WESTERN SYDNEY UNIVERSITY

Comparative Study of Healthcare Messaging Standards for Interoperability in eHealth systems

BOAZ ABRAHAM | STUDENT ID: 18481798 | SUPERVISOR: DR ANUPAMA GINIGE |SUBMISSION YEAR: 2017

DEDICATION

To my loving wife Ruth and daughter Sharon Rose

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STATEMENT OF AUTHENTICATION

The content presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the references. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.
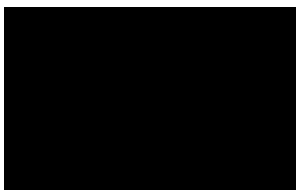
Boaz Abraham

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Abbreviations

ACCD	Australian Consortium for Classification Development
ACHI	Australian Classification of Health Interventions
ACS	Australian Coding Standards
ADA	American Dental Association
ADT	Admissions, Discharges and Transfers
ANSI	American National Standards Institute
API	Application Programming Interface
ASTM	American Society for Testing and Materials
AWAHS	Albury Wodonga Aboriginal Health Service
BSI	British Standards Institute
CA	Certificate Authority
CAP	College of American Pathologists
CCD	Continuity of Care Document
C-CDA	Consolidated CDA
CCR	Continuity of Care Record
CDA	Clinical Document architecture
CDISC	Clinical Data Interchange Standards Consortium
CHW	Children's Hospital at Westmead
CMETs	Common Message Element Types
CPT	Current Procedural Terminology
DES	Data Encryption Standard
DICOM	Digital Imaging and Communications in Medicine
DoHA	Department of Health and Ageing
EMR	Electronic Medical Records
FHIR	Fast Healthcare Interoperability Standards
FTPS	File Transfer Protocol Secure
GSAHS	Greater Southern Area Health Service
GWAHS	Greater Western Area Health Service
HCFA	Healthcare Financing Administration
HI	Healthcare Identifiers
HIMSS	Healthcare Information and Management Systems Society
HIPAA	Insurance Portability and Accountability Act
HL7	Health Level Seven
HTTPS	Hyper Text Transfer Protocol Secure
iCAT	(ICD) Collaborative Authoring Tool
ICD	International Classification of Diseases
ICHI	International Classification of Health Interventions
IHE	Integrating the Healthcare Enterprise
IHTSDO	International Health Terminology Standards Development Organisation
ISO	International Standardisation Organisation
JHAHS	John Hunter Area health Service
JSON	JavaScript Object Notation
KRSS	Knowledge Representation System Specification
LOINC	Logical Observation Identifiers Names and Codes
LPP	Low Level Protocol
MBS	Medicare Benefits Schedule
MBS-E	Medicare Benefits Schedule-Extended
MRI	Magnetic Resonance Imaging
MSH	Message header
MyHR	My Health Record

NASH	National Authentication Service
NCAHS	North Coast Area Health Service
NCCC	National Casemix and Classification Centre
NCCH	National Centre for Classification in Health
NCPDC	National Council for Prescription Drug Programs
NSA	National Security Agency
OSI	Open Systems Interconnection model
PACS	Picture Archiving and Communication Systems
PAS	Patient Administration System
PCEHR	Personally Controlled Electronic Health Record
PHR	Personal Health Record
PID	Patient Identification Details
PKI	Public Key Infrastructure
PV	Patient Visit
RELMA	Regenstrief LOINC Mapping Assistant
REST	Representational State Transfer
RFH	Resources for Health
RIM	Reference Information Model
RMIM	Refined Message Information Model
SDO	Standards Development Organisations
SESIAHS	South Eastern Sydney and Illawarra Area Health Service
SFTP	Secure File Transfer Protocol
SHA	Secure Hash Algorithm
SMIME	Secure/Multipurpose Internet Mail Extensions
SNOMED CT	Systematised Nomenclature of Medicine - Clinical Terms
SNOMED RT	Systematised Nomenclature of Medicine - Reference Terminology
SNOP	Systematised Nomenclature of Pathology
SOA	Service Oriented Architecture
SSL	Secure Sockets Layer
SSWAHS	Sydney South West Area Health Service
UML	Unified Modeling Language
VPN	Virtual Private Network
WHO	World Health Organisation
XDS	Cross-enterprise document sharing
XML	Extensible Markup Language

Abstract

Advances in the information and communication technology have created the field of "health informatics," which amalgamates healthcare, information technology and business. The use of information systems in healthcare organisations dates back to 1960s, however the use of technology for healthcare records, referred to as Electronic Medical Records (EMR), management has surged since 1990's (Net-Health, 2017) due to advancements the internet and web technologies. Electronic Medical Records (EMR) and sometimes referred to as Personal Health Record (PHR) contains the patient's medical history, allergy information, immunisation status, medication, radiology images and other medically related billing information that is relevant.

There are a number of benefits for healthcare industry when sharing these data recorded in EMR and PHR systems between medical institutions (AbuKhousa et al., 2012). These benefits include convenience for patients and clinicians, cost-effective healthcare solutions, high quality of care, resolving the resource shortage and collecting a large volume of data for research and educational needs.

My Health Record (MyHR) is a major project funded by the Australian government, which aims to have all data relating to health of the Australian population stored in digital format, allowing clinicians to have access to patient data at the point of care. Prior to 2015, MyHR was known as Personally Controlled Electronic Health Record (PCEHR). Though the Australian government took consistent initiatives there is a significant delay (Pearce and Haikerwal, 2010) in implementing eHealth projects and related services. While this delay is caused by many factors, interoperability is identified as the main problem (Benson and Grieve, 2016c) which is resisting this project delivery.

To discover the current interoperability challenges in the Australian healthcare industry, this comparative study is conducted on Health Level 7 (HL7) messaging models such as HL7 V2, V3 and FHIR (Fast Healthcare Interoperability Resources). In this study, interoperability, security and privacy are main elements compared. In addition, a case study conducted in the NSW Hospitals to understand the popularity in usage of health messaging standards was utilised to understand the extent of use of messaging standards in healthcare sector.

Predominantly, the project used the comparative study method on different HL7 (Health Level Seven) messages and derived the right messaging standard which is suitable to cover the interoperability, security and privacy requirements of electronic health record. The issues related to practical implementations, change over and training requirements for healthcare professionals are also discussed.

The study finds that HL7's FHIR (Fast Healthcare Interoperability Standards) is the most suitable messaging standard satisfying all the modern demands for healthcare interoperability requirements. These interoperability requirements are communication methods, security, usage of encryption, privacy, compatibility, flexibility and reliability. FHIR has satisfied all these requirements well and it is the most preferred one among other HL7 standards. The adoption rate of FHIR is expected to be high as it has the flexible transport and client-side features. However, FHIR is still in draft status and it may take considerable time to plan for resource repository and training to healthcare professionals. Further, the study recommends a solution for the suitable health messaging standard, for the technology professionals, implementing healthcare systems that can effectively communicate with other systems such as MyHR.

(1)   Introduction

The demand for Electronic Health Records (EHR) is increasing globally because of how it benefits healthcare systems due to the lower costs and easier usage. Many developed countries are now investing in EHR systems. To improve the efficiency of their healthcare facilities, they help to encourage the use of digital health records, even though there are security and privacy challenges to be resolved. Australian National level electronic health record system, previously known as Personally Controlled Electronic Health Record (PCEHR) and now known as My Health Record (MyHR), is the major project funded by the Australian government. MyHR aims to have all the Australian population's health-related data stored in a digital format (Health, 2017). This allows clinicians to have access to the required patient's health data at the point of care. Sharing this data electronically between institutions brings numerous advantages (AbuKhousa et al., 2012). Although the Australian government took constant initiatives and funded at the state and federal levels, there is a major delay in implementing eHealth projects and related services (Pearce and Haikerwal, 2010). This delay was caused by many factors. However, lack of interoperability between the healthcare information systems was identified as the main problem which is resisting this project delivery (Benson and Grieve, 2016c). In addition, health data security and privacy are other critical problem to be resolved together with interoperability (Ray and Wimalasiri, 2006).

In the context of information technology, interoperability refers to connecting more than one system and exchange their data efficiently. Every health organisation maintains their patients' health records either with the internationally approved standard or with the organisation approved local standard. These data and health message standards help their system to exchange the data and make it interoperable by avoiding duplicates and delays (Benson and Grieve, 2016).

The interoperable healthcare information systems can achieve the good quality and low cost healthcare services. The health messaging standards are helpful to overcome the lack of interoperability between the healthcare information systems (Benson and Grieve, 2016c). This project discusses the health data standards such as ICD (International Classification of Diseases), LOINC (Logical Observation Identifiers Names and Codes), SNOMED CT (Systematised Nomenclature of Medicine Clinical Terminology), healthcare messaging standards such as HL7(Health Level Seven) versions 1, 2, 3 and FHIR (Fast Healthcare Interoperability Standards). The project compares the different messaging standards utilised in between healthcare information systems, such as between a hospital system and a national level health record like MyHR. The analysis on different health messaging standards has used criteria on interoperability methods, security, usage of encryption, privacy, compatibility, flexibility, reliability and other miscellaneous features such as technology, transport mechanism, granularity features, popularity, adoption rate, and implementation cost.

As part of the research study, there was a case study conducted in eHealth, New South Wales (NSW) State to measure the usage of health messaging system in the NSW hospitals. The case study has revealed the challenges faced by the healthcare organisations on interoperability and created a strong interest to conduct further research in the health messaging interoperability and associated features such as security and privacy.

One of the most important aspects of healthcare is interoperability, However, it is one of the more misunderstood aspects (Benson and Grieve, 2016c). This is partly due to the skills required to manage the interoperability in healthcare. Most of the earlier research completed in healthcare interoperability either cover the medical field (Leroux et al., 2017, Pais et al., 2017, Boussadi and Zapletal, 2017) or the information field (Smits et al., 2015, Ruiz, 2016, Lubamba and Bagula, 2017, Guinan, 2013). There are very few research projects (Legner and Lebreton, 2007) completed has covered both the fields. The coverage of

interoperability with the usage of modern technologies together with Australian standard is very few to none. This project covers both medical and information communication fields with Australian specific standards. Moreover, this work is comparing the modern features of FHIR (Fast Healthcare Interoperability Standards) and its practical usage in Australian hospitals and MyHR systems, which is not addressed in previous research.

The thesis is structured to cover the literature review in chapter 2 which covers the healthcare data and messaging standards with the relevant background details. Also, the literature review covers the interoperability, security and privacy in the subsections. Research objectives and methodology are covered in chapters 3 and 4, followed by a detailed study of healthcare messaging standards in chapter 5 and healthcare data standards usage within messaging systems in chapter 6. Chapter 7 covers the case study completed in eHealth, NSW department which explains the healthcare interoperability and its associated benefits in NSW hospital environment. Chapter 8 covers all the comparative study findings on HL7 V2, V3 and FHIR messaging standards using the features such as interoperability methods, security, usage of encryption, privacy, compatibility, flexibility, reliability, granularity features and other miscellaneous features. Chapter 9 and 10 discuss and conclude the findings of this thesis based on the analysis derived from the comparison study and case study which are covered in the earlier chapters.

(2) Literature Review

2.1. Standards in Healthcare

As per the definition of ISO (International Standardisation Organisation), standard as a document, established by consensus and approved by a recognised body, that provides, for common and repeated use, rules, guidelines aimed at the achievement of the optimum degree of order in a given context (Benson and Grieve, 2016a). The evolution of health data standards was started from the year 1901 (Braunstein, 2015b). Early data standards were lists such as medical diagnoses, laboratory tests or medications. Those are generally referred as list standards or classifications. Later, attention has been paid to coding more details about each identity and relationships among the entities. Using these standards, more details including relationships as ontologies can be established. International Classification of Disease (ICD) is the first known health standards, introduced by World Health Organisation (WHO) in the year 1901 (Moriyama et al., 2011). It was followed by Current Procedural Terminology (CPT), introduced by American Medical Association in the year 1966 (Moriyama et al., 2011). Later in the year 1970 Systematised Nomenclature of Medicine Clinical Terms (SNOMED) was introduced (Lundberg et al., 2008). Then in the year 1993, Arden syntax (Hripcsak et al., 1990) was introduced. In the year 1994, Logical Observation Identifiers Names and Codes (LOINC) were introduced (Forrey et al., 1996) by Regenstrief Institute, a US non-profit medical research organisation. In the year 1997, Integrating the Healthcare Enterprise (IHE) profiles were introduced by a non-profit organisation with the same name Integrating the Healthcare Enterprise (Siegel and Channin, 2001).In this literature review, the healthcare standards section discusses the key health data standards such as ICD, LOINC, SNOMED CT, DICOM and OpenEHR. Integrating the Healthcare Enterprise (IHE) is a technical framework and is not a data standard (Henderson et al., 2001). IHE can be used together with other health messaging standards such as HL7 (Health Level Seven) to improve the interoperability in healthcare domain. IHE is covered under the healthcare messaging standards section of the literature review in detail.

2.1.1. International Classification of Diseases, ICD

ICD (International Classification of Diseases) helps to monitor and report data referring to diseases and deaths throughout the world by providing a common language so that the data can be shared between hospitals, countries and regions in a consistent way (Benson and Grieve, 2016c). ICD is used for morbidity cording within medical records and mortality coding with death certificates (World-Health-Organisation, 2017b). The World Health Organisation published ICD-9 in 1977, and a clinical modification of it (ICD-9-CM) was used in the USA for payment purposes up until 2015 (Benson and Grieve, 2016c). ICD-9 was used in Australia up until 1998 (The-Medical-Journal-of-Australia, 2017). ICD-10 was published in 1992. Now, over 117 countries use ICD-10, which was published in 1992, to report data relating to mortality (Makary and Daniel, 2016). The coding scheme used in ICD-10 is alphanumeric at the four-character level, made up of one letter followed by three numbers. The extended clinical modification of the 10th version is referred as ICD-10-CM. The extended Australian version of ICD-10 is referred to as the ICD-10-AM (Australian Modification) (Sundararajan et al., 2004). ICD-10-AM uses an alphanumeric coding scheme for diseases and external causes of injury. It is structured by body system and aetiology, and comprises three, four and five character categories (Quan et al., 2005).

Here is the sample code and meaning for ICD-10, ICD-10-CM and ICD-10-AM that shows how specificity of various diseases explanations varies from base version to country specific modifications.

Table 2.1.1-1 ICD 10 code and meaning (ICD-10-Data, 2017)

ICD 10 Code	Meaning
H49.1	Paralytic strabismus, Fourth [trochlear] nerve palsy
H59	Postprocedural disorders of eye and adnexa, not elsewhere classified
J38.0	Paralysis of vocal cords and larynx

Table 2.1.1-2 ICD 10 CM code and meaning (ICD-10-Data, 2017)

ICD 10 CM Code	Meaning
H49.11	Paralytic strabismus, Fourth [trochlear] nerve palsy, right eye
H59.111	Intraoperative hemorrhage and hematoma of right eye and adnexa complicating an ophthalmic procedure
J38.02	Paralysis of vocal cords and larynx, bilateral

Table 2.1.1-3 ICD 10 – AM code and meaning (Cumerlato, 2017) (Huang et al., 2008)

ICD 10 AM Code	Meaning
H49.1	Paralytic strabismus, Fourth [trochlear] nerve palsy
H59.1	Accidental puncture and laceration of eye and adnexa during a procedure
J38.02	Paralysis of vocal cords and larynx, unilateral, complete

When looking at the above examples, it is evident that use of a clinical classification system coded data allows comparison of data from different countries. This is especially valuable when clinical data is recorded in various languages, which gives the ability to compare the coded data irrespective of the language in which the medical record was kept in.

Since 1988, the Australian Classification of Health Interventions (ACHI) has also been in use. Previously known as the Medicare Benefits Schedule-Extended, ACHI was based on the Medicare Benefits Schedule (Doyle and Dimitropoulos, 2009). ACHI was developed by the National Centre for Classification in Health (NCCH), and the development was assisted by clinical coders and specialist clinicians (ACCD, 2017). ACHI codes have seven digits. The first five digits are MBS item number, and the two-digit extension represents specific interventions that are included in the item. The classification is structured by site, body system and intervention type. Interventions currently not listed are also included in MBS, such as dental, cosmetic surgery and allied health interventions (ACCD, 2017). ACHI consists of an alphabetic index with a tabular list of interventions.

ACHI Code and Description

ACHI Code	Description
38500-00 [674]	Coronary artery bypass, using 1 LIMA graft
38500-02 [676]	Coronary artery bypass, using 1 radial artery graft

Currently, there is no international level WHO approved classification system for medication interventions and procedures.

WHO (World Health Organisation) is currently revising the current ICD version 10 towards the new version ICD-11(World-Health-Organisation, 2017c). ICD-11 have definitions for each disease entity that provide guidance and key descriptions for the meaning and human readable format (Endicott, 2013). The current ICD 10 version has only the title headings. The release of ICD-11 was planned for the year 2017 but has been shifted the release to the year 2018 (World-Health-Organisation, 2017a). In addition to ICD-11, WHO also wishes to release an international level healthcare interventions (World-Health-Organisation, 2017d) called ICHI (International Classifications of Health Interventions) in 2018.

2.1.2. Logical Observation Identifiers Names and Codes, LOINC

The data for research, clinical care, quality improvement and reporting and public health reporting need to be merged by clinical and laboratory systems. Most systems use their own codes to help identify the results coming from electronic messages that transmit results, which usually come from other systems. Receiving systems cannot understand the contents of these without having to map every item to their own codes as a result of this, so there was a need for identifiers for laboratory and clinical observations. There was a demand for the identifiers for clinical and laboratory observations. To fix this issue, LOINC (Logical Observation Identifiers Names and Codes) provides a set of universal identifiers (Lin et al., 2011). LOINC is community-built and is a universal code system that assists with laboratory and clinical systems, and how they would exchange and process between systems (Benson and Grieve, 2016a). This technology is controlled and it is built using a formal structure which contains fully

specified names and unique identifiers. In 1994, the Regenstrief Institute made a way that the database would be developed, which is due to the setup of the LOINC Committee (Forrey et al., 1996). Later LOINC Committee and the Regenstrief Institute have published more than 50 versions of the standard. LOINC has been adopted in both the public and private sector by government agencies, laboratories, care delivery organisations, health information exchange efforts, healthcare payers and research organisations standards (Benson and Grieve, 2016a). LOINC is available in 21 languages and dialects and it is used in 170 countries by over 40,000 people.(Regenstrief-Institute, 2017a) and LOINC team have enabled multilingual searching capacities in their searching tools, RELMA (Regenstrief LOINC Mapping Assistant) and search.loinc.org (Regenstrief-Institute, 2017b).

Table 2.1.2.1 LOINC Code and related clinical observation details

LOINC Code	System	Short Name	Long Name	Type
29463-7	Patient	Weight	Body weight	Clinical
11450-4	Patient	Problem List - Reported	Problem List - Reported	Clinical

LOINC is available for free (Regenstrief-Institute, 2017c) and is distributed from the LOINC website, where an updated version is released twice in a year. The main LOINC database is published in several different file formats. A software program that helps users to browse the database and map local terminology to LOINC terms is also distributed by Regenstrief Institute. It is called the Regenstrief LOINC Mapping Assistant (Regenstrief-Institute, 2017d), or RELMA. LOINC also provides alternate names along with the fully specified names, which are used in other situations, and it also contains codes for the atomic elements that make up these alternate names. To organise LOINC terms, link descriptions and link synonyms, constructed hierarchies by LOINC parts are utilised. They are also the basis for efficiently translating LOINC names. LOINC also holds a robust coverage which represents a listed collection of observations (Forrey et al., 1996)

that capture attributes of individual data, elements, hierarchical structure of the elements, value sets and panel-specific features of data elements.

2.1.3. Systematised Nomenclature of Medicine - Clinical Terms, SNOMED CT

SNOMED is similar to ICD and LOINC in principle. However, it is much more meaningful to humans i.e. healthcare professionals, as opposed ICD and LOINC more suitable to be used in healthcare systems. Since it is based on an ontology (Harispe et al., 2014), the hierarchy data can also be kept. The difference between the LOINC and similar other classification based standards and SNOMED is those are categories and list (Bodenreider, 2008). However, SNOMED CT can show a relationship among the categories and subtypes (Beale and Heard, 2007). SNOMED CT has had two direct successors, one of which is the Read Code (Benson, 2011). Read codes are used in primary care. Since 1990, all general practitioners from the UK and New Zealand have been using the Read Code. There is 4-byte, Version 2 and Version 3 are some versions of the Read Codes that have been released. New Zealand still uses the original 4-byte Read Code today. The College of American Pathologists founded a committee in late 1955 to develop a nomenclature for anatomic pathology (Benson, 2010a). Later in 1965, they published the Systemised Nomenclature of Pathology, which talks about the findings of pathology using four axes: Topography (anatomic site affected), Etiology (the causes for diseases), Morphology (structural changes associated with diseases) and Function (physiologic alterations associated with disease) (Benson, 2011). SNOMED CT is the successor of the Systemised Nomenclature of Pathology (SNOP) (Cornet and de Keizer, 2008). In 1975, SNOP had been extended by adding additional data and dimensions regarding diseases and procedures by Roger Cote and his colleagues (Benson, 2011).

SNOMED CT is the most comprehensive multilingual clinical healthcare terminology available. It helps to facilitate clinical documentation and reporting

and to retrieve and analyse clinical data. SNOMED CT contains two key features, the first being that is it virtually future-proof (Romero et al., 2011), as it evolves constantly and inherently. Terms and concepts and their codes can be freely added or removed, and their relationship with other terms and concepts can also be freely updated. These all make SNOMED CT a major improvement over other coding systems that are used in healthcare. It is also flexible as it supports many different languages. In addition, SNOMED CT also supports the change of relationships between data, including many parent-child relationships. This reflects the nature of reality and the code's practicality (Stearns et al., 2001). The number of descriptions, concepts and relationships differ with every version release. It contains around one million English descriptions, 300,000 active concepts and more than 1.4 million relationships (Benson and Grieve, 2016d). It can only be accessed via special software, which includes SNOMED CT browsers, so this cannot be used with a paper version. SNOMED CT does very little on its own, however, when it is built into software such as electronic health records (EHR), (Giannangelo and Fenton, 2008), its value is realised. SNOMED CT gives us an extensive foundation when expressing clinical data in interoperability and data warehouses and local systems. It is organised into a hierarchy (Benson and Grieve, 2016d). In a hierarchy, a node represents each concept, including one or more subtype relationships to its parent. Components such as relationships, concepts, descriptions, cross maps and reference sets are what make up the SNOMED CT (Lee et al., 2013). A SNOMED CT Identifier's role is to identify every component. All components carry an active field. Permanence is an important principle of the SNOMED CT. Once a component, such as a relationship or a description is created, it can never be deleted; however the active flag's status may be set to inactive. They each also have a module ID, which helps identify the origin and the organisation that is responsible for maintaining this component. (Benson and Grieve, 2016d).

Table 2.1.3.1 Description detail for a concept - myocardial infarction (disorder) (Australian-eHealth-Research-Centre, 2017)

Concept Id	Description	Description type	Acceptability
22298006	Myocardial infarction (disorder)	Fully Specified Name (FSN)	Preferred
	Myocardial infarction	Synonym	
	Infarction of heart		Acceptable
	Cardiac infarction		
	Heart attack		
	Myocardial infarct		
	MI Myocardial infarction		

Search on Concept Id	Hierarchical structure for the concept Id:22298006
SNOMED CT AU - 20170930 22298006 Myocardial infarction	
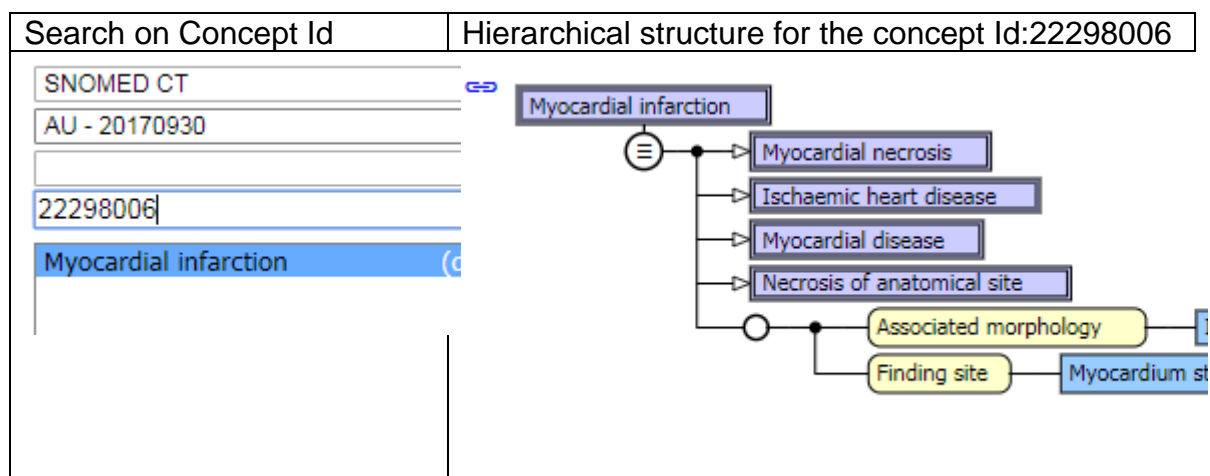
Figure 2.1.3.1 The hierarchical structure for myocardial infarction (disorder) (Australian-eHealth-Research-Centre, 2017)

The concepts and their hierarchies in SNOMED fall into three different categories: object hierarchies, value hierarchies and miscellaneous hierarchies (Benson, 2010b). The three main ways of entering coded data into SNOMED include using options, text parser matching and single concept matching. Options are used when rather than entering in text; the user selects the data from a bunch

of options. In text parser matching, the user enters notes as unconstrained free text and the SNOMED server takes it and matches words and phrases from its database. In single concept matching, a note is entered by the user and they select an appropriate match made by the server and elaborated as required. This requires the system to correctly match and identify SNOMED concepts as well as construct post coordinated expressions that are based on sanctioned attribute relationships from the text (Benson, 2010b).

2.1.4. Digital Imaging and Communications in Medicine, DICOM

DICOM (Digital Imaging and Communications in Medicine) standard was conceived in 1983 by a joint committee formed by the American College of Radiology (ACR), and the National Electrical Manufacturers Association(NEMA) (Pianykh, 2009). The DICOM standard is free and can be found on the official DICOM website, http://medical.nema.org, maintained by the National Electrical Manufacturers Association (NEMA). However, for enterprise and professional use, DICOM can usually be implemented in devices and software. DICOM use the compression techniques of all well-known image compression algorithms such as RLE (Run Length Encoding), JPEG (Joint Photographic Experts Group), JPEG2000, JPEG –LS (JPEG Lossless), and ZIP (Pianykh, 2009). It is primarily implemented in medical equipment that is used by all of the main manufacturers. DICOM is the universal format for PACS (picture archiving and communication systems) image storage and transfer. All of the main PACS manufacturers use DICOM, although each unit only implements a subset of DICOM (Le et al., 2009).

DICOM role in the health messaging standard, particularly in the interoperability is crucial. DICOM covers the data transfer, storage and display protocol built and designed to handle all functional aspects of contemporary medicine. DICOM comprise of three aspects. They are modalities, digital image archives and Workstations (Bidgood Jr et al., 1997). Modalities are digital image acquisition devices, such as CT scanners or ultrasound. Digital image archives are the storage where the acquired images are placed. The Workstations are where radiologists view the images (Pianykh, 2009). DICOM defines the formats for

medical images that can be exchanged with the data and quality necessary for clinical use. DICOM is used for most imaging modalities including radiography, ultrasound, nuclear medicine, magnetic resonance imaging (MRI), tomography, echocardiography, X-ray, CT, ultrasound and other modalities used in cardiology, radiology, ophthalmology, radiotherapy and dentistry (Benson, 2010b). DICOM system uses .dcm for its file extension and it consists of a header, followed by pixel data. The header consists of the patient name, other patient particulars and graphical details. The graphical details include width, height and image bits per pixel (CODE-Project, 2017).

The screen capture of sample anonymised image and its DICOM code are printed in figure 2.1.4.1 and 2.1.4.2. The image and its converted DICOM code can be accessed using DICOM viewer tool from www.dicomlibrary.com website. The DICOM file has all these associated details in the form of tags and values (DICOM-NEMA, 2017). The DICOM file cannot be opened using tools such as notepad, word and other related text editing tools. It can be viewed using the appropriate DICOM viewer tools (CODE-Project, 2017).
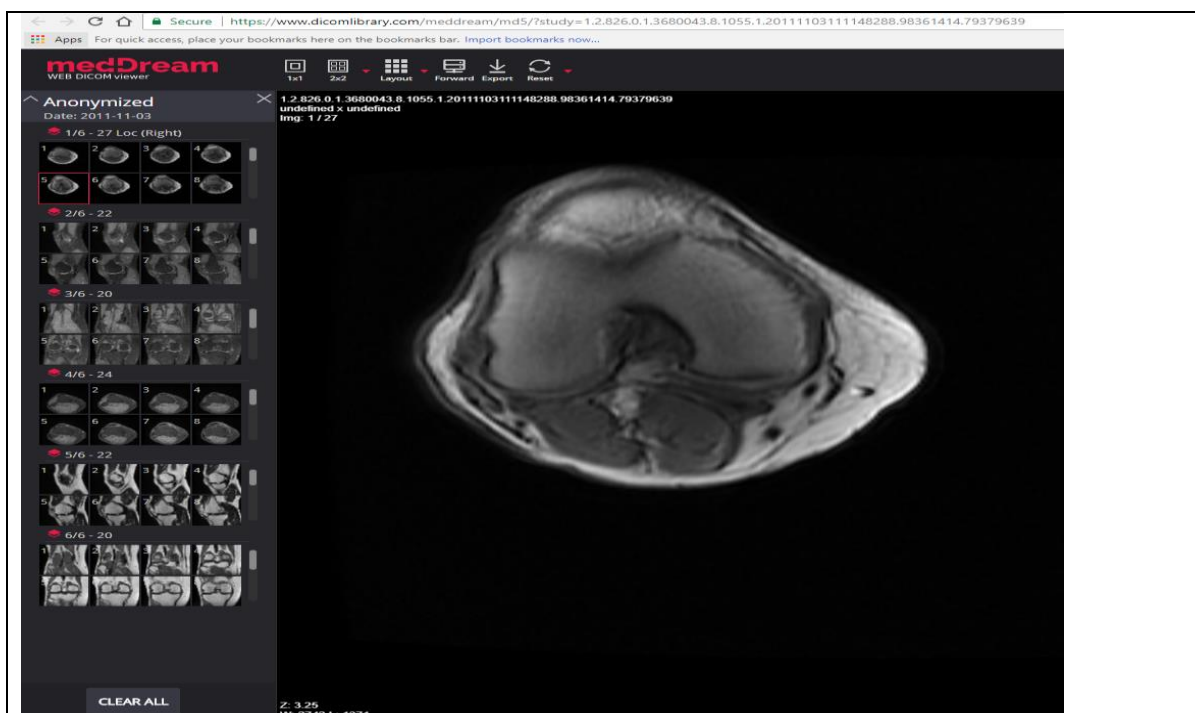
Figure 2.1.4.1. DICOM anonymised image (DICOM-library, 2017)
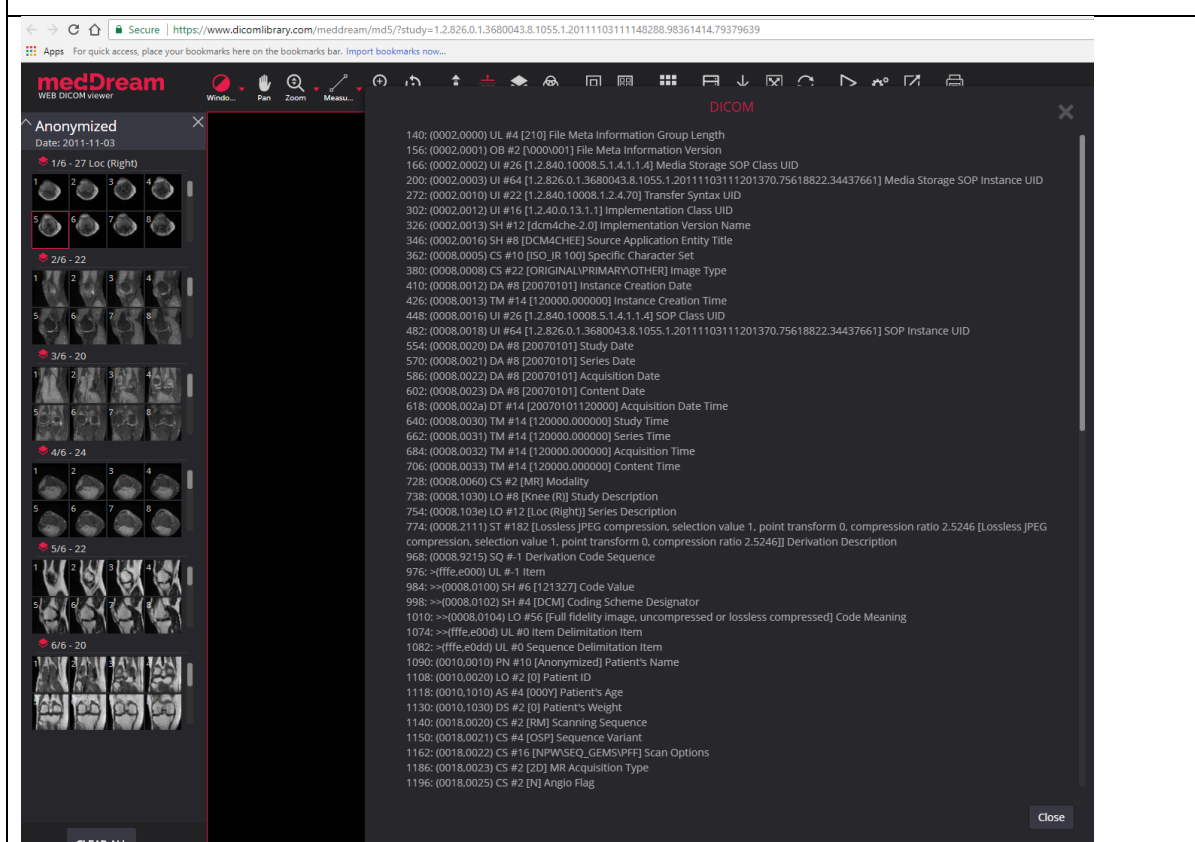
Figure 2.1.4.2. DICOM Code for the anonymised image (DICOM-library, 2017)

2.1.5. OpenEHR

OpenEHR is an open standard specification in health messaging standard systems that manage the retrieval and exchange of health data in electronic health records (EHR) system. In openEHR, all health data for a person is stored permanently, vendor-independent, and patient-centred EHR (Benson and Grieve, 2016c). The openEHR specifications are maintained by the openEHR Foundation, a not for profit foundation supporting the open research, development, and implementation of openEHR. OpenEHR covers demographics, clinical workflow and archetypes. An archetype is a computable expression of a domain content model in the form of structured constraint statements, based on some reference model (Benson and Grieve, 2016c). Two-level modelling is the key concept used in the openEHR systems. This approach separates the semantics of information and knowledge into two levels. Reference Model is placed at first level and this concept improves maintenance over single-level systems. Formal definitions of clinical content in form of archetypes and templates are placed at the second level, and it is called as knowledge level. So, the clinical content can be developed and sustained directly by domain specialists and not by IT personnel (Pahl et al., 2015).

There are useful templates which support the openEHR model, which is available for access freely (openEHR-Atlassian, 2017). A sample openEHR template which supports medication ordering and prescribing process is displayed below (DCM-NEHTA, 2017). Using this template, context-specific clinical data sets and documents can be created and used in the EHR systems(openEHR-Atlassian, 2017).

Figure 2.1.6.1 PRESCRIPTION Template which supports openEHR model

2.2 Standards in Healthcare Messaging

There are many international organisations supporting health message standards and those details were covered in section 2.1. Here, the two important messaging standards, HL7 and FHIR are discussed in detail.

2.2.1. Health Level Seven, HL7

Health Level Seven (HL7) standards are one of the standards that support clinical practice, administration, delivery, and evaluation of health services (Dolin et al., 2001). HL7 standards are formed by HL7 International, an international standards organisation which is similar to the ANSI (American National Standards Institute) and ISO (International Organisation for Standardisation). The HL7 organisation has affiliates in 31 countries. HL7 produces the world's most widely used standards for healthcare interoperability. HL7 does not develop software, but simply provides healthcare organisations with specifications for making their systems interoperable (Benson and Grieve, 2016c). HL7 collaborates and provides a meeting place for healthcare information experts from the healthcare IT industry and healthcare providers to work together and with other standards development organisations. HL7 standards refer the application layer, which is layer 7 in the OSI, Open Systems Interconnection model. The OSI model is made up of 7 layers. The first three relate to applications and the other four layers relate to the transmission of data. The application level interface performs common application services for the application processes (Health-Level-Seven-International, 2017b). In the year 1987, HL7 version 2 was introduced. The earlier versions of HL7 are a simple prototype and no real implementations were done with those versions. Most of the major health organisations use HL7 health messaging standard. In the year 2000, HL7 based CDA (Clinical document architecture) and CCD (Continuity of Care Document) were introduced. In the year 2004, XML based HL7 version 3 was introduced (Guo et al., 2004). The technical details of each HL7 version are covered in details under the section 5, Healthcare messaging standards of this document.

2.2.2. Fast Healthcare Interoperability Standards, FHIR

FHIR, also from HL7 International, was mainly created after facing implementation issues with the earlier HL7 standards version 2.xx and 3.xx. HL7 FHIR is built based on RESTful interfaces (Khalilia et al., 2015). Additional resources, extensions, and a human readable XHTML display may be referenced in the resources of FHIR (Smits et al., 2015). FHIR has a formal maturity process (Imler et al., 2016) that is linked to an implementation outcome, also has an open licence and fully focused on implementation.

2.3 Interoperability technologies in Healthcare

The intention to have interoperability in the electronic medical records (EMR) applications is to take safer decisions and also to avoid duplicates and delays in the health message exchange (Benson and Grieve, 2016d). The majority of the investments in EMR and eHealth related services were failed due to poor interoperability (Keshavjee et al., 2009). Interoperability is the critical communication element connecting components of different healthcare departments within and outside the systems(Kumar and Aldrich, 2010). For an example, clinical care is made up of many numbers of discrete tasks, each with its own information and communication needs. Their terms and classifications tailored to the needs of the task. The characteristics and difficulty of the tasks are determined by the complexity and variety of the natural history of disease processes and their corresponding diagnostic, treatment and administrative procedures. At the end, with so much volume of task information and health data, the decision making process is so difficult (Raghupathi and Raghupathi, 2014). An Australian study about hospital doctors found that they spent about 33 % of their time in communicating with fellow professionals, compared with 15% of their time in direct care. 70 % of the tasks performed by junior hospital doctors (Benson and Grieve, 2016c) was with another member of staff, usually another doctor. Interns spent twice as much time on documenting (22 %) as on direct care (11 %) (Rodriguez et al., 2010). So, communication is playing a critical role in health domain and clinicians need excellent communication within their work-group, between doctors, nurses and other professionals. Interoperability is nothing but communication among health systems so that the messages can be

exchanged effectively and understood clearly at both from the sending and receiving systems. The eHealth policies in Europe expected interoperability is the only sustainable way to maintain data transfer between two health organisations. To meet the current technical demands of the healthcare systems, the modern healthcare system architectures much achieve and implement interoperability in all the healthcare domains (Aguilar, 2005).

The health messaging standards such as HL7 is used to improve the communication element so that the best interoperability can be achieved. Each ward in the hospital, process different sort of information as per their own need. Each department can run their preferred software platform. For example, the Mayo Clinic in Rochester, Minnesota, a large hospital, processed up to two million HL7 messages a day, which then calculates to 660 million messages a year.(Benson and Grieve, 2016e). Establishing the interoperability between these systems is hard and badly need a procedure or standard to understand the transaction messages (Vernadat, 2010).

Interoperability basically has four layers. These layers are namely technology, data, human, and institutional. Technical interoperability is domain independent. The data exchanged in the technical interoperability will be independent. In other words, the technical interoperability does not care about the meaning of what is exchanged. The data or semantic interoperability is specific to domain and context and it needs unambiguous codes and identifiers (Benson and Grieve, 2016e). To allow computers to understand, interpret, use and share data without any mistake is what semantic interoperability does. Both the receiver and sender of this data need to recognise it in the same way. Achieving a semantic interoperability in eHealth domain is challenging. The recommendations of the European Commission have stated that the semantic interoperability of EHR systems is essential to improve the quality and safety of patient care, clinical research, public health, and health service management (Martínez-Costa et al., 2010). The process or human interoperability is achieved when human beings manage to share a common understanding of different business systems and

achieve a coordinated process by working together. People achieve benefits when they use information originating elsewhere in their day-to-day work. Process interoperability ensures seamless communication between different healthcare systems by developing the shared understanding of their process artefacts (Khan et al., 2013). The institutional or clinical interoperability is specific to the healthcare field and is defined as the ability for two or more clinicians in different care teams to transfer patients and provide seamless care to the patient. Clinical interoperability is a subset of process interoperability. To improve safety in medical environments, there is a need to develop interoperable medical devices that can automatically operate with safety interlocks so as to operate without a human in the loop (Kim et al., 2010). This is to increase interoperability among medical devices to reduce accidents caused by human errors (Kim et al., 2010). Semantic and technical processes and clinical interoperability are co-dependent, and to deliver substantial business benefits to the healthcare domain they are all necessary. Every health organisation maintains their patients' health records with the organisation approved standard. If they would like to exchange their health data with other health organisation and if they both follow the same standards, the health data might be exchanged efficiently without any major issue. However, if both organisations follow different standards, the data is not interoperable or exchangeable between these organisations. Even with the same standards, the data schema might not be same due to their preferred operating system. In both scenarios, the interoperability is not realised and ruined the benefits of eHealth initiatives (Batra and Sachdeva, 2016). This is a tiny example of interoperability's role in improving the progress of eHealth services.

Using web services, XML based messaging standards and service oriented software architecture instead of the closed database (Pearce et al., 2011) could fix the interoperability issues in the current healthcare domain. The Australian federal government allocated $466.7 million over 2 years in its 2010 budget for MyHR (My Health Records), previously known as Personally Controlled Electronic Health Record (PCEHR) (Pearce and Haikerwal, 2010). However, the Australian healthcare system lags behind all other sectors of the economy. The hospital sector is not computerised well enough compared to general practice

and community pharmacy. The general practice and community pharmacy sectors' data are not integrated into hospital sectors. Moreover, every health organisations function like a silo and health data are not shared and interoperable between organisations. Considering the extensive benefits offered by the eHealth initiatives, it is worth to resolve all these interoperability related issues associated with MyHR initiative.

2.4 Security technologies in Healthcare

eHealth security includes the protection of data integrity, availability, authenticity, confidentiality and privacy (Dritsas et al., 2006). eHealth security is critical to gain health professionals' and patients' trust and acceptance to use the eHealth systems efficiently. The privacy law to protect patients' confidentiality should be followed by healthcare providers. At present, all countries are facing breaches on privacy data persistently. The main reason for these data breaches is to steal the privacy data (McCann, 2014). These discouraging acts will create negative impacts to health professionals and patients to accept and keep their privacy and medical data in EHR system. Privacy data associated with health data may be used to harm the data owner by the negative individuals with cruel intent. Once these negative individuals recognize the value of the personal medical and health data, then they use both external and internal attack to steal the privacy data (Al Ameen et al., 2012). Any organisation's reputation will be damaged by the cyber-attacks (Team, 2015) and afterwards the customer trust on these organisations will be lost. Verizon's report evaluates the cost per record, linked with specific damage cost on privacy data associating with every kind of cyber-attack. Lisa Gallagher, HIMSS (Healthcare Information and Management Systems Society) senior director of privacy and security, when addressing the 2012 Boston privacy and security forum, revealed that around 40 to 45 million patient records have been compromised.

The resolution for these security issues can be achieved when the nature of the threat is identified and analysed properly. At the time of eHealth application security design, adequate time and effort should be spent appropriately. A

suitable security pattern should be adopted to achieve the right security solution (Schumacher et al., 2013). The well-proven and existing security models should be adapted to design and promote effective software design practices (Dritsas et al., 2006). Peace of mind of patients is the main goal to be considered and to achieve this goal, audit trails and access-based model such as role-based access to different healthcare services must be enabled to address these eHealth challenges (Win, 2005). Identification using biometrics and RSA token device based electronic tag with additional security code will also strengthen and provide improved authentication mechanism. There are several other security standards such as e-certificate, digital signature and multi-factor authentication are available to safeguard the privacy data and make sure these privacy data can be managed by authorised users. The traditional authentication pattern using logon ID and password is a weak means of data protection as the password can often be compromised and accidentally revealed. A multi-factor authentication is a right solution to overcome this authentication issue and it is useful to improve the overall security process (Fung, 2006).

e-Certificate is a digital file that authorises and identify the key ownership of an individual or an organisation or a computer based system. There are few recognised Certificate Authority in Australia. National Authentication Service (NASH) is a certificate authority in Australia who is the provider of Health Public Key Infrastructure (PKI) certificates. Healthcare providers and supporting organisations must have a National Authentication Service for Health (NASH) PKI certificate to access the My Health Record system. NASH issues public keys and software to generate private keys for individuals to access MyHR (My Health Records), securely share data between MyHR and health information software at clinician end and access the NASH PKI directory (Shen et al., 2012). A healthcare provider, a contracted service provider, or a general supporting organisation that assists in the delivery of digital health (IT company) who are registered in the Healthcare Identifiers (HI) are eligible to apply PKI from NASH (Coles et al., 2013).

Digital signatures are analogous to ordinary physical signatures on paper which bind the message origin to the exact contents of the message. It establishes sender authentication and message integrity. A tamper resistant and persistent evidence of "who did what to whom" can be created by a digital signature, which is important for any compliance requirements and carry out high legal risks related tasks. Transaction integrity, authentication and non-repudiation are achieved using digital signatures. The digital signature in the document is to ensure that it is reliable and validated document, and any act of changing the document after it is signed will invalidate the digital signature that is on it. Since the owner of a digital signature cannot later deny that he or she signed the document (Menezes et al., 1996), the assurance on non-repudiation of document origin can be achieved easily. PKI certificates use secure hash algorithm (SHA) technology to send secure messages and other transactions online. A hash function takes a variable length input and returns a shorter output of fixed length. MD5 and SHA-1 are two modern hash functions available. MD5 was designed by Ronald Rivest in 1991 (Li, 2003), was widely used. SHA-1 was designed by National Security Agency (NSA) in 1993. It was popularly used in SSL, PGP, SSH and S/MIME certificates. Digital signatures bind the authority information directly to messages and Digital certificates can convey credentials, licences, affiliations and other similar authority information, to streamline the transaction processing (Wilson, 2005).

Apart from the main security standards such as digital certificates, cryptography and multi-factor authentication, there are few other techniques such as anonymisation, pseudonymization (Neubauer and Heurix, 2011) and audit trails can also be used to protect patients' data. Anonymization is the process of removing personal and identifiable elements from the data (Kushida et al., 2012), which makes it lesser subject to stringent privacy regulations of personal data and less sensitive while maintaining its value for legitimate purposes. Pseudonymization is the process of replacing the personally identifiable data with other values (Gilbert et al., 2001) such as replacing a patient ID with an arbitrary number. Audit trails preserve a record of activities occurred in the past on the electronic health information. The patient identification, user identification, activity

date and time (Shamos, 1993) are logged when electronic health information is accessed, modified, created, or deleted, with a log of which actions occurred and by whom. Every transaction is logged and can be tracked. The log file can be used to detect any abnormal activity patterns and subject to routine observation.

Security when communicating with partner health organisations is critical. There are different aspects to be covered during the health message communication. It can be characterised by communication content, partners, infrastructure, and services. These present different communication conditions and may lead to diverse security threats and demands the suitable countermeasures (Blobel, 1997). If the security is implemented at the message level, then the message data size will increase to accommodate the additional security features (Voos et al., 2010). Basically, the security in the communication between the system and the web server is established using transport level or message level security. To avoid the complexity of implementing encryption and signing software components at both ends of the communication channels, and to reduce the message size, many eHealth systems offer transport level security. However, transport level security has the main disadvantage, which is the message could be changed without detection at an intermediary point.

Encryption at the message level can be completed by few different patterns. Implementing encryption and component signing at both communication channels or using a SOA, service oriented architecture or by enabling suitable web service. When an XML message is added with a security feature, it will increase the message size during communication from one system to another. Since the message size is the critical factor when transferring data from one health organisation to another or from one ward to another in the same hospital, implementing the security in the web layer is optimum. This will enable efficient data communication between health organisations. FHIR has few open source solutions such as SMART (Substitutable Medical Applications, reusable technologies) FHIR APIs. The SMART FHIR APIs can be integrated easily with

REST (Representational State Transfer) based health messaging standards. H7 V3 can use these features using the RIM (Reference Information Model) features.

2.5 Privacy technologies in healthcare

The law of privacy to ensure patients' privacy data and confidentiality should be followed by healthcare providers carefully. All countries have legislation to protect health information privacy. However, all countries are facing challenges in privacy data breaches. Privacy data stealing (McCann, 2014) is the main reason for these data breaches. These discouraging acts will create negative impacts to general public and patients who prefer to keep their medical data in EHR system which subsequently resists the progress of further eHealth growth.

As per *NSW Health Records and Information Privacy Act 2002*, health data must not be exposed to anyone other than for its prime purpose. Explicit consent should be attained before processing the health and medical data. In specific situations such as a health professional who undertook the task and owes a duty of confidentiality (Win, 2005) and the medical data are required for an urgent medical needs may be excluded. However, in certain circumstances, the consent model may not be executed as per the Information Privacy Act such as patient's violent behaviour and their emergency status and threat to public safety. To cover this scenario, the consent model in healthcare services needs to be categorised and implemented according to their category. There are few different types of consents (Coiera and Clarke, 2004), such as 'General Consent', 'General Denials', 'General consent with specific denials' and 'General denial with specific consent' to balance patients' privacy and health professional's efficient service delivery. According to the practical implications, these consent models need to be amended and implemented in the current EHR services and applications.

HL7 privacy related standards for HL7 version2, version 3 and FHIR are targeted for the audience such as public health laboratories and clinics, immunisation registries, standards development organisations (SDOs), local and state departments of health, pharmaceutical vendors, EHR, PHR vendors, equipment vendors, quality reporting agencies, regulatory agency, health care IT vendors, clinical decision support systems vendors, lab vendors, HIS vendors, emergency services providers, medical imaging service providers and healthcare institutions such as hospitals, long term care, mental health and home care (Health-Level-Seven-International, 2017c). HL7 messaging standards (all versions) address many key objectives. Identify important concepts in the area of privacy and security in the IT domain, establish standardised names for concepts in the area of healthcare IT security and privacy, provide clear, precise textual definitions to concepts in the area of healthcare IT security and privacy, constitute an authoritative ontology such as formally and unambiguously defined using OWL, Ontology Web Language and classified in an organised taxonomy, support consistent and effective Healthcare IT software implementations, especially by enabling security and privacy systems, align with other Healthcare IT terminologies such as SNOMED CT and the HL7 vocabularies (Health-Level-Seven-International, 2017c).

2.6 Interoperability, Security and Privacy in healthcare messaging

The interoperability, security, and privacy are closely related to each other. For better interoperability, the eHealth application security should be strong and reliable. The healthcare domain has a specific set of regulations for security and privacy related matters. Privacy, according to the Healthcare Insurance Portability and Accountability Act (HIPAA) of 1996, is defined as an individual's interest in limiting who has access to his or her personal healthcare information. (Kahn and Sheshadri, 2008). It also specifies that all the physical, administrative and technical safeguards in an information system must be encompassed by security measures. For healthcare providers, a set of rules and regulations has been established by the HIPAA, demanding that uses of protective health data not needed for payment, treatment or operations be limited, that all employees are in covered entities and that all patients be informed of their privacy rights.

There are two main security concerns within the EHR systems (Kahn and Sheshadri, 2008) which are access and transmission security. The healthcare delivery organisation's ability to ensure that system access is granted only to appropriate individuals is referred to as access security (Alhaqbani and Fidge, 2007). The healthcare's ability to ensure that transmitted data is secured from potential security threats is referred to as transmission security. Whoever has the authority to create usernames should be designated by the healthcare delivery organisation, and the organisation should disable authority to anyone who leaves. User identification should not be shared, but should be individual. Access should also be based on roles. The minimum access that is necessary for he or she to perform their job is required. Firewalls would be required for internet-facing remote access solutions as to limit access to certain devices, such as remote access servers.

Healthcare providers have been able to enable eHealth services to share and export aggregated administrative and clinical data electronically with patients and other healthcare providers. This is possible due to recent developments in eHealth services. Until the release of CCR, Continuity of Care Record, interoperability issues limited the capability to share healthcare data electronically between healthcare providers. However, the American Society for Testing and Materials (ATSM) unveiled the CCR in June 2005. The CCR had various data elements with demographic information appearing at the top, which was followed by clinical information and a plan of care, all based on a paper form. Extreme strict rules for both implementation and vocabulary are in place for any healthcare delivery organisation that exports CCRs. Later HL7 international organisation worked with ASTM (American Society for Testing and Materials) to harmonise the CCR with CDA (Clinical Document Architecture) which has improved the interoperability and helped to exchange the required health data between healthcare providers. The new joint standard, the Continuity of Care Document (CCD), lets institutions aggregate the data sets defined in the CCR and share this information electronically with HL7 messaging. In a paper-based office, the

privacy of protected medical information depends entirely on the physical safeguards the office maintains. This is almost same for the digital office as well. It is not possible to eliminate all the paper in a patient's medical records. HIPAA privacy policies require that protected health information in any office be kept from the general public's view at all times (Kahn and Sheshadri, 2008).

As part of the study, a detailed search was conducted in the existing research papers to gather analysis information about health messaging standards comparison focusing on features interoperability, security and privacy. Here are the details with research article title and its coverage about interoperability, security and privacy.

Research Article Title	Comparison information about interoperability, security and privacy in HL 7 v 2 and 3 and FHIR
HL7 FHIR: An Agile and RESTful Approach to Healthcare Information Exchange (Bender and Sartipi, 2013)	This research article has covered the basic details about the evolution of the HL7 messaging standards mostly on HL7 FHIR. In addition, there is a comparative analysis between HL7 FHIR and previous HL7 messaging standards on features such as semantic interoperability, architectural paradigm and other general support related aspects. The research did not provide any details on security and privacy related features. It did not provide adequate details on interoperability.
A comparison of two Detailed Clinical Model representations: FHIR and CDA (Smits et al., 2015)	This research article has explained the Detailed Clinical Model (DCM) paradigm which is to separate the data models from their underlying technical data model. Further, this research compares the implementation of DCM in HL7 CDA and FHIR. This is slightly covering the interoperability issues by transforming a message from CDA to FHIR. Here, Security and privacy features in CDA and FHIR are not compared.
Standard Guide for Implementing EDI (HL7) Communication Security (Blobel et al., 1998)	This research article has covered the communication security when implementing HL7 messages. However, the article release date is sept 1998 and it is clearly outdated. Though it has covered the security aspects up to protocol level, it might not be very useful with the modern technological advancements with sophisticated security enablement with web services. HL7 V3 with RIM and FHIR have latest security features which were not available during this article release. Also, there are no details covered on interoperability and privacy related features.
FHIR: Cell-Level Security and Real Time Access with Accumulo (Ruiz, 2016)	This research article has covered cell-level security for HL7 FHIR messaging standard. The interoperability and privacy aspects are not covered in this article.
Towards a HL7 based Metamodeling Integration Approach for Embracing the Privacy of Healthcare Patient Records Administration (Feltus et al., 2014)	This research article has covered the metamodeling integration approach to cover privacy and related interoperability. However, there is no comparative analysis done with other HL7 messaging standards.

DMAG contribution to the HL7 Security and Privacy Ontology (Delgado et al., 2010)	This research article has covered privacy ontologies and related standardisation process which is specific to HL7 security related methods. However, there is no comparison with other HL7 messaging standards on interoperability and privacy related features done. Moreover, the security details about the messaging details are not covered in detail.
An application of the Privacy Management Reference Model & Methodology (PMRM) to HL7 consent directive use cases (Guinan, 2013)	This research article has covered privacy related details, particularly privacy protection measures based on the Canadian's electronic medical records system. The article used the methodology called Privacy Management Resource Model (PMRM) to analyse the HL7 use cases. However, this article did not compare with other messaging models particularly for Interoperability, security and privacy features.
Towards achieving semantic interoperability of clinical study data with FHIR (Leroux et al., 2017)	This research article has covered the semantic interoperability benefits when studying the clinical data with FHIR based messaging standard. None of the HL7 version message standards except FHIR is analysed and compared in this article. Moreover, the security and privacy-related issues are not covered.
Suitability of Fast Healthcare Interoperability Resources (FHIR) for Wellness Data (Pais et al., 2017)	This research article has covered the wellness data to improve the interoperability between a healthcare provider and patient. The wellness data contains details such as blood glucose readings, blood pressure readings and Body Mass Index (BMI) data. The article has only analysed HL7 FHIR and no other health messaging standards are covered here. The security and privacy issues are also not covered.
A Fast Healthcare Interoperability Resources (FHIR) layer implemented over i2b2 (Boussadi and Zapletal, 2017)	This research article has covered the feasibility of implementing a Java layer over the i2b2 database model to expose data of the clinical data warehouse as a set of FHIR resources. Though it has covered the semantic interoperability related features in FHIR, it did not cover enough details on the earlier versions of HL7 message standards. The security and privacy issues are not covered as well.
Cyber-healthcare cloud computing interoperability using the HL7-CDA standard (Lubamba and Bagula, 2017)	This research article has analysed the interoperability in cloud and fog computing platforms. Most of the analysis was done using HL7 CDA. There is no comparison made on the HL7 messaging standards among version 2, version 3 and FHIR. The security and privacy issues are not covered as well.

The study process shows clearly that there is no such comparative study conducted in the past on the health messaging standards namely HL7 v2, v3 and FHIR to achieve interoperability, security and privacy cohesively.

(3) Research Objectives

As the above literature review shows, there is relatively a large gap in research that cohesively and completely compare of healthcare messaging standards, in the presence of healthcare data standards, in order to ascertain the success of each messaging standard in achieving the security, privacy and interoperability needed in the health domain. Therefore this research project addresses this gap by associating interoperability, security and privacy issues by conducting comparative study on different health messaging standards. When comparing the different messaging standards, choosing the exact health standard which satisfies all the requirements of interoperability, security and privacy, is the prime objective. HL7 family products, HL7 v1, v2, v3 and FHIR are the main standards to be compared for the features covering with interoperability, security and privacy. Exploring how these messaging standards interact with health data standards such as ICD, LOINC and SNOMED is also an objective of this research. The technical flexibility of using the latest technologies such as RESTful APIs, XML data transfer and JSON client side script approaches are additional requirements to choose the right health messaging standard. Implementation friendliness and cost to implement, training to health professionals and popularity are other minor considerations when selecting the right messaging standard.

3.1 Research Questions

Following is identified as the main research question of this study:

Out of healthcare messaging standards, namely HL 7 v1, v2, v3 and FHIR, which is the best to achieve interoperability, security and privacy needed in the healthcare domain, with the appropriate use of healthcare data standards, in a cost effective and easily implementable manner?

As part of answering this research question, a comparative study is conducted and analysis is derived. The main research question raises these sub-questions:

1. How does HL 7 v1, v2, v3 and FHIR structurally differ from each other?
2. How are these messaging standards practically implemented using other commonly known standards such as CDA (Clinical Document Architecture) and IHE (Integrating the Healthcare Enterprise)?
3. What is the interaction between health messaging standards such as HL7 (Health Level 7), FHIR (Fast Healthcare Interoperability Resources) with related health data standards such as SNOMED CT, ICD, DICOM and LOINC?
4. What are the costs and training needs associated with the implementation of health messaging standards such as HL7 and FHIR?
5. How does HL7 and FHIR compare in terms of effort needed in implementation?

Section 5 captures the data required for answering the above sub-research questions 1 and 2. Followed by section 6 answering the sub-research question 3. Sub-research question 4 and 5 are answered in section 7, case study and in section 8, findings.

(4) Research Methodology

The research method used in this project is a comparative study based on qualitative analysis. It consists of studying the existing comparative studies conducted in the health messaging and data standards, discovers the gaps and proposes a solution for the identified gaps. The study process started from finding relevant literature in relation to core the identified sub-research questions. The collected data is tabulated and analysed in arriving at a conclusion.

The tools used to find appropriate and relevant papers are Google Scholar (https://scholar.google.com.au), Pubmed (https://www.ncbi.nlm.nih.gov/pubmed/) and Western Sydney University online library (library.westernsydney.edu.au). Selected papers are first shortlisted based on the title and abstract. Shortlisted papers are further read to extract the information needed for this research.

For the comparison of the health messaging standards, few specific criteria are selected. The comparison criteria were developed based on current literature that discusses the importance of each of them in the healthcare domain. The comparison criteria include:

1. Interoperability method (Bender and Sartipi, 2013)
2. Security (Blobel et al., 1998)
3. Usage of encryption (Marshall, 2004)
4. Privacy (Harispe et al., 2014)
5. Compatibility (Mead, 2006)
6. Flexibility (Mandel et al., 2016)
7. Reliability (Mykkänen and Tuomainen, 2008)
8. Granularity features (Yan et al., 2017) and
9. Other miscellaneous features such as technology (Bender and Sartipi, 2013), transport mechanism (Beyer et al., 2004), popularity (Bender

and Sartipi, 2013), adoption rate (Lin et al., 2012), and implementation cost (Bender and Sartipi, 2013).

The above features are used as the column headings of the comparison table.

The comparison study result is summarised in table format with the features which are taken into the research study and how these features are handled by each health messaging standards such as HL7 V1, V2, V3 and FHIR. At the end of the tabulation of data, the recorded data were analysed to arrive at the conclusions.

In order to understand the inner working of HL7 v1, V2, v3 messaging standards, a software tool HL7spy (Mann et al., 2011) was utilised. Further, a mock implementation of HL7 messaging testing was implemented in order to gain a better understanding of the capabilities and limitations of each and also to gain an opinion on how easy the implementation of each messaging standard. The tabular data is recorded in a MS Word file and used for comparisons.

There was a case study analysis conducted in eHealth, New South Wales (NSW) State to understand the popularity in usage of messaging standards and other ongoing challenges in the maintenance cost and training requirements. The complete study information is covered in detail in section 7 case study.

There are few limitations which affect the proposed solution and the dissertation. The limited time did not allow to test the implementations for the full level that would facilitate the ease of implantation using a number of programmers. Only the findings of the researcher combined with what is recorded in the literature are reported here. Further, a thorough testing was not able to be completed in such a manner so that system is ethically hacked to understand the limitations of the messaging standards.

(5) Healthcare Messaging Standards

HL7 standards are formed by HL7 International, which provides healthcare organisations with standards and specifications for enabling their systems interoperable. HL7 standards refer the application layer, which is layer 7 in the OSI, Open Systems Interconnection model. The OSI model consists of seven layers. The upper three layers are covering the application related functions and the bottom four layers are covering the transmission of data. There are three major versions of HL7, namely HL7 v1, v2 and v3. The earlier versions of HL7 v1 are a simple prototype and no real implementations were done with those versions. HL7 V2 is the popular and most implemented version. HL7 V3 is RIM (Reference Information Model) based and less flexible as there are more compulsory details for medical records to be entered.

5.1. HL7 Version 1 release

The first version, HL7 version 1.0 (v1) was issued in the year 1987. Admissions, discharges and transfers (ADT) within hospitals were the initial focus of HL7. HL7 v1 was the simple prototype and there was not any implementation done using this version. Compared the later versions, especially HL7 version 2, HL7 version 1 was the least implemented one.

```
Admit a Patient - Trigger Event 01

MH*\*SYS01*SND01*PW*SYS08*SYS08PW19870821*1409*ADT*MSG0005*P*19-
870801*N<cr>
AT*01*19870821*1401<cr>
pid BLT*PATID1234*BLGNO4567<cr>
PT1*JONES\WILLIAM\A\III*H*19500204*C*P*M*FATHER*JONES\WILLIAM-
\A\JR*4155551212*415545122134<cr>
PT2*I*1W\3002\1*19870821*1401**DR912**SURG**1CD01***AD<cr>
ADR*12 W MAIN STREET**GREENSBORO*NC*99012<cr>
MT*271*XO4<cr>

Patient William A. Jones, III was admitted on August 21, 1987 at
2:01 p.m.  by doctor  DR919 for  surgery SURG.  He was given Room
3002, bed 1 in department 1W.  The  admitting diagnosis  code was
1C\01.  Because this was a new admit, the event date and time are
the same as the admit date and time.

The message was sent  from  /stem  SYS01 to  system SYS08  on the
same date as the admission took place but eight minutes after the
admit.  The standard version date of the sending system is August
1, 19876.  No Acknowledgment was requested.
```

Figure 5.1.1 Sample ADT message with HL7 V1 (Spronk, 2014)

The handwritten correction on the PID (Patient Identification) section by the reviewer was due to the segment name change during the HL7v1 development process.

5.2. HL7 Version 2 release, HL7 V2

HL7 V2 (version 2) is the most commonly used healthcare messaging standard in the world (Eichelberg et al., 2005). HL7 version 2.1 of HL7 was the first implementable version since its release. In HL7 V2, the messaging events are triggered upon receiving the HL7 messages. HL7 messages are structured and defined by an abstract message syntax table (Benson, 2012) and are categorised by segments. Segments hold fields and fields hold components. The components may hold subcomponents (Huang et al., 2003), which are separated by delimiters. The HL7 v2 messaging standard has been in development phase for more than 25 years (Health-Level-Seven-International, 2017a). The scope and size of HL7 v2 have changed significantly during its long development period. But, the base messaging design pattern is not altered. HL7 v2.0 was released in the year 1988, and this has covered a major addition to the reports for exchanging orders which are used for medical tests and treatment in hospitals. Then later HL7 v2.1 was released in the year 1991, which was the first widely used version. The complete documentation of HL7 v2 has almost one million words with 2500 pages.

The abstract syntax for HL7 version 2 is as below:

MSH	Message header
PID	Patient Identification Details
PV1	Patient Visit
OBR	Results header
OBX	Results detail (repeats)

The design pattern of an HL7 v2 message to meet this requirement is:

```
MSH|delimiters||sender|||dateTime||messageType|messageID|processingStatus|syntaxVersion
PID|||patientID^^^source^IDtype||familyName^givenName||dateOfBirth|sex|||streetAddress^addre
ssLine2^^^postCode
PV1|||patientLocation||||||patientsGPOBR|||accessionNumber|testCode^testName^codeType|||spe
cimenDate|||||||||specimenSource^^^bodySite^siteModifi er|requester
OBX||valueType|observableCode^observableName|observationSubID|valueCode^valueText^valu
eCodeType|||abnormalFlag
OBX ...
```

Then when substituting the values,

```
MSH|^~\&||^123457^Labs|||200808141530||ORU^R01|123456789|P|2.4
PID|||123456^^^SMH^PI||MOUSE^MICKEY||19620114|M|||14Disney Rd^Disneyland^^^MM1 9DL
PV1|||5 N|||||G123456^DR SMITH
OBR|||54321|666777^CULTURE^LN|||20080802|||||||||SW^^^FOOT^RT|C987654
OBX||CE|0^ORG|01|STAU|||||||F
OBX||CE|500152^AMP|01||||R|||F
OBX||CE|500155^SXT|01||||S|||F
OBX||CE|500162^CIP|01||||S|||F
```

The above example shows the OBX component repeated.

There are mandatory and optional segments. MSH, PID, PV1 and EVN are
mandatory. PD1 is indented and nested inside the PID segment and this is an
optional segment. NK1 is repeatable optional segment. Every segment starts with
a three character identifier such as MSH and PID. The three character identified
is followed by the pipe field separator, "|". To indicate an empty field, two adjacent
separators, "||" is used. To represent a null character, a character such as |""| is
used. Apart from the field separator, the component separator is represented with
a hat character, "^". Then the tilde, "~" character is used to represent the repeat
separator.

5.3. HL7 Version 3 release, HL7 V3

The presence of optional data segments in the HL7 V2 makes it as a flexible messaging standard. However, these optional elements also make it impossible to have reliable data integrity when it comes to health messaging implementation. HL7 V3 solve this issue with a well-defined approach with much lesser optional segments and more reliable (Beeler, 1998) techniques. HL7 V3 uses a RIM, Reference Information Model with an object oriented development methodology to create messages.

Table 5.3.1 RIM Core classes and its definition (NormanGilliam, 2017)

RIM Core Classes	Definition
Entity	A physical thing, a group of physical things or an organisation capable of participating in Acts, while in a role
Role	A competency of the Entity playing the Role as identified, defined, guaranteed, or acknowledged by the Entity that Scopes the Role
Participation	An association between an Act and a Role with an Entity playing that Role. Each Entity (in a Role) involved in an Act in a certain way is linked to the act by one Participation-instance.
Act	A record of something that is being done, has been done, can be done, or is intended or requested to be done
Role Link	A connection between two roles expressing a dependency between those roles
Act Relationship	A directed association between a source act and a target act
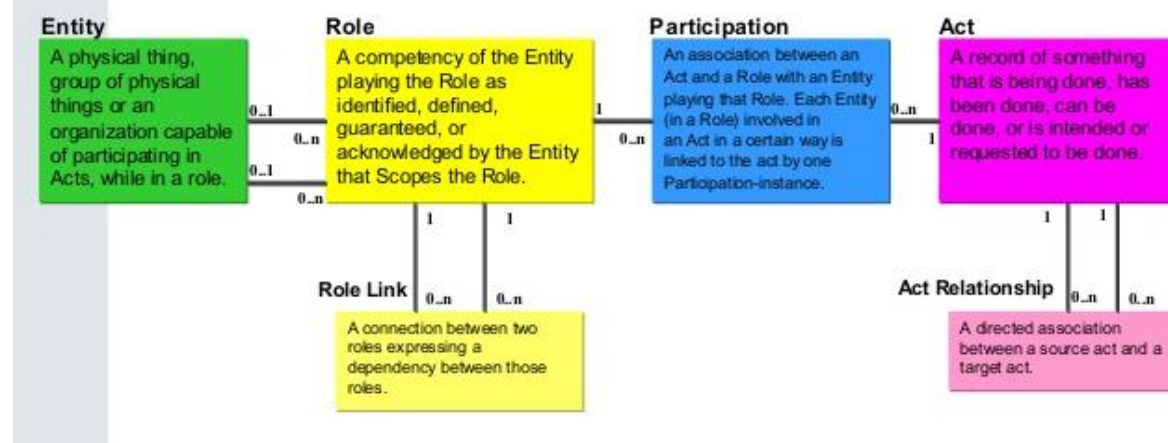
Figure 5.3.1 RIM Core Classes relationship (NormanGilliam, 2017)

The RIM provides basic building blocks and structure for HL7 v3 messages. RIM has Act, Role and Entity as the main classes. There are linked together by Act Relationship, Participation and RoleLink (Dolin et al., 2006) association classes. The XPath notation is used to denote these classes and attributes. Act class is identified by Act-id and the Role class is identified by the Role-id (Umer et al.). HL7 v3 has two types of code. The first one covers the structural attributes and is defined by HL7 itself and the second one covers the externally defined terms and code such as LOINC and SNOMED CT. The relationship part is managed by the RoleLink, association class which establish a relationship between two roles such as between jobs in an organisation chart.

In HL7 v3, the RIM role is critical and considered as a healthcare interoperability universal reference model (Hasman, 2006), covering the whole health domain. The RIM backbone core classes, relationships and structural attributes. The structural attributes, classCode and moodCode determine the meaning of each class. Each class may have specialisations (Orgun and Vu, 2006) and a predefined set of attributes. Each attribute further contains a data type. RIM

based model is too complex to learn and use. The XML attributes used in HL7 v3 are derived from the HL7 v3 data types (Yuksel and Dogac, 2011). HL7 v3 data schemas are complex, verbose and detailed.

Each class in RIM has a pre-defined attributes and HL7 v3 allows only these messages. Each attribute has a specific data schema (Umer et al., 2012). These data schema and attributes represent the elements of HL7 XML messages. Refined Message Information Model, RMIM is a graphical representation of HL7 v3 (Yuksel and Dogac, 2011) and shows the structure of a message as a colour coded diagram. HL7 provides a special toolset to support RMIMs functionalities. The new generation tools replace the old Microsoft Access and Visio tools which were the original toolsets available at the earlier time. Model Interchange Format (MIF) (Scott and Worden, 2012), a set of inter-related XML schema, is the basis of these tools. The primary artefacts which are defined by these MIFs, can be exchanged as a result of HL7 V3 standards implementation.

HL7 Development Framework (HDF) (Lopez and Blobel, 2009), the HL7 v3 standard development process, defines the RIM based governance rules to derive the domain information models and the refinement of those models into HL7 standard specifications. The HL7 Version 3 Development Framework (HDF) is a continuous practice that strives to develop standards. HDF is the latest version of the HL7 V3 development methodology (Blobel et al., 2006). It supports to enable interoperability within healthcare application and services. In addition to the documents messaging, HDF covers the tools, actors, rules, processes and artefacts relevant to HL7 standard development specifications. HL7 specifications draw upon codes and vocabularies from a variety of sources. The HL7 V3 dictionary work guarantees (Hasman, 2006) that the systems implementing HL7 messaging standards have a clear and unambiguous understanding of the code sources and code value domains used in the HL7 specifications. HL7 v3 was implemented in places where there are little or no existing systems.

5.4. HL7 v3 - CDA, Clinical Document Architecture

Clinical document architecture, CDA is the popular and the most widely adopted implementation of HL7 v3. Document is used to exchange the messages in CDA. There are three levels (Dolin et al., 2001) of document exchange pattern available in CDA. Level 1, single human readable document, Level 2 can include multi documents and Level 3 can include organised information. Level 1 with a human readable body has a header which contains basic metadata for information retrieval. For an example, a jpeg image, a pdf document, or a text document can be a body and possibly contain formatting markup.

```
1    <?xml version="1.0"?>
2    <!DOCTYPE levelone PUBLIC "-//HL7//DTD CDA Level One 1.0//EN" "levelone_1.0.dtd">
3    <levelone>
4      <clinical_document_header>
5        <id EX="a123" RT="2.16.840.1.113883.3.933"/>
6        <set_id EX="B" RT="2.16.840.1.113883.3.933"/>
7        <version_nbr V="2"/>
8        <document_type_cd V="11488-4" S="LOINC"
9          DN="Consultation note"/>
10       <origination_dttm V="2000-04-07"/>
11       <confidentiality_cd ID="CONF1" V="N" S="HL7_Confidentiality"/>
12       <confidentiality_cd ID="CONF2" V="R" S="HL7_Confidentiality"/>
13       <document_relationship>
14         <document_relationship.type_cd V="RPLC"/>
15         <related_document>
16           <id EX="a234" RT="2.16.840.1.113883.3.933"/>
17           <set_id EX="B" RT="2.16.840.1.113883.3.933"/>
18           <version_nbr V="1"/>
19         </related_document>
20       </document_relationship>
21       <fulfills_order>
22         <fulfills_order.type_cd V="FLFS"/>
23         <order><id EX="x23ABC" RT="2.16.840.1.113883.3.933"/></order>
24         <order><id EX="x42CDE" RT="2.16.840.1.113883.3.933"/></order>
25       </fulfills_order>
26       <patient_encounter>
27         <id EX="KPENC1332" RT="2.16.840.1.113883.3.933"/>
28         <practice_setting_cd V="GIM"
29           S="HL7_PracticeSetting" DN="General internal medicine clinic"/>
30         <encounter_tmr V="2000-04-07"/>
31         <service_location>
32           <id EX="KXLPa123" RT="2.16.840.1.113883.3.933"/>
33           <addr>
34             <HNR V="970"/><STR V="Post St"/><DIR V="NE"/>
35             <CTY V="Alameda"/><STA V="CA"/><ZIP V="94501"/>
36           </addr>
37         </service_location>
38       </patient_encounter>
39       <legal_authenticator>
40         <legal_authenticator.type_cd V="SPV"/>
41         <participation_tmr V="2000-04-08"/>
42         <signature_cd V="S"/>
43         <person>
44           <id EX="KP00017" RT="2.16.840.1.113883.3.933"/>
45           <person_name>
46             <nm>
47               <GIV V="Robert"/><FAM V="Dolin"/><SFX V="MD" QUAL="PT"/>
48             </nm>
```

Figure 5.4.1 Sample HL7 v3 CDA message (Dolin et al., 2006)

Level 2 of CDA is similar to Level 1, as they have the same header but the body may be a blob (Binary large object) with an unstructured file format. CDA Level 3 (Calamai and Giarré, 2010) allows both narrative block and structured data. Although Level 3 may seem complex, it offers the benefits of both machine

processed structured documents and human readable documents, making it more popular than Levels 1 and 2.

The CDA defines HL7 v3 RIM based documents which include administrative and clinical data, for specific purposes. After the specific use, a consolidation effort removes the discrepancies of the initial documents, resulting in the current version called Consolidated CDA (CCDA) (Chronaki et al., 2014). The CCD is the key CCDA document which primarily used for transitions of care such as referring by a PCP (Primary Care physician) to a specialist. CCDA documents are reusable XML which are assembled from standard templates (Braunstein, 2015a). Templates are constructed at the data entry levels which are very similar to paper form, such as forms used by physicians where specific medical details can be noted.

5.5. IHE XDS, cross-enterprise document sharing

IHE XDS (Integrating the Healthcare Enterprise cross-enterprise document sharing), is a common portal to share documents between different healthcare enterprises. The document metadata is kept in the XDS registry, which can be used to find out and retrieve the right search results (Dogac et al., 2006) stored in XDS repositories. The IHE XDS collaborative and distributive approach share clinical documents that are held by different healthcare organisations. The Registry and Repositories are physically and logically separate. The registries stores metadata and are used to retrieve the stored documents. The document repositories have the actual documents. Scanned letters, images, folders, results and other related documents can be received by the user from one or more repositories in a consistent and quick way through user applications connected with XDS.
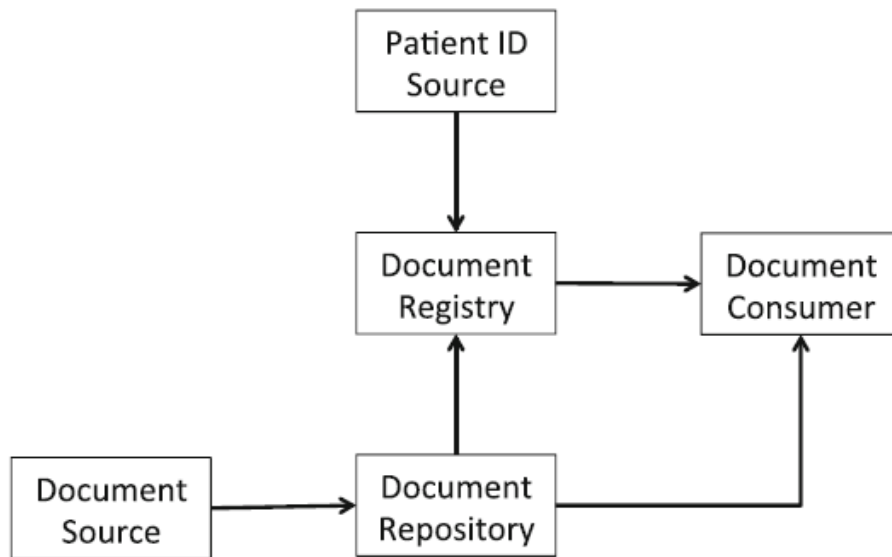
Figure 5.5.1. IHE XDS, Cross Enterprise Document Sharing Model

As indicated in the figure 5.5.1, the documents are submitted to Document Source, usually, HL7 CDA XML documents, to a local Document Repository with the metadata details about each document. The Document Repository provides a persistent storage for all documents and prepared metadata and submit to the Document Registry. Then a distinct Id is generated for each document for Document Consumer to retrieval at a later stage. The local repository still holds these documents and each care provider registers the data they would like to share with other care provider. The user application such as Document Consumer submits search criteria to the registry to locate (Duftschmid et al., 2013) documents that meet the specified search condition. The Document Registry returns the specific identifier with the location and a metadata list from Document Repositories. A distinct identifier is generated for each patient in the affinity domain by the Patient Identity Source. The IHE PIX/PDQ (Patient Identity Cross-referencing / Patient Demographics Query) (Benson and Grieve, 2016d) server may be used to provide the Patient Identity Source. The patient demographic details are retrieved from multiple patient identifier domains using Patient Demographics Query, PDQ and Patient Identity Cross-Referencing, PIX, (Melament et al., 2011) is used for cross- referencing of patient identifiers.

The best example to illustrate the successful implementation of the IHE XDS is the BioMIMS, a SOA Platform for Research of Rare Hereditary Diseases (Melament et al., 2011).
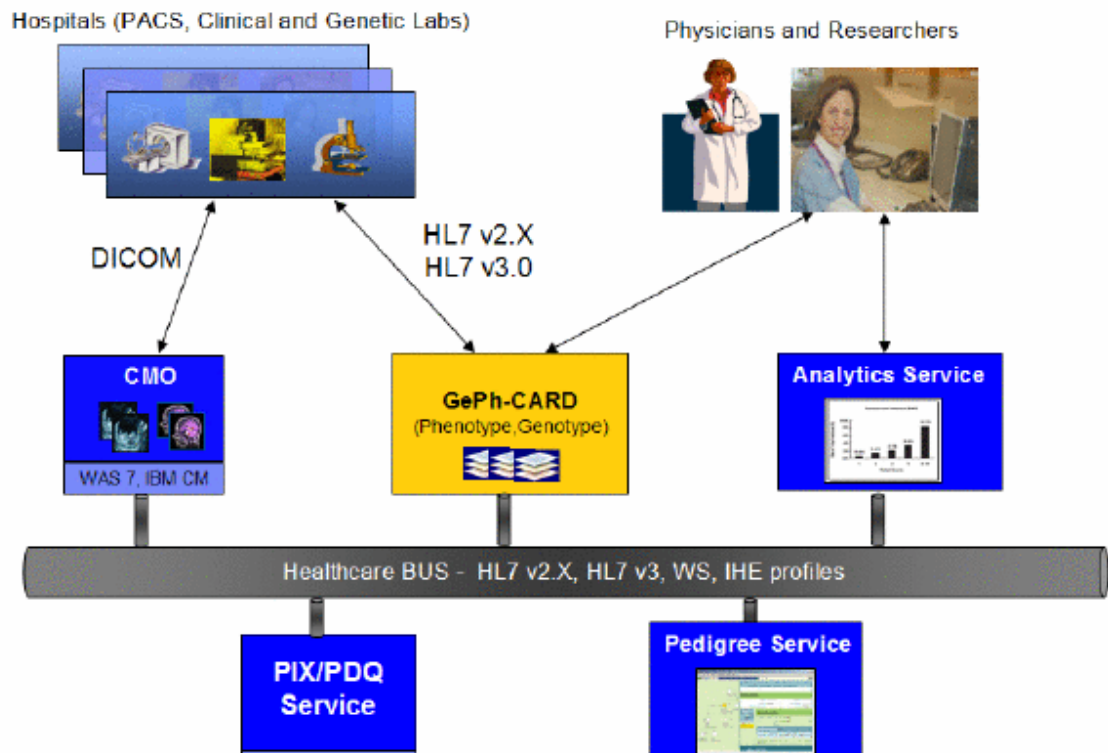
Figure 5.5.2 BioMIMS - SOA Platform for Research of Rare Hereditary Diseases

As per the BioMIMS, SOA platform, the required medical images are retrieved and uploaded to and from the relevant system service with the DICOM v3.0 format. The details of clinical history are transferred according to HL7 v2.x and HL7 v3 standards. The patient identifier's data type might be different from each system. For the patients' identification and their data integrity, IHE Patient Identifier Cross-Reference (PIX) and Patient Demographic Query (PDQ) transactions are used. This allows a single holistic view of combining patients' data which are gathered from different research centres. The metadata is extracted according to IHE Cross-enterprise Document Sharing (XDS/XDS-I) profiles. The advantage of this IHE XDS architecture is the scalability (Melament et al., 2011) of each service layer. The decoupled architecture can be easily upgraded without any effect on the other services implementation.

5.6. Fast Healthcare Interoperability Standards, FHIR

Fast Healthcare Interoperability Standards, FHIR, was established after the earlier HL7 Standards such as HL7 v2, v3 had trouble with implementation issues. FHIR is implementation focused and is built based on RESTful interfaces. All resources in FHIR have references to other resources (Smits et al., 2015), extensions, and a XHTML view which is human readable.

Though HL7 V3 have more advantage than HL7 v2 on consistent definitions and structure, it was complex, time consuming to learn and hard to use. However, FHIR addressed all these issues as FHIR is more on implementation focused (Kasthurirathne et al., 2015) and built with RESTful interfaces. Resources for Health, RFH (Benson and Grieve, 2016d) was the first draft version of the FHIR and it was based on a RESTful API. RESTful paradigm is used by many organisations and published numerous web APIs. The companies such as Google, Apple, Facebook and Twitter are few who are using REST based web APIs (Gravina et al., 2017). The interoperability specifications in FHIR can be grouped into different specifications such as messages, Services and documents.

For data transfers between healthcare systems, FHIR is used as a general messaging standard. Therefore, compared with normal RESTful APIs, FHIR specification is more flexible and wide. In addition, Healthcare information can easily be exchanged across RESTful APIs. FHIR extends support specification (Bender and Sartipi, 2013) for messaging and document approaches using RESTful APIs.

The sample URL for FHIR will display as below:
http://server.sample.com/fhir/Patient/45678
The URL has three sections: [base-address]/[Type]/[id]

Table 5.6.1: FHIR URL Structure (Peterson et al., 2016)

Base-Address	Identifies a FHIR system service. A server that makes the information available in conformance with the FHIR specification.
Type	Identifies a FHIR type service that manages a collection of resources that all have the same type. The type must be one of those defined in the FHIR specification.
Id	Identifies a FHIR instance service that manages an instance of a resource within the collection.

The base feature of FHIR is that every resource contains a narrative, or a human readable form. The narrative is in limited HTML, containing text, images, lists, tables and styles. However, it does not contain scripts, forms, objects or the use of local storage and other similar active content. The data exchange in FHIR API uses record centric approach (Benson and Grieve, 2016d) which initiates the client to not ask the server to perform some operation, but rather tell the server what the contents of the record should be. These are basically called as CRUD services, since the client can do tasks such as Create, Read, Update and Delete records. Each FHIR resource has a UML definitions, JSON and XML templates. All resources have a set of common data, and also have a set of data elements using common data types. The FHIR logical definition which defines all the types (Benson and Grieve, 2016d), represented by a UML diagram or logical table with specific JSON and XML representations.

HL7 FHIR supports multiple paradigms with a great flexibility and simply offers the modern governance of data. FHIR enabled extensions and APIs have been made available to C#, Java, JavaScript, Objective C, Delphi and similar programming systems. Facebook, Twitter, and Amazon organisations are embracing RESTful (Christensen, 2009) web services as their prime API. The related technologies such as XML, JSON, and OAuth (Cabarkapa, 2013), with suitable encoding and authorisation techniques are also used commonly in FHIR. With all these FHIR supported technologies and tools the healthcare industry is not isolated into specific industry standards but can embrace what is used across

all industries. The base requirement of the concept of human readability was introduced with the HL7 CDA standard. Because of this, data could be viewed in a standard web browser, which was the idea. This concept is continued by HL7 FHIR to ensure that the option of human readability will always be available.

The success of FHIR relies on the security and of patient data, which is of utmost importance and it further supports the governance and related maintenance. FHIR enable policies to be built in a way that is protective to the system but not restraining and limiting the capabilities. The data exchange secured with the TLS/SSL (Transport Layer Security / Secure Sockets Layer) and suitable authentication can be made in a number of ways. OAuth (Bloomfield et al., 2017) is the preferred and recommended practice for web centric use. HL7 FHIR fully supports workflows from small devices such as mobile to large hospital information systems. FHIR enables traditional communications between related healthcare applications, patient engagement and other workflows. FHIR can enable any outside open source applications and services which further enable the latest and sophisticated extensions of healthcare services. In addition to the normal content, FHIR resource can carry one or more extensions. As per the FHIR resource format, a value in XML format and a URL that identifies the extension is shown below:

```
<extension url="http://hl7.org/fhir/StructureDefinition/iso21090-en-qualifier">
<valueCode value=" NB"/>
</extension>
```

The URL retrieves (Peterson et al., 2016) a formal definition of the extension that the URL indicated. This will allow the system to process and display this data. The base FHIR data types have the value and data type of the extension. Without accessing the definition of the extension, FHIR data types allow every implementation can write and read the relevant extensions. The implementers

are encouraged to, through their local affiliate or HL7 itself, register their extensions with HL7. HL7, with the support of FHIR specification, provides strong social networks to encourage responsible use of these extensions. HL7 advertise users to register extensions and help to leverage social media to consult with the community specialists so to avoid needing to make their own extensions.

The SMART on FHIR is such an extension (Mandel et al., 2016), and its specifications provide means for healthcare organisations to access clinical data such as lab results, medications, problems, immunisations and patient demographics. FHIR tries to use the best features of HL7 v2 and v3 and fill the gaps that exist with the messaging standards today. In addition, other standards organisations are prepared to support HL7 in the FHIR development process. IHE International is one of those organisations, which plan to enable FHIR across MHD (mobile XDS), VPIXm/PDQm (patient identification), X mACM (alerting) and several other profiles.

FHIR was built to improve security using HTTP(s) and provides a more strongly defined model with easy customisation. FHIR is REST based which enables organisations and developers to implement and use it easily. Since it is easier to implement (Bender and Sartipi, 2013) and use compared to HL7 v2 and v3. It translates into cost savings and greater ROI from the service itself versus something like HL7 v2 and v3 which might need more customisation. The FHIR team has adopted the priorities with the focus on support cross industry web technologies, implementers, engage human readability at the base level of interoperability and make content available freely (Hughes et al., 2017). However, FHIR is still early on and read only. Though its goals are to reduce the obstacle of entry to the healthcare digital ecosystem, and FHIR hopes to solve that with an easier, more streamlined (Khalilia et al., 2015) REST-based interface. The future of FHIR is expected to be an evolving one because of the nature of it being open source (Mandel et al., 2016). This is important because the only way FHIR will continue to remain useful is if it is adaptable to trends and standards evolve.

(6) Healthcare Data Standard Usage within Messaging Standards

The health data standards and message standards are interlinked to achieve the best possible interoperability. The HL7 messages can specify a suitable LOINC, SNOMED or ICD codes so that the health data standards integrated into messaging standards efficiently. The linkage of HL7 with ICD, LOINC and SNOMED are discussed further in this section.

6.1. ICD with HL7

ICD is a set of tables being developed for health care financing administration (HCFA) by 3M Corporation and contains more than a million procedural codes (McDonald et al., 1998). HL7 version 3 places in the RIM an explicit data semantics model from which implementing the messages locally and top-down. This stresses reuse of same codes across multiple contexts. Moreover, RIM has a systematic process for vocabulary support. It has a strong semantic foundation in explicitly defined concept domains drawn from the best terminologies such as ICD (Della Valle et al., 2005).

As shown in the figure 6.1.1 (Kabak et al., 2008), validation rules for entry level constraints in the "Examination" EHR. The first rule states that the "code" of the "ClinicalDocument" should be "Examination". The second rule states that "Examination" ("MUAYENE") and "Admission" ("KABUL') sections should exist in the CDA Body. The third rule is an entry level rule and states that "Diagnosis" entry must exist in the "Examination" section and this element should obtain values from ICD-10.

```
<sch:pattern name="rule 2a validation">
 <sch:rule context="hl7:ClinicalDocument/hl7:code">
  <sch:assert      test="compare(string(@code),      'MUAYENE')=0      and
compare(string(@codeSystem), '2.16.840.1.113883.3.129.2.2.1')=0"/>
 </sch:rule>
</sch:pattern>
<sch:pattern name="rule 2b validation">
 <sch:rule
context="hl7:ClinicalDocument/hl7:component/hl7:structuredBody/hl7:comp
onent/hl7:section/hl7:code">
  <sch:assert     test="     (compare(string(@code),      'MUAYENE')=0      and
compare(string(@codeSystem), '2.16.840.1.113883.3.129.2.2.2')=0)  or
  (compare(string(@code), 'KABUL')=0 and compare(string(@codeSystem),
'2.16.840.1.113883.3.129.2.2.3')=0)"/>
 </sch:rule>
</sch:pattern>
<sch:pattern name="rule 3 validation">
 <sch:rule context="hl7:component/hl7:section//hl7:observation">
  <sch:assert test="    not(compare(string(hl7:code/@code), 'ANATANI')=0)
or    (compare(string(hl7:value/@codeSystem),    '2.16.840.1.113883.6.3')=0
and   compare(string(hl7:value/@codeSystemName), 'ICD-10')=0)"/>
 </sch:rule>
</sch:pattern>
```

Figure 6.1.1 ICD usage in HL7 standard (Kabak et al., 2008)

The validation rule with HL7 CDA and ICD 10 is powerful for automation and share medical data between healthcare organisations.

6.2. LOINC with HL7 CDA and FHIR

The LOINC Document Ontology is a special set of LOINC codes (Regenstrief-Institute, 2017c) that are built on a framework for naming and classifying the key attributes of clinical documents. The HL7/LOINC document ontology (DO) is an existing and evolving document standard developed to provide consistent naming of clinical documents and to guide the creation of LOINC codes for clinical notes. They provide consistent semantics for documents exchanged between systems for many uses. When there is a link for a local note title to LOINC codes is created, instead of cryptic and idiosyncratic note titles, there will be a principled set of document name attributes. With these systematic attributes, it's easy to create a logical navigation tree in the document viewer that pull back all the cardiology notes or discharge summaries. The HL7 Clinical Document

Architecture (CDA) standard specifies that the clinical document code for any CDA document (Dixon et al., 2015) should come from LOINC. Implementation guides like the consolidated CDA templates for clinical notes require LOINC codes to identify the document types. LOINC codes from the Document Ontology are required in the C-CDA value sets for documents such as consult notes, discharge summaries, progress notes, procedure notes and op notes.

Figure 6.2.1 and 6.2.2 (Dolin et al., 2006) illustrate a representation of allergies and adverse reactions in a HL7 CDA document. Here many required components are left out to simplify the example. A CDA document is wrapped by the <Clinical Document> element and contains a header and a body. The header lies between the <Clinical Document> and the <structured Body> elements and identifies and classifies the document. A CDA document section is wrapped by the <section> element. Each section can contain a single "narrative block" and any number of CDA entries and external references. The narrative block contains three items, of which one is also represented as a nested observation. That the patient has a history of hives is recorded as a distinct observation, which is then linked to another observation of penicillin allergy via an entryRelationship with typeCode of "MFST".

```
<ClinicalDocument>
   ... CDA Header ...
  <structuredBody>
    <section>
      <text>(a.k.a. "narrative block")</text>
      <observation>...</observation>
      <substanceAdministration>
        <supply>...</supply>
      </substanceAdministration>
      <observation>
        <externalObservation>...
        </externalObservation>
      </observation>
    </section>
    <section>
        <section>...</section>
    </section>
  </structuredBody>
</ClinicalDocument>
```

Figure 6.2.1 LOINC usage within HL7 standard (Dolin et al., 2006)

```
<section>
  <code code="101155-0" codeSystem="2.16.840.1.113883.6.1"
   codeSystemName="LOINC"/>
  <title>Allergies and Adverse Reactions</title>
  <text>
    <list>
      <item>Penicillin - Hives</item>
      <item>Aspirin - Wheezing</item>
      <item>Codeine - Itching and nausea</item>
    </list>
  </text>
  <entry>
    <observation classCode="OBS" moodCode="EVN">
      <code code="247472004" codeSystem="2.16.840.1.113883.6.96"
       displayName="Hives"/>
      <entryRelationship typeCode="MFST">
        <observation classCode="OBS" moodCode="EVN">
          <code code="91936005" codeSystem="2.16.840.1.113883.6.96"
           codeSystemName="SNOMED CT" displayName="PCN Allergy"/>
        </observation>
      </entryRelationship>
    </observation>
  </entry>
</section>
```

Figure 6.2.2 LOINC usage within HL7 standard (Dolin et al., 2006)

6.3. SNOMED with HL7

On a much larger scale, we have SNOMED, Read codes, and the MED are covering code systems that provide the vocabulary necessary for coding clinical content including the coded values of HL7 in OBX-3 (McDonald et al., 1998). Clinical Document Architecture (CDA) documents are encoded with XML. They derive their machine processable meaning from the HL7 RIM and use the HL7 version 3 data types. The RIM and the V3 data types provide a powerful mechanism for enabling CDA's incorporation of concepts from SNOMED CT. Post-coordination such as Observation.code, is allowed in CDA components that use the CD data type. For example, SNOMED CT defines a concept "cellulitis," an attribute "finding site," and a concept "foot structure," which can be combined in Observation.code to create a post-coordinated expression (Dolin et al., 2006).

As shown in figure 6.3.1 (Sáez et al., 2013), the approach is to facilitate semantic interoperability to rule-based CDSSs (Clinical Decision Support Systems) consists on syntactically and semantically relate the inference-engine knowledge-base to standardized HL7-CDA input and output documents. The output of the

CDSS is generated following the proposed HL7-CDA template with the relevant
SNOMED CT code as displayed in the figure 6.3.1.

```
<ClinicalDocument>
    … CDA Header …
    <structuredBody>
        <section>
            <text> <!--narrative block-->
                <table>
                    <tbody>
                        <tr> <!--one for each input data-->
                            <td>Standing height</td>
                            <td>186 cm</td>
                            <td>2006/04/07 14:30</td>
                        </tr>
                    </tbody>
                </table>
            </text>
            <entry> <!--one for each input data-->
                <observation>
                    <code code="248333004" codeSystem="2.16.840.1.113883.6.96"
                        codeSystemName="SNOMED CT" displayName="Standing height"/>
                    <effectiveTime value="200604071430"/>
                    <value xsi:type="PQ" value="186" unit="cm"/>
                </observation>
            </entry>
        </section>
    </structuredBody>
</ClinicalDocument>
```

Figure 6.3.1 SNOMED usage within HL7 standard(Sáez et al., 2013)

6.4. DICOM with HL7

DICOM can be used between two different imaging systems. If two different
systems, connected with the HL7 messaging standards, need to exchange an
image data such as image data such as ultrasound, radiography, magnetic
resonance imaging, nuclear medicine, echocardiography, topography CT and X-
Ray, then it can be translated or embedded within an appropriate HL7 message
using DICOM.

Patients' clinical information exchange between healthcare facilities is an
important requirement in the health domain. Medical images between the
facilities can be shared using DICOM. MERIT-9, (MEdical Records, Images,
Texts, -Information eXchange), a patient information exchange guideline using

MML, is the best example (Kimura et al., 1998) to illustrate the usage of DICOM with HL7. By MERIT-9, a patient's narrative episode which is described in MML, with detailed lab test results, prescriptions and diagnostic images supported by HL7 messages, DICOM files, TIFF files, etc.
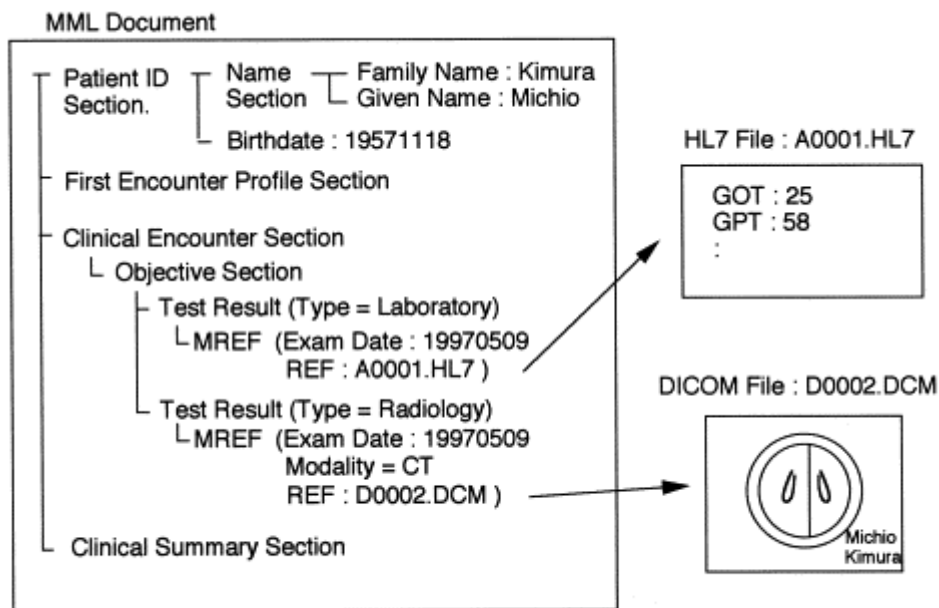
Figure 6.4.1 - MML file refers an HL7 message and A DICOM file (Kimura et al., 1998).

(7) Case Study for the HL7 usage in eHealth, NSW Department of Health

There was a case study conducted in eHealth, New South Wales (NSW) State to measure the usage of health messaging system in the NSW hospitals. At present (2017 Sep), eHealth, NSW organisation is using HL7 version 2.5. There are two different source systems used for Patient Administration System (PAS) in eHealth, NSW State. These PAS systems are based on Cerner and iPM systems.
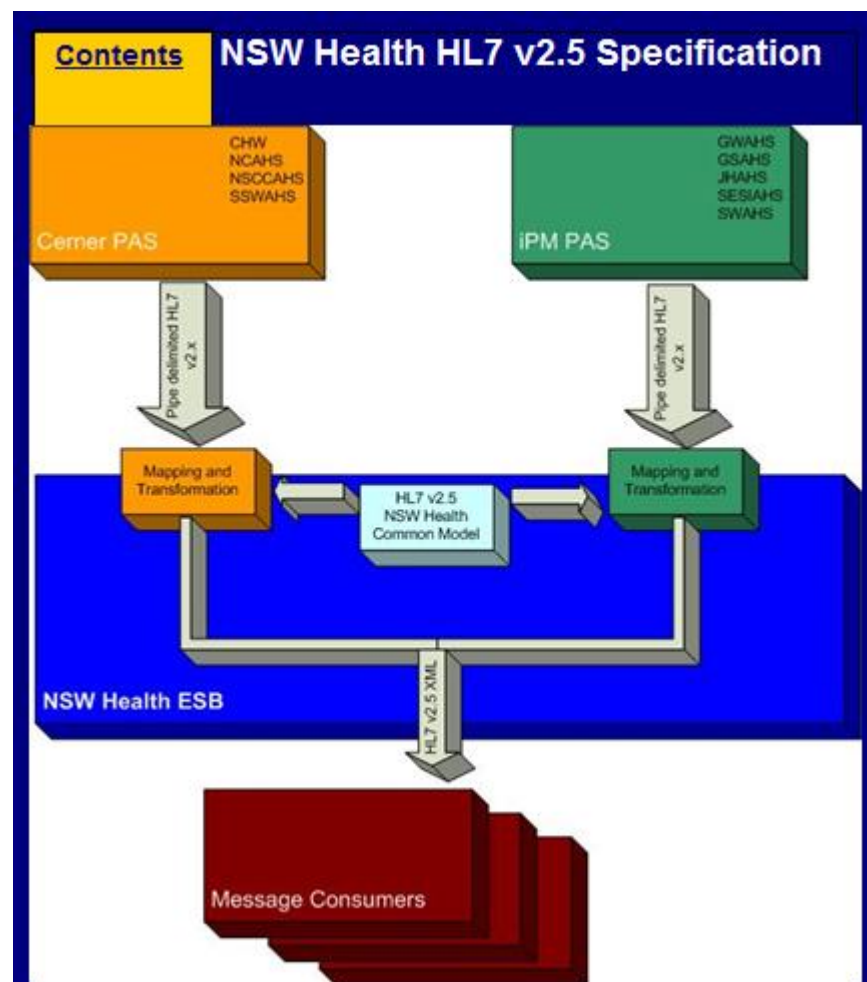
Figure 7.1. NSW Health PAS system connection with HL7 messaging standards

As indicated in the image, CHW (Children's Hospital at Westmead), NCAHS (North Coast Area Health Service), NSCCAHS (Northern Sydney Central Coast

Area Health Service) and SSWAHS (Sydney South West Area Health Service) are using Cerner PAS. GWAHS (Greater Western Area Health Service), GSAHS (Greater Southern Area Health Service), JHAHS (John Hunter Area Health Service), SESIAHS (South Eastern Sydney and Illawarra Area Health Service) and AWAHS (Albury Wodonga Aboriginal Health Service) are using iPM PAS system. Enterprise Service Bus (ESB) is managing both PAS systems and converting the HL7 2.5 based health messages to standard XML format. These XML messages are consumed by all the internal health applications. The challenges such as identification format for patient ID and data type mismatch for patient records from two different systems are few known issues. The historical engagement of vendors by individual AHS and their own budget are the reasons for the existence of two different PAS systems.

Figure 7.2 shows an example of one of the HL7 message consumer application in NSW Health organisation which uses the HL72.5 messaging system and its data feeds from systems such as EMR (Electronic Medical Records), EPR (Enterprise Patient Registry), billing and other reporting systems. The HL7 messaging system connects very few systems and the remaining systems are connected either at the database layer or at the web layer. The message parsing mechanism used on these systems and its standard differs from the HL7 messaging mechanism.
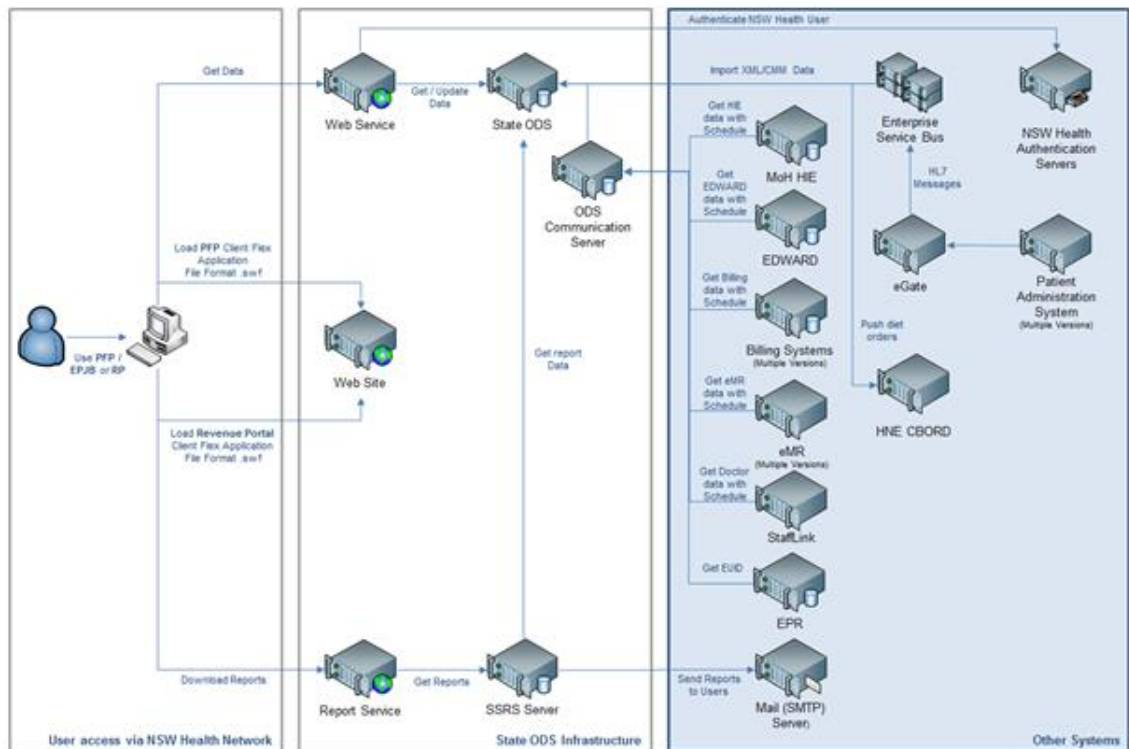
Figure 7.2. NSW Health sample consumer application with HL72.5 messaging system

The interoperability is a big challenge in this environment. Any new changes in the internal health applications create changes to both PAS systems and a further increase in the maintenance cost. Any operating and system specific changes created in each PAS systems will create changes further into ESB system and other internal health applications which are consuming the PAS data. In addition to the HL7 connected systems, the PAS changes will create changes to the systems which are connected at the database and web layers. In addition to the cost, the training, associated implementation efforts and technology adoption to health professionals are additional challenges on interoperability. So, the recommendation from the case study is to have a centralised and interoperable PAS system and integrate rest of the systems which are not enabled with HL7 into a centralised HL7 messaging model to overcome the current ongoing issues with interoperability and maintenance cost.

(8) Findings

The comparative study was started from basic health data standards to advanced interoperability standards. Standards such as ICD (International Classification of Diseases), LOINC (Logical Observation Identifiers Names and Codes), SNOMED CT (Systematised Nomenclature of Medicine - Clinical Terms), HL7 V2, V3 and FHIR were studied. Finally, a feature table covering the major HL7 versions and FHIR was derived. Features such as interoperability methods, security, usage of encryption, privacy, compatibility, flexibility, reliability, granularity features and other miscellaneous features such as technology, transport mechanism, popularity, adoption rate, and implementation cost were compared to different health standards.

8.1. Interoperability methods

The latest HL7 version 3 with reference information model (RIM) and FHIR support both syntactic (data syntax) and semantic (meaning) interoperability methods based on the usage of data in the context. In addition, FHIR uses REST-based approach to read and format EHR data using tools which supports JSON and XML technologies. JSON and XML technologies work at client side attached to any technology platform and covert to the required format. This allows flexibility in EHR server data format. In other words, the client side script can read the raw data and convert to the interoperable format required at the client end. The FHIR API significantly reduces the effort required to implement interoperability specific changes by preventing health developers (Technical) from having to learn or work with a domain specific API. RIM in HL7 v3 enforces the data types such as numbers, characters and null values with strict precise measures. This has created issues for the implementation team. Though it establishes stability and data integrity on patient data, due to the implementation struggles, it was not well received in the health domain (Bender and Sartipi, 2013) . Compared to FHIR and HL7 version 3 health messaging standards, HL7 version 2 is based on the Syntactic model. It used pipe (|) and hat (^) characters for delimiters. It primarily uses code to interoperate with other systems. If every

vendor has their own data standards, then establishing a standard interoperable connection between the supporting applications will be a big challenge. Though HL7 version 2 has many issues such as data stability and integrity, there were more implementations done using HL7 version 2 (Bender and Sartipi, 2013) as it is not complex like HL7 version 3 which was released to fix the data integrity issues in HL7 version 2. Moving from HL7 version to HL7 version 3 with RIM or FHIR to improve the interoperability, need a substantial volume of work. Though FHIR appears to be having all the best features of HL7 v2 and V3, it is still in draft standard.

8.2. Security

For HL7 v2 and v3, the security layer is built in the transmission layer. In FHIR, with modern web services, the security such as SSL can be enabled in the transmission layer with https protocol. With FHIR, stateless interactions can be established and the required messages can be communicated in the URLs, headers and the body. There is no client context information stored at the server end. These specifications in FHIR makes very easy for client and server to communicate easily and securely. Since HL7 v2, v3 and FHIR are primarily established to manage the interoperability in the health messaging system and are not focused on the security standards, the security is to be done in a separate layer. Most of the implementation need communications security, authentication, authorisation, access control, Audit, digital signatures, content security, consent and data management policies. This entire security requirement can be fulfilled partly by the FHIR enabled features. Web security protocols cover the rest of the security requirements. The security elements can be incorporated either server side or at the client side. Compared to HL7 v2 and v3, FHIR has richer client-side features where flexible security features can be enabled. FHIR have a set of open specifications called "Smart on FHIR". This is used to integrate apps with healthcare data provider system such as EHR (Electronic Health Records). FHIR API combined with Smart on FHIR integration layer makes an efficient and secured FHIR based interoperable application.

8.3. Usage of encryption

Encryption of data needs significant technical overhead and hence a separate protocol such as Secured socket layer, SSL (HTTPS) can be used to manage the encryption in all HL7 versions and HL7 FHIR standards. SSL works best with OAuth(Benson and Grieve, 2016b). With SSL (HTTPS), client and server are communicated using bidirectional encryption. It ensures that the communication between the website and the user cannot be forged by anyone. Due to the simple architecture of HL7 v2, it is easy to implement encryption in the transport layer. Since HL7 v3 have a complex architecture, enabling encryption is a tedious work. FHIR generally use open standards for encryption and other related functionalities. So it is easy to enable encryption layer for this version. Virtual Private Network (VPN) is a cost effective and simple solution for a secure connection in an open network. In addition to HTTPS, SFTP, FTPS, or SMIME protocols can also be used for the data transmission channels. However, HL7 standards were adopted long before these standards. So enabling these protocols in HL7 v2 and v3 are not practical. However, these modern protocols can easily be enabled with FHIR and FHIR based related APIs. Different levels of the OSI model provide different protocols to secure data in transmission. Since it is difficult to store application-specific passwords, auditing, and rules, and to determine application-specific access rights, implementing the data protection at the application level is too difficult and complex for all HL7 versions and FHIR based health messaging standards (Marshall, 2004).

8.4. Privacy

Privacy related features are difficult to implement in HL7 v2. HL7 V2 is a well-established messaging standard that works fine to connect applications within healthcare institutions. However, it has custom tools, unique syntaxes, and custom tools making it a legacy standard. It makes a hefty learning curve for those wanting to enter into the IT Healthcare industry. The design of this standard is also limited to more modern apps and devices which try to leverage patient data. Making patient data in a more convenient format and patient engagement now has a barrier due to these limitations. HL7 V3 was based on a reference model and leveraged modern standards available at that time, however it became

even more overly complex to implement with a steep learning curve. Privacy features are easy to implement in HL7 v3 compared to HL7 v2. But the usage of HL7 v3 is less compared to HL7 v2. Backwards compatibility with HL7 V2 was also not available. With the latest HL7 FHIR, the privacy features are quite easy and flexible to implement (Benson and Grieve, 2016d). The success of FHIR relies on the governance to maintain the privacy of patient data. A flexible pattern in such a way that policies could not constrain but still be protective can be constructed by the modern capabilities of FHIR. In FHIR, The exchange of production data will be secured by TLS/SSL. OAuth is recommended for web-centric use for authentication; however, it can also be achieved in a number of different ways. FHIR defines provenance and security event resources used for tracking down the origins, status, history, authorship and access to resources (Sánchez et al.). FHIR also defines Security Label infrastructures to support access control management.

8.5. Compatibility

All HL7 V2 minor versions are compatible with each other. But HL7 V3 is not compatible with earlier versions of HL7 v2. Some of the FHIR features are compatible with HL7 V3 and there is no compatibility with HL7 V2. HL7 RIM is a prime feature in the HL7 v3 messaging standards and all data components in HL7 v3 instances are derived from either from ISO data types or from the HL7 RIM mappings. The derivation of serialisation format of FHIR is the minor difference as it is not driven by the RIM mappings. However, the organisations can implement FHIR with no skills and knowledge of the HL7 RIM. Compared to HL7 V2, V3 and FHIR have features to work best with LOINC, ICD, SNOMED and CPT. HL7 V3 CDA header can hold a XML body which can be coded with the RIM vocabulary such as SNOMED, ICD, LOINC and CPT. Many other healthcare data ISO standards such as DICOM are in the process of being mapped to HL7 v3 messaging standard. A process with the name harmonisation is adopted by HL7 organisation to the map the required new structural codes to RIM. HL7 is encouraging and willing to enter harmonisation efforts with any standards organisation. The harmonisation efforts can be easily done with the HL7 v3 and FHIR based messaging standards. HL7 version 3 and FHIR have

features to enable SNOMED CT codes. However HL7 version 2 is limited and cannot work with SNOMED CT codes appropriately.

DICOM is a popular standard used for the exchange of medical images such as X-rays, CT Scans, and MRI. DICOM community works closely with the HL7 organisation and involve in the process to make image object selection resources available and related imaging study. FHIR resources use the availability of images from DICOM endpoints to the wider EHR system. However, this is complex task in HL7 v2 and v3 versions. Another important organisation which supports HL7 is IHE. IHE resolves few issues such as lack of agreement around use cases which cannot be resolved by HL7. Though IHE does not resolve the actual issue of disagreement around use cases, it allows a very narrow flexibility for a smaller people of possible stakeholders. The FHIR community collaborates closely with IHE in the Mobile Health Documents approach so to make resources such as DocumentReference, AuditEvent and DocumentManifest are available. These will expose XDS repositories over the RESTful interface.

8.6. Flexibility

Most of the HL7 v2.xx version based messaging standards are flexible to manage as there are very few mandatory details to be entered. The HL7 V3.xx based messaging standard, which is based on RIM, reference information model, is less flexible as there are more compulsory and complete details for medical records need to be entered. FHIR is very flexible as it is compatible with the latest APIs. Since FHIR uses the RESTful API services, it is more flexible and easy to use with other API service providers. RESTful web services are embraced by organisations such as Amazon, Facebook and Twitter as their preferred API. In addition, OAuth, XML, and JSON are also well supported by RESTful services when dealing with encoding and authorisation functions. So, this flexibility will allow healthcare domain not be locked into unique industry standards but can embrace what is used in other industries. HL7 v3 is designed with the strict data type and consistent model. Any kind of healthcare communication is represented in the HL7 RIM based data types. Once the models become familiar to the implementer, they turn out to be less abstract. The HL7 v3 are extensive in their

coverage and capability and this will make the standard as more abstract. They are designed in this way to make sure to cover all other scenario and additional possible implementations. However, FHIR uses a different technique. FHIR resources do not represent all data elements that could possibly be used in a space. Instead, use those data elements which are expected in most of the implementations are considered part of the core resource definition. The extensions will be used to handle the rest of the data elements. Profiles are used define extensions appropriately and also to constrain resources. Serialisation format interoperability is used across all profiles on a given resource.

8.7. Reliability

Flexibility is the main reason for the more number of implementations and success of HL7 V2 compared to HL7 v3. Optional data segments and elements make it adaptable to almost any other healthcare applications or services. Though HL7 v2 provided the great flexibility, it contains many optional elements which make it hard for the reliable conformance tests when it comes to implementations. It forces the implementers to spend more efforts and time to plan and analyse the interfaces to manage the optional elements. So HL7 v2 is less reliable to depend on any medical records as there are more optional columns. RIM, Reference information model in HL v3 addresses the optionality issues in HL7 v2 with a strong message building techniques and analytic model. HL7 V3 is more reliable as most of the field entries are made compulsory. It helps to take the consistent decision. FHIR is expected to be more reliable as there are specific resources are maintained by the specialist. FHIR is also based on RIM and use the both the best features of HL7 v2 and v3.

8.8. Granularity Features

HL7 v2 models are restricted to enable granular features. Compared to HL7 V2 models, HL7 version 3 models have more granular features which can be enabled based on the need. HL7 v3 models are categorised into 3 major types – payloads, wrappers, and CMETs (Common Message Element Types). To define

a set of content, these are combined into interactions. FHIR resources have the very similar granularity level of HL7 v3 models. HL7 FHIR has covered the good features of both HL7 v2 and v3 with more granular level. It uses the latest web elements such as JSON and is fully focused on implementation. HL7 v3 models are categorised based on the re-use. FHIR models are categorised based on whether the objects they represent can be considered to stand alone. In HL7 v3, several models can represent the same essential healthcare information concept. For example, at the HL7 International level, there are 10 different CMETs for the concept of a patient. Further variation exists in the HL7 v3 models created by HL7 v3 implementers and affiliates. These CMETs has their own schema and may use different levels of nesting, different element names, and different constraints. But, in FHIR, there is only one Patient resource. Many profiles can be created on that resource, but each profile will use the same schema and support the same serialization format.

8.9. Other miscellaneous features

Under these miscellaneous sections, features such as technology, transport mechanism, popularity, adoption rate, and implementation costs are analysed. HL7 v2 models are based on implicit information model. It was built historically in an ad-hoc way because no other standard existed at the time of developing the messaging based standard. The HL7 version 2 technology is based on the old pipe hat characters encoding with limited features. HL7 version 2 does not have options to upgrade to latest tools and technologies. HL7 organisation and the respective health professionals spent many decades of efforts on HL7 v2. The HL7 V2's flexibility is what the success of it is largely attributable to. It is adaptable to almost any healthcare site, since it contains many optional data segments and data elements. Compared to HL7 v2, HL7 v3 model are based on RIM, Reference Information Model, which is an ultimate source from which all HL7 V3 standards draw their information-related content. HL7 v3 supports Object Oriented approach. HL7 FHIR has almost all the features and technologies of HL7 V2 and V3. In addition, it is flexible by enabling all the latest technical standards, APIs and extensions. HL7 FHIR is Http based RESTful protocol. The

transport mechanism in HL7 v2 is built by using the pipe and hat characters encoding. The conversion engine which understands the delimiters and separate data and control characters. In HL7 V3, XML is used as a transport method. So it is human readable. FHIR have an Option of XML or JSON structures. It is human readable XHTML display. Among the popularity, HL7 v2 is most popular, and this version is generally assumed as HL7. According to the survey conducted with the information and Health professionals who are currently working in the NSW Department of Health, HL7 v2.xx version messaging standards are implemented in most of the hospitals compared to other versions of HL7 messaging standards. Compared to HL7 V2, HL7 v3 is not famous. HL7 v3 CDA is generally assumed as HL7 V3. Due to the complexity and training requirements, HL7 V3 is not accepted well by the healthcare professionals. HL7 FHIR has all the best features of both HL7 v2 and V3. But it is still in draft standard. Depending on Implementation cost, flexibility and adoption rate, FHIR may become popular. Due to the flexibility and optional fields in HL7 V2, the adoption rate for v2 is high. However, the adoption rate for HL7 v3 is not high as v2. This is mainly due to the expensive implementation cost and training requirement for the health professionals with HL7 v3 RIM (reference information model) concepts. FHIR is in draft standard and may take considerable time to plan for resource repository and training to healthcare professionals. But still, the adoption rate of FHIR is expected to be high as it has the flexible transport and client-side features such as XML and JSON. In addition, FHIR can use open source extensions such as SMART FHIR APIs, an open source solution, using which a relevant function can be extracted and used in the popular health messaging standards. The implementation cost is low for HL7 v2 as it is message based. However, the HL7 v3 implementation cost is expensive as v3 is RIM (reference information model) based and careful, time-consuming planning efforts are required to implement. Since HL7 v3 have less optional components and planned for long-term benefit, the implementation cost will not be realised easily. Also, HL7 v3 need a training requirement for health professionals. FHIR is in draft standard and it is expected to be less costly. But there is also a cost involved to retrain and retooling activities.

8.10. Comparison summary

The summary of all the above mentioned features, when comparing HL7 V1, V2, V3 and FHIR are tabulated as below:

Table 7.10.1: HL7 v1, v2, v3 and FHIR feature comparison table

Feature	HL7 - V1	HL7 - V2	HL7 - V3	FHIR
Interoperability methods	Syntactic only	Syntactic only	Support both syntactic and semantic approach	Support both syntactic and semantic approach
Security	Basic Proto type	Security is built in the transmission layer	Security is built in the transmission layer	Since FHIR is built using the web services, the security such as SSL can be enabled in the transmission layer
Usage of Encryption	Basic Proto type	Encryption of data in transit needs significant technical overhead and hence a separate protocol such as SSL (HTTPS) can be used to handle the encryption.	Similar to the encryption option available in HL7 v2 version. However, due to the complex architecture, enabling encryption in the application layer is complex.	Enabling SSL encryption (with https protocol) is very similar to HL7 v2 and v3 versions. In addition, FHIR is compatible with many latest open standards and it is easy to use them in the encryption layer.
Privacy	Basic Proto type	Privacy related implementations are difficult.	Privacy and security are easy to implement compared to HL7 v2	Privacy and security are quite easy and flexible to implement.
ICD usage within HL7	Basic Proto type	Lacks a sufficiently robust infrastructure for specifying and binding concept-based terminology values. Support to ICD is limited or no support.	With the support of RIM various terminology Models and domain-specific terminologies like ICD can be enabled efficiently.	ICD can be easily used within FHIR with the advanced RIM and related features.
LOINC usage within HL7	Basic Proto type	Limited support to LOINC binding	With the RIM and semantic interoperability support, LOINC codes can be integrated into V3 easily.	LOINC can be easily used within FHIR with the RIM and relevant advanced features.
SNOMED usage within HL7	Basic Proto type	Limited support to SNOMED	With the RIM and semantic interoperability support, SNOMED codes can be integrated into V3 easily.	SNOMED can easily be integrated within FHIR with the RIM and APIs such as SMARTAPI.
DICOM usage within HL7	Basic Proto type	Limited support to DICOM	With the RIM and semantic interoperability support, DICOM sections can be integrated into V3 easily.	DICOM can easily be integrated into FHIR with the support of RIM and other latest client side features such as JSON and XML.

Compatibility	NA	All V2 versions are compatible with each other (within V2.XX)	V3 is not compatible with earlier versions of v2	Few features are compatible with V3. No compatibility with V2.
Flexibility	NA	More flexible as there are very few mandatory details to be entered	Less flexible as there are more compulsory and complete details for medical records to be entered	FHIR is in draft standard and it is expected to be flexible
Reliability	NA	Less reliable to depend on any medical records as there are more optional columns of medical data are allowed	More reliable as most of the field entries are made compulsory. It helps to take consistent decision.	Expected to be more reliable as there are specific resources (repository) are maintained by specialist.
Granularity features	Basic Proto type	Restricted access to enable granular features	Compared HL7 V2, more granular features are enabled.	FHIR has the best features of HL7 v2, v3 and CDA with more granular features. It uses the latest web standards and a tight focus on implementation.
Other miscellaneous features:				
Technology	Basic Proto type	Implicit information model. Historically built in an ad-hoc way because no other standard existed at the time of developing messaging-based standard	RIM, Reference Information Model. Many decades of efforts. Model-based standard. It supports Object Oriented approach	Http-based RESTful protocol. FHIR is a Model-based standard
Transport Mechanism	Basic Proto type	Built with pipe and hat characters encoding. Parser which understands the delimiters and separate Data and control characters	XML as transport method	Option of XML or JSON structures, Human readable XHTML display, API based access
Popularity	NA	Quite Popular. V2 is generally assumed as HL7.	Not very famous like V2. CDA is generally assumed as HL7 V3	FHIR is still in draft standard. Depending on Implementation cost, flexibility and adoption rate, FHIR may become popular.
Adoption rate	NA	High	Low	FHIR is in draft standard and may take considerable time to plan for Resource repository and training to healthcare professionals.
Implementation Cost	NA	Since it is message based, the implementation cost is less	Expensive and planned for long term benefit	FHIR is in draft standard and it is expected to be low cost. But there is a cost involved to retrain and

				retooling activities.

(9) Discussion

The objective is to find out the best healthcare messaging standard, out of HL 7 v1, v2, v3 and FHIR, to achieve interoperability, security and privacy needed in the healthcare domain. When HL 7 v1, v2, v3 and FHIR are compared, on interoperability, security and privacy, there is a range of positive and negative impacts is realised.

The security requirements can be achieved easily in FHIR, with the advanced web services support such as RESTful and JSON client-side scripts. Compared to HL7 v1, v2 and v3, FHIR has richer client-side features where flexible security features can easily be enabled. The combination of the Smart on FHIR integration layer and the FHIR API creates a secure and efficient, FHIR based interoperable application. The confidence to share the patients' medical data between medical institutions and to transact online will increase due to the security issues being fixed. Because of this, the cost of capturing medical data such as their blood group and any other inheritance data will be reduced. This also helps to take appropriate decisions for medical emergencies when the patient is unconscious and their consent is required for critical medical conditions.

Though HL7 V2 is a well-established standard, privacy related features are difficult to implement in V2. Privacy features are easy to implement in HL7 v3 RIM compared to HL7 v2. But the usage of HL7 v3 is less compared to HL7 v2. With the latest HL7 FHIR, the privacy features are quite easy and flexible to implement. FHIR provides good support for all exchange of production data with suitable SSL enabled security. Authentication can easily be achieved in FHIR using oAuth or similar methods. FHIR also defines provenance and security event resources suitable for tracking the origins, authorship, history, status and access to resources. When the patients and the Australian public maintain their own personal medical data, they feel empowered. They will evidently feel responsible and reflect these changes in their healthier habits when a patient

takes initiative to maintain their own medical data. This will be helpful as patients can then receive clinical support over the phone or online for basic clinical treatments. Waiting times in hospitals would be reduced as prescriptions could be ordered online. Doctors and other healthcare professionals would have to learn to work smartly with these devices which are enabled as to provide services to patients remotely. However, the public may not disclose their specific health-related information when it comes to employment or other insurance related claims if medical records are personally maintained, leading to few negative impacts.

The interaction of HL7 v1, v2, v3 and FHIR with health data standards such as ICD, LOINC, SNOMED CT and DICOM are analysed and provided in the comparison table. FHIR support both syntactic (data syntax) and semantic (meaning) interoperability when compared to the earlier versions of HL7 messaging standards which makes FHIR suitable for easier adoption. FHIR provides flexible support to JSON and XML technologies compared to the HL7 v1, v2 and v3, which enable FHIR based messaging standard to be attached with any technology platform and covert to the required client side format. Due to the technical limitations, this is not possible at all with the earlier versions of HL7 messaging standards. FHIR uses the HL7 supported SNOMED- CT extension namespace efficiently with the appropriate APIs which significantly reduces the effort required to implement interoperability specific changes. This will reduce the implementation challenges and further reduce the cost and efforts. The usage of interoperability can be extended for numerous wellbeing and preventive health activities, when interoperability is improved. For example, if a patient has medical data such as their blood pressure that is accessible on their mobile phone, when their blood pressure gets to a certain limit they would be warned with suitable messages. Regular weight measuring and other small health-related activities would also be captured, consolidated and stored to provide useful health data. Sharing healthcare data between different institutes would reduce time spent on interpreting the data and extra charges. The medical billing transactions between insurance companies and health organisations would be seamless as medical

data would be shared smoothly. This would further ease the process of claiming from the patients' end.

(10) Conclusion

The objective of the research is to find out the best healthcare messaging standard, out of HL 7 v1, v2, v3 and FHIR, to achieve interoperability, security and privacy needed in the healthcare domain, with the appropriate use. As per the literature review, case study and comparison study, FHIR seems to be the best healthcare messaging standard compared to the HL7 v1, v2 and v3.

The comparison study covered the structure of HL7 v1, v2, v3 and FHIR and their compatibility with other commonly known standards such as CDA (Clinical Document Architecture) and IHE (Integrating the Healthcare Enterprise). All these comparisons showed the leading status of FHIR compared to the other health messaging standards. The interaction of HL7 v1, v2, v3 and FHIR with health data standards such as SNOMED CT, ICD, DICOM and LOINC are analysed further and found FHIR is the better choice among others.

The case study conducted in the NSW Department of Health reveals that HL7 v2.xx version messaging standard is the most implemented one compared to other versions of HL7 messaging standards. Due to the flexibility and optional fields in HL7 V2, the adoption rate for v2 is high. Due to the complexity and training requirements of HL7 V3, it is not accepted well by the healthcare community. But HL7 FHIR has all the best features of both HL7 v2 and V3. FHIR have an option of XML or JSON structures. It is human readable XHTML display. With the existing interoperability issues in NSW Health organisation, it is recommended to use FHIR as it resolves the ongoing interoperability challenges. Since FHIR is latest and implementation focused, the cost to implement these changes is minimal.

Though the status of the FHIR is in draft standard, its technological advantage and implementation focused approach is more promising and addressing the current needs. FHIR can use cost-effective extensions such as SMART FHIR APIs, an open source solution, using which a relevant function can be extracted and used in the popular health messaging standards. However, FHIR is in draft standard and also there is a cost involved for the healthcare community to retrain and retooling activities. Moreover, the health organisations have practical limitations such as their budget constraint to adopt a new health standard and training the health professionals who will be involved to use these health standards. So instead of using FHIR directly at this stage, the useful and modern features such as RESTful APIs, SMART FHIR and other relevant functions can be extracted and used with the existing health messaging standards such as v2.xx. Once the FHIR standard becomes stable, then these features can be used in FHIR easily. In this way, the health professionals also can meet the training requirements by managing gradual changes and get an opportunity to work with the latest features. Later this will be helpful to negotiate for further FHIR or any other advanced messaging standard implementations.

This study has minor limitations. The limited time did not allow to test the implementations for the full level that would facilitate the ease of implantation using a number of programmers. Further, a thorough testing was not able to be completed in such a manner so that system is ethically hacked to understand the limitations of the messaging standards.

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