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mHealth4Afrika - Implementing HL7 FHIR Based Interoperability

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Abstract

Supported by the European Commission under Horizon 2020, mHealth4Afrika is co-designing and validating a modular, multilingual, state-of-the-art health information system addressing primary healthcare requirements in resource constrained environments. mHealth4Afrika has co-designed a comprehensive range of functionality and medical programs in partnership with Ministries of Health, district health officers, clinic managers and primary healthcare workers from urban, rural and deep rural health facilities in Ethiopia, Kenya, Malawi and South Africa. This paper provides insights into how mHealth4Afrika is leveraging HL7 FHIR to support standards-based data exchange and interoperability between Electronic Medical Records and DHIS2. This work is currently being validated in the field.

Keywords:

Health Information Interoperability, Electronic Health Records, HL7 FHIR

Introduction

While electronic patient records are gradually being introduced into larger hospitals in Ethiopia, Kenya, Malawi and South Africa (current mHealth4Afrika beneficiary countries), paper-based registries [1, 2, 5-7] remain the default data capture method in resource constrained urban, rural and deep rural health facilities. mHealth4Afrika supports the objectives of UN Sustainable Development Goal 3 (SDG3) by co-designing a comprehensive, patient-centric health platform that is adaptable and extensible, modular and multilingual [1 - 6]. It integrates Electronic Medical Record (EMR) and Electronic Health Record (EHR) functionality, with the use of medical sensors and data visualization tools at the point of care [5, 6]. It supports the automatic counting of aggregate program indicator data required by Ministries of Health, SMS appointment notifications and lab system integration.

In some resource constrained environments, including Africa, donors have adopted a silo-based application approach, addressing requirements for specific programs they fund, including ART (HIV/AIDS) and Tuberculosis (TB) [6, 8].

Standards and interoperability are key enabling environment components of the WHO and ITU National eHealth Strategy Toolkit [9]. As the number of patient centric technology-enabled health applications (eHealth and mHealth) grow, the importance of interoperability becomes ever more critical to avoid unnecessary duplication of effort and fragmentation of electronic health record data. mHealth4Afrika has taken a standards-based approach to data interoperability to support data exchange between applications and systems.

The South African National Department of Health published the National Health Normative Standards Framework for Interoperability in eHealth in South Africa (HNSF) in 2014 [10]. This aims to provide a framework supporting the development of interoperable health systems. It proposed that Health Level Seven (HL7) is used as the messaging standard for the exchange and integration of electronic clinical healthcare information between systems.

In April 2017 the Ministry of Health of Kenya published the Kenya Standards and Guidelines for mHealth Systems [11] to support data and information sharing across multiple health systems. It is even more specific than South Africa, requiring that eHealth/mHealth solutions used in Kenya should leverage HL7 FHIR (Fast Healthcare Interoperability Resources) APIs (Application Programming Interfaces) [12].

mHealth4Afrika research objectives include to co-design a comprehensive, patient-centric health platform leveraging some of the functionality of District Health Information System 2.0 (DHIS2) [6] and support standards-based data exchange to transfer medical sensor readings and lab requests to and from the patient medical record, and import and export of patient records between EMRs. DHIS2 and the Tracker Capture application have several limitations. As a result, mHealth4Afrika has designed a comprehensive and extensible patient-centric, multi-program custom platform and user interface for use in medical facilities which interacts with the mHealth4Afrika data model set up in DHIS2 via the native DHIS2 WebAPI [6].

mHealth4Afrika has co-designed a comprehensive range of medical programs supporting easy and systematic data capture, storage and searching of patient centric data. Based on priorities of initial intervention countries (Ethiopia, Kenya, Malawi and South Africa) [1, 2, 5, 6], medical programs currently implemented and validated include: medical history, maternal health, family planning, cervical cancer screening, child under 5, tuberculosis, antiretroviral therapy, diabetes, general and specialist outpatient department (OPD). mHealth4Afrika supports single registration of a patient at a health facility and subsequent enrolment in a range of different programs based on their health conditions over time [1, 6].

mHealth4Afrika has applied a standards-based approach to data interoperability, taking account of state-of-the-art standards and international good practices, while respecting national policies and legislation in intervention countries. In the context of introducing medical sensors at the point of care, mHealth4Afrika developed a HL7 FHIR Service in 2017 to authenticate users and support data transfer of readings from BLE medical sensors to the appropriate patient record in the

mHealth4Afrika data model stored in the DHIS2 server via the DHIS2 API. We are not aware of any other project to date that has used HL7 FHIR for data transfer of readings from medical sensors (e.g. for blood pressure, blood glucose, SpO2, heart rate, weight, temperature) with a data model set up in DHIS2 or similar implementations designed for use in primary healthcare facilities in resource constrained environments.

During 2018 the mHealth4Afrika HL7 FHIR service was extended to support standards-based data exchange of lab requests to a laboratory system and the transfer of lab results into the appropriate mHealth4Afrika patient medical record.

A design requirement for mHealth4frika was to support standards-based data exchange of patient clinical data between health information systems. The target use case is to support a hospital referral or a patient moving temporarily or permanently from one health facility to another. Currently DHIS2 does not support exporting or importing the health record of a specific patient. mHealth4Afrika has extended its HL7 FHIR service to support import and export of a patient's health records between mHealth4Afrika platform instances and to support HL7 FHIR data exchange of patient's records with other EMR and EHR being used nationally.

This paper provides an overview of the design of the standards-based approach to support the import and export of patient health records by extending the mHealth4Afrika HL7 FHIR Service. The methods section provides insights into mHealth4Afrika compliance with Continua Design Guidelines (CDG) by Personal Connected Health Alliance (PCHA), the two-way data mapping between the mHealth4Afrika data model set up in DHIS2 and HL7 FHIR STU3 resources. The following section summarizes and discusses early results, while the last section presents the conclusion.

Methods

The mHealth4Afrika FHIR Service is designed as an independent service to achieve full HL7 FHIR based interoperability without disrupting how the mHealth4Afrika browser-based custom application communicates via the native DHIS2 WebAPI with the mHealth4Afrika data model set up in the DHIS2 server. The service supports exporting and importing data. The mHealth4Afrika application has been extended to include a user interface to support import/export functionality and interaction with the FHIR Service.

Data flow is explained below in Figure 1.

For authentication between the service and DHIS2 server, the mHealth4Afrika application passes the 'Cookie' header in each call made to the Import / Export service. The appropriate 'Cookie' header is obtained through the user login process.

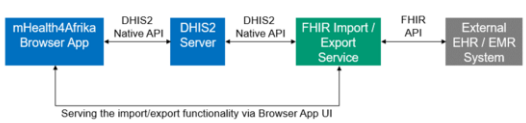

Figure 1 – mHealth4Afrika Import / Export Service Data Flow

Continua Design Guidelines Compliance

The mHealth4Afrika FHIR Service has been implemented with the purpose of achieving standards-based interoperability between the DHIS2 server and other EHR/EMR systems. Figure 2 briefly summarizes mHealth4Afrika compliance with the Continua Design Guidelines (CDG) by Personal Connected Health Alliance (PCHA) [13].

The Personal Health Devices Interface already implemented between medical devices supported by mHealth4Afrika and the mHealth4Afrika application, and the Services Interface already implemented between mHealth4Afrika applications and DHIS2 server, are beyond the scope of this paper.

This paper focuses on the mHealth4Afrika HL7 FHIR Service, which acts as a Healthcare Information Service (HIS) Interface between DHIS2 server and EHR / EMR systems.

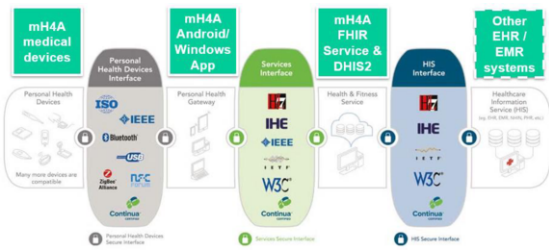

Figure 2 – mHealth4Afrika Compliance with Continua Design Guidelines

DHIS2 Data Model

Two-way data mapping between the DHIS2 data model and HL7 FHIR STU3 resources is required to support import and export capabilities based on FHIR. In this context the DHIS2 data model has been analyzed and data model elements which must be mapped to FHIR resources have been identified:

- DHIS2 OrganisationUnit represents healthcare facilities.
- DHIS2 TrackedEntityInstance represents patients.
- DHIS2 User represents practitioners or clinic managers.
- DHIS2 ProgramStage defines the content of the program specific forms, i.e. which DataElements should be presented in each mHealth4Afrika program stage (e.g. In Maternal Health program expected date of delivery should exist in Antenatal Care visits but not in Postnatal Care visits).
- DHIS2 Event represents patient visits corresponding to a program stage, i.e. filled-in program data.
- DHIS2 DataElement represents the leaf-level patient data definitions, such as vital sign measurements (e.g. blood glucose reading) as well as observational questions (e.g. Does the patient have edema?), which are all used in program stage definitions.
- DHIS2 Enrollment represents patient enrollments to mHealth4Afrika programs (Maternal Health, Tuberculosis, etc.). A patient may be enrolled in multiple programs.

Mapping of Resources

TrackedEntityInstance and Event are the two main DHIS2 resources directly related to patient healthcare records. TrackedEntityInstance contains demographic information about patients, while Event contains medical information captured during clinical (or program stage) visits by patients.

FHIR Patient resource is used to represent DHIS2 TrackedEntityInstances. TrackedEntityInstance attributes are mapped to respective FHIR Patient attributes. Standard FHIR attributes are used where possible and some extensions are defined for mHealth4Afrika specific attributes, e.g. patient type (adult or child). Figure 3 provides an example of some of the mHealth4Afrika TrackedEntityInstance set up in DHIS2 with the corresponding FHIR Patient resources presented in Figure 4. To date, a total of 61 TrackedEntityInstance attributes have been mapped to FHIR Patient attributes.


```
{
    "trackedEntityInstance": "t4TA3mk3hT6",
    "orgUnit": "YimTrMUaHPT",
    "attributes": [

      {"displayName": "Date of Birth",
       "valueType": "DATE",
       "attribute": "gCafpJzwByC",
       "value": "1995-11-02" },

      {"displayName": "Last Name/ Surname",
       "valueType": "TEXT",
       "attribute": "PUt8IjUQ5s6",
       "value": "Johns" },

      {"displayName": "First Name",
       "valueType": "TEXT",
       "attribute": "sQG4zPPzP5x",
       "value": "Mike" },

      {"displayName": "Patient Type",
       "valueType": "TEXT",
       "attribute": "DqsQdsl08uG",
       "value": "adult" },

      {"displayName": "Medical Record Number",
       "valueType": "TEXT",
       "attribute": "r9wKBvoh4WT",
       "value": "34708253912" },

      {"displayName": "Gender",
       "valueType": "TEXT",
       "attribute": "Tgz9w5PrpJM",
       "value": "male" },

      {"displayName": "Marital Status",
       "valueType": "TEXT",
       "attribute": "rncpcIYS0Jn",
       "value": "single" }
    ]}
```


Figure 3 – mHealth4Afrika Tracked Entity Instance

FHIR QuestionnaireResponse resource is used to represent DHIS2 Events. Events contain multiple dataValues that are similar to the QuestionnaireResponse attribute "item". As mentioned before, Events represent program stage visits and each dataValue contains a dataElement attribute which references the respective dataElement in the ProgramStage resource. In other words, ProgramStage contains a template of what the visits should contain (i.e. metadata) and Event contains actual values that is gathered in a visit (i.e. instances). The structure is similar in FHIR Questionnaire and QuestionnaireResponse. Questionnaire resource contains questions and, in some cases, possible values and option sets of the questions and QuestionnaireResponse resource contains answers to those questions defined in the Questionnaire. Having a very similar structure, Questionnaire resources are used to represent ProgramStages and QuestionnaireResponse resources are used for Events. Mapping of attributes, and the relations between ProgramStage, Event, Questionnaire and QuestionnaireResponse resources can be seen in Figure 5.

Event attributes are mapped to respective FHIRQuestionnaireResponse attributes. Similar to TrackedEntityInstances, standard FHIR attributes are used where possible and some custom extensions are defined for mHealth4Afrika specific values such as program. ProgramStage attributes are mapped to respective FHIR Questionnaire attributes.

FHIR Organization and EpisodeOfCare resources are used to represent OrganisationUnits and Enrollments for the purpose of having a complete and consistent FHIR Bundle. As outlined in Figure 4, FHIR Patient resource contains a reference to the managing organization with its id. Without including an Organization resource with the same id in the FHIR Bundle, the bundle will fail referential integrity. Hence, respective FHIR Organization resources are created corresponding to the OrganisationUnits in DHIS2. It is similar with Enrollments and Events, which contain enrollment references.


```
{
"resourceType": "Patient",
"id": "LoKI7VAJX8k",
"extension": [{
  "url": "http://www.mhealth4afrika.eu/fhir/PatientType"
  "valueCode": "adult"
}],
"identifier": [{
 "system":"http://www.mhealth4afrika.eu/fhir/MedicalRecordNo",
 "value": "34708253912"
}],
"name": [{
 "family": "Johns",
 "given": [ "Mike" ]
}],
"gender": "male",
"birthDate": "1995-11-02",
"maritalStatus": {
 "coding": [{
  "system": "http://hl7.org/fhir/v3/MaritalStatus",
  "code": "S",
  "display": "Never Married"
 }]
},
"managingOrganization": {
 "reference": "Organization/YimTrMUaHPT"
}
}
```


Figure 4 – HL7 FHIR Patient Resource

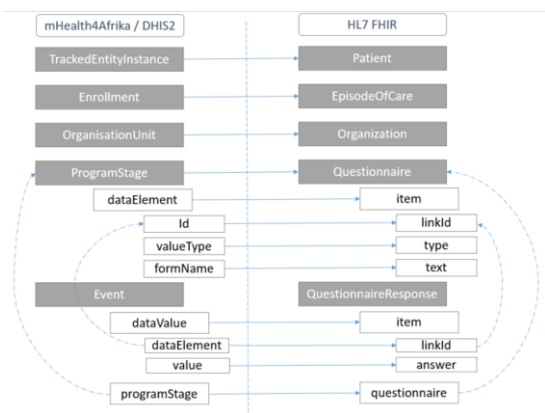

Figure 5 – DHIS2 Data Model to FHIR Resource mapping

FHIR Export

The service provides an endpoint that is used to export HL7 FHIR bundles containing information about the demographics and medical visits of the patients. The program, organizationUnit and the individual patient is specified at the request call to customize the output. The service uses several methods from the DHIS2 Native API to gather relevant data from DHIS2, transforms the gathered data to FHIR resources based on the mapping explained in the previous section, and finally returns a HL7 FHIR Bundle containing HL7 FHIR resources. The export can include all patient specific medical records or only a specific program, depending on the permission provided by the patient and why the electronic medical record is being provided to a different health facility.

The bundle contains several types of FHIR resources.

- Patient: This resource contains demographic information about the patient.
- QuestionnaireResponse: This resource contains actual data about the program stage visits of the patient.
- Questionnaire: This resource contains metadata about the program stage visits.
- Organization: This resource contains information about related Organisational Units.
- EpisodeOfCare: This resource contains information about program enrollments of the patients.

FHIR Import

The service provides an endpoint that is used to import HL7 FHIR bundles containing information about the complete or partial medical history of the patients. It enables patients to receive medical care in different health facilities as required and request that their electronic medical record is transferred between facilities and kept up to date.

The output of the FHIR Import, i.e. FHIR bundle, is parsed and relevant resources are mapped to the mHealth4Afrika DHIS2 data model. Several DHIS2 API calls are used sequentially to preserve referential integrity, e.g. patient demographic information must be imported before a lab result.

Initial Results and Discussion

The mHealth4Afrika platform has been co-designed and validated with Ministries of Health, District Health Offices, Clinic Managers and nurses in Ethiopia, Kenya, Malawi and South Africa over the past three years. It is currently being used in a mix of primary health care facilities and hospitals.

The initial focus of this extension to the mHealth4Afrika FHIR service commenced with a mapping of patient centric data attributes and data elements to FHIR resources. As outlined above, it has been necessary to use some extensions based on specific mHealth4Afrika program requirements. When the export and functionality was implemented, this required a modification of the mHealth4Afrika platform to engage with the extended FHIR service.

The standards-based approach being implemented builds on an existing HL7 FHIR service that mHealth4Afrika developed in 2017 to support data exchange of medical sensors readings and lab requests and lab results to and from the patient's electronic medical record. It takes account of national policy and legislative requirements in intervention countries, while leveraging the most up to date international standards.

In the current mHealth4Afrika beneficiary countries, individual patient medical records are only stored within the health facility that provides the healthcare services.

This interoperability work will enable mHealth4Afrika to both export and import complete individual patient records (as well as specific programs from individual patient records) from an instance in one health facility to an instance in another health facility. This ensures that existing electronic medical records can be transferred as required between health facilities, based on patient consent. This is a practical requirement that is not currently supported within DHIS2 standard tools.

It is normal in many countries that a pregnant mother may move from her place of normal residence to another location closer to family members towards the end of her term. In this context, it is important that the healthcare facility where she is currently receiving care has access, with her consent, to her full medical record - medical history, details of medical data captured during antenatal visits etc. The mHealth4Afrika platform allows the health facility managers to print off reports of data captured across antenatal visits. However, if the healthcare facility providing delivery and postnatal care are using the mHealth4Afrika platform or another EMR that supports data exchange using HL7 FHIR, it is more efficient if the electronic health record can be imported, updated and then exported as a FHIR bundle. This will allow the patient's health record to be kept fully up to date when they return to the health facility where they are normally resident.

This functionality will also support patients with medical conditions, such as TB, HIV, Diabetes, and Chronic Hypertension, to move their electronic health records for the purposes of referral or when transferring to another facility.

This import / export functionality is exposed to the clinic manager role via the mHealth4Afrika custom interface. This functionality is currently field tested in the intervention countries and will be adapted as necessary going forward.

Related Work

Healthcare system interoperability is an essential topic in the domain as modern medical care is inherently distributed. Standards-based transfer of medical information is researched and developed over decades and more recently HL7 FHIR based interoperability solutions are being implemented. OpenMRS FHIR Module is such an example [14].

When the FHIR HL7 service work commenced in mHealth4Afrika during 2017 and the import / export work described in this paper commenced during early 2018, there was no implementation of such a FHIR based interoperability service in DHIS2. In September 2018, DHIS2 started work on a use case focused on importing TrackedEntityInstances (patient data) with Observations and Immunisations as Events into a DHIS2 server using HL7 FHIR. This will allow EMRs and applications to connect to a FHIR repository to upload patient data. An adapter can then connect to the FHIR repository and enroll patients in the DHIS2 server. It is proposed mapping is done through a transformation engine.

While this use case was only a sub-set of our current requirements, mHealth4Afrika had meetings with DHIS2 to learn more about this proposed approach and share insight about the approach we have been implementing since 2017.

Recently, the DHIS2 team started to implement an interface based FHIR adapter, similar to the mHealth4Afrika

import/export service. This has the objective of eliminating the need of a FHIR repository to simplify integration of the interoperability functionality into non FHIR repository related use cases. This work is initially focused on import.

Conclusions

This paper provides insight into some of the research objectives of mHealth4Afrika, including designing a standards-based approach to support both import and export of patient health records by extending the existing mHealth4frika HL7 FHIR Service. It outlines two-way data mapping between the mHealth4Afrika data model set up in DHIS2 and HL7 FHIR STU3 resources.

Some of the mapping decisions are designed to be as generic as possible. For example, FHIR QuestionnaireResponse is used to represent program stage visits, as it allows multiple types of items that can cover all program stage data elements. While some of the data elements exactly fit to questionnaire questions, some of them represent specific laboratory tests or vital sign measurements which might be more suitable to be mapped to more specific FHIR medical resources such as Observation or DiagnosticReport. This has been implemented within mHealth4Afrika as an import mechanism, while acquiring vital sign measurements from patients via Bluetooth LE medical sensors, with the mHealth4Afrika Android Application acting as a sensor gateway. This initial import capability was extended within the context of the full program set, extending the FHIR service to support exporting individual patient records using specific FHIR resources.

The import/export functionality for individual patient's medical records was completed in February 2019 and is currently being field tested in the mHealth4Afrika intervention countries.

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