RELIABLE AND REALTIME ARCHITECTURE OF MOTHER CHILD HEALTH INFORMATION SYSTEM WITH ENHANCED USABILITY

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ABSTRACT

Electronic Healthcare Record (EHR) of an expectant mother is a key source of information and serves as a tool for continuity of care with intent to improve efficiency and reduce error. Healthcare information systems have contributed significantly in reducing the mother-child mortality rate in different countries. Now, several underdeveloped nations are shifting towards healthcare information systems which are technology driven to improve their maternal healthcare. In such regard plenty of recent efforts made are commonly targeting commercial aspect of healthcare rather than doctor-patient interaction. But few available systems which can be considered reliable are either difficult to use implement due to lack of resources and deficient computer literate stakeholder. Our primary target is economically suppressed countries were mother-child health care is vulnerable. Proposed is a Mother Child Health information system with enhanced usability which is implemented based on standards of FHIR HL7, WHO, Western Australia Heath Dept. and Perinatal Services British Columbia. Our system provides an interactive graphical interface making it easy to operate. The unique architecture provides several forms for maternal health provided by WHO with added details from other renowned healthcare standards. Creating patient records, update and view can be achieved by simply adding details to the forms as per the trimester visits. Our system maintains the information in FHIR HL7 V4 format enabling global message exchange format. In addition, the system allows access to the JSON documented patient resources using RESTfull approach by making API calls for research and development purposes. Our system could be a potential solution to overcome several prenatal care problems. This system can be used in low socioeconomic index countries as it requires less resources and can be operated easily by minimal computer skills.

KEYWORDS

FHIR, WHO, HL7, Mother-child, Healthcare information, EHR, API, RESTful.

INTRODUCTION

Best use of technology is to make human life easier. With the emerging technologies the gap for improving the existing Maternal and Child Health (MCH) system is required. As World Health Organization (WHO) stated that each year 536000 maternal deaths occurred around the world and out of which 22% were only from India. WHO also added that many of them suffered pregnancy related morbidity [1]. Moreover, the vast majority of maternal deaths occurred due to the complication during the labor. However due to continuous efforts the maternal mortality rate has gradually decreased but still an estimate of more than 500,000 women would die every year due to pregnancy and child birth complications. Unfortunately,

95% of them are from under developing countries which includes Africa and Asia [2]. However, deaths are merely small when compare to the surprising observation of injured women. Ratio of death to injured women is 1:30 which is generally overlooked. These injuries may cause temporary to permanent disabilities such as obstetrical fistula, social devastation which results in turned out from families and community which results in forced isolation of women. Approximately 2 million women are suffering from obstetric fistulas and 50,000-100,000 getting added each year. It's difficult to achieving basic maternal and child health facilities in underdeveloped and developing countries as it requires a lot of investment in the infrastructure, improvements in the services, and quality of care [3] as well as the availability of reliable healthcare data [3, 4]. The table 1 illustrates the comparison of mortality rate in developed countries with developing and under developed countries. One major contribution to improve the infrastructure can be achieved by introducing health care records which are easy to use and can be maintained for longer time as a reference to historic data. For instance, Japan initiated the Maternal and Child Health Handbook [5] in 1942 (referred as MCHHJ in this manuscript), to create awareness and log necessary information related to pregnancy and delivery, child development, and health education. This handbook greatly contributed in decreasing maternal mortality rate (MMR) and infant mortality rate (IMR) in Japan [6]. Later on, customized handbooks were implemented in many countries such as Bangladesh [7], Indonesia [8], Thailand [8], Cambodia [9], and Mongolia [10]. However, MCHHJ is a record book and lack the electronic form of patient health care data.

Table I : Estimates of Maternal Mortality, 2000.

Region	Maternal Mortality Ratio no. of deaths/ 100,000 live births	Maternal Deaths no.	Lifetime Risk of Maternal Death
World total	**400**	**529,000**	**1 in 74**
Developed regions	**20**	**2,500**	**1 in 2800**
Europe	**24**	**1,700**	**1 in 2400**
United States	**17**	**660**	**1 in 2500**
Developing regions	**440**	**527,000**	**1 in 61**
Africa	**830**	**251,000**	**1 in 20**
Sub-Saharan Africa	**920**	**247,000**	**1 in 16**
Asia	**330**	**253,000**	**1 in 94**
East Asia	**55**	**11,000**	**1 in 840**
South Central Asia	**520**	**207,000**	**1 in 46**
Southeast Asia	**210**	**25,000**	**1 in 140**
West Asia	**190**	**9,800**	**1 in 120**
Latin America and the Caribbean	**190**	**22,000**	**1 in 160**
Oceania	**240**	**530**	**1 in 83**

Data is from the World Health Organization (WHO). According to the WHO, the maternal mortality ratio is a measure of the risk of death after a woman has become pregnant, and the lifetime risk of maternal death takes into account the probabilities of becoming pregnant and of dying as a result of pregnancy cumulated over a woman's reproductive years. Developed

regions include, in addition to Europe and the United States, Canada, Japan, Australia, and New Zealand, which are excluded from the regional totals.

Mother Child health information systems gave major contribution to overcome the above problems of health care data and record maintenance. Even now several health care practitioners spend most of their time with patients in an examination room without computer device and often provide the scratch notes on paper during encounter which are later dictated or typed after the visit [11]. This is because of lack of infrastructure and less computer aware doctor. According to the recent fact sheets [12] of WHO globally 830 maternal deaths occurring every day and 99% occur in developing countries. The key factors of deaths are due to unavailable skilled practitioners, lower economic background, less resources and lack of education. To overcome such issues several contributions were made out which an Ontology Model for Maternal and Child Health Information System [16] was also introduced. The architecture of this system was novel but it majorly lacked usability. Due to which only a limited audience could use it. As several stakeholders are less educated and reluctant to use computer based systems. Although practitioners were intimidated to use the system, but RESTful architecture was a challenge. We introduced a new and much enhanced MCH system which more advanced and easier to use. Our system not only overcomes the limitations but also enhances the usability for the stakeholder.

This paper is structured as follows. Related work and existing systems with their limitations are briefly discussed in section II. Then, our proposed system is introduced in section III. Followed by system architecture of enhanced MCH system with implementation and evaluation in section IV and V. Finally, the conclusion and future directions of the system is given in section VI.

1.EXISTING SYSTEMS

There are several e-Health record systems available, but the limitations are persistent as many applications are developed to target only the billing or commercial aspect of health care and few efforts are witnessed to improve the patient-doctor encounter. A recent study about the challenges in e-Health care systems [13] stated that interoperability, availability and visual display are few of the 7 identified challenges of current EHR systems. One methodology to overcome the maternal mortality rate such as FLTR (Find, Link, Treat, Retain) method [14] was applied and implemented. FLTR was deployed in six different counties near MOI University, Kenya. They initially gathered the data using papers by conducting surveys and recorded the information. Later perform several analyses. Similar effort was made to reduce the gap between healthcare facility and rural population by introducing community health workers (CHW) [15] who reached out to the expecting mother in the rural area of West Bengal, India. Workers used to encourage, recommend and educate expecting mother to acquire the addition care and avoid complications. Nearly 90% mothers gave birth at the care center and a 67% of satisfactory feedback was received. This study also observed a need of technology blended Mother Child healthcare system were health records could be maintained electronically to reduce the further gap. Both [14] [15] systems were mostly targeting under developed countries. The team members or workers were less technically aware and which in turn added the data entry tasks as an extra work in order to make healthcare data ready to perform analysis by the doctors. The limitation of paper based record of other systems was acknowledged by a Mother Child Healthcare Records system (MCHR)[16] which was introduced in 2017. MCHR was a FHIR based layered system in which first layer consist of RESTful web services that

process the API calls made by the clients which include both MCH system users and other external systems. The web services are defined for each resource category with respect to FHIR specifications. API calls enables create, read, search, update, and delete operations on these resources. In response the system fetches the client with JSON object to be consumed by the client through URI's.

Second Layer consist of Data Access Objects (DAOs). The information received from the client-side web applications are then parsed into JSON documents by DAOs. Data objects provide an interface to the underlying MongoDB repository and it is also responsible to validate the payloads, append identifiers, and transfer contents to the database repository for storage in an appropriate collection. Data objects are also responsible of fetching the results of URI calls made by the client. Finally, the data is stored in different collections where each collection in the database represents a category of resources.

Fig:1 illustrates the example: Let the resources be "Patient", "Practitioner" and "Organization". Each patient-related document, like lab report, is then placed as a nested JSON document within the relevant patient resource in a NoSQL database. Whereas in relational databases items are stored in separate tables and are linked through foreign keys. Contrarily a patient resource in this database represents a comprehensive record of all related actions and outcomes.

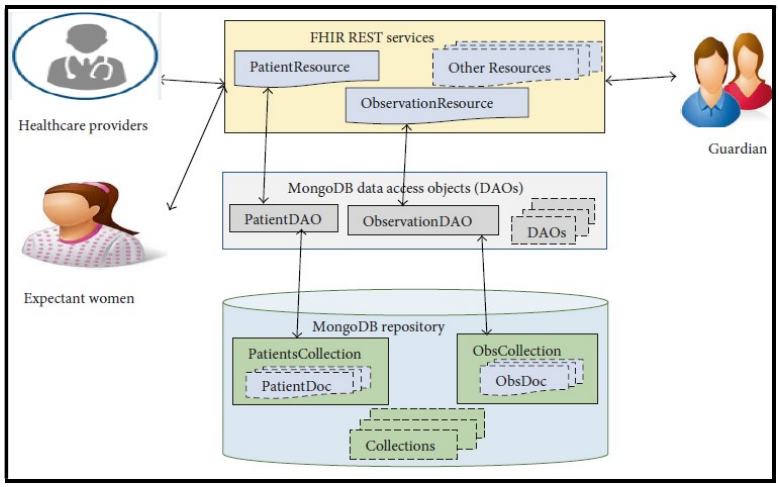


Fig 1: Existing Mother Child Healthcare Architecture [13]

A. LIMITATIONS OF THE EXISTING SYSTEMS:

- The system can be accessed only through API calls.
- Data fetched by the system will be a JSON document in FHIR HL7 message exchange format.
- The data can be accessed only by applications and it will be very difficult for the normal users to understand or interpret.

- Usability is suppressed as the target audience are the people from under developing countries were patients could barely use computer.
- Health practitioner are computer are but complex system, different data formats and API services could be a challenge for them.
- Practitioners and patients being the major stakeholder may not understand the codes and keywords of HL7 format.
- The system resources of FHIR are mainly general purposed and not specific to mother child health care.

1.PROPOSED SYSTEM

The proposed mother child health information system provides electronic healthcare records which eliminates the limitations of existing systems by introducing a simple and highly interactive architecture. This system has advance features of API support with global standards of message exchanged for post processing of data. The proposed system architecture involves following layer:

A. Interactive GUI Component.

B. Underlying Database model.

A. GUI Component of Enhanced MCH system:

The proposed model is an enhanced version of existing MCH system. The architecture as described in fig:2 includes EMCH forms component which is developed using a scripting language. Purpose of these forms is to collect the patient details in an effective way as it may affect the overall usage of healthcare information system. Interviewing and questioners are the most traditional and effective ways to gather the information and practitioners are already used to this technique. Proposed system is a collection of different forms which can be filled by the doctor at every visit while interviewing the patient. These forms are specific to mother child health care. The idea of having all the forms specific to mother child health is achieved using FHIR HL7 resources but as HL7 provides the resources which are quite general in nature. For instance, Observation resource can be used to record patient vital signs and this resource also refers to the observations related to eye color, chest X-rays for respiration and social history like tobacco use, etc. Which are generic and not directly related to Mother Child healthcare. To get more precise details regarding pregnancy we included the forms which were proposed by WHO. According to WHO [17] there should be at least four antennal care visits by an expecting mother before delivery and each visit will have certain clinical tests and observations which must be recorded and compare with the previous one. These forms are merged and incorporated in the proposed system and to further enhance these forms. We studied the recommendation of Department of health, government of Western Australia [18] and Perinatal Services British Columbia [19]. Their recommendation for prenatal screening, diagnostic tests and other recommendation to record the detailed observations of the patient can be significant tool for decision support. For instance, if sever chromosome conditions such as Down syndrome, Trisomy 13 and Trisomy 18, neural tube defects such as spinal bifida and anencephaly, birth defects such as congenital heart conditions and malformed kidneys can be detected in a much early stage. The details of expecting mother which are gathered using these

forms will be saved in the underlying database. Any authorized user can have access to these details which can be extracted from the database and data will be fetched in the same form which were used to gather the information. Also the data can extracted using API calls which can be further used for any other useful purposes. Data will be presented to the user in two different formats.

i. Information in GUI forms for user like patients, practitioners, laboratories.

ii. JSON formatted data through API calls in FHIR HL7 format for post processing.

B. Underlying Database Model:

Fig:2 illustrates the FHIR based NoSQL database which uses JSON formatted data. The architecture of underlying database model remains same as the existing system. But pre and post processing of data is an added feature in the proposed system. At First data is collected through the GUI forms which then converted and saved in a JSON document. The JSON document is then placed according to the respective DAO's such as patient collection, Obs collection, others.

1.IMPLEMENTATION OF ENHANCED MCH CARE SYSTEM

Proposed system is implemented into two components. First is the Graphical User Interface and second is underlying database. Server-side technologies are used to develop this system. This system also provides an API access through URI's. GUI component is a collection of forms based on the trimesters of an expecting mother. Different forms are used in each meeting with the doctor and the details of patient can be recorded.

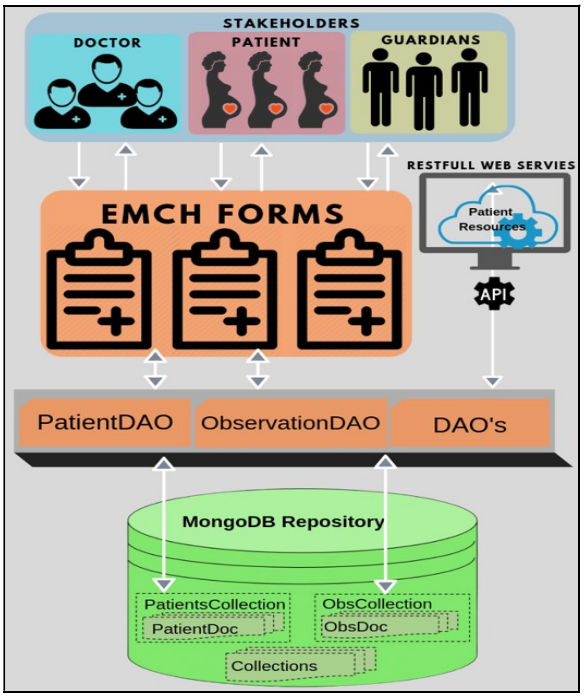


Fig 2: Enhanced Mother Child Healthcare system

Proposed system will provide a unique Id or patient number for each patient and this will be the primary access for all the records of that patient. Patient will be examined for several tests and diagnosis to detect any uncertainty in the fetus.

i. Initial classification form as shown in fig 3 will be used to record the initial details of patient during the first visit to the practitioner. In this form basic details regarding patient previous medical history will be recorded in the system such as:

   a. Obstetric history
   b. Current pregnancy
   c. General Medical

ii. During the same visit Form-1 as shown in fig-4 will also be used to record the further details of the patient.

   a. Patient Details will be recorded as per FH resources.

   b. List of initial test initial tests

   - Full blood count

   c. Some Diagnosis for any major disease such a

   - Down syndrome.
   - Trisomy 13
   - Trisomy 18

- Glucose challenges for diabetes
- Blood group and antibodies test
- Midstream urine test
- Syphilis test
- Rubella test
- Hepatitis b test
- Hepatitis c test
- An HIV antibodies test
- Chlamydia screening
- Full blood count
- Random blood glucose test
- Spinal bifida
- Anencephaly
- Check for dates, number of fetuses and their development.

d. Physical examinations during clinical visit.

- Clinical examination for anemia
- Consider vaginal examination
- Uterine height
- Fetal heart rate
- Blood pressure
- Maternal weight

e. Medication and recommendations will be recorded as per FHIR resource.

Visit-1 or Form-1

Patient Details:

Patient ID

First Name

Middle Name

Family Name

Phone Number

Gender : Male

dd/mm/yyyy

Address

City

Postal Code

Country

Any Births before

Managing Organization

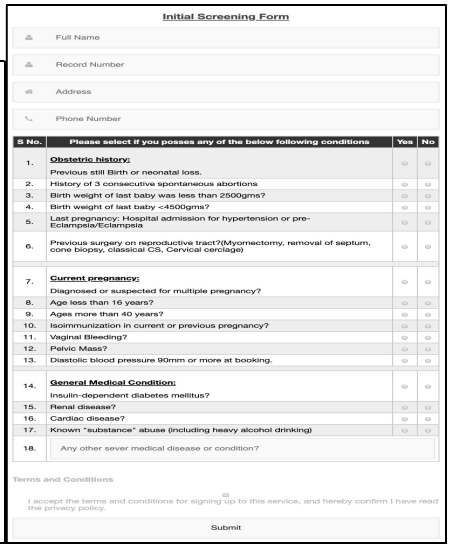
Initail Tests:

S No.	Initial tests to be performed	Yes
1.	Full blood count.	
2.	Glucose challenges for diabetes	
3.	Blood group and antibodies test	
4.	Midstream urine test.	
5.	Random blood glucose test.	
6.	Syphilis test.	
7.	Rubella test.	
8.	Hepatitis b test.	
9.	Hepatitis c test.	
10.	An HIV antibodies test.	
11.	Chlamydia screening.	
12.	Full blood count.	

Initial Diagnosis

S No.	Mandatory Diagnosis
1.	Down syndrome
2.	Trisomy 13

Fig 3: Initial classification form



Initial Screening Form

Full Name

Record Number

Address

Phone Number

S No.	Please select if you posses any of the below following conditions	Yes	No
1.	Obstetric history: Previous still Birth or neonatal loss.		
2.	History of 3 consecutive spontaneous abortions		
3.	Birth weight of last baby was less than 2500gms?		
4.	Birth weight of last baby >4500gms?		
5.	Last pregnancy: Hospital admission for hypertension or pre-Eclampsia/Eclampsia		
6.	Previous surgery on reproductive tract?(Myomectomy, removal of septum, cone biopsy, classical CS, Cervical cerclage)		
7.	Current pregnancy: Diagnosed or suspected for multiple pregnancy?		
8.	Age less than 16 years?		
9.	Ages more than 40 years?		
10.	Isoimmunization in current or previous pregnancy?		
11.	Vaginal Bleeding?		
12.	Pelvic Mass?		
13.	Diastolic blood pressure 90mm or more at booking.		
14.	General Medical Condition: Insulin-dependent diabetes mellitus?		
15.	Renal disease?		
16.	Cardiac disease?		
17.	Known "substance" abuse (including heavy alcohol drinking)		
18.	Any other sever medical disease or condition?		

Terms and Conditions

I accept the terms and conditions for signing up to this service, and hereby confirm I have read the privacy policy.

Submit

Fig 4: First Form

To reduce the risk for both mother and child. several test and diagnosis are suggested during the first visit. According to WHO [17] the best time to perform these tests are the early weeks of pregnancy. The number of tests and diagnosis are recommended by WHO [17], Prenatal screening and diagnostic tests [18], Standards for Obstetrical Ultrasound Assessments [19]. The key observations can be added in the recorded by the practitioner. Also, the medication and suggestions can be added within the same form. The patient information will be stored in the underlying database of the system. Prescribe medication and recommendations will be recorded and store in the system according FHIR HL7 resources standards. The next visit of the patient is expected to be on the second trimester and form-2 can be used by the practitioner. Firstly, Form-2 will display the results of initial test and major diagnosis which were performed in visit-1. Links of all the test results will be available including the imagery results of this form also includes the results of physical examinations performed by the doctor during the encounter. Practitioners can update the form-2 by suggesting new tests, diagnosis and other physical tests during the encounter. Also, the medication and recommendation will be saved in the system under the same patient ID as per the FHIR. Form-3 and form-4 are expected to be used for next consecutive visits based on the trimesters of the patient or as suggested by the practitioner. Practitioner can also provide the instruction for delivery to mentally prepare the expectant mother. Recommendations for lactation and contraception can be provided. After the fourth visit recommendation to get admitted in the hospital will be provided. All the above forms have encrypted user access and data will be available after authentication of stakeholders. Also, these forms are scalable, and practitioner can suggest any other test, diagnosis based on the patient condition.

SYSTEM EVALUATION

Proposed MCH is been evaluated by comparing with the existing open source EHR systems based on the features mentioned in the below table [20]. These feature of the open EHR systems which can operate in low-resource setups without becoming an economical burden. The proposed system is highly interoperable and provides custom reposts with universal coding standards (HL7, FHIR). Proposed system also provides custom interfaces with different portals for stakeholders (patient, doctor, laboratory) with strong access control to avoid uninformed changes in the records. Our system is precisely privileges mother child health care and we made efforts to make it less general. The proposed system clearly outperforms the other existing systems. The enhanced model can be depicted as a solution to the existing problem of usability. This system in easy to use with provided navigations and helps the doctor to automate the regular activities and focus more on the patient. It avoids the difficulty of stake holders who are less/uneducated11 to efficiently use the system. As the enhanced MCH is an opensource specific mother child health care EHR system which targets mostly developing countries

Table II: Matrix with several aspects of the evaluated electronic health records software. Some features were evaluated according to a ranking that varies between 1 (low) and 3 (high)

Feature or system		**GNU Health**	**OpenEMR**	**FreeMED**	**OpenMRS**	**Bahmni**	***Proposed system***
1.	Integrated applications	EHRa, HISb	EHR, PMSc, ERPd	EHR, PMS	EHR	EHR, PMS, ERP, LISe, PACSf	EHR, HIS, PACS
2.	Configurable reports	Yes	Yes	No	Yes	Yes	Yes
3.	Custom reports	No	No	No	Yes	Yes	Yes
4.	Custom forms	-	1	-	3	3	3
5.	Interoperability	FHIR, custom	HL7h	HL7, DICOMi		Interoperability	HL7, FHIR
6.	Coding systems	ICD-10j	ICD-9/10, SNOMEDk, CPTl, HCPCSm	ICD-10, CPT, LOINCn, ATCo	HL7, DICOM, FHIR, CIEL/MVPp, LOINC ICD-10	HL7, DICOM, FHIR, CIEL/MVP, ICD-10, SNOMED	HL7, FHIR, SNOMED
7.	Authentication methods	LDAPq	LDAP, ADr	-	-	-	RBAC
8.	Patient portal	No	Yes	No	No	No	Yes
9.	Access control model	RBACs	ACLt	ACL	RBAC	RBAC	RBAC
10.	Cryptographic features	Sign, encrypt	Encrypt	-	-	-	-
11.	Flexible data model	No	No	No	Yes	Yes	Yes
12.	Offline support	Yes	No	No	No	Yes	No
13.	Web client	Yes	Yes	Yes	Yes	Yes	Yes
14.	Native client	Yes	No	No	No	No	No
15.	Other clients	Yes	No	No	No	Yes	No
16.	Code-based language	Python	PHP	PHP	Java	Java	PHP
17.	Development activity	3	3	2	3	3	3

18.	Software modularity	3	1	2	3	3	3
19.	User interface	2	1	3	2	3	3
20.	Community support	3	3	1	3	3	1
21.	Customization	1	2	1	3	3	2
22.	Specific mother child system	-	-	-	-	-	Yes

CONCLUSION

The enhanced MCH was developed ideally to address several limitations of existing systems. Although the level of awareness and education[11] among the patients is quite low when compared to doctors but using only the RESTfull approach without GUI forms was difficult for them either. According to the research records [21] several eHR systems lack proper user interaction even in develop countries where healthcare systems are quite mature. A popular study [21] conducted by U.S. Department of Health and Human concluded that the record access method should be simple and less ambiguous for the patients which includes accessing health record, transfer of records and access previous history by patient and doctors. If not it may leads many patients to again use paper based records. Our system consists of forms which are gathered form different standard sources to cater the usability of the system. It is also flexible enough to accommodate missing requirements and open-ended issues to further enhance the system. Such as more fields can be added to the existing forms, visual decision support can enhance the performance of the system. As new doctors are more willing to adopt such systems the continuous feedback and reports can be implemented after deploying the system.

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