Journal of Health Informatics in Africa

eHealth Architecture based Health Data Exchange: Ethiopia DHIS2 and SmartCare

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Background and Purpose: Blueprint of national level arrangement of health system components in Ethiopia is depicted in the eHealth Architecture (eHA). The lack of practical implementation experience is limiting Ethiopia's ability to move toward maturing the architecture. In this study, the team was set out to explore practical implementation and scaling solutions that leverage open standards and tools. Two major components of the eHA are used to demonstrate the health data exchange, legacy Electronic Medical Record (EMR) system and national electronic Health Management Information System (HMIS) instances. HMIS contains 53 data sets used by more than 35, 000 health facilities serving at different layers of the health sector, including health posts, health centres, hospitals and other facilities to deliver reports of various types. It is the major source of information by the Federal Minister of Health. Main purpose of this study is to exploit potentials and overcome challenges that focus on health data exchange patterns of national eHA.

Methods: Thorough assessment of related works is conducted with national and local perspectives. eHA based health data exchange model is developed leveraging open tools and standards. HAPI FHIR is adopted to extract local relational EMR data to FHIR messaging. It is an open source, and java-based HL7 FHIR implementation. With the main focus on scalability of design, the team developed a strategy for mapping local data elements to FHIR resources and created an OpenHIM based mediator. Components with high impact factor on national level health data quality are selected to demonstrate the developed model. Evaluation method to compare interoperability based and manual tally sheet based data entry is conducted. Top 10 diseases were used to test and evaluate the experiment.

Results: The developed model adhering to national eHA data exchange patterns resulted to enhanced data quality. Data quality in terms of timelines, accuracy, completeness and cost parameters over 12 months of production EMR data for top ten disease classifications were examined. Scalable local EMR data to FHIR resource data element mapping was developed using HAPI FHIR library. Its effectiveness was proven as it effectively mapped the elements for the identified FHIR resources. Study results also showed use of eHA interoperability patterns produced enhanced HMIS data quality and established reusable data exchange modules with national impact. Though Ethiopia has standardized national classification of disease, adopted from World Health Organization ICD-10, our extensive experiment revealed fragmented efforts toward health data reporting has resulted in inconsistent data elements. To overcome the challenge, the study suggests using national terminology service instances with capability to cascade concepts at facility level.

Conclusions: The study asserts use of open global standards and tools facilitates maturity of national eHA. Scalable health data exchange model was developed and tested with the major data source components of eHA, EMR and the national HMIS instances. In conclusion, interoperability of those systems significantly fosters national eHA maturity.

Keywords: Health Data Exchange, EMR Interoperability, EMR FHIR Support, HAPI FHIR, Legacy EMR, Commercial EMR

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 J Health Inform Afr. 2021;8(1):9-18. DOI: 10.12856/JHIA-2021-v8-i1-330

1. Introduction

1.1. Background

The Health Sector in Ethiopia has been long working to enhance health care service delivery through digital solutions. The sector with its partners has been rolling out different projects in different parts of the health system to support the realization of the Ethiopian Health Sector Transformation Plan (HSTP) [1] [2]. So far, various Health Information Systems (HIS) are introduced, and different studies are conducted to support the HIS activities in leveraging emerging technologies for better health services.

An Information Revolution Roadmap(IRR) was prepared and implemented, as one of the four pillars of the HSTP, to support the digitization and information use of the sector [3] [4]. The IRR agenda is to realize the methods and practices of collecting, analyzing, presenting, and disseminating information. One of the fruitions of the roadmap is the Ethiopian eHealth Architecture (eHA) [5]. The eHA defines guidelines and principles to facilitate the standardization and interoperability of HISs. It is developed to plan for and consider future needs and embrace global data exchange practices. Conventional practices are often focused on local implementation needs with little concern for interoperability and data sharing across systems.

In low resource settings, HISs are introduced for data collection needs. Such silo systems are not designed for future expansion and data sharing needs, making it challenging to retrospectively incorporate emerging national and international data exchange needs. On the other hand, replacing existing systems with new systems pose feasibility challenges including challenges of data migrations, budget constraints and resource scarcity. This creates a juxtaposition of constraints; the need for legacy/commercial systems integration that puts the health sector in a better position yet the associated cost for doing that is not feasible. Development of an architected solution to enable the integration of those disparate systems with the simplest effort is needed. Large scale and impactful digital healthcare projects need to be supported and backed by studies that explore demonstration of pragmatic approaches, solutions, findings, outcomes that create a strong foundation for the approaches of the large-scale projects. HISs and standards that play a significant role in early adoption of eHA include Electronic Medical Recording (EMR), Health Management Information System (HMIS), Health Information Exchange (HIE) and the widely accepted health data exchange HL7 standard, Fast Healthcare Interoperability Resources (FHIR).

The introduction of an EMR system has played a great role in the enhancement of health service quality [6] [7]. International organizations such as PEPFAR are beginning to encourage a move toward use of patient-level data [8] and countries are promoting the implementation of national scale EMR [9]. But, the nationwide implementation of EMR in the context of health information exchange and interoperability has been given minimum priority [10] [6]. The main challenges that come with legacy system transformation are universal patient identification, data safety, and technical complexity concerning standards definition, data structure, and terminology harmonization. On the other hand, there is also an issue of nationwide implementation modality whether to consider a single central information exchange platform or a federated architectural design [11] [10].

Recent trends show developing countries are increasingly involved to introduce local and global goods to the health sector. In Ethiopia, before the implementation of DHIS2, there were two different homemade electronic applications. As new requirements emerge the systems are not adoptable to entertain the high data demand and information use. For this reason, the FMOH endorsed DHIS2, a globally known platform, as a country wide HMIS software to collect, validate, analyze, and present aggregate data [12]. Point of service applications, such as EMR systems, are data sources for national level HMIS systems. Suitable interoperability scheme that considers the national eHA data exchange patters and utilize health data standards is vital to bring about a significant change.

Interoperability is a mechanism by which two or more systems interact to exchange information and work together [13] [14] [15]. This usually leads to a central repository where data is collected and persisted from which data analysis is to be carried out. This in hand, enables retrieval of important information visualized to depict trends that help the health sector how and when to act in certain situations [11]. Scalable and incremental health information architecture that leverages an interoperability layer to facilitate information exchange and orchestration among HIS without a major change of technology and design paradigm is needed [16] [17] [18]. The major improvements are availability of longitudinal patient medical records and the exchange of aggregated reports in-between point-of-service application and routine health information systems [12] [10] [19] [20]. Different practices have been implemented as a showcase and prototype

 J Health Inform Afr. 2021;8(1):9-18. DOI: 10.12856/JHIA-2021-v8-i1-330.

to the real-world interoperability of systems. Some of them focus on a specific use case reporting such as mortality or other wellness data. A different use case is to utilize wearable devices as a source of data for EMR system [21] [22]. Data extracted from EMR systems is relevant for other third party systems depending on their needs. In order to use such data, persisted and transiting messages need to be standards based. One of the widely used messaging standards to share resources between HISs is FHIR [23].

FHIR (HL7, 2020) is an interoperability specification that ties health care systems with a common and standardized representation of resources. It enables those systems to communicate as they understand what information is communicated and what is expected in response to a request [24] [25] [26]. Regardless of data representation and persistence of data within a health system, the specification aims to have a common format during communication with other systems. This ultimately helps health systems to be able to provide correct and timely data. FHIR is a data model and representational state transfer (RESTful) API which is developed with the experience from HL7 ancestors, HL7 V2 and HL7 V3. In recognition of today's industry best practices for complex business systems design, it employs iterative and incremental development processes, referred to as agile approach, and utilizes RESTful principles [21].It is based on web technologies that have already widespread acceptance and utilizes existing integration tools and methods.

1.2. Objectives

The purpose of this study is to establish patterns for implementing and scaling solutions of major HISs data exchange in low and limited resource settings. In this study we aim to show the existing infrastructure and coordination of eHA components in a holistic approach and trigger the concerned the concerned bodies for informed long and short term planning toward eHA maturity. In this study, the following major tasks are performed:-

- Assess global open standards data exchange trends and their application in low and resource limited settings.
- Develop adaptation strategy of open health data exchange in low resource environments
- Enable legacy facility and community based HISs to expose health data for use in the broader health context
- Develop a reusable common mediation module for sharing data

2. Materials and methods

2.1. Related works

To understand the current trends on health data exchange patterns, the team reviewed literature and observed global practices. Keywords and phrases were used to identify potentially related articles and results that spanned more than 15 journals were obtained. The team discussed on highly related papers and identified technical patterns and approaches. We have observed a trend to move toward use of patient-level data for calculation of HMIS metrics [27] [28]. Another trend is integration of national HMIS and point-of-service EMR systems with scalability, efficiency, messaging standards and use of open tools as a targets of achievement [17] [29] [9] [30] [27] [28]. The identified trends, automated indicator reporting and mapping EMR data elements to FHIR resource elements are two important challenges identified at implementation level.

A middle layer FHIR server using HAPI FHIR was implemented to enable the interoperability of an EHR system with bedside(i2b2) clinical warehouse(CDW) [27] [31]. Warehouse data model is represented as an entity-attribute-value model, though the java implementation is based on regular relational tables. After manually inspecting the local database, mapping of data elements from the i2b2 CDW to FHIR resources has been achieved with java hibernate persistent entities for each FHIR resource. A more general approach is proposed by [10] that utilize NLP methods to map EHR data, structured and unstructured, to FHIR Models as opposed to similar solutions that are specific to clinical domains. Data annotation is carried out that is used to compute over and pass through NLP based pipeline, NLP reusable modules that transform the input data based on the annotations. UIMA, a software framework to analyse unstructured content, is used to reuse and develop modules that transform the annotated data. HAPI FHIR is used to expose the processed data. The experiment is conducted on MedicationStatement FHIR resources. Observed difficulty

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of mapping EHR elements to FHIR elements, as EHR elements are numerous to work with [17] suggests automation means to perform this task with minimum human intervention. The study used a reconfigurable setting using semantic and morphological similarity computation to map EHR and FHIR elements. With an aim of exposing processed extracted health data with a single FHIR server, element mapping is explained in terms of equivalence to name, element type, and resource representation similarity during the computational processing.

Study results show data quality and process efficiency enhancements are achieved through health data exchange and interoperability [28] [27]. In terms of FHIR data exchange, promising milestones are achieved to map local data with FHIR resource elements [17] [10]. But Use of custom data representation and integration of systems using a direct link (point-to-point) puts a challenge to repeat the same effort during scale up. On the contrary, an architectural approach toward national health data interoperability as a holistic approach to address the challenges associated is crucial [32].

The rapidly growing and increased global acceptance of FHIR standard has instigated studies to target automated approaches for legacy and commercial EHR systems to benefit from FHIR containers. Main challenges have revolved around unpredictability of data representation on legacy and commercial EHR systems. Mapping of local data elements with FHIR resources is a great deal of work but reusability in production systems is also an important determinant. The general objective of our study is to develop a health data exchange model suited for low resource settings with reusable common data exchange modules that drive an overall workflow harmonization at a regional and national scale. It aims to reduce efforts of data exchange modules rework by utilizing heuristic inputs and automatically mapping local data elements of an EHR to FHIR resources, to ease usage of the system in practical environments.

2.2. Current state assessment method

The team conducted an assessment to identify barriers of eHA components HIE and interoperability adhering to the eHA architectural specification. The goals of the assessment were to identify systems capable of being piloted to meet data exchange needs through:

- identification of health data exchange needs that can be supported by the data source
- identification of barriers to health data exchange
- identification of eHA components that are currently in use
- assessment of capabilities for data sharing
- assessment of the accuracy and completeness of the data source

The team followed similar methodology to [33], where onsite observation of health facilities and authors own experience is used to conceptualize local, national and international perspectives. The team also assessed the current status of eHA to identify components that are currently in use and considered FMOH trust for data utilization for a larger impact. Besides, we considered systems that can have better contribution to the known need for data sharing and are able to be piloted using real data.

2.3. Health data exchange model

Health data exchange and interoperability is the driving factor toward eHA maturity. Our model used the existing national eHA as a basis. The core aspects of our study spanned the eHA components including point-of-service applications, the interoperability layer and shared HIS components. To demonstrate our model, we used adoption maturity of HISs from each layer and utilized reference technologies of each HIS component to implement our demonstration. The eHA is based on an interoperability layer to enable registry services and point-of-service applications to communicate and exchange data. The team assessed eHA components current adaptation status in practice in alignment with needs of the FMOH to select important HISs for our study. An important challenge is taken to involve legacy HIS in order to affirm a pragmatic conclusion is reached.

2.4. Technology

The Ethiopia eHA outlines the overall health data exchange patterns and shows implementation technologies of each HIS component. Consequently, as per the eHA guidelines, OpenHIM (http://openhim.org/), an

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open source software, is an interoperability layer reference implementation technology. The national HMIS, DHIS2, from the shared services layer and SmartCare, an EMR system, are selected for their adoption maturity to conduct our study. The team adopted HAPI FHIR to expose SmartCare EMR local data, which involves developing EMR and FHIR resource data element mapping strategy. To demonstrate the data exchange of selected components for the identified use case, the team developed a Disease Registry Mediator[1] to retrieve data from the FHIR server, make aggregation and transformation of the data. Finally the mediator sends a monthly aggregate report to DHIS2 using the DHIS2 API, Figure-1 shows the integration model.

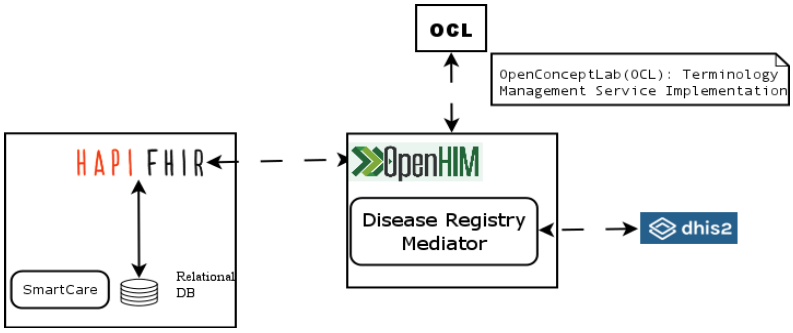

Figure 1. Health data exchange model

2.5. Test and evaluation method

In adherence to eHA guidelines and use of reference technologies, the team implemented integration testing for the identified use case and conducted experiments in a real world environment and production HISs. The major emphasis is given on the overall health data exchange and the impact in data quality and scalability of local data and FHIR data element mapping. A comparison of data retrieved by the adopted FHIR server and manually inspected data from the tally sheet is conducted to assess the data quality, data demand and information availability. Relevant dimensions of data quality were assessed and compared with the manual practice. Hence implementation feasibility in terms of cost, time, and technical capacity associated with collecting and aggregating the data and human resource needs are investigated to the proposed solution. These evaluation criteria examine durability and long term use of the integration model in support of functionality and capability of HISs seamless integration.

3. Results

The main aim of our experiment is to enable eHA components to exchange data adhering to eHA principles. Analysis of our experiment is explained in three major actions taken. First, the eHA contains point-of-service applications in its lower layer. The point-of-service applications are main data sources to the top most layers, the shared services or registries layer. Accordingly, in this study legacy EMR system is used as a data source. It is a closed source desktop application that lacks an API to exchange data. In order to overcome this challenge, we leveraged HAPI FHIR library and developed new data element mapping scheme to extract data from relational database. Second, in this study, we used the most common data exchange use case to implement data exchange adhering to eHA principles that leverage the interoperability layer. A mediator is developed that triggers health data exchange to extract data from HAPI FHIR API, make aggregation and submit to a national HMIS instance. Thirdly, we conducted data quality assessment on the existing practices to exchange health data. This is used to show the significance of our study and illustrate the existing need for data quality improvement.

3.1. Standards based legacy EMR data extraction

Making use of standards based health data exchange and interoperability is a foundation for effective and sustainable approach. Following our assessment, FHIR is a de-facto standard for health data exchange with

[1] https://github.com/haftamuk/openhim-mediator-SmartCare-DHIS2-DiseaseRegistry-Data

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growing acceptance and implementation cases across various countries. HAPI FHIR is built for an extensive use and realization of HL7 FHIR standard powering interoperability. It is an open source java based implementation with RESTFull interface and abstraction of local data using FHIR resources. In addition to exchange local data adhering to FHIR standard, it provides security implementation to enable clients to authenticate themselves. Harnessing the capabilities with an extended use in commercial and legacy EMR systems, in this study, the team developed EMR local data and FHIR resources mapping scheme. HAPI FHIR is adopted4 to expose SmartCare local relational data.

An approach to map local EMR data with FHIR resource data elements involved creating java entities for each identified FHIR resource. To minimize duplication of effort and reuse implementations java persistent entities is not used as it will require refactoring during different EMR instances. Tested and ready-made SQL queries for the identified FHIR resources provided by the database administrator are used to retrieve data from the relational database. Result set of the query was then parsed to instantiate objects and build a collection of objects. This data element mapping model requires creating java entities for each FHIR resource. Incorporation of dynamic query is an important aspect for scalability and flexibility properties of the integration. Only the SQL query to the corresponding FHIR resources and use cases at hand need to be modified during scale up efforts. Thereby, deployment of the adopted HAPI FHIR server in other EMR instances requires adjusting the raw sql queries accordingly. The intention is to ease the scale-up of our implementation to regional and national level. The developed legacy EMR data extraction scheme is tested on Patient and Condition resources that are relevant for the identified use case demonstration. In order to not create an additional layer, the adopted FHIR server was deployed within a similar machine where the EMR is deployed for demonstration purpose. FHIR web API was used to access the resources and expected results were obtained, which proved effectiveness of the developed standards based data extraction scheme.

3.2. eHA based health data exchange

In order to demonstrate the results, an experiment using eHA data exchange patterns with the most common use case is conducted. We selected the national HMIS, and an EMR to demonstrate the data exchange. DHIS2 is a web-based national HMIS implementation. It contains 53 data sets used by more than 35, 000 health facilities serving at different layers of the health sector, including health post, health center and hospitals, to deliver reports of various types and it is the major source of information by the FMOH. To limit the scope of the implementation, we demonstrated the implementation in Ayder Comprehensive Specialized Hospital and considered all data elements that are reported using DHIS2. The hospital uses SmartCare, an electronic medical record system. It is windows based desktop application with a centralized database. The integration model is reached adhering to Ethiopia's eHA in consultation with experiences of open source software, and thorough investigation of the international community groups working on similar studies, OpenHIE(https://ohie.org/). We selected disease registry reporting use cases to demonstrate the integration model as it is one of the most widely used datasets utilized by multiple work units including outpatient departments (OPD) to report monthly disease registry data. We observed that OPD transactions are more requiring follow-up of updates in daily basis and building the report received from each department is made monthly by the HMIS department. Of the dataset registration forms provided in DHIS2, disease registry reporting is the most time consuming operation. In the selected use case, data entry is filled in aggregation of gender and age groups(six age groups to each gender) for each disease classifications, a total of more than 4000 disease classifications. Selection of the disease registry data set is also reinforced as EMR is a typical source of such data. For those reasons we chose to consider integration of DHIS2 and SmartCare on disease registry reporting as a use case.

Table 1. Ayder comprehensive specialized hospital profile

Location	Mekelle, Tigray, Ethiopia
Services	IPD and OPD
Staff	Over 2,165
Patient Flow	Over 170, 000

The data exchange model involved development of a disease registry data exchange mediator. The selected use case operates on two FHIR resources, Patient and Condition. Targeted FHIR resources, with only minimized elements that are relevant to disease registry reporting include resourceType, id, identifier, code and subject for Condition Resource and resourceType, identifier, code, gender, and birthDate for Patient

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Resource. In adherence to patients data policy and health data regulations in general, the exchanged data was anonymous making the integration scenario applicable. The data exchange workflow involved is shown in (Figure 2).

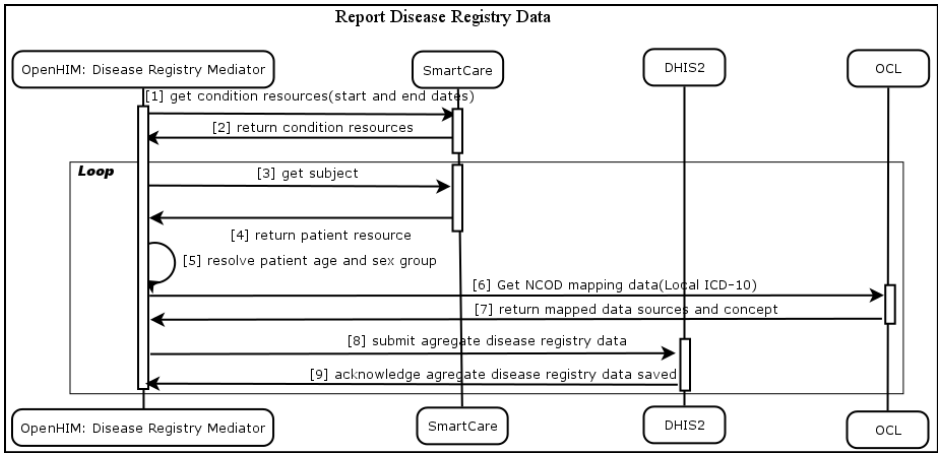

Figure 2. Disease registry aggregate data report workflow

The data exchange mediator utilized a terminology management services to resolve disease classification mismatch of the two systems. In this study, we found that for the range of dates provided as parameters of a web request, an aggregate report is built and sent to DHIS2. We observed the submitted data via DHIS2 Disease registry dataset report for the selected work unit and is accurate in comparison to the manually inspected expectation of aggregate data values.

3.3. Data quality gap assessment

In order to show the significance of this study, we conducted data quality assessment in the existing data exchange approach.The evaluation was conducted on 12 months of data, from September 2019 to August 2020. The report entries of the disease registry are extracted from DHIS2 and the equivalent EMR entries via the HAPI FHIR based adapter in order to compare and contrast using data quality and efficiency parameters. Having inspected the data values for top ten disease classifications, their summed value is used for comparison (Figure 3). We used HAPI FHIR web API to retrieve Condition resources bound to start and end time of registration.

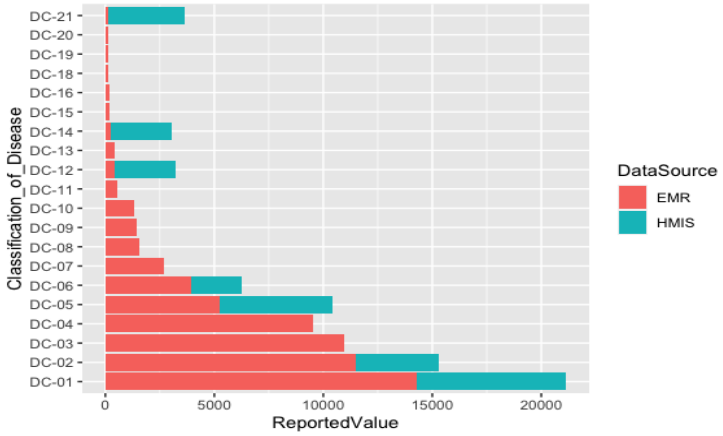

Figure 3. Top-10 disease registry report data - HMIS and EMR

We have observed the tally based entry has resulted in a significant increase in the reported number for the first, second, fifth and six disease classifications. The cause of this difference can be seen in three

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perspectives, firstly how effectively the physicians are using the EMR, secondly accuracy of recorded data in the tally sheet and thirdly how much similarity exists in coding disease classification in both systems. Though reports of the first and last months may be affected by late reports, the approach to use sum of 1 year data for comparison should compensate the late reports. In practical sense, manual tally based aggregate reporting from different OPD departments is time taking and agreeably reports may be delayed to be reflected in the national HMIS instance. Coding mismatch is the main source of reporting difference. This implies aggregate reports at various levels lack accuracy. We found different disease classification levels and diseases aggregation values are summed manually in the HMIS tally sheet. This caused data inconsistency for aggregation of specific disease value category does not have harmonized guidelines. This is also reinforced as physician's free text is manually inspected in the tally sheet. As data is handed from primary source to extended level, quality is compromised. Tally sheet is collected from the hospital departments and sub departments, compiled and submitted to the HMIS department. As different layers of data sources exist raw data values can change in the process causing mismatch and inconsistency. In this study, the main aim is to show the data quality problems that practically exist. We observed the data available in the HMIS system is not exact reflection of the data available in the EMR. Now the intention is not to stress on which data source is accurate but how the manual tally based data exchange in fragmented systems is a cause of data quality problem. The assessment proved a significant data quality improvement can be achieved using eHA based health data exchange.

4. Discussion

Substantiating the practical implementation and obtained results of this study, we found important eHA aspects that support moving toward interoperability. To explore the need for interoperability of currently fragmented legacy systems, we experimented on the most practiced eHA components, HMIS and EMR systems. Leveraging open tools such as HAPI FHIR leads to effective and reusable outcomes. The current manual systems and processes for HMIS disease reports require an expert to register case data to the OPD register and tally according to disease, age, and gender disaggregation. This manual process has been a source of different kinds of errors. Besides client follow-up, nurse professionals were assigned to dedicate OPD to handle the activity of disease registration and reporting. This resulted in health care professionals that were overburdened in the process of data collection and aggregation. Currently, DHIS2 software is manually populated even though data is available in corresponding systems. This manual process results in autonomous systems that lack integration, duplication of effort, and inevitable human errors. Despite the human resources dedicated to reporting, aggregated reports collected from each OPD in the HMIS department were facing different data quality issues as the collected data is questionable, time-consuming and error-prone. The ability of HISs to interoperate and exchange data minimizes the overburden, duplication of effort, eliminates human errors and most importantly assures data quality.

One of the important works to underpin national level harmonized report is the development of national disease classification, an adoption from WHO's ICD-10. This needs to be cascaded to the facility level where EMR systems should utilize similar classifications and provide appropriate mapping information. In this study, we observed disease classification coding differences that ultimately impact factuality of the service delivery report. This mismatch did not impacted our study as it dealt with only top-10 diseases, the team managed to manually inspect and map the elements using OCL[2], a terminology management system hosted in a cloud, to retrieve reports by changing request parameters.

Demonstration of FHIR and local EMR data mapping was conducted only with FHIR Patient and Condition resources and two Java entities were created to support these FHIR resources. To demonstrate on a larger scale with more use-cases, relevant FHIR resources and FHIR Implementation Guides should be identified beforehand. The focus of our study was to demonstrate the methodological aspect for mapping FHIR resources with EMR local data and assure the scalability.

We took the first step to demonstrate Ethiopia eHA components data exchange and interoperability and explored their practical challenges. The team has also identified and reflected on important concerns identified in the process. These include harmonization of National Classification of Disease (NCOD) and cascading use of terminology to health service delivery facilities. It is highly emphasized that use of standards and scalable approaches of health data exchange play an invaluable role towards eHA maturity.

[2] https://www.openconceptlab.org

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Finally Interoperability involves multiple systems communicating and sharing information and that requires establishing health data and information security policy and regulations. This becomes prevalent when thinking about the scale up of activities for a broader impact. Reusable mediator development and using consistent approaches to avail health data from point-of-service systems play an important role in health data reports and support facilitating health data exchange. Taking appropriate measures to assure technical solutions can be scaled to support use-cases is a significant driver toward maturing eHA.

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