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Implementation of a cloud-based electronic medical record for maternal and child health in rural Kenya

John Haskew [1*], Gunnar Rø [1,2], Kaori Saito [3], Kenrick Turner [4], George Odhiambo [5], Annah Wamae [5], Shahnaaz Sharif [5], Tomohiko Sugshita [3]

[1] Uamuzi Bora, Kakamega, Kenya, [2] University of Durham, UK, [3] Japanesese International Cooperation Agency, Tokyo, Japan, [4] British Antarctic Survey Medical Unit, Plymouth, UK, [5] Ministry of Health, Kenya

[*] **Corresponding Author:**

Email: john.haskew@uamuzibora.org

Tel: +254 789 696188

Address: Rondo Retreat Centre, PO Box 2153-50100, Kakamega, Kenya

Present Contact Details:

Dr John Haskew

World Health Organization, Amman, Jordan

Email: john.haskew@gmail.com

Tel: +962 799 762071

Abstract

Background: Complete and timely health information is essential to inform public health decision-making for maternal and child health, but is often lacking in resource-constrained settings. Electronic medical record (EMR) systems are increasingly being adopted to support the delivery of health care, and are particularly amenable to maternal and child health services. An EMR system could enable the mother and child to be tracked and monitored throughout maternity shared care, improve quality and completeness of data collected and enhance sharing of health information between outpatient clinic and the hospital, and between clinical and public health services to inform decision-making.

Methods: This study implemented a novel cloud-based electronic medical record system in a maternal and child health outpatient setting in Western Kenya between April and June 2013 and evaluated its impact on improving completeness of data collected by clinical and public health services. The impact of the system was assessed using a two-sample test of proportions pre- and post-implementation of EMR-based data verification.

Results: Significant improvements in completeness of the antenatal record were recorded through implementation of EMR-based data verification. A difference of 42.9% in missing data (including screening for hypertension, tuberculosis, malaria, HIV status or ART status of HIV positive women) was recorded pre- and post- implementation. Despite significant impact of EMR-based data verification on data completeness, overall screening rates in antenatal care were low.

Conclusion: This study has shown that EMR-based data verification can improve the completeness of data collected in the patient record for maternal and child health. A number of issues, including data management and patient confidentiality, must be considered but significant improvements in data quality are recorded through implementation of this EMR model.

Keywords: Electronic medical record; maternal and child health; resource-constrained settings; data verification; medical informatics

Introduction

Complete and timely information is essential to inform public health decision-making and improve health service delivery, including for maternal and child health. [1,2] Data quality in resource-constrained setting is often compromised by incomplete data and untimely reporting, however, and local health information systems may be the only data sources available for the continuous, routine monitoring. [3,4] Few studies have assessed data quality and completeness for maternal and child health. A study of routine primary care data in South Africa showed 26% of data in prevention of mother to child transmission of HIV (PMTCT) records was complete and only 12.8% of those data recorded was accurate. [5]

The paper-based mother and child health booklet has been a successful and integral tool of maternity shared care in Kenya and is an important source of data for routine and continuous monitoring of maternal and child health. [6] The pregnant woman carries and retains the paper record with her and the care provided is documented at each community outpatient or hospital visit. Paper records can increase women's engagement in care [7] but a limitation of using the hand-held booklet in Kenya is that no individual patient record is kept by the health service provider. Other forms of patient information are retained at the clinic, for example as registers.

Electronic medical record (EMR) systems are increasingly being adopted to support the delivery of health care in a variety of settings in resource-constrained settings, including for HIV, tuberculosis and child health. [8-11] EMR system implementation is also particularly amenable to maternal and child health, in which the pregnant mother must follow a continuum of care, starting with routine antenatal visits until delivery and then through postnatal and neonatal follow-up, including provision of routine immunisation. [12] An EMR system can enable both the mother and child to be tracked and monitored throughout this continuum and could also be used to improve access to and use of health information at different levels of shared care both between outpatient clinic and the hospital, and between clinic, district levels and above to inform clinical and public health decision-making.

Few studies have focused on the application of EMR systems in maternal and child health [12], or their application in resource-constrained settings, where unique challenges and barriers to implementation are encountered, including limited human resources and financial costs. [13,14] Traditional models of EMR implementation have installed local systems infrastructure, such as a server and network in each clinic, which can be costly to implement and maintain [9], and which require specialised human resources. [13] These limitations underscore the need for innovative solutions that are appropriate for resource-constrained settings. [9]

In this study, we describe the implementation of a novel cloud-based EMR system for maternal and child health in Western Kenya, its impact on completeness of the antenatal record and implications for shared maternity care in resource-constrained settings.

Methods

Study setting

Maternal and child health care in Kenya is provided in outpatient clinic and hospital settings, through which antenatal, delivery and postnatal care and support services are provided to the mother and newborn child. This study was conducted between April and June 2013 in five outpatient clinics in Kisumu County, Western Kenya.

Electronic medical record

The EMR system – called Uamuzi Bora [15] (a Swahili phrase meaning "the right choice") – was built using free, open source software and builds on common platforms and previous work, notably that of the Open Medical Record System (OpenMRS). [16] The system was approved for use in Kenya by the Ministry of Health and adheres to national EMR standards. [17] The electronic patient record replicates information currently collected in the paper-based mother and child health booklet. [6]

The EMR system implemented a cloud-based model, rather than a local clinic model, which removed the need for local clinic infrastructure and enhanced data access and sharing at different levels of health care. In using the term "cloud-based" we refer to the fact that the server and data are hosted centrally and not by the individual clinic, and that all processes (including the EMR software, analysis and reporting) is run on the server not locally on individual clinic computers. The system used a secure virtual private network (VPN), provided by a mobile phone operator in Kenya, to which the server and clinic computers connected via a mobile data network. Google Chromebooks were used in the clinic, with built-in mobile data connection, to connect directly with the VPN. Clinic computers were air gapped from the internet and only those using SIM cards registered by the project could access the VPN. Daily copies of an anonymised version of the patient database were used to provide health information to different users at different levels of care. The server and data were hosted for the Ministry of Health at the Uamuzi Bora project office, located in Kakamega, to provide maintenance, security, and reliable power supply. The server connected to the VPN via a Worldwide Interoperability

for Microwave Access (WiMAX) wireless communications standard and ran a customised version of OpenMRS on Ubuntu Linux.

Data management and protection

The EMR system stored patient data securely and in accordance with best practices [18], including the following data management, storage, security and anonymisation procedures. The server was physically secured in a locked office and access was limited to select project staff. Patient identifiable information was saved on an encrypted file system and the decryption key stored on removable media, which was held in a different secure physical location to the server. Connections between the clinic computers and the server used exclusively Hypertext Transfer Protocol Secure (HTTPS) over an Internet Protocol Security (IPsec) VPN. Project staff could also connect to the server from the internet using public-key authenticated Secure Shell (SSH), a cryptographic network protocol for secure data communication, over the IPsec VPN. All connection attempts to the server were logged and audited.

Encrypted backups were made of patient identifiable data using GnuPG and held for six months for the purpose of disaster recovery, after which time they were securely deleted. Temporary files were securely deleted after encryption was completed. Daily anonymised versions of the database were also created automatically by the server, which contained no patient identifiable data. This anonymous database was encrypted and transferred over the VPN to a public webserver, exposing an application programming interface (API), which allowed partners to access aggregated data. [19]

Study Design

The study followed a pre-post EMR intervention design among patients enrolled in maternity shared care at five rural Kenyan clinics.

Data collection occurred over two phases. The pre-intervention phase took place between 2 April and 5 May 2013, when information contained within the paper-based mother and child health booklet of women registered at each study clinic was entered into the EMR system but no EMR-based data verification was implemented. During this phase, data were double entered from the paper record into the EMR system using data-entry assistants recruited for the study. During the intervention phase,

between 6 May and 24 June 2013, EMR-based data verification was activated. Any new patients' data continued to be entered into the EMR system during this time. Clinic staff were provided training in how to interpret and act on the data verification flags and reminders to ensure actions were followed up. Any patient visiting one of the study clinics was eligible for inclusion into the EMR during the study period.

Automated structured query language (SQL) queries of all patient data were run daily on the server to identify records that contained missing data. Individual records in the EMR system were flagged according to these SQL queries and daily reports were produced, based on the SQL query results. Clinic staff reviewed these daily reports and individual patient flags to correct missing data accordingly. Missing data were corrected during the subsequent patient consultation to verify appropriate patient history and to conduct appropriate clinical or laboratory investigations.

Statistical analysis

Primary outcomes of the study were completeness of the antenatal care record, namely provision of screening for hypertension, HIV, TB and malaria, HIV status and whether HIV positive women were receiving ART or not.

Frequencies and proportions are reported for categorical variables. The impact of EMR-based data verification on completeness of antenatal record screening services was assessed using a two-sample test of proportions, and presented with 95% confidence intervals and corresponding p-values. All analyses were carried out using STATA version 12.1 (Stata Corp; College Station, TX).

Ethical issues

Implementation of the EMR was a public health intervention to improve access to health information recorded in the maternal and child health booklet, in line with Ministry of Health national targets, and thus did not require institutional review board (IRB) ethical approvals. The EMR system was approved for use in Kenya by the Ministry of Health and adhered to national EMR standards. The electronic patient record only replicated information currently collected in the paper-based mother and child health booklet.

The intervention was approved by the Director of Public Health, Ministry of Health, Kenya. Patient consent for registration of data into the electronic medical record and participation in the study was obtained by the clinical officer or nurse at each clinic during each consultation.

Results

A total of 561 pregnant women were registered in antenatal care in the EMR system, across the five study clinics, prior to implementation of EMR-based data verification (Table 1). The mean age of women attending clinic was 23.7 years and each woman attended antenatal care an average of 1.7 times during the pre-intervention phase (Table 1). A total of 104 deliveries were recorded during the pre-intervention period, of which 52 (50.0%) were attended by a midwife, 68 (65.4%) took place in hospital and 99 (95.2%) were spontaneous vaginal delivery (Table 1). A total of 158 babies were registered during the pre-intervention period, of which 86 (54.4%) were girls (Table 1).

At the end of the study, a total of 946 pregnant women were registered in the EMR system, which included the 561 women registered during the pre-EMR intervention phase (Table 1). The mean age of women attending clinic was 23.6 years and each woman attended antenatal care an average of 1.9 times across the whole study period (Table 1). A total of 206 deliveries were recorded, of which 107 (52.0%) were attended by a midwife, 136 (66.0%) took place in hospital and 195 (94.7%) were spontaneous vaginal delivery (Table 1). A total of 302 babies were registered at the end of the study, of which 160 (53.0%) were girls (Table 1).

The impact of EMR-based data verification on selected missing data within the antenatal care record pre- and post-intervention was assessed using two-sample test of proportions (Table 2). Overall, a 42.9% (95% CI 38.5 – 47.4, $p < 0.01$) difference in missing data was recorded pre- and post-implementation of EMR-based data verification of the variables of interest (screening results for hypertension, tuberculosis, malaria, HIV status or ART status of HIV positive women) (Table 2). Significant difference ($p < 0.05$) in the amount of missing data for screening of hypertension (25.1%, 96% CI 20.5 – 29.7), tuberculosis (36.2%, 95% CI 31.8 – 40.7), malaria (29.6%, 95% CI 24.8 – 34.3), HIV status (22.9%, 95% CI 18.4 – 27.4) and ART status of HIV positive women (16.7%, 95% CI 13.0 – 32.0) were recorded pre- and post- implementation of EMR-based data verification (Table 2). Despite this impact on completeness of the antenatal record, only five (0.5%) patients were screened for hypertension during the whole study period. Two women (0.2%) were receiving TB treatment, 44

(4.7%) had confirmed malaria and 132 (14.0%) were HIV positive (Table 2). A total of 68 (50.4%) of women confirmed HIV positive were recorded as receiving ART during the study (Table 2).

Discussion

In this study, we describe the implementation of a novel cloud-based EMR system for maternal and child health and its impact on completeness of data collected in the antenatal care record. Implementation of the cloud-based EMR was associated with a 42.9% difference in missing data (based on screening results for hypertension, tuberculosis, malaria, HIV status or ART status of HIV positive women).

This study compared implementation of the cloud-based EMR with the existing paper record. The cloud-based EMR model enables data to be shared across multiple sites in real-time, potentially enhancing access to data at different levels of care. A limitation of the cloud-based model of EMR implementation, and its applicability in other settings, is the need for mobile data network infrastructure. Other limitations of this study include the short study period and not controlling for other potential confounding factors that may have influenced the effect of cloud-based EMR data validation, such as improvement in training or clinical practice during the study period.

Improving the quality and completeness of data during this study highlighted gaps and weaknesses in program implementation that were unknown prior to EMR implementation, for example that only five patients were screened for hypertension during the whole study period. The EMR system could be used to address these gaps and inform the design of proactive interventions and support services to improve provision of clinical care, including screening services. More accountability could be introduced into programming with improved access to data and EMR-based data could be used to inform program innovation for maternal and child health. The EMR system could also be used to monitor the number of antenatal clinic visits attended, for example, and improve retention in care.

Further studies are encouraged to explore these potential applications of EMR system implementation for maternal and child health in real-time program settings. Further work is also encouraged to compare the cloud-based EMR model with local clinic-based EMR systems, including impact on cost-effectiveness, data completeness and data sharing and to consider the scalability of cloud-based models in settings where data network infrastructure is functional.

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Tables

Table 1. Number of pregnant women, deliveries and children registered in antenatal clinic, by socio-demographic and clinic characteristics

Characteristic	**Pre-EMR intervention n (%)**	**Post- EMR intervention n (%)**
Women registered	**561 (100.0%)**	**946 (100.0%)**
Location of women		
Bar Korwa Clinic	83 (14.8%)	123 (13.0%)
Bodi Clinic	76 (13.6%)	124 (13.1%)
Kombewa Clinic	0 (0.0%)	353 (37.3%)
Manyuanda Clinic	56 (10.0%)	137 (14.5%)
Rodi Clinic	51 (9.1%)	71 (7.5%)
Missing	295 (52.6%)	138 (14.6%)
Age of women		
<15 years	2 (0.4%)	4 (0.4%)
15-24 years	336 (59.9%)	577 (61.0%)
25-34 years	188 (33.5%)	305 (32.2%)
35-44 years	35 (6.2%)	59 (6.2%)
>44 years	0 (0.0%)	1 (0.1%)
Deliveries registered	**104 (100.0)**	**206 (100.0%)**
Delivery conducted By		
Clinical Officer	0 (0.0%)	2 (1.0%)
Doctor	1 (1.0%)	1 (0.5%)

Midwife	52 (50.0%)	107 (52.0%)
Nurse	30 (28.9%)	65 (31.6%)
Other	1 (1.0%)	3 (1.5%)
Missing	20 (19.2%)	28 (14.0%)
Place of Delivery		
BBA	0 (0.0%)	1 (0.7%)
Clinic	15 (14.4%)	36 (12.6%)
Home	2 (1.9%)	7 (22.8%)
Hospital	68 (65.4%)	136 (57.6%)
Missing	19 (18.3%)	26 (6.3%)
Method of Delivery		
Caesarean section	1 (1.0%)	1 (0.5%)
Vaginal Delivery	99 (95.2%)	195 (94.7%)
Other	1 (1.0%)	2 (1.0%)
Missing	3 (2.9%)	8 (3.9%)
Children registered	**158 (100.0%)**	**302 (100.0%)**
Gender of child		
Male	72 (45.6%)	142 (47.0%)
Female	86 (54.4%)	160 (53.0%)
Location of child		
Bar Korwa Clinic	15 (9.5%)	28 (9.3%)
Bodi Clinic	11 (7.0%)	14 (4.6%)
Manyuanda Clinic	94 (59.5%)	201 (66.6%)
Rodi Clinic	8 (5.1%)	21 (7.0%)
Missing	30 (19.0%)	38 (12.6%)

Table 2. Missing antenatal and delivery record data recorded for patients registered in the EMR system pre- and post-intervention

Missing delivery data	**Pre-EMR intervention n (%)**	**Post-EMR intervention n (%)**	**% diff** [*]	**95% CI**	**P-value**
Antenatal record missing data					
Hypertension screening	219 (39.0)	132 (14.0)	-25.1%	20.5 – 29.7	0.000
Tuberculosis screening	271 (48.3)	182 (12.1)	-36.2%	31.8 – 40.7	0.000
Malaria screening	266 (47.4)	169 (17.9)	-29.6%	24.8 – 34.3	0.000
HIV status	201 (35.8)	122 (12.9)	-22.9%	18.4 – 27.4	0.000
HIV+ women receiving ART	28 (49.1)	44 (32.6)	-16.7%	13.0 – 32.0	0.02
Total [**]	334 (59.5)	250 (16.6)	-42.9%	38.5 – 47.4	0.000

[*] Two-sample test of proportions

[**] Patient record missing screening for hypertension, tuberculosis, malaria, HIV status or ART status of HIV positive women

Summary Points

What was already known on the topic:

- Maternity care is a continuum that starts with routine antenatal visits until delivery and then through postnatal and neonatal follow-up, including provision of routine immunisation.
- Reasons for gaps within shared maternity care are multi-factorial but include systemic factors such as inadequate training and lack of access to timely and reliable data (electronic or paper based).
- Electronic medical record (EMR) systems are increasingly being adopted to support the delivery of health care in resource-constrained settings and their implementation is particularly amenable to maternal and child health.

What this study added to our knowledge:

- A cloud-based model of EMR implementation removes many barriers to EMR adoption in resource-constrained settings, including the need for local clinic infrastructure.
- Implementation of a cloud-based EMR system can reduce gaps in shared maternity care and significantly improve the quality and completeness of data collected.
- Further work is encouraged to compare cloud-based and local clinic-based EMR models, with respect to cost-effectiveness, data completeness and data sharing at different levels of health care.

Authors' Contributions

All authors contributed to the paper. JH conceived and designed the study. JH, KT, GR designed and implemented the EMR system. JH analysed the data. JH, KS, TS wrote the paper. All authors reviewed the final draft of the manuscript.

Conflict of Interest

JH has worked as a consultant for Vestergaard Frandsen. This does not alter the authors' adherence to policies on sharing data and materials. No authors were paid for analysis or writing of the manuscript.

Highlights

- The study describes implementation of a novel cloud-based MCH EMR
- The cloud-based EMR improves completeness of data in the MCH patient record
- Further work is encouraged to compare cloud- and local clinic-based EMR models