions-discharge-transfer (ADT) systems.
5. Monitoring, Evaluation, and Patient Tracking System: any system used for aggregate reporting of information, program monitoring and tracking of patient statuses. Examples include district health information systems (DHIS) or health Management information systems (HMIS).
6. Clinical Decision Support System (CDSS): information systems designed to improve clinical decision making where characteristics of individual patients are matched to a computerized knowledge base, and software algorithms generate patient-specific recommendations.[21]
7. Telemedicine: any system used to exchange clinical information from one site to another via electronic communications to improve patients' health status,[38] the most common example being teleradiology.
8. Patient Reminder System: a system used to prompt patients to perform a specific action for example take medications or attend the clinic.
9. Research or Data Collection System: any electronic system used for collecting data from different locations or for storing, managing, or reporting on data used for research purposes.

Evaluations were classified into two major categories: qualitative and quantitative. In this review, qualitative evaluations will be those where users, patients, or staff gave their opinion regarding a system. These could take the form of questionnaires, focus groups, or interviews. This definition is different from the one proposed by Strauss and Corbin of "any type of research that produces findings not arrived at by statistical procedures or other means of quantification."[39] Quantitative evaluations were those whose outcomes were data quality, administrative changes, patient care, or economic assessment. The evaluation designs were grouped according to the definition by Friedman and Wyatt:[40] (1) descriptive (uncontrolled) study; (2) historically controlled (before-after) study; (3) case-control (retrospective) study; (4) prospective self-controls (subjects performing same action in both systems);[1] (5) simultaneous nonrandomized controls; (6) simultaneous randomized controls; and (7) externally and internally controlled before-after study. Two cost studies[41] [42] and two studies that modeled future medication requirements[43] [44] were categorized as self-controls, since the authors compared the impact of the system against the same situation without the system. Due to the inherent limitation of performing a case-control, descriptive, or qualitative study without statistics, we will not comment on the limitations of these studies in the results sections.

Results

Searches retrieved 1947 citations. Five of these articles were excluded because they did not have abstracts and full text versions were not available.[45-49] After the initial screening of article titles and abstracts, we found 154 articles that appeared relevant. An additional five articles were identified by hand searching bibliographies of eligible articles and prior reviews. Of these, 56 were deemed to fulfill the inclusion criteria of the review after full review of their abstracts, and are listed by type of system and evaluation in Table 1. For three of these articles, we were only able to retrieve the abstract, but still included them in the analysis.[50-53] Brief descriptions of outcomes and limitations are described under each category of system type in Tables 2-10.

[1] This category was added by the authors

Though it is not in a developing country, we included an evaluation from the Indian Health Services in the U.S. since conditions were similar to those in developing countries.[54] If a system had multiple evaluations, only those with different outcomes are listed. If they had the same outcome, we took the one with the largest sample size. There were two articles reporting that an evaluation did not occur because of a failed system implementation.[55 56] These are not part of the results, but we considered it relevant to list them since articles on unsuccessful systems are not commonly published and can provide insight into implementations.

15 articles performed qualitative evaluations and 48 performed quantitative evaluations. If an evaluation performed both types it was counted in both categories. Two qualitative and 16 quantitative evaluations performed some sort of statistical analysis on the results. Of all these evaluations, two (11%) of the qualitative and eight (19%) of the quantitative were performed by an outside evaluator that was not the system developer. The number of evaluations has increased in the last few years. The number of evaluations per year are: 1 (1991), 1 (1994), 1 (1995), 1 (1996), 3 (1998), 1 (1999), 1 (2000), 3 (2001), 1 (2002), 4 (2003), 7 (2004), 5 (2005), 11 (2006), 6 (2007), 3 (until May 2008).

Table 1 Number (percent) of total articles (n=63) for the different eHealth categories by type of evaluation. If an article had both qualitative and quantitative studies or multiple types of systems, it was counted in both categories.

eHealth Category	Qualitative	Quantitative	
		Descriptive Studies	Controlled Studies
Electronic Health Record (EHR)	4 (6)	1 (2)	3 (5)
Laboratory Information Management Systems (LIMS)	0	1 (2)	2 (3)
Pharmacy Information Systems	1 (2)	2 (3)	2 (3)
Patient Registration or Scheduling Systems	1 (2)	0	2 (3)
Monitoring, Evaluation and Patient Tracking Systems	0	2 (3)	4 (6)
Clinical Decision Support Systems (CDSS)	1 (2)	0	3 (5)
Telemedicine	4 (6)	4 (6)	8 (13)
Patient Reminder Systems	0	1 (2)	2 (3)
Research or Data Collection Systems	4 (6)	1 (2)	10 (16)
TOTAL	**15 (24)**	**12 (19)**	**36 (57)**

Electronic Health Record (EHR)

EHRs are the core application on which other clinical systems such as computerized clinical decision support (CDSS), computerized order entry (COE), and sometimes telemedicine systems can be implemented and sustained. Because of this they usually need to encompass a variety of different functionality making their implementations complex[57] and often prone to failure.[58] This complexity provides an additional challenge in evaluating these systems. In our search we were only able to find one evaluation that had a control group (Table 2); four were qualitative, with only one of them using statistics; two were case-control studies that could provide an insight into possible impacts, but had limited scientific rigor.[40]

The Vista system used by the Indian Health Services (IHS) was the most complete system, as it includes services for clinical reminders, radiology order entry, medication order entry, and lab order entry. Several of the other EHRs also incorporated multiple services,[59-61] however all of

them will only be reported in the EHR sections because none performed evaluations on the separate parts of the system.

The MMRS evaluation provided data on the impact that an EHR could have on improving staff productivity and reducing patient wait times. The other evaluations gave insights into the ability of EHRs to improve staff satisfaction, providing higher quality data to relevant personnel, and ultimately improving the care provided to patients.

Table 2 Description of EHR evaluations in increasing order of evaluation strength with multiple evaluations of a single system placed together

System or Institution	Evaluation Type	Outcome
PDA-EHR[62]	Cost	Their system cost $750 dollars total for satellite communication for 2700 patients and a one-time fixed cost of a satellite phone ($500 plus monthly fees).
MCHS[63]	Case-control study	Over 4 years immunizations increased from 45.4% to 81.9% and 46.1% to 77.7% in DPT and polio vaccines; antenatal registration increased from 384 to 705 patients.
Nutrition Support-Philippines[64]	Case-control study	Decreased percentages of wrong entries and non-entries either of weight or height ($p<0.05$); Increases seen in nutrition support services ($p<0.05$); referrals to clinical dietitians ($p<0.05$), and dietician productivity ($p<0.05$).
HMIS-Korea[61]	Staff & patient surveys	Increased staff productivity and satisfaction. Did not increase staff persuasion and decision abilities. Increased visitors' satisfaction with services
Oman-EMR[60]	Physician survey	**Advantages:** Physicians recorded improved communication (95%); improved quality care (85%); accurate entry and retrieval of data (80%); easy access to data (70%); usable in physician liability cases (64%); reduced medical errors (67%); enhanced productivity (59%). **Disadvantages:** disease coding was a problem (70%); system was time consuming to use (67% agree); and too slow (60%).
IHS-Vista[54]	Physician survey	**Advantages:** EHR implementation was viewed positively (66%); improved quality of care (35%); 34% self-reported that EHRs improve quality, this was associated with increased utilization (odds ratio 3.03, 95% confidence interval 1.05– 8.8). IT could improve quality of care in underserved settings (87%) **Disadvantages:** decreased quality of patient–doctor interaction (39%).
MMRS[59]	User opinion	Hospital matron noticed a cluster of sexually transmitted disease and therefore dispatched a team to investigate. Also noted lack of child immunizations therefore dispatched nurses to that site. Reports that previously took a clerk two weeks, now takes minutes; allowed the director to reassign two clerks to other duties.
MMRS[59]	Before-after	Duration of visits dropped from 41 to 31 minutes; providers time with patients dropped by half, from a third to a sixth of their workday ($p = 0.004$); providers spent two thirds less time interacting with other staff ($p = 0.0002$) and tripled their time spent in personal activities ($p = 0.001$); clerks spent two thirds less time interacting with other staff and almost doubled their time registering patients.

Laboratory Information Management Systems (LIMS)

There were only three evaluations of LIMS, of which only one had a control group. However they suggest two major benefits that a LIMS system can provide: (1) decreasing turn around times in the communication of results and (2) improving productivity of the laboratory. An additional impact, reduction in errors, has not yet been studied. However, our group (Partners In Health) is currently performing a cluster RCT in Lima, Peru of the impact of a laboratory information system[65] on communication times, errors, and patient outcomes.

Table 3 Description of LIMS evaluations in increasing order of evaluation strength

System or Institution	Evaluation Type	Outcome
SGPGIMS[50]	Descriptive	Cholera was isolated in 22.6% (7/31) of samples sent to a central laboratory. Information was relayed to hospital and health authorities, who took strict measures to improve hygiene at a festival. Subsequently, the number of diarrhea cases during festival decreased and an epidemic was averted.
Tesilab[66]	Case-control study	Productivity indexes showed an increase of 41% in number of patients handled and 28% in number of tests processed.
VPN-LIS[67]	Before-after	Turn around times for routine samples decreased from 1 to half day; number of samples processed increased by a factor of 2; annual laboratory revenue increased 4 times, from 55,000 to 220,000 euro per month.

Pharmacy Information Systems

Four of the five evaluations performed were on COE systems: one had a control group, two were qualitative, and one descriptive. The fifth evaluation was comparing a medication requirements prognostication tool against the actual medication use for Peru (Table 4).

COE can provide a key incentive for clinical staff, especially clinicians, to use an information system since they can reduce the time to order medications (especially repeat orders) and provide easy access to past information. As shown in the three qualitative evaluations[52 68 69] in Table 4, both of these benefits were the main advantages cited. Many have also been shown in developed countries to reduce errors which was the outcome of the only evaluation with a control group.[70] A benefit from pharmacy systems that can be valuable in developing countries is the ability to forecast medication requirements, as shown by the PIH-EMR evaluation.[43 44] This is especially useful if a country or organization needs to order medications six to eight months in advance, for example to get lower prices by going through the Green Light Committee for drug-resistant tuberculosis medications.

The major limitations of the COE evaluation with a control group[70] was the small number of users (n=3) and that they were unable to explain the large difference in baseline errors rates between the intervention and control group (17.4% vs. 8.6%). Both evaluations of the medication forecasting were of the same system (PIH-EMR). The first study's limitation[43] is that there was no comparison to what had actually been ordered, only what the use had been. The second evaluation's limitation[44] is the small number of patients (n=58) used to compare the model to the order placed.

Table 4 Description of Pharmacy Information System evaluations in increasing order of evaluation strength with multiple evaluations of a single system placed together

System or Institution	Evaluation Type	Outcome
CPOE-Brazil[52]	Descriptive	In 28.2% of medication orders there was dubious or misleading information **Advantages:** ease of data access and ordering. **Disadvantages:** repetition of orders from previous days without a review and incorrectly typed information.
HCFMRP[68]	Staff survey	**Advantages:** user-friendly interface; quickness and clarity of information; ease of use; reduction of time between drug prescription and administration; believed to result in a drastic reduction in the risk of error. **Disadvantages:** insufficient number of terminals; system got stuck; technical support was unsatisfactory.
ANVISA-CPOE[69]	Staff survey	**Advantages:** legibility (37.5%); less time to order (20.5%); more practical and organized (8%). **Disadvantages:** repetition of previous prescriptions (34%); typing mistakes (17%); dependence on computers (11%); alterations made manually (7%).
PIH-EMR[43]	Model vs. actual use	Accuracy of prediction per medication were 117% over-estimate in 2002, 5% underestimate in 2003 and 2% under-estimate in 2004.
PIH-EMR[44]	Model, order placed vs. actual use	For subgroup of 58 patients on individualized treatment, model predicted 99% of actual use, the actual order placed was 145% of actual use.
PIH-EMR COE[70]	Externally controlled before-after	17.4% error rate fell significantly in the study group to 3.1% per patient (p=0.008). Error rate did not differ statistically in control group (8.6% to 6.9%, p=0.66).

Patient Registration and Scheduling

There were three evaluations of patient registration systems, two of which had a randomized control group. There were none of scheduling systems. In several cases, patient registration is part of a larger EHR system as is the case with the MMRS, PIH-EMR, and Vista systems. However, none of these systems have performed a specific evaluation on the patient registration system. The two systems described by Aviles et. al (Table 5), fingerprint scanners and barcode readers, were shown in RCTs to decrease the time to locate records by 74% and 97%, respectively. In the evaluation of the Baobab touchscreen system, users preferred it over paper despite limitations in the training and technical support provided, as well as the need to maintain a parallel paper system. The major limitations of the RCTs performed in Nicaragua were the number of samples tested (approximately 30 samples each) and that the outcomes were process indicators rather than direct effects on care.

Table 5 Description of Patient Registration and Scheduling evaluations

System or Institution	Evaluation Type	Outcome
Baobab touchscreen system[71]	Clinical user survey	Most of the users (70%) expressed a clear preference for the touchscreen over the paper system. However, every respondent also identified on-going problems that need to be addressed.
PDCS-Nicaragua[72]	Simultaneous randomized controls	Mean time to locate record with fingerprint scan was 7.0 (SD 3.5) seconds, versus 27.3 (SD 7.1) seconds using the traditional method.
PDCS-Nicaragua[72]	Simultaneous randomized controls	Average time to locate a patient's chart using traditional methods was 2.9 (SD 2.1) minutes, whereas using barcode-based methods the average was 0.09 minutes, or 5.5 (SD 1.2) seconds.

Monitoring, Evaluation, and Patient Tracking Systems

Evaluations of systems to track and monitor patients' statuses are limited to two case control studies performed by the same organization.[36] Both of these studies suggest that an electronic system can effectively alert staff of patients who have "fallen through the cracks" and prevent rates of patients lost to follow up as high as 76% (after two years) as has been reported in some African antiretroviral therapy (ART) Programs.[73]

Two RCTs look at the effect of Global Positioning Systems (GPS) in finding households once a patient has been identified. Both RCTs compared using handheld GPS systems and paper to identify households. The evaluation from South Africa showed that the GPS system reduced the time to find a household by 20-50%[74], whereas the one from Nicaragua showed no difference between the two systems.[72] Both Nicaraguan systems were tested in similar urban settings using novice users, therefore no immediate reason for the difference can be found. The major limitations of both studies were their small sample size (identifying 10-50 households) and lack of statistical analysis.

Two evaluations, one descriptive and one cost analysis, looked at monitoring departments within a hospital in Cambodia[53] or health establishments nationwide in Tanzania.[75] They suggest that electronic systems can help to efficiently allocate resources and improve infection control[53] and can be relatively low cost.[75] However, the Cambodian evaluation is descriptive and therefore does not have a control group, nor does it describe the specific tasks in hospital management which were benefitted by the system. The Tanzanian evaluation does not provide details of the system[75] aside from stating that it is a national survey of facility-based information, does not have a control group, and only states the cost of the system without any measurement of outcomes.

Table 6 Description of Monitoring and Evaluation system evaluations in increasing order of evaluation strength with multiple evaluations of a single system placed together

System or Institution	Evaluation Type	Outcome
SIM[53]	Descriptive	Data are invaluable for the short-term management of the hospital. SIM helped set up infection control committee.
Tanzania HMIS[75]	Cost	Total annual systems cost was US$2,119,941, $0.13 per participant, and $0.06 per capita.
HIV-EMR[36]	Case-control study	For patients with CD4 counts between 101 and 350, those entered into system within 14 days had an odds ratio of 3.2 (p= .008) for starting treatment within 14 days compared to those without early CD4 entry.
HIV-EMR2.0 (OpenMRS)[36]	Case-control study	Logged patient follow-up visits allowed staff to rapidly identify a decline among patients who had stopped receiving food supplementation. New strategies were implemented within 3 weeks, and clinic attendance returned to original level of over 90%.
PDA-GPS-South Africa[74]	Simultaneous randomized controls	Time taken to locate ten households was reduced by 20% and 50% in each of two communities using the PDA/GPS device compared to paper.
PDCS-Nicaragua[72]	Simultaneous randomized controls	GIS did not significantly decrease the time necessary to locate a home.

Clinical Decision Support System (CDSS)

For developing countries, CDSSs have received attention as a possible solution to the lack of trained clinical personnel, especially in rural areas. Perhaps because of this, the three evaluations found were of high rigor. They all had control groups and used statistics. The expert system for mechanically ventilated neonates (ES-MVN) tested in Thailand was a multimedia interactive system to predict actions based on case simulations and train intensive care unit (ICU) nurses on those actions.[76] This evaluation showed that nurses performed better on a standardized test after using the ES-MVN system and also felt that they had better judgment. The evaluation of the e-IMCI, a PDA device to perform the Integrated Management of Childhood Illness (IMCI) approach, against the paper IMCI booklet showed that the e-IMCI was able to get more clinical staff to fully comply with the protocol. It also showed that it took the same amount of time (12.5 minutes) to fill out the questionnaire by either e-IMCI or the booklet. The evaluation of the EDPS, the only RCT, showed that patients' opinions of the care they had received was significantly higher if they been seen by an operator using the PC-based CDSS before the clinical staff and that there was a large increase in new patients at health centers where the EDPS system was being used.

However, the two RCTs had major limitations. The evaluation of the e-IMCI was only a formative study performed immediately after implementing the system and the introduction of new technology rather than its usefulness could have been the reason for additional completeness. In the case of the EDPS the increase in patients attending the intervention health centers can not be directly attributed to the intervention, and the Global Patient Assessment of Care Index, based on patients' opinions, could have been biased by the presence of the computers, the motivation of computer operators, and length of time spent with operator, none of which were present at control sites. This could cause a large bias since most patients in that

situation have probably never seen a computer before and are used to spending only a brief moment with health center staff. These issues are covered in more detail in the discussion.

Table 7 Description of CDSS evaluations in increasing order of evaluation strength with multiple evaluations of a single system placed together

System or Institution	Evaluation Type	Outcome
ES-MVN[76]	Before-after qualitative	Nurses perceived they had better judgment and information access (p=0.0001), all participants wanted permanent installation.
ES-MVN[76]	Before-after quantitative	Mean judgment performance score for case simulations increased by 42% (p=0.0001).
e-IMCI[77]	Simultaneous nonrandomized controls	With e-IMCI, 84.7% of required steps of IMCI protocol were completed compared to 61% with the chart booklet (p<0.01). The amount of time for both IMCI and e-IMCI sessions averaged 12.5 minutes.
Early Diagnosis and Prevention System (EDPS)[78]	Longitudinal RCT	Increase of 430 new patient visits per month at intervention sites (p= 0.005), increase from baseline of 18% at intervention sites compared with decline of 5% at control sites. Intervention was associated with significant improvements in Global Patient Assessment of Care Index (p< 0.001).

Telemedicine

Telemedicine applications had by far the largest number of evaluations. 11 of these were qualitative, descriptive or case-control studies, four were quantitative and had a control group and two of these were RCTs. In the 11 non-control group studies, the case-control studies suggest that telemedicine can provide the correct treatment initially,[51] keep patients from having to return to the hospital,[79] and reduce the length of chief complaints.[80 81] Physicians' opinions in general show that teleconsultation systems provide additional confidence that they are making the correct diagnoses[82] and improved their case management.[83] The two patient surveys also show that patients feel the system enables better care[80 81 84] or they are willing to pay a fee for its service. [80 81]

Four studies looked at the cost of these systems. One study cataloged the costs to set up a simple remote consultation system through email.[85] The two cost analyses found that telemedicine systems were able to decrease overall costs to the health care system by assuming that patients would not have to be taken to an ICU[42] or by a comparison of pre- and post-implementation activities.[32] Finally, a cost-effectiveness study looked at the technological transfer of tele-ophthalmology services from the UK to South Africa and found these new services could be provided in South Africa for £53 per DALY averted.[41] The three cost or cost analysis studies are limited in their scope since they did not include the cost of the physicians' time performing the consult or receiving it. This and the fact that their system was based solely on email make it difficult to generalize their findings to more formalized telemedicine implementations. In the case of the cost-effectiveness study, there was a large range in the cost of DALY averted (£44-£449) due to uncertainty in costs and this was a formative study performed during the first 12 months that the system was implemented.

For controlled studies of the effect on patient care and outcomes, a before-after study of the EHAS telecommunication/telemedicine system in the Amazon of Peru showed that evacuation of emergency cases was 40% faster after system implementation;[33] they were not, however, able to

ascertain the effect this had on patients. The two RCTs performed were on tele-monitoring of diabetics or pregnant women in Poland[84] and Hungary,[86 87] respectively. They were both the most rigorous evaluations performed and showed that the system could have an effect on patient outcomes, though results in the Polish diabetic study were not statistically significant.

Table 8 Description of Telemedicine evaluations in increasing order of evaluation strength with multiple evaluations of a single system placed together

System or Institution	Evaluation Type	Outcome
Burn care-Oman[88]	Descriptive	**Advantages:** Provides uniform and appropriate initial treatment preventing hypovolemia and death; Offers best care to all burn patients; Minimizes risks of complications and sequalae of burns; is economic. **Disadvantages:** Increased workload on main center; Inability for physicians at main center to control patient compliance with follow-up advice.
Neurosurgery-South Africa[79]	Case-control study	Six hospitals with teleradiology services had mean patient return rate fall to 17%. In comparison, almost half the patients seen from the hospitals with no services were returned after assessment at the specialist center (Wentworth Hospital).
Teleradiology, Durban-KwaZulu Natal[51]	Case-control study	Service changed patient management in 10% of cases. Undetected pathology was recognized by radiologist in 20 patients--pulmonary tuberculosis in 10, spinal tuberculosis in 3, miliary tuberculosis in 2 and fractures in 5.
Sihanouk Hospital[80 81]	Case-control study	Mean duration of chief complaint at the initial patient visit was 37 months for initial six months and eight months by the end of study period. Proportion of patients referred to other facilities decreased by 51% during last year ($p<0.001$).
Sihanouk Hospital[83]	Physician survey	All referring doctors who responded made positive comments about the service and half said that it improved their management of the case.
Sihanouk Hospital[80 81]	Patient survey	Patients were either satisfied (54%, n=34) or very satisfied (46%, n=29) with experience in telemedicine clinic. 78% (n=49) were willing to pay, on average, US$0.63 for their visits.
Bhaktivedanta Hospital[82]	Physician opinion	Physicians in India reported increase in confidence in managing patients with advanced diseases and treating various symptoms.
EHAC-TTEM[89]	Descriptive, comparison to other countries	Average time delay to hospitalization was 30 min compared to 44 min in an Israeli study and over 3 hours in other hospitals in Israel (similar to other places in the world); 628 patient visits to the hospital were avoided (assuming users would have come in if they didn't have monitoring).
Yale-CECON[85]	Cost	Costs associated with remote consultation were approximately US $20 for all patients screened. The total cost of the hardware was US $4400 for 2 computers and 2 video cameras.
King Edward Hospital-India[42]	Cost analysis	Cost of system was Rs12,000 (US$240), amount saved by not taking babies to NICU was Rs546,000 (US$10,920), giving a benefit ratio of 1:45.
EHAS[32]	Cost analysis	Prior to system, mean referrals per year were 11.1 from health posts and 14.0 from health centers. After implementation, they fell to 2.5 from health posts ($p=0.03$) and 8.4 from health centers ($p=0.17$). Net economic effect over four years period amounted to annual net savings of US$320,126.
EHAS[33]	Before-after	Reduced trips to convey reports by 25%, reduced mean evacuation time from 8.6 to 5.2 hours due to increased coordination available.
Tele-ophthalmology-South Africa[41]	Cost-effectiveness	The base case estimate of £53 per DALY averted in reducing the burden of eye disease. Practitioners in South Africa learned novel procedures that could help future patients and improve cost-effectiveness.
Contraction Monitor[87]	Simultaneous randomized controls	Preterm birth rate in intervention group was half that of control group.
Diabetes	Patient survey	Wanted to continue with telemedicine support (75%); wanted to change from

Monitoring[84]		traditional methods to telemedicine support (60%).
Diabetes Monitoring[84]	Simultaneous randomized controls	Patients' quality of life (based on HbA1c) improved in telemonitoring (mean score 3.4) more than the traditionally monitored group (mean score 3.2), but was not statistically different.

Patient Reminder Systems

Two evaluations of patient reminder systems compared short message service (SMS) text messages or mobile phone reminders to alert patients to mediation or clinic appointments. One is a descriptive study of an SMS reminder system in South Africa.[90] They compared the completion rates of TB treatment for patients at an urban clinic before and after the clinic implemented SMS text message reminder and found that though there were higher completion rates of TB treatment, the cure and treatment success rates were the same as previously. A major limitation of this comparison was that the before data was taken from the city's TB program register, whose data quality was not verified and was different from the source of the prospective data. One of the recommendations of this report was that the technology seemed to function, though the authors argued that the implementation had not been successful. A three-arm RCT in Malaysia comparing no intervention, SMS text messaging, and mobile phone reminders found that both interventions significantly increased attendance (by 21%) over the control group and though they both had similar effectiveness, the SMS text messaging was half the cost of the mobile phone reminders. This evaluation had no major limitations. They did not confirm that participants received SMS text message and did not leave phone messages, but each of these limitations would probably underestimate the effectiveness of each system.

The South African evaluation calculated the cost of sending SMS text messages per patient and month. The Malaysian study performed a well-designed cost-effectiveness study showing that SMS messaging cost RM 0.45 per patient attendance and was almost half the cost of the mobile phone reminder per attendance. This evaluation especially showed that SMS text messaging implemented correctly can be a cost-effective method to increase clinic attendance.

Both TB and HIV treatments require constant supervision of patients and strict adherence to a regimen of medications daily and sometimes injections for the first several months of treatment. However, patients in resource-poor settings encounter many obstacles that can prevent them from getting their medications. The obstacle addressed by these systems is that patients may forget to take medications or to attend a scheduled clinical visit. One of the reasons for the success of Directly Observed Therapy Short Course (DOTS)[91] for TB, DOTS-Plus for MDR-TB,[92] and DOT-HAART[93] for HIV is the ability to support patients by reminding them of their medications and appointments.

Table 9 Description of patient reminder systems evaluations in increasing order of evaluation strength with multiple evaluations of a single system placed together

System or Institution	Evaluation Type	Outcome
On Cue Compliance Service[90]	Cost	Cost of 120 SMS reminders were R13.90/patient/month (US$2.43).
On Cue Compliance Service[90]	Before-after	Intervention had higher completion rate (10.6 vs. 3%), but similar cure rate (62.3 vs. 66.4%) and treatment success rate (73 vs. 69%) compared to data from City of Cape Town's TB Control Program for same clinic in 2003.
Reminders-Malaysia[94]	Cost-effectiveness	It cost RM 0.45 per attendance for text messaging reminder as compared with RM 0.82 per attendance for mobile phone reminder. The ratio of cost per unit attendance of text messaging versus mobile phone was 0.55.
Reminders-Malaysia[94]	Simultaneous randomized controls	Attendance rates of control, text messaging and mobile phone reminder groups were 48.1, 59.0 and 59.6%, respectively. The text messaging group was significantly higher than control group, no difference between text messaging and mobile phone group. Text messaging reminder system cost less than half of the mobile phone reminder per attendance.

Research or Data Collection Systems

Research or data collection systems was the other group with a large number of evaluations. All of these systems were on PDAs or used PDAs as the point of contact with the user and then had a back end database to collect and store data. Four RCTs showed that the main benefits of PDA systems were: data quality similar to paper systems[95 96] or higher,[97 98] less time to perform interviews,[97] and decreased data collection time.[98] Two of the RCTs compared the PDA system to paper, but not to a gold standard,[95 96] one had a small number of users (n=4), [98] and one was performed 17 years ago.

All three evaluations that had user surveys reported that users preferred the PDA system over traditional paper, two reported that users could fix most technical problems with the device, though technical support is still a critical need. Further, the organizations that implemented the PDA systems in Uganda[30 31] and South Africa[96] had experience with hundreds of users and over a dozen implementations combined which empirically suggests the feasibility of these systems.

The cost-analyses showed that these systems were able to recuperate the high initial costs by providing increased efficiency and continuous material costs. The Uganda system[30 31] showed a cost savings of 91% over the paper system. The South African analysis[96] calculated that after using the PDA system for data collection in eight studies of medium scale, the system would equal the costs of paper. The system in Lima, Peru[98] would pay for its original development and implementation in 5.5 years, and for expansion to other health districts in 3 months.

Table 10 Description of research or data collection system evaluations

System or Institution	Evaluation Type	Outcome
PDA-Tanzania[99]	Descriptive	Collected data on 83,346 individuals over seven weeks with no PDA problems. Dataset was available within 24 hours. Median time to form completion was 14 minutes during training and nine minutes during survey.
Uganda Health Information Network[30 31]	User survey	87% reported that health content received helped them make faster more accurate diagnoses. 86% integrated PDA into other activities. 73% able to solve problems; 68% reported problems to health unit with only 41% of them being answered.
Uganda Health Information Network[30 31]	Cost analysis	System provides up to 91% saving per unit spending compared to paper-based HMIS data collection and reporting approaches. Reporting compliance to MOH improved from national average of 63% to 94-100% for districts using UHIN.
UN-Vodafone Partnership[10]	User survey	**Advantages:** Time savings (95 percent); the ability to quickly mobilize or organize individuals (91 percent); reaching audiences previously difficult or impossible to reach (74 percent); transmit data more quickly and accurately (67 percent); gather data more quickly and accurately (59 percent).
PDA-Gabon[100]	Self-controls	Rate of discrepant entries was 1.7%. Categorical data were more commonly discrepant than were continuous "typed in" data (2.4% versus 1.2%; p= 0.001).
PDCS-Nicaragua[72]	Self-controls	In 558 patient interviews accuracy of PDA and paper methods was 97.1% and 97.6%, respectively. For 1,543 field visits, accuracy rate for PDA and paper methods was 98.9% and 99.3%, respectively.
PDA-PREVEN[95]	Before-after (first survey), RCT (second survey)	First survey, almost perfect agreement between paper and PDA. Second survey, rates of responses to sensitive questions were similar between both kinds of questionnaires. PDA had 96% less inconsistencies (p = 0.0001) and 66% less missing values (p = 0.001) than paper.
HIV-PDA interview system[101]	Block RCT	There was no difference between participants' self-reported comfort across handheld and paper conditions. However, participants in the handheld condition were more likely to give socially desirable responses to the sexual behavior questions (p<0.01).
PDACT[96]	Cost analysis	Cost of PDA survey is slightly less than paper when cost of hardware is annualized over four studies and the programming cost excluded. When programming cost is included, upfront costs need to be discounted over eight studies to obtain a comparative cost with paper.
PDACT[96]	User surveys	85% of PDA users preferred PDA and 7% preferred paper for answering questions about sex. 53% of paper users preferred PDA and 28% preferred paper.
PDACT[96]	Simultaneous randomized controls	Intra-scale reliability and the test-retest reliability were found to be adequate and similar between paper and PDAs.
PIH-EMR PDA[102]	User Survey	User satisfaction higher for PDA (mean 5 of 5) than paper (3.5 of 5). PDA reduced mean work-time per result from 6.75 to less than 2 minutes. Mean 1.13 technical problems per month which could be fixed in the field (2 users) or back at the office (2 users).
PIH-EMR PDA[102]	Cost analysis	Work hours required decreased by 60% (p<0.001). Total cost and time to develop and implement was US$26,092 and 22 weeks. Cost to expand to 9 districts was $1,125 and to implement collecting patient weights $4,107.
PIH-EMR PDA[98]	Cluster RCT	PDA-based system had a processing time of 6.2 days, significantly lower than both the baseline and control site measurements of 54.8 and 64.4 days, respectively (p<0.0001). Reduced errors from 10.1% to 2.8%.
PDA-Gambia[97]	Cross-over simultaneous	Handheld showed a 30% improvement for collection of identification data and a 100% improvement for dates and times [system automatically time

	randomized controls	stamped]. Significant reduction in inter-individual variability in data accuracy. By the third week the average interview times were 31% shorter for field workers who used handheld (p=0.007).

Discussion

This review shows that, with the exception of PDA data collection, there are still few scientifically rigorous data on the effectiveness and cost-effectiveness of eHealth systems in developing countries. Of all the evaluations described in this review, only nine had randomized controls and only two, performed in middle income countries (Poland and Hungary), had patient outcomes as an endpoint.

These initial evaluations suggest that the following functions are of positive impact in developing countries:

1. Ability to track patients through the treatment initiation process, monitor adherence, and detect those at risk for loss to follow-up.
2. Tools to decrease communication times of information within and between institutions.
3. Tools to label or register samples and patients.
4. Ability to electronically monitor and remind patients of responsibilities.
5. Collection of clinical or research data using PDA.
6. Reductions in errors in laboratory and medication data.

Evaluations of eHealth systems are challenging and require significant resources in addition to the creation and implementation of the system itself. Implementation should have evaluations built into the implementation process. This may provide useful feedback to improve the project and may also demonstrate the impact of the system.

There are benefits of electronic systems that are difficult to quantify. One is the ability to perform operational research with greatly reduced costs. During our search we found several articles that used electronic databases and probably could not have been performed if manual data collection were required.[103-110] Another benefit is the increase in communication across large distances of emergency data such as in a cholera outbreak[50] or refugee situations.[111]

However, more robust and better evaluated information systems are going to be necessary to overcome the additional implementation challenges in developing countries. These systems must be evaluated to ensure that they are safe, effective, and have a reasonable cost. When looking at the software systems included in PEPFAR's ART Software Inventory Report[5] and EngenderHealth-OpenSociety software tools[6 112] comparison, only three systems, the PIH-EMR/HIV-EMR, MMRS and Vista, had any evaluations performed.

Challenges and biases in evaluating medical information systems

Carrying out successful evaluations of medical information systems is challenging in any environment as there are many factors that influence a system's effectiveness. Determining if an improvement in data quality or clinical care is due to an information system requires carefully controlling for potential biases and confounders.[40] Historical controls (before and after studies) can be hard to interpret as healthcare delivery changes rapidly and improvements are often due to

other factors. Studies with prospective control groups address this problem, but it is important to ensure the groups are equivalent. Selecting the appropriate unit of analysis can also be challenging, as it may not be appropriate to randomize the use of the system for some patients and not others in the same clinic, both from a practical and ethical stand point, and because there may be carry over benefits from the information system such as better access to information or laboratory data. Randomizing by clinic or hospital may be a better approach (cluster randomization), the main challenge being the need to include multiple clinics to have an adequate sample size. One pragmatic and fairly robust strategy for quantitative studies is to carry out before and after comparisons in the intervention sites and also include contemporary controls. This can be accomplished in a staged intervention where some clinics are randomized to get the system before the others.[65 113]

Another important potential bias is the "Hawthorne effect" where staff are aware that they are being monitored and therefore behave differently. This is particularly a problem if the intervention sites are aware they are being studied but the control sites are not. A related issue is when additional resources are invested in the intervention site such as training or better infrastructure. These biases can be minimized by treating the intervention and control sites as similarly as possible and just varying the information system or one of its components.

Both the software system implemented and the implementation process are extremely important in determining the impact that the system will have on clinical and administrative processes. Further, the system and implementation process used become even more critical as EHR systems begin to encompass more processes and users, or if the organizations adopting them grow in scale. In such cases, implementing systems that have been evaluated and shown to work in similar conditions can provide an initial, secure foundation.

For evaluations of information systems in resource poor environments all of the above issues need to be taken into account, as well as factors specific to the environment and staffing. Deploying an information system in a country like Haiti or Kenya first requires an assessment of the feasibility and sustainability of running PCs and/or servers in the location and the ability to provide technical support and training. A simple and important test is if the system is still functional and in use one and three years after implementation. Measures of system usage and data completeness are also necessary both as an end in themselves and as an important prerequisite to a full evaluation study, otherwise a great deal of time and effort can be wasted.

It is clear from the evaluations reviewed here that none met all the criteria described above. However the system for drug order entry in Peru[70] was re-studied three years after implementation and was still in use and functional generating warning alerts for 5.3% of medication orders. The PDA-based laboratory data collection tool in Peru[102] was still in active use three years after initiation, and had been extended to more sites and data types by local staff. The Satellife[30] and On Cue Compliance Service[90] were shown to be well liked by users several years after implementation and, perhaps more importantly, by an independent evaluation team. The strongest evidence for beneficial impact of eHealth on healthcare will come from long-term follow-up carried out by independent evaluators.

Conclusions

There is clearly an urgent need for solid evidence of the impact of medical information systems in developing countries. This review has shown that there has been significant progress in recent years in the publication of evaluation studies. However, most of these studies have been small, have focused on process indicators rather than patient outcomes, or on attitudes of users and patients.

While evaluations of important indicators of care are difficult to do well, this review has confirmed that they are feasible even in very resource poor environments. In future we would recommend that funders include resources for the evaluation of information systems developed and deployed in developing countries and perhaps make them a requirement for continued funding. This could include standard designs for studies that are suitable for resource poor environments, minimize biases, and are more easily comparable to the results from other projects.

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References

1. Routine Health Information Network (RHINO). RHINO Literature Database (http://www.iphealth.info/refbase/index.php), 2008.
2. Edworthy SM. Telemedicine in developing countries. *Bmj* 2001;323(7312):524-5.
3. World Health Organization. Electronic Health Records: A Manual for Developing Countries. Geneva: World Health Organization, 2004.
4. World Health Organization. Electronic Health Records: A Manual for Developing Countries. Geneva: World Health Organization, 2007.
5. President's Emergency Plan for AIDS Relief. PEPFAR Software Inventory Report. Washington DC, 2004.
6. EngenderHealth-Open Society Institute. Health Toolkit: Information Management Challenges and Opportunities for Community-based Organizations Serving People Living With HIV/AIDS. New York, 2004.
7. McGowan JJ, Cusack CM, Poon EG. Formative Evaluation: A Critical Component in EHR Implementation. *J Am Med Inform Assoc* 2008;15(3):297-301.
8. Cusack CM, Poon EG. Health Information Technology Evaluation Toolkit. Rockville, MD: Agency for Healthcare Research and Quality, 2007.
9. Rigby M. Impact of telemedicine must be defined in developing countries. *Bmj* 2002;324(7328):47-8.
10. Kinkade S, Verclas K. Wireless Technology for Social Change. Washington, DC: UN Foundation-Vodafone Group Foundation Partnership, 2008.
11. Fraser HS, Jazayeri D, Nevil P, Karacaoglu Y, Farmer PE, Lyon E, et al. An information system and medical record to support HIV treatment in rural Haiti. *Bmj* 2004;329(7475):1142-6.
12. Tomasi E, Facchini LA, Maia MD. Health information technology in primary health care in developing countries: a literature review. *Bull World Health Organ* 2004;82(11):867-874.
13. Mitchell E, Sullivan F. A descriptive feast but an evaluative famine: systematic review of published articles on primary care computing during 1980-97. *BMJ* 2001;322(7281):279-82.
14. Roine R, Ohinmaa A, Hailey D. Assessing telemedicine: a systematic review of the literature. *Cmaj* 2001;165(6):765-71.
15. Whitten PS, Mair FS, Haycox A, May CR, Williams TL, Hellmich S. Systematic review of cost effectiveness studies of telemedicine interventions. *Bmj* 2002;324(7351):1434-7.
16. Rind DM, Safran C, Phillips RS, Wang Q, Calkins DR, Delbanco TL, et al. Effect of computer-based alerts on the treatment and outcomes of hospitalized patients. *Arch Intern Med* 1994;154(13):1511-7.
17. Pollak VE, Lorch JA. Effect of electronic patient record use on mortality in End Stage Renal Disease, a model chronic disease: retrospective analysis of 9 years of prospectively collected data. *BMC Med Inform Decis Mak* 2007;7(1):38.

18. Garrido T, Jamieson L, Zhou Y, Wiesenthal A, Liang L. Effect of electronic health records in ambulatory care: retrospective, serial, cross sectional study. *Bmj* 2005;330(7491):581.
19. Wang SJ, Middleton B, Prosser LA, Bardon CG, Spurr CD, Carchidi PJ, et al. A cost-benefit analysis of electronic medical records in primary care. *Am J Med* 2003;114(5):397-403.
20. Evans D, Nichol W, Perlin J. Effect of the implementation of an enterprise-wide Electronic Health Record on productivity in the Veterans Health Administration. *Health Economics: Policy and Law* 2006;1:163-169.
21. Garg AX, Adhikari NK, McDonald H, Rosas-Arellano MP, Devereaux PJ, Beyene J, et al. Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: a systematic review. *Jama* 2005;293(10):1223-38.
22. Bates DW, Teich JM, Lee J, Seger D, Kuperman GJ, Ma'Luf N, et al. The impact of computerized physician order entry on medication error prevention. *J Am Med Inform Assoc* 1999;6(4):313-21.
23. Koppel R, Metlay J, Cohen A, Abaluck B, Localio A, Kimmel S, et al. Role of Computerized Physician Order Entry Systems in Facilitating Medication Errors. *JAMA* 2005;293(10):1197-1203.
24. Malkin RA. Barriers for medical devices for the developing world. *Expert Rev Med Devices* 2007;4(6):759-763.
25. Malkin RA. Technologies for clinically relevant physiological measurements in developing countries. *Physiol Meas* 2007;28(8):R57-63.
26. Malkin RA. Design of health care technologies for the developing world. *Annu Rev Biomed Eng* 2007;9:567-87.
27. International Monetary Fund. World Economic Outlook Database. Washington DC: International Monetary Fund, 2008.
28. Mallapaty G, Kim S, Astion ML. Using interactive software to teach image-based clinical laboratory tests in developing countries: a pilot trial in Nepal. *Clin Chem Lab Med* 2003;41(5):711-3.
29. Edmonson SR, Esquivel A, Mokkarala P, Johnson CW, Phelps CL. Using technology to teach technology: design and evaluation of bilingual online physician education about electronic medical records. *AMIA Annu Symp Proc* 2005:946.
30. Bridges.org. Evaluation of the SATELLIFE PDA Project, 2002: Testing the use of handheld computers for heathcare in Ghana, Uganda, and Kenya. Boston, MA: Satellife, 2003.
31. Satellife and Uganda Chartered HealthNet. Uganda Health Information Network, Phase-III: June 9, 2006 – June 8, 2007. Boston: Satellife and Uganda Chartered HealthNet, 2007.
32. Martinez A, Villarroel V, Puig-Junoy J, Seoane J, del Pozo F. An economic analysis of the EHAS telemedicine system in Alto Amazonas. *Journal of Telemedicine and Telecare* 2007;13(1):7-14.
33. Martinez A, Villarroel V, Seoane J, del Pozo F. A study of a rural telemedicine system in the Amazon region of Peru. *J Telemed Telecare* 2004;10(4):219-25.
34. Fraser H, Biondich P, Moodley D, Choi S, Mamlin B, Szolovits P. Implementing electronic medical record systems in developing countries. *Informatics in Primary Care* 2005;13.
35. Forster M, Bailey C, Brinkhof M, Graber C, Boulle A, Spohr M, et al. Electronic Medical Record Systems, Data Quality and Loss to Follow-up: Survey of Antiretroviral Treatment Programmes in Resource Limited Settings. 2008.
36. Fraser HSF, Allen C, Bailey C, Douglas G, Shin S, Blaya J. Information systems for patient follow-up and chronic management of HIV and tuberculosis: A life-saving technology in resource-poor areas. *Journal of Medical Internet Research* 2007;9(4):38.
37. Shortliffe EH, Perreault LE, editors. *Medical Informatics: Computer Applications in Health Care and Biomedicine*. Second ed. New York: Springer, 2001.
38. American Telemedicine Association. Defining Telemedicine, 2008.
39. Strauss A, Corbin J. *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*. Newbury Park, CA: Sage, 1990.
40. Friedman C, Wyatt J. *Evaluation Methods in Medical Informatics*. 2nd ed. New York: Springer-Verlag, 2005.
41. Johnston K, Kennedy C, Murdoch I, Taylor P, Cook C. The cost-effectiveness of technology transfer using telemedicine. *Health Policy Plan* 2004;19(5):302-9.
42. Deodhar J. Telemedicine by email--experience in neonatal care at a primary care facility in rural India. *J Telemed Telecare* 2002;8 Suppl 2:20-1.
43. Fraser H, Jazayeri D, Choi S, Blaya J, Bayona J, Levison L, et al. Forecasting three years drug supply for a large MDR-TB treatment program in Peru. *Int J Tuber Lung Dis* 2006;10(11 Suppl. 1):S245.
44. Yamanija J, Durand R, Bayona J, Blaya J, Jazayeri D, Fraser H. Comparing actual medication consumption against the quantities ordered and a prediction using an information system. *Int J Tuber Lung Dis* 2006;10(11 Suppl. 1):S69-S70.
45. Halbwachs H. The technical and financial impact of systematic maintenance and repair services within health systems of developing countries. *Health Estate* 1999;53(4):6-8, 10-1.
46. Desikan P, Koram MR, Trivedi SK, Jain A. An evaluation of the effectiveness of the laboratory information system (LIS) with special reference to the microbiology laboratory [2]. *Indian Journal of Pathology and Microbiology* 2005;48:418%N 3.
47. Grigor'ev AI, Orlov OI. [Telemedicine in Russia]. *Vestn Ross Akad Med Nauk* 2004(10):30-5.
48. Janecki J, Podsiadly T. [Computer-assisted analysis of patients' medical records]. *Pol Tyg Lek* 1992;47(20-21):470-2.
49. Swaminathan R, Black RJ, Sankaranarayanan R. Database on cancer survival from developing countries. *IARC Sci Publ* 1998(145):19-25.
50. Ayyagari A, Bhargava A, Agarwal R, Mishra SK, Mishra AK, Das SR, et al. Use of telemedicine in evading cholera outbreak in Mahakumbh mela, Prayag, UP, India: An encouraging experience. *Telemedicine Journal and E-Health* 2003;9(1):89-94.
51. Corr P. Teleradiology in KwaZulu-Natal. A pilot project. *S Afr Med J* 1998;88(1):48-9.

52. Cassiani SH, Freire CC, Gimenes FR. [Electronic medical prescription at a university hospital: writing failures and users' opinions]. *Rev Esc Enferm USP* 2003;37(4):51-60.
53. Fabre-Teste B, Sokha O. [Calmette Hospital, Phnom Penh, Cambodia. Assessment of the implementation of the Medical Information System (SIM). Global analysis of the 1998 results]. *Sante* 1999;9(6):367-75.
54. Sequist TD, Cullen T, Hays H, Taualii MM, Simon SR, Bates DW. Implementation and use of an electronic health record within the Indian Health Service. *J Am Med Inform Assoc* 2007;14(2):191-7.
55. Littlejohns P, Wyatt JC, Garvican L. Evaluating computerised health information systems: hard lessons still to be learnt. *BMJ* 2003;326(7394):860-3.
56. Iluyemi A, Briggs J, Fitch T. Electronic Health Records in Developing Countries, Integrating with Mobile Technology and Legacy Systems for Community Based Health Workers: Organisational and End-Users' Issues. *The European Conference on Information Management and Evaluation.* Montpellier, France, 2007.
57. Brender J, Ammenwerth E, Nykanen P, Talmon J. Factors influencing success and failure of health informatics systems--a pilot Delphi study. *Methods Inf Med* 2006;45(1):125-36.
58. Heeks R. Information Systems and Developing Countries: Failure, Success, and Local Improvisations. *The Information Society* 2002;18:101-112.
59. Rotich JK, Hannan TJ, Smith FE, Bii J, Odero WW, Vu N, et al. Installing and implementing a computer-based patient record system in sub-Saharan Africa: the Mosoriot Medical Record System. *J Am Med Inform Assoc* 2003;10(4):295-303.
60. Al Farsi M, West DJ, Jr. Use of electronic medical records in Oman and physician satisfaction. *J Med Syst* 2006;30(1):17-22.
61. Chae YM, Kim SI, Lee BH, Choi SH, Kim IS. Implementing health management information systems: measuring success in Korea's health centers. *Int J Health Plann Manage* 1994;9(4):341-8.
62. Merrell RC, Merriam N, Doarn C. Information support for the ambulant health worker. *Telemed J E Health* 2004;10(4):432-6.
63. Singh AK, Kohli M, Trell E, Wigertz O, Kohli S. Bhorugram (India): revisited. A 4 year follow-up of a computer-based information system for distributed MCH services. *Int J Med Inform* 1997;44(2):117-25.
64. Llido LO. The impact of computerization of the nutrition support process on the nutrition support program in a tertiary care hospital in the Philippines: report for the years 2000-2003. *Clin Nutr* 2006;25(1):91-101.
65. Blaya JA, Shin SS, Yagui MJ, Yale G, Suarez CZ, Asencios LL, et al. A web-based laboratory information system to improve quality of care of tuberculosis patients in Peru: functional requirements, implementation and usage statistics. *BMC Med Inform Decis Mak* 2007;7:33.
66. Alvarez Flores MG, Guarner J, Terres Speziale AM. [Productivity before and after installing a computerized system in a clinical laboratory]. *Rev Invest Clin* 1995;47(1):29-34.
67. Turhan K, Kayikcioglu T. Implementation of a virtual private network-based laboratory information system serving a rural area in Turkey. *Laboratory Medicine* 2006;37(9):527-531.
68. Costa AL, de Oliveira MM, Machado Rde O. An information system for drug prescription and distribution in a public hospital. *Int J Med Inform* 2004;73(4):371-81.
69. Gimenes FRE, Miasso AI, De Lyra Jr DP, Grou CR. Electronic prescription as contributing factor for hospitalized patients' safety. *Pharmacy Practice* 2006;4(1):13-17.
70. Choi SS, Jazayeri DG, Mitnick CD, Chalco K, Bayona J, Fraser HS. Implementation and initial evaluation of a Web-based nurse order entry system for multidrug-resistant tuberculosis patients in Peru. *Medinfo* 2004;11(Pt 1):202-6.
71. CDC Global AIDS Program. Responses to the Touchscreen System User Survey: Queen Elizabeth Central Hospital. Malawi: CDC Global AIDS Program, 2007.
72. Aviles W, Ortega O, Kuan G, Coloma J, Harris E. Quantitative assessment of the benefits of specific information technologies applied to clinical studies in developing countries. *Am J Trop Med Hyg* 2008;78(2):311-5.
73. Rosen S, Fox MP, Gill CJ. Patient retention in antiretroviral therapy programs in sub-Saharan Africa: a systematic review. *PLoS Med* 2007;4(10):e298.
74. Dwolatzky B, Trengove E, Struthers H, McIntyre JA, Martinson NA. Linking the global positioning system (GPS) to a personal digital assistant (PDA) to support tuberculosis control in South Africa: a pilot study. *International journal of health geographics [electronic resource]*. 2006;5:34.
75. Rommelmann V, Setel PW, Hemed Y, Angeles G, Mponezya H, Whiting D, et al. Cost and results of information systems for health and poverty indicators in the United Republic of Tanzania. *Bull World Health Organ* 2005;83(8):569-77.
76. Jirapaet V. A computer expert system prototype for mechanically ventilated neonates development and impact on clinical judgment and information access capability of nurses. *Comput Nurs* 2001;19(5):194-203.
77. DeRenzi B, Lesh N, Parickh T, Sims C, Mitchell M, Maokola W, et al. e-IMCI: Improving Pediatric Health Care in Low-Income Countries. *CHI*. Florence, Italy, 2008.
78. Peters DH, Kohli M, Mascarenhas M, Rao K. Can computers improve patient care by primary health care workers in India? *International Journal for Quality in Health Care* 2006;18(6):437-445.
79. Jithoo R, Govender PV, Corr P, Nathoo N. Telemedicine and neurosurgery: experience of a regional unit based in South Africa. *J Telemed Telecare* 2003;9(2):63-6.
80. Heinzelmann PJ, Jacques G, Kvedar JC. Telemedicine by email in remote Cambodia. *J Telemed Telecare* 2005;11 Suppl 2:S44-7.
81. Brandling-Bennett HA, Kedar I, Pallin DJ, Jacques G, Gumley GJ, Kvedar JC. Delivering health care in rural Cambodia via store-and-forward telemedicine: a pilot study. *Telemed J E Health* 2005;11(1):56-62.

82. Bharadwaj P, Vasava S, Pisharodi S. Los Angeles to Mumbai: providing palliation using technology. *J Palliat Med* 2007;10(5):1037-9.
83. Wootton R, Youngberry K, Swinfen P, Swinfen R. Prospective case review of a global e-health system for doctors in developing countries. *J Telemed Telecare* 2004;10 Suppl 1:94-6.
84. Bujnowska-Fedak MM, Puchala E, Steciwko A. Telemedicine for diabetes support in family doctors' practices: a pilot project. *J Telemed Telecare* 2006;12 Suppl 1:8-10.
85. Otake LR, Thomson JG, Persing JA, Merrell RC. Telemedicine: low-bandwidth applications for intermittent health services in remote areas. *Jama* 1998;280(15):1305-6.
86. Torok M. Hungarian tele-medical preterm birth prevention project: a randomized multicenter, clinical study. *International Journal of Gynecology and Obstetrics* 1994;46(Suppl. 3):58.
87. Torok M, Turi Z, Kovacs F. Ten years' clinical experience with telemedicine in prenatal care in Hungary. *J Telemed Telecare* 1999;5 Suppl 1:S14-7.
88. Thomas C, Prasanna M. The role of a 'satellite-service' in the national organisation of burn care in the Sultanate of Oman. *Burns* 2000;26(2):181-5.
89. Rissam HS, Kishore S, Bhatia ML, Trehan N. Trans-telephonic electrocardiographic monitoring - experience in India. *Journal of Telemedicine and Telecare* 1998;4:8-11.
90. Bridges.org. Evaluation of the On Cue Compliance Service Pilot: Testing the use of SMS reminders in the treatment of Tuberculosis in Cape Town, South Africa. Cape Town: City of Cape Town Health Directorate and the International Development Research Council (IDRC), 2005.
91. The five elements of DOTS. *http://www.who.int/tb/dots/whatisdots/en/index.html:* WHO, 2006.
92. Farmer P, Kim JY. Community based approaches to the control of multidrug resistant tuberculosis: introducing "DOTS-plus". *BMJ* 1998;317(7159):671-674.
93. Farmer P, Leandre F, Mukherjee J, Gupta R, Tarter L, Kim JY. Community-based treatment of advanced HIV disease: introducing DOT-HAART (directly observed therapy with highly active antiretroviral therapy). *Bulletin of the World Health Organization* 2001;79(12):1145-1151.
94. Leong KC, Chen WS, Leong KW, Mastura I, Mimi O, Sheikh MA, et al. The use of text messaging to improve attendance in primary care: a randomized controlled trial. *Fam Pract* 2006;23(6):699-705.
95. Bernabe-Ortiz A, Curioso WH, Gonzales MA, Evangelista W, Castagnetto JM, Carcamo CP, et al. Handheld computers for self-administered sensitive data collection: a comparative study in Peru. *BMC Med Inform Decis Mak* 2008;8:11.
96. Zwarenstein M, Seebregts C, Mathews C, Fairall L, Flisher AJ, Seebregts C, et al. Handheld Computers For Survey and Trial Data Collection in Resource-Poor Settings: Development and Evaluation of PDACT, a Palm™ Pilot Interviewing System. unpublished.
97. Forster D, Behrens RH, Campbell H, Byass P. Evaluation of a computerized field data collection system for health surveys. *Bull World Health Organ* 1991;69(1):107-11.
98. Blaya J, Fraser HS. Development, Implementation and Preliminary Study of a PDA-based tuberculosis result collection system. *AMIA Annu Symp Proc* 2006:41-5.
99. Shirima K, Mukasa O, Schellenberg JA, Manzi F, John D, Mushi A, et al. The use of personal digital assistants for data entry at the point of collection in a large household survey in southern Tanzania. *Emerg Themes Epidemiol* 2007;4:5.
100. Missinou MA, Olola CH, Issifou S, Matsiegui PB, Adegnika AA, Borrmann S, et al. Short report: Piloting paperless data entry for clinical research in Africa. *Am J Trop Med Hyg* 2005;72(3):301-3.
101. Cheng K, Ernesto F, Truong K. Participant and Interviewer Attitudes toward Handheld Computers in the Context of HIV/AIDS Programs in Sub-Saharan Africa. *CHI: Healthcare in the Developing World.* Florence, Italy, 2008.
102. Blaya J, Rodriguez P, Fraser H. Cost and implementation analysis of a personal digital assistant (PDA) system for laboratory data collection. *Int J Tuberc Lung Dis* (accepted).
103. da Silva AAM, Ribeiro VS, Junior AFB, Coimbra LC, da Silva RA. Evaluation of data quality from the information system on live births in 1997-1998. *Revista De Saude Publica* 2001;35(6):508-514.
104. da Silva AS, Laprega MR. Critical evaluation of the Primary Care Information System (SIAB) and its implementation in Ribeirao Preto, Sao Paulo, Brazil. *Cadernos de saude publica / Ministerio da Saude, Fundacao Oswaldo Cruz, Escola Nacional de Saude Publica.* 2005;21(6):1821-1828.
105. Ng YS, Jung H, Tay SS, Bok CW, Chiong Y, Lim PA. Results from a prospective acute inpatient rehabilitation database: clinical characteristics and functional outcomes using the Functional Independence Measure. *Ann Acad Med Singapore* 2007;36(1):3-10.
106. Anna B, Elisa R. Pressure ulcer: Statistics analysis of an electronic database. *Stud Health Technol Inform* 2006;122:548-51.
107. Gomes SC, Jr., Almeida RT. [A comparative analysis of the ambulatory care production register in oncology in the Brazilian Unified Health System]. *Cad Saude Publica* 2006;22(1):141-50.
108. Zhou J, Kumarasamy N. Predicting short-term disease progression among HIV-infected patients in Asia and the Pacific region: preliminary results from the TREAT Asia HIV Observational Database (TAHOD). *HIV Med* 2005;6(3):216-23.
109. Brustolin S, Souza C, Puga AC, Refosco L, Pires R, Peres R, et al. Assessment of a pioneer metabolic information service in Brazil. *Community Genetics* 2006;9(2):127-132.
110. Shennan DH. The Ciskei tuberculosis information system. *Cent Afr J Med* 1993;39(8):159-65.
111. Babille M, Decolombani P, Guerra R, Zagaria N, Zanetti C. Post-Emergency Epidemiologic Surveillance in Iraqi-Kurdish Refugee Camps in Iran. *Disasters* 1994;18(1):58-75.

112. EngenderHealth-Open Society Institute. Software Tools Comparison (http://www.healthtoolkit.org/?show=tools&id=0). New York, 2004.
113. Blaya J, Cohen T, Rodriguez P, Fraser H. PDAs to collect tuberculosis bacteriology data in Peru reduce delays, errors, workload, and are acceptable to users: Community randomized trial. *International Journal of Infectious Diseases* 2007 (submitted).