Maudrie Alexis. How can Increased Electronic Health Record Interoperability be Achieved through the use of APIs?. A Master's Paper for the M.S. in I.S degree. April, 2019. 42 pages. Advisor: Fei Yu

This paper investigates how application programming interfaces can be used to improve the interoperability (or shareability) of health records. Electronic health records store health information that originates from various sources like prescription order systems, medical devices and even other EHRs. An API helps these disparate systems exchange information with one another. APIs can improve data sharing by using secure standards like FHIR. Having all off this integrated and usable data can aid in the clinical decision process. This would also allow patients to have a more comprehensive look at their health data in patient portals.

Headings:

Electronic Health Records

Health Information Exchange

Application Programming Interfaces

Interoperability

FHIR

HOW CAN INCREASED ELECTRONIC HEALTH RECORD INTEROPERABILITY BE ACHIEVED THROUGH THE USE OF APIS?

by
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Introduction

Centuries of changes and improvements have evolved the medical field into what it is today. Throughout the history of medicine new technology has consistently been introduced into its common practices and procedures. Thermometers, stethoscopes and x-rays were considered new technologies in the 1800s. Fast forward to the computer revolution in the late 20th century and newer technologies allowed improved imaging of the body. More recently, electronic health records (EHRs) have become an indispensable tool to the medical field in the United States. They now fulfill the tasks that written records once held and have the potential to do so much more. However, this new technology must overcome a few obstacles before it can be best utilized. One main issue is difficulty in sharing. Health information from different sources isn't effortlessly integrated into EHRs and the EHRs themselves can be challenging to share with multiple providers. This is where an application programming interface can be applied. This paper will look into how EHR interoperability be achieved in the United States through the use of application programming interfaces (APIs).

1.1.1 Background Context

Generally, an EHR is a digital record of an individual's medical data which can be updated by medical professionals. This record may include a patient's demographics, lab records, prescription information, and medical history. A great deal of this information is created, updated and stored in various medical settings. An individual may have pieces of

health information at a combination of locations depending on where they go to see a doctor or pharmacist.

An API acts as an intermediary between two or more different applications and allows them to communicate despite structural differences. APIs are used quite frequently in everyday interactions that utilize the internet. One popular example of an API in action is when an individual goes to a site like Expedia or Travelocity to search for the best airline deal. These third-party websites do not generate the information that they display, they simply retrieve information from official airline pages. This third-party page uses an API from the JetBlue or American Airlines website to gather the information and then output it on their own page as you search. All of the sites are unique, but the third-party website can easily retrieve the information due to the API.

Interoperability refers to how well "systems and devices can exchange data, and interpret that shared data" as defined by the Healthcare Information and Management Society (Healthcare Information and Management Systems Society (HIMSS), 2013). Ideally, this means that health data should be shared seamlessly—regardless of the data's origin or destination—and be instantly usable. However, with the current systems today health data still has to be frequently checked for quality, especially when it is being shared (Susan Anderson-Lenz, Oachs, Amy Watters, & Ryan Sandefer, 2015). Health information management professionals ensure that the data meets certain data standards and security criteria. Nationwide interoperability of all health records doesn't exist yet, but some guidelines and incentives have been created by HIMSS and the Medicare and Medicaid EHR Incentive Programs. In 2015 they aimed to improve meaningful use with goals to improve EHR interoperability. (Susan Anderson-Lenz et al., 2015). These efforts

were met by criticism and considered “watered down requirements for connectivity” (Susan Anderson-Lenz et al., 2015). The incentive programs were also overshadowed by a switch in focus to private health information exchanges (HIEs) by HIMSS. Private HIEs took precedence over widespread interoperability and this encouraged more personalized and disconnected EHR systems.

An interoperability issue is significant since EHRs are increasingly used across the United States. Therefore, it is imperative that patients’ information is easily accessible and shareable. As more offices switch from paper to digital records there is a need to make this process more intuitive and organized. As of late, large technology companies have launched new projects and services to address the issues with interoperability. Google has created the new Cloud Healthcare API that takes into account different healthcare data standards such as HL7, FHIR and DICOM (Moore, 2018). Apple recently released a new Health Records API which would allow patients to view their health data and share it with specific apps. This encrypted and protected data enables a more holistic view for patients.

1.1.2 Research Question

The main research question is, *How can APIs make EHRs more interoperable?* More specifically, this paper will investigate if APIs can improve health record access, data integration, and if it can do so according to health data standards.

Literature Review

EHRs are created and managed by various vendors which creates an issue when the data needs to be shared. Currently, Epic has the largest market share while Cerner, Meditech, Mckesson, Medhost, Healthland and Allscripts are ranked as the top 7 vendors in the

United States (Holmgren, Adler-Milstein, & McCullough, 2018). Differences in terminology, user IDs, data translations and more create a challenge since a universal standard is not in place. Highly interoperable records could positively impact the quality and cost of care.

APIs have already successfully been implemented in sites like Google, Facebook, YouTube and Twitter. It helps users interact with various games, widgets, apps and more while on a mobile device or computer (Bodle, 2011). For example, if someone wants to share a CNN story to their Facebook story an API is used. This process is generally straightforward and users can share information across diverse websites. A similar feat can be obtained with EHRs if APIs are applied to this field. Health information from multiple sources can be viewed an accessed in a more centralized way.

1.1.3 Overview: Electronic Health Records (EHRs)

1.1.3.1 What is an EHR?

An electronic health record is an imperative tool that has changed how health care professionals have created, shared and used health records. Based on The International Organization of Standardization (ISO) an electronic health record is a, "repository of information regarding the health status of a subject of care, in computer processable form, stored and transmitted securely and accessible by multiple authorized users (Hovenga & Grain, 2017). EHRs are used in the U.S. and internationally in hospitals around the globe (Boonstra, Versluis, & Vos, 2014)

EHRs also play an active role in the health care setting aside from data storage. EHRs have tools that can detect drug interactions, provide reminders for specific services and issue alerts. These all play a role in assisting doctors and their patients manage chronic

diseases, provide short term preventative care and even recommend disease prevention tasks (Hillestad et al., 2005). Detailed health summaries flowing amid various healthcare providers and patients will help produce desirable health outcomes, increase productivity and decrease costs for patients and providers. More organized, reliable, and useful data will be highly valuable in the health care field.

1.1.3.2 Information in an EHR

What exactly goes into one of these records? These records contain numerous facts and details regarding a patient's health. It houses various types of data and information. Information that can be held in these records include, "daily charting, medication administration, physical assessment, admission nursing note, nursing care plan, referral, present complaint (e.g. symptoms), past medical history, life style, physical examination, diagnoses, tests, procedures, treatment, medication, discharge, history, diaries, problems, findings and immunization (Häyrinen, Saranto, & Nykänen, 2008). It has also been shown EHR systems have been conducive to more comprehensive documentation (Häyrinen et al., 2008) .

1.1.4 Overview: Application Programming Interfaces (APIs)

1.1.4.1 What is an API?

APIs are, "a set of rules that determine how requests of a particular system can be made and a set of parameters that define how the response from that system will be returned" ("What are APIs?," 2017). Web based APIs can be written in scripting languages like Python, PHP and Ruby; these are used in conjunction with XML or JSON to parse through information (Adams Jr, 2018). There are two main types of web service APIs known as Simple Object Access Protocol (SOAP) and Representational State Transfer

(REST). These rules permit information sharing and presentation from internal and external sources. It enables information from different sources to be retrieved and viewed in one location regardless of initial formatting.

The API acts as an intermediary and allows the user to access, search or share information from various sources. This increases access to resources that are in different locations**.** APIs have the potential to transform and advance the EHR market as it has done for the consumer technology market. Popular technology companies like Apple, Google, Amazon and Facebook have implemented this technology into their platforms which has helped these companies remain competitive and innovative (Brown & Landman, 2015). APIs have allowed companies to grow and evolve since the early 2000s –websites like Flickr, Google Maps, and Twitter have integrated it into their sites. Companies including e-Bay and Salesforce have also utilized APIs since the early 2000s (Plantin, Lagoze, Edwards, & Sandvig, 2018). Google Maps uses APIs to enhance the user experience by integrating information that is useful during direction searching. APIs allow users to view shopping information, transit information and reviews all within Google Maps while information seeking. It allows for a highly interactive and united experience all within one page. Without APIs a user would have to find these details separately which can be time consuming.

1.1.4.2 API Release Policies

According to information from Red Hat, there are three main types of release policies that could be applied to APIs: private, partner or public/open ("What are APIs?," 2017). For this paper, the most relevant two are private and public APIs. These are exact opposites with one allowing the most freedom and the other allowing the least freedom.

These two release policies vary in the way that source code and data are stored, secured and used. The type of release policy used will depend on the type of access and rights required. Having control of the API code allows an entity to change, update or remove accessibility criteria and security settings for the API's parameters. More detailed descriptions of private and open APIs are below.

Private: Private APIs are used by companies that need an API solely for internal use to integrate systems internal to the organization. This gives the company the highest level of control over the API and is not usually shared with other companies.

Public: Public or Open APIs are open to companies, partners and third-parties. The API and other systems can be accessed by others that are not necessarily involved with the business. This is an API that is available to everybody and third-party developers can change or edit the API. This is least secure method.

1.1.4.3 Protocol and Standards

Protocol specifications have been established since APIs have acquired a more widespread usage. One popular protocol is called SOAP which stands for Simple Object Access Protocol ("What are APIs?," 2017). SOAP relies on XML and allows APIs to access, integrate and share information from different applications on the web. Another is called REST which is less robust than SOAP but runs more efficiently on the web. Both promote interoperability on the web by bringing together information that can be written in different scripting languages.

1.1.5 Overview: Interoperability, EHRs and APIs

1.1.5.1 Legislature promoting EHRs (HITECH)

Around 2009 the Health Information Technology for Economic and Clinical Health (HITECH) Act was created to help fund and incentivize the implementation of EHRs within medical practices. Around $35 billion dollars was supplied to this cause and a projected 5 year timeline was set, starting in 2011 (Reisman, 2017). Each stage had a few requirements that had to be met to demonstrate the "meaningful use" of the EHR technology. These would assess the effectiveness and quality of patient care affected by EHRs. Interoperability was briefly mentioned but not clearly defined in these meaningful use standards. This is part of the reason why there have been issues promoting interoperability (Yen & Bakken, 2012). The first stage of HITECH focused on EHR design and adoption by health care providers; but it did not include clear strategies for interoperability. Stage 1 was a huge success and 96% of hospitals in the United States have "a federally tested and certified EHR program" as of 2015(Charles, Gabriel, & Searcy, 2015). This is a demonstration to the power of legislature and how it can completely transform and incentivize positive change. There are no strict guides in place that mandate standardized interoperability for all EHRs.

1.1.5.2 Interoperability Standards in Healthcare

In the healthcare field an important standard is called FHIR (pronounced "*fire"*) developed by HL7. It specifies how health information ought to be structured and distributed throughout the web. It encourages a universal standard for all EHRs to follow (McLaughlin, 2017). Currently, electronic health record vendors aren't mandated to follow all components of FHIR. This has led to various private and public APIs only

following parts of FHIR. However, in 2019 the Office of the National Coordinator for Health IT proposed to make FHIR a requirement for all APIs used in healthcare. Having one API standard would allow health data to be accessed, exchanged and used "without special effort" (Slabodkin, 2019a). This new rule would also prohibit charging extra for API functions, which some vendors have done in the past with their private and proprietary APIs. These APIs aided in the integration of EHRs, labs, claims processing systems and other data. FHIR does not define security protocols but it ensures that data transfers agree with existing security protocols for health data.

1.1.5.3 Successful Examples of APIs improving EHR Interoperability

Currently two promising projects are underway: The Argonaut Project and the Promoting Interoperability Program. These projects demonstrate the success of using APIs to allow more integrated and accessible health data in EHRs. The Argonaut Project was created to swiftly develop and advance interoperability in the healthcare field with APIs. It follows FHIR data standards crated by HL7 to expand information sharing based on "internet standards and architectural partners and styles" ("HL7 Argonaut Project Wiki," 2018). The Promoting Interoperability Program is through the Centers for Medicare and Medicaid Services (CMS). All of their healthcare providers must agree to have their data available to the FHIR API by January 2019. Its main goal is to allow secure access to Medicare data. This would allow providers to have a comprehensive dashboard of patient information or allow patients to securely retrieve and even store their health data through their iPhones (Haas, Halamka & Suk, 2019). The ventures of CMS to incorporate APIs have been extensive. Recently, they began using their Blue Button 2.0 API. It had been in development since 2015 and evolved into a standardized web based API (Scrimshire,

2019). eClinicalWorks, a healthcare IT company, has integrated their EHR system with this API as well. CMS developed the API to work with the current Medicare/Medicaid system and took advantage of their semi-homogenous system. Their API can search and retrieve information within the entire system. It allows 4 years of Medicare Part A, B and D data to be easily accessible. It connects vital information from a variety of sources such as outpatient claims, inpatient claims, home health agency claims and skilled nursing facility claims. Over 1,300 fields have been mapped to provide access to drug prescriptions, primary care treatments and other pertinent health information (*Blue Button API Docs*, 2017). Health care providers can easily view and access this information as well as patients. Patients have full control over who can view their data, too. Physicians within the system can view other treatments that their patient received, and pharmacies can track medication adherence from multiple sources. The API used by this system was created with the help of Google. It utilized coding systems found with Medicare billing which mandate what each claim should use like IDs, patient status, treatment cost (*Blue Button API Docs*, 2017).

1.1.5.4 Summary

This study attempts to summarize and culminate ideas on how APIs are affecting the healthcare field with respect to EHRs. The summarization of current literature can help others assess the usefulness and impact of APIs on the healthcare sector. Information explaining EHRs as well as API standards and architecture were looked at in detail to provide background and context. The two are not widely known by everyone outside of healthcare or technology and background information will help readers understand them. The importance of interoperability was explored and so was past legislature.

The question of how APIs can improve interoperability within the health records landscape will be explored in various ways. Due to the newness of this topic there is a lack of extensive research in this area. Also, there appears to be a lack of research focusing on APIs to the healthcare field.

Highly interoperable systems will allow EHRs to be received and exchanged simply. However, there are multiple obstacles in the way. Silos and fragmented processes found in the U.S. Healthcare system have only exacerbated these issues in the past. Similarly, the current EHR market houses hundreds of different government-certified EHR systems with different capabilities and clinical terminologies. (Reisman, 2017). Lastly, a lack of standardized data across systems is present since systems have been custom-made with different controlled vocabularies, layouts and schemas (Murphy, 2016). An API will allow EHR systems to access more robust information housed in different EHRs and medical devices. APIs can help in the 3 following ways: improving access to health data, integrating fragmented health data and providing secure connectivity. APIs are a viable solution since they are relatively accessible and usable. They can be accessed and used through the web and work with a variety of programming languages.

Methods

1.1.6 Overview

A systematic review was conducted to summarize report trends found in current peer-reviewed resources and grey literature. This section attempts to clearly describe and define how relevant literature will be selected for review. It will also explain how the studies selected were "gathered, so that readers are in a better position to determine the representativeness of the studies" (Kelly & Sugimoto, 2013). This study follows the

guidelines set by PRISMA. The PRISMA 2009 Checklist was used as a guide for this systematic review.

1.1.7 Types of Literature Searched

A diverse set of sources were utilized to give an up-to-date and useful understanding of EHRs and APIs. Resources in this review included peer-reviewed articles as well as grey literature. A brief description of both will be provided as well as motivations for inclusion. Peer-reviewed literature is typically written for researchers or experts in a specific field and then revised by professionals and assessed for validity. This source was chosen so that scholarly publications of high quality could be included in my study. The definition of grey literature is provided by the International Conference of Grey Literature as, "information produced on all levels of government, academia, business and industry in electronic and print formats not controlled by commercial publishing i.e. where publishing is not the primary activity of the producing body" (Schöpfel, 2011). Grey literature was included due to the newness of the topic. Conference proceedings and articles can provide the most up-to-date and cutting-edge information that scholarly articles won't have due to extensive and time-consuming standards.

1.1.8 Databases Searched

Five databases were chosen to search for peer-reviewed and grey literature. Each database was chosen based on their emphasis on the research topic, journal access and coverage of the medical or tech aspect of search. The selected databases included PubMed, EMBASE, Web of Science, Scopus and ProQuest Health Management Database. Summaries of each database can be viewed in Table 1.

TABLE 1: Sources Searched for Materials

List of Searched Sources	Description
PubMed	From the National Library of Medicine. Contains journal articles from the 1950s on medicine, nursing, dentistry, veterinary medicine, and public health.
Web of Science	A popular citation index that has provides access to indexes on science, social sciences, arts and humanities. Contains articles from conference proceedings, peer-reviewed journals and books.
Scopus	A citation and abstract database that provides coverage of the peer-reviewed journal and conference literature with links to full-text where available through the library.
Embase	Embase is a database from Elsevier that contains resources for biomedical literature. Embase is more expansive than MEDLINE since it covers more literature like conference abstracts, European journal titles and more.
ProQuest Health Management Database	A database for those in the field of health administration. Information and topics found in this database include hospitals, statistics, business management, ethics, health economics, and public health administration.

1.1.9 Optimizing Databases Searches

Each database provides a unique set of search options to enhance citation retrieval. Searches in PubMed and ProQuest Health Management Database utilized the following fields: [ti], [ab] and [MeSH] while searches in Embase utilized [ti] and EMTREE. Scopus search used more general search strategies and did not include controlled vocabulary.

1.1.10 Search Terms

Search terms were identified to formulate the most comprehensive search. Search terms typically focused on three main areas: Electronic health records, application programming interfaces and FHIR standards.

The term FHIR was included since it is significant in detailing how APIs can be used with EHRs and HIEs. Health information exchange is a key goal where professionals and patients can securely share health data. FHIR standards allow health organizations to use independent EHR vendors or devices and still be able to share data. It can be plugged into any web application or electronic health record systems that complies with its standards. FHIR was even supported by numerous EHR vendors (like Epic, Duke Medicine, CMS, Cerner and more) during the American Medical Informatics Association (AMIA) (Raths, 2014). FHIR standards are valued for its adaptability and capability to allow new functions or protocols, including APIs.

Interoperability was excluded from search terms because it made the query too narrow. Preliminary searches showing a low number of retrieved records. As an example, the query in PubMed with the term *interoperability* (as the last term) retrieved 22 results but a search without the term retrieved 100 results. A large quantity of relevant articles was unnecessarily excluded. Instead, the search queries included words that are correlated with interoperability. This was seen when a quite a few papers had the term *interoperability* appear even with the word interoperability was removed from the query. The selected terms and their synonyms were used to create effective searches. The usage of synonyms and controlled vocabulary varied based on database. A variety of search techniques such as Boolean operators (AND, OR); truncation/stemming (*); parentheses and quotes were used to enhance the terms entered into the databases.

The synonyms that were applied to queries are listed below:

- *Electronic Health Records:* (EHR, electronic medical records, electronic patient record, ambulatory medical record, computer-based medical record, computerized patient records health record, clinical support system, medication administration

record, Clinical Physician Order entry system, clinical decision support system (CDSS)

- *Application Programming Interface:* (API, software intermediary, software-to-software interface, communication protocols and transmission interface)
- *Health Information Exchange Standards:* (FHIR)

1.1.11 Database Search Queries and General Eligibility

Unique search queries were created for each database. The same search terms were used for all databases, but queries varied. The exact queries can be found in Table 2. A set of basic inclusion criteria was selected to find the most relevant materials. During the initial search, articles were eligible based on the following criteria: (1) Date: 2007-2019; (2) Language: English; (3) Country of Research: United States; (4) Full-Text Availability through UNC or Open Access; (5) Peer Reviewed Literature: Scholarly Articles; (6) Grey Literature: Conference Documents and Trade Journals.

The selected timeline was between the years 2007 and 2019 to retrieve the most recent information of EHRs and APIs. Materials older than this date often only referred to the initial wave of EHRs and did not have much focus on APIs or interoperability. The second and third criteria were created to focus on U.S. healthcare system. The fourth requirement specified that I have complete access to the literature through UNC Libraries. The last two criteria make sure to include both peer reviewed and grey literature. Including all types of grey literature would be too extensive and that is why only conference documents and trade journals are included. Trade journals are "written for professionals in a particular field but are not strictly research related" and include Health Purchasing News (NC State University Libraries, n.d.).

TABLE #2: Search Queries by Database

Database	Search Terms Used
Web of Science	TS=((((api OR apis OR fhir OR hapi) AND (program* OR computer*)) OR "Application programming interface" OR "application programming interfaces" OR (application AND programming AND interface*)) AND ("health record" OR "health records" OR "medical record" OR "medical records" OR "electronic health records" OR ehr OR ehrs OR emr OR emrs OR "Health Information Exchange" OR "health information exchanges" OR "medical information exchange" OR "medical information exchanges" OR "electronic health record*" OR "Medical Records System*" OR “clinical decision support system” OR “clinical physician order entry system”))
PubMed	((((api[tiab] OR apis[tiab] OR fhir[tiab] OR hapi[tiab]) AND (program*[tiab] OR computer*[tiab])) OR "Application programming interface" OR "application programming interfaces" OR (application[tiab]AND programming[tiab] AND interface*[tiab]))) AND (health record OR health records OR medical record OR medical records OR "electronic health records" OR "electronic health record" OR ehr[tiab] OR ehrs[tiab] OR emr[tiab] OR emrs[tiab] OR Health Information Exchange OR health information exchanges OR medical information exchange OR medical information exchanges OR electronic health records[mesh] OR Medical Records Systems, Computerized[mesh] OR “clinical decision support system” OR “clinical physician order entry system”)
Scopus	TITLE-ABS-KEY ((((api OR apis OR fhir OR hapi) AND (program* OR computer*)) OR "Application programming interface" OR "application programming interfaces" OR (application AND programming AND interface*)) AND ("health record" OR "health records" OR "medical record" OR "medical records" OR "electronic health records" OR ehr OR ehrs OR emr OR emrs OR "Health Information Exchange" OR "health information exchanges" OR "medical information exchange" OR "medical information exchanges" OR "electronic health record*" OR "Medical Records System*" OR “clinical decision support system” OR “clinical physician order entry system”)
ProQuest Health Management Database	((((api OR apis OR fhir OR hapi) AND (program* OR computer*)) OR "Application programming interface" OR "application programming interfaces" OR (application AND programming AND interface*)) AND ("health record" OR "health records" OR "medical record" OR "medical records" OR "electronic health records" OR ehr OR ehrs OR emr OR emrs OR "Health Information Exchange" OR "health information exchanges" OR "medical information exchange" OR "medical information exchanges" OR "electronic health record*" OR "Medical Records System*" OR “clinical decision support system” OR “clinical physician order entry system”))
Embase	((((api OR apis OR fhir OR hapi) AND (program* OR computer*)) OR ‘Application programming interface’ OR ‘application programming interfaces’ OR (application AND programming AND interface*)) AND (‘health record’ OR ‘health records’ OR ‘medical record’ OR ‘medical records’ OR ‘electronic health records’ OR ehr OR ehrs OR emr OR emrs OR ‘Health Information Exchange’ OR ‘health information exchanges’ OR ‘medical information exchange’ OR ‘medical information exchanges’ OR ‘electronic health record*’ OR ‘Medical Records System*’ OR ‘clinical decision support system’ OR ‘clinical physician order entry system’))

1.1.12 Screening Process: Context Based Inclusion/Exclusion Criteria

Additional inclusion and exclusion criteria were used during the screening process. These served as additional criteria to ensure that the studies selected were most relevant. A significant portion of this revolves around the context and the thematic instance of which

EHRs and APIs are discussed. Generally, any papers that discussed APIs and its usage to other technology that didn't included electronic health records were excluded. Electronic health records had to be discussed in relation to interoperability or being improved through the usage of APIs. Table 3 summarizes all thematic inclusion and exclusion criteria.

Table 3: Thematic Inclusion and Exclusion Criteria

	Inclusion	**Exclusion**
Location	U.S. or U.S. Affiliated Healthcare	International or Non-U.S. Affiliated Healthcare
Paper's connection to the following: *APIs, EHRs or Standards*	APIs • Usage with EHRs • Usage with mobile devices linked with EHRs EHRs • Improvement of EHRs through interoperability Standards • FHIR (Improving or Applying Standards) • API standards applied to EHRs	APIs • Usage outside of healthcare setting • Usage to improve other HIT (Imaging Devices, etc.) excluding EHRs EHRs • Barriers to implementing EHRs • EHRs solely as innovative technology Standards • General HIT Standards w/o relation to EHRs (ICD-10 codes etc.)
Study Design	No Limits	
Timing of Study	(≥ 2007	(< 2007)

The exclusion criteria for both EHRs and APIs will be discussed in detail. First, the criteria for APIs will be explained. API usage within healthcare should be the principal goal or one of principle goals of the paper. Descriptions as to how APIs can change the

current EHR market regarding technology and standards will be included. If this is not met, then the resource will be removed. Other topics may be discussed but there must ultimately be a tie-in to healthcare. For example, the following situations mentioned are criteria for exclusion: (1) if APIs are mentioned in a non-healthcare related setting; (2) with discussion of ArcGIS, Java, Python and .NET or Ardunio projects to create non-health related websites or apps; (3) uses of APIs within Facebook, Apple, Google for uses such as maps, online shopping and other unrelated areas.

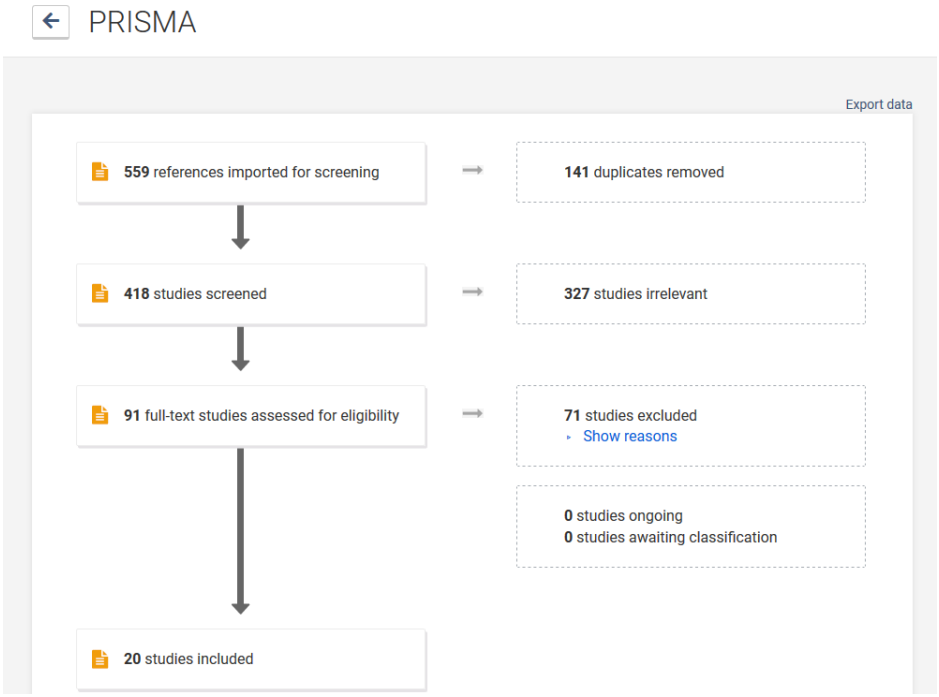
Next, we will look more closely into criteria and context of how EHRs are discussed in the resources. One way to look at this is by analyzing the current state of EHRs in relation to interoperability. The resources should primarily discuss EHRs in relation to interoperability and/or APIs. The following would be criteria for exclusion: (1) EHRs as a disruptive technology without mention of interoperability or APIs; (2) EHR adoption rates in the United States; (3) EHR in relation to big data and health; (4) User experience outside of the realm on increasing the ability to disseminate these records. If a paper or article was read and it was determined that the above contexts were not met, then it was removed from the search.

1.1.13 Screening and Risk of Bias

All retrieved articles underwent two rounds of thorough screening. All screening occurred in Covidence and followed guidelines as recommended by PRISMA. All abstracts, titles and full-text screening was performed by one reviewer. First a title and abstract screening occurred which was then followed by Full-Text Screening. The following inclusion and exclusion criteria were used to assess eligibility for studies. These were based on topic and thematic choice. A PICO format was not used and there

weren't any clinical queries that looked into therapies, diagnoses, etiologies or prognoses. A basic quality assessment was done for all papers and relied on the following questions, including grey literature. A PRISMA flow diagram is seen in Figure 1 to show the amount of studies removed until the final set was reviewed.

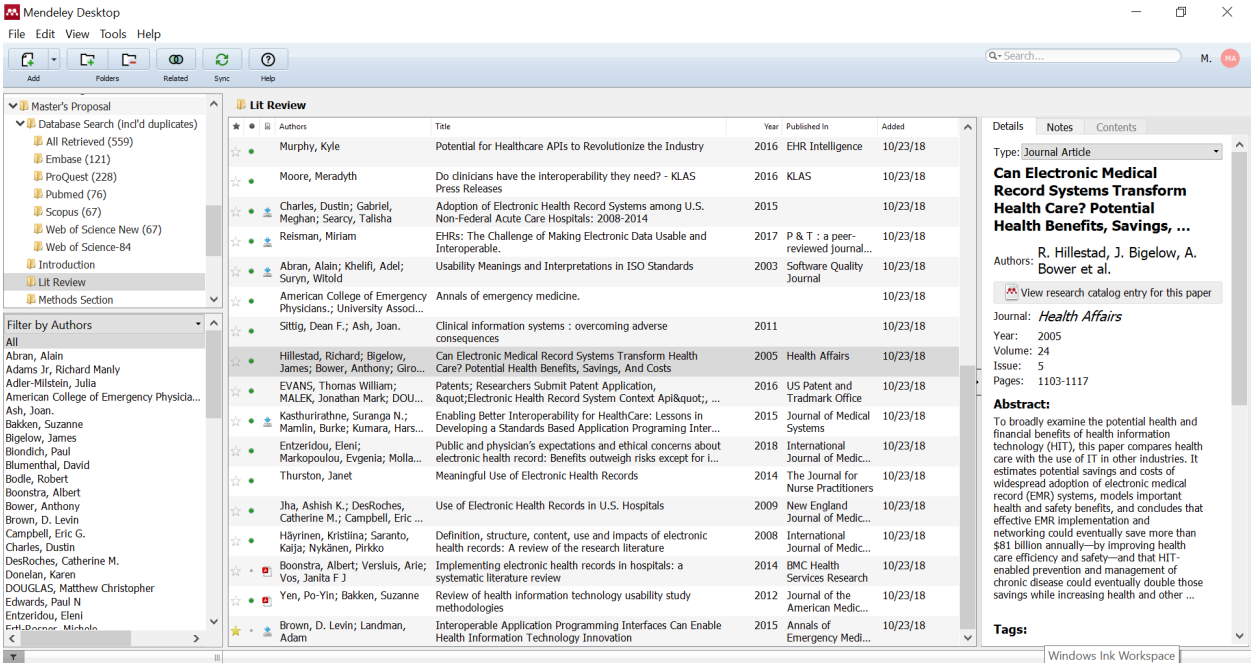
Figure 1: PRISMA Flow Diagram



1.1.14 Data Management

A vast quantity of papers was found during the systematic review. Mendeley Reference Manager, Covidence and Excel were used to manage and screen resources. An image of Covidence can be seen in Figure 2.

Figure 2: Screenshot of Mendeley



References were stored, exported and imported with Mendeley Reference Manager. Mendeley is a reference management tool that can be used to organize, search, annotate and cite literature. Mendeley offers a web and desktop version of its product; both were used to manage the articles that were found. Web databases also have a feature that enables articles, citations, metadata and other data to be exported and saved in the Mendeley –this was also used.

Covidence is a well-known tool to assist those performing a systematic review. It also allows reviewers to iteratively go through the systematic review process delineated by PRISMA. Titles, Abstracts, and full-text articles were screened based on the thematic inclusion and exclusion criteria. Covidence was also used to de-duplicate articles and then a second check was done by hand. Multiple reviewers can be added to screen and review but this review will only have one reviewer.

Results

After the initial search in the 5 above mentioned databases the following peer-reviewed and grey literature results were found: Web of Science (67), PubMed (76), Scopus (67), ProQuest Health Management Database (228) and Embase (121). (Table 4)

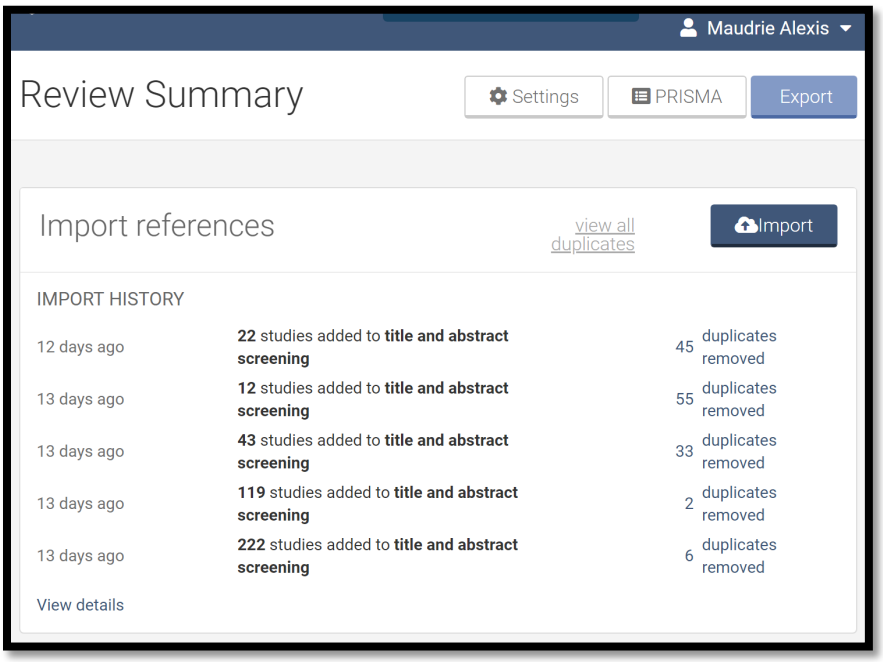
Table 4: Records retrieved by Database

Database	Results Retrieved
Web of Science	67
PubMed	76
Scopus	67
ProQuest Health Management Database	228
Embase	121
Total	**559**

1.1.15 Basic Overview of 20 Studies

The majority of articles were retrieved from ProQuest Health Management Database and the fewest number of articles were found in Web of Science and Scopus. Covidence removed 141 duplicates and 5 were found by hand for a total of 146 duplicates being removed. Duplicates found by Covidence can be seen in Figure 2.

Figue 2: Screenshot of Covidence – Duplicates



After the full-text review, 20 publications were included and reviewed in detail. Of the papers reviewed 13 were peer-reviewed and the remaining 7 were grey literature. Most of the peer-reviewed literature was published in the Journal of the American Medical Informatics Association and the majority of Grey Literature was from the Health Data Management Magazine. An overview of all studies retrieved can be found in Table 5.

Table 5: Elementary Characteristics of Studies *in Alphabetical Order of Author Last Name

Author(s)	Year Published	Literature Type	Source title
Alterovitz, Gil, et al.	2015	Peer-Reviewed	Journal of the American Medical Informatics Association
Barrett, Lee	2015	Grey Literature	Health Management Technology
Ayvaz, Serkan, et al	2015	Peer-Reviewed	Journal of Biomedical Informatics
Bloomfield Jr, Richard A., et al.	2017	Peer-Reviewed	International Journal of Medical Informatics
Boemer, David	2015	Grey Literature	Health Management Technology
Bosl, William, et al.	2013	Peer-Reviewed	Journal of Medical Internet Research
Crump, Jacob K., et al.	2018	Peer-Reviewed	AMIA Summits on Translational Science Proceedings
Demski, Hans, Sebastian Garde, and Claudia Hildebrand	2016	Peer-Reviewed	BMC Medical Informatics and Decision Making
Hussain, Mohannad A., Steve G. Langer, and Marc Kohli.	2018	Peer-Reviewed	Journal of Digital Imaging
Kasthurirathne, Suranga N., et al.	2015	Peer-Reviewed	Journal of Medical Systems
Mandel, Joshua C., et al.	2016	Peer-Reviewed	Journal of the American Medical Informatics Association
Mandl, Kenneth D., Daniel Gottlieb, and Alyssa Ellis	2019	Peer-Reviewed	Journal of Medical Internet Research
Mandl, Kenneth D., and Isaac S. Kohane	2016	Peer-Reviewed	The New England Journal of Medicine
McCoy, Allison B., et al.	2011	Peer-Reviewed	AMIA Annual Symposium Proceedings
Paris, N., et al.	2018	Grey Literature	Journal of the American Medical Informatics Association
Slabodkin, Greg	2019	Grey Literature	Health Data Management (Online)
Slabodkin, Greg	2018	Grey Literature	Health Data Management (Online)
Slabodkin, Greg	2018	Grey Literature	Health Data Management (Online)
Ta, Casey N., et al.	2018	Grey Literature	Scientific Data
Zhang, Mingyuan, et al.	2013	Peer-Reviewed	AMIA Annual Symposium Proceedings.

Discussion

1.1.16 Qualitative Summary of Themes

After all studies were reviewed and selected based on the inclusion criteria they were analyzed. All articles (N=20) were reviewed and qualitative findings were summarized. Each study was associated with certain keywords that were considered important to the research question (Table 5). All keywords were found within an article and chosen by the

reviewer. *Keywords* are terms that showed up multiple times and *Unique Keywords* are terms that were unique to that one specific article or paper (not all articles will have this). Choice of keywords were selected based on the following two rules:

1. The term(s) is frequently associated with one or all of the main three search terms.
2. The term is linked to any real-world projects, companies or medical devices that used APIs to improve interoperability.

Each article detailed varying aspects of how EHRs can be improved by APIs. Common ideas or findings were synthesized into themes. The findings from the 20 articles were organized into a concise and organized tabular format (Table 6).

Table 6: Thematic Summary of Papers (N=20)

Author(s)	Title	Keywords	Unique Keywords
Alterovitz, Gil, et al.	SMART on FHIR Genomics: Facilitating standardized clinico-genomic apps	HL7, FHIR, SMART, Data integration, API, HTML5, OAuth 2.0 Authentication, EHRs	Clinico-genomic apps
Barrett, Lee	HL7 launches Argonaut Project to advance FHIR interoperability standard	HL7, FHIR, Argonaut Project, EHRs	
Ayvaz, Serkan, et al	Toward a complete dataset of drug-drug interaction information from publicly available sources	APIs, RxNorm, EHRs	PDDI CDS
Bloomfield Jr, Richard A., et al.	Opening the Duke electronic health record to apps: Implementing SMART on FHIR	Epic, SMART, FHIR, HTML, REST, JSON Web Token, open API, OAuth 2.0 Authentication, EHRs	Duke Health
Boemer, David	What APIs bring to EMR/EHR interoperability?	APIs, EMRs, open API, Centers for Medicare and Medicaid Services	

Bosl, William, et al.	Scalable decision support at the point of care: A substitutable electronic health record app for monitoring medication adherence	SMART, API, EHRs	
Crump, Jacob K., et al.	Prototype of a Standards-Based EHR and Genetic Test Reporting Tool Coupled with HL7-Compliant Infobuttons	APIs, EHRs	InfoButton
Demski, Hans, Sebastian Garde, and Claudia Hildebrand	Open data models for smart health interconnected applications: the example of openEHR	openEHR, SMART, FHIR, API	
Hussain, Mohannad A., Steve G. Langer, and Marc Kohli.	Learning HL7 FHIR Using the HAPI FHIR Server and Its Use in Medical Imaging with the SIIM Dataset	HL7, HAPI, RESTful API, SOAP, XML, Java	SIIM Hackathon Dataset, medical imaging
Kasthurirathne, Suranga N., et al.	Enabling Better Interoperability for HealthCare: Lessons in Developing a Standards Based Application Programing Interface for Electronic Medical Record Systems	HL7, XML, FHIR, openMRS, RESTful	
Mandel, Joshua C., et al.	SMART on FHIR: A standards-based, interoperable apps platform for electronic health records	JSON, XML, FHIR, API, EHRs, SMART, RESTful API, HL7,	Harvard Medical School, Boston Children's Hospital
Mandl, Kenneth D., Daniel Gottlieb, and Alyssa Ellis	Beyond One-Off Integrations: A Commercial, Substitutable, Reusable, Standards-Based, Electronic Health Record-Connected App	EHRs, SMART, FHIR, Apple Health App	eClinicalWorks, Meducation App, Century Cures Act
Mandl, Kenneth D., and Isaac S. Kohane	Time for a Patient-Driven Health Information Economy?	API, Meaningful Use	
McCoy, Allison B., et al.	A prototype knowledge base and SMART app to facilitate organization of patient medications by clinical problems	SMART, API, EHRs, RxNorm, HIT, HIEs, Veterans Health API	SNOWMED, UMLS
Paris, N., et al.	2b2 implemented over SMART-on-FHIR	Veterans Health API, SMART, FHIR, EHRs, XML, Oracle, OAuth 2.0 Authentication, SQL,	i2b2

		Argonaut Project, HTTP	
Slabodkin, Greg	VA to offer patient access to health data on iPhones	U.S. Department of Veteran Affairs, Health Records, Veterans Health API	
Slabodkin, Greg	Feds want Blue Button 2.0 initiative to spark data sharing in industry	FHIR, API, Centers for Medicare and Medicaid Services, EHRs	Blue Button 2.0, MyHealthData initiative,
Slabodkin, Greg	Apple expands effort to give patients iPhone access to medical records	Apple Health App, HL7, FHIR, Apple Health Records	
Ta, Casey N., et al.	Columbia Open Health Data, clinical concept prevalence and co-occurrence from electronic health records	EHRs, API, SNOMED, JSON,	Columbia Open Health Data,
Zhang, Mingyuan, et al.	Enabling cross-platform clinical decision support through Web-based decision support in commercial electronic health record systems: proposal and evaluation of initial prototype implementations	EHRs, API, HTML, HIT	Clinical Decision Support, eClinicalWorks, CPOE, ICD Codes,

1.1.17 Thematic Characteristics of Studies

Most articles discussed how APIs can be used to improve EHR interoperability. This can refer to a few main areas. Three key themes that frequently appeared were: ease of access to data, data integration. and availability of secure standards. These were determined by reading through full texts and looking at the keywords selected by the reviewer that were significant.

1.1.18 Three Main Themes

1.1.18.1 Ease of Access to Data

There are some promising cases that demonstrate improved EHR access by patients or physicians as seen in the peer-reviewed article by Mandel et al. (2016), the 2018 articles by Greg Slabodkin and the article by Mandl et al. (2019). Successful implementation of APIs was observed while reading the literature. These are deemed as APIs that led to improved sharing of health records on a large scale The addition of APIs has greatly improved access for those within the Veterans Association and those using Apple Health Records or CMS Blue Button (Mandel, Kreda, Mandl, Kohane, & Ramoni, 2016; Slabodkin, 2018b, 2018a). Successful sharing is defined as health records that was able to be easily shared or viewed by multiple people or systems. This typically means that there was easier EHR access in comparison to when the API was not used.

One notable example was when the U.S. Department of Veteran Affairs became committed to improving access to health records (Slabodkin, 2019b). An initial campaign to improve access was called *VA Blue Button*. It was announced in 2010 but simply allowed patients to download their health data through a patient portal. As of 2019, the new Veterans Health API is a novel venture that is a major advancement upon the original VA Blue Button. It utilizes the VA's Health API and Apple's health app called *Health Records on iPhone* (Slabodkin, 2019b). Those who receive care at VA facilities will be able to access their health records on their phone or online and share it with their provider. A RESTful API was created in compliance with FHIR standards to achieve this. This is unique as it allows health data from various sources to be amassed and updated through a third-party source. Veterans do not have to login to multiple portals or sites and

can view their allergies, lab results and prescriptions or book appointments all from one location. This API will help all of this information become integrated into one location every 24 hours. This Health APIs will also include clinician facing as well so that they can access synthesized health data.

1.1.18.2 Improved Data Integration

Research from the 20 articles has shown that APIs can assist in the transfer of data from medical devices to EHRs (Bosl et al., 2013; G. et al., 2015; S. et al., 2015). APIs allow EHRs to assimilate information from multiple devices and sources. The included studies supported the idea that data from different sources can be integrated into EHRs. APIs could facilitate that process. Vital signs are commonly transferred through manual entry where a person would read and transcribe this data into an EHR. This data is critical to decision support in health care facilities. APIs are a tool that can be used to simplify this process but there are some limitations. If vitals are stored in different units in different systems, then there may be a problem. For example, an API can share HbA1c levels from 2 different APIs but if one is recorded in mmoL/C and the other is mg/dL the data won't be meaningful if these differences aren't clarified and converted. Nevertheless, it is clear that APIs can be used to aggregate data from RxNorm, genomic data apps and medical imaging software into EHRs (Bosl et al., 2013; G. et al., 2015; S. et al., 2015).

One noteworthy case was when a framework was designed to facilitate the transfer of genomic data to an EHR (G. et al., 2015). The impact of genomic data has grown due to advancements in gene editing and analysis. Genomic data is highly proprietary with select systems managing and storing this type of data. These systems are already equipped with their own respective private APIs that aren't shared. To resolve this a new

API was created based on SMART on FHIR protocols, RESTful APIs, EHR systems with web access and HTML5. This would allow genomic data sources to be queried and retrieved reliably despite the original genomic data format. A prototype was designed and created that would allow genomic data to be integrated by EHRs, data vendors and app developers. This could then be implemented on a considerable scale. The API used was SMART certified and complied with all health data security standards. Combining these distinct data sources is important to advancing personalized medicine and data analysis.

1.1.18.3 Secure Standards

Standards were discussed frequently throughout the majority of the 20 studies that were reviewed. The healthcare field has been cautious when adopting new technologies. In terms of interoperability, this has led to slow adoption of new technology. Having access to robust and accessible health data is important. In the past few years the significance of shared data has become increasingly focused upon. Open APIs and Standards based APIs have become recognized as a potential solution. All APIs follow a standard, but the quality of that standard makes a difference. Strong standards, like FHIR by HL7 ensure that the data being transferred are secure and consistent. The main benefit of open APIs is that anyone can use it to send and receive data from various sources. If these two are combined, it encourages open APIs that other institutions can use to improve their EHRs functionality.

One prominent instance is the usage of an open API by Duke Health (Bloomfield, Polo-Wood, Mandel, & Mandl, 2017). In a recent study the organization described their endeavor to have easily accessible and integrated data from their EHRs provided by EPIC. A proof of concept system was initiated in 2014 that allowed physicians to access

patient data from an Android device and view up-to-date patient data Health (Bloomfield et al., 2017). Later, the project evolved to include FHIR APIs along with open APIs which seamlessly allowed data accessibility and authentication. The open API was created by developers from Boston Children's Hospital and the Department of Biomedical Informatics. Because of this, Epic web services, Clarity (a relational database), and Chronicles (an Epic database) to interact and share data with each other. This would allow new and useful apps to share with patient data to produce more comprehensive data. For example, a new app called MeTree allows patients to streamline their family health information and be used to predict diseases using evidence-based algorithms.

1.1.19 Findings Related to the Research Question

The research question inquired into how APIs can improve health information exchanges, particularly for EHRs. The reviewed literature shows that APIs can indeed facilitate this process. Successful attempts were seen in multiple papers –from large organizations like CMS or the VA and even smaller projects from labs. These revealed that APIs can successful be used to improve data exchanges amongst different devices and EHRs. It also revealed exactly how it can be facilitated. The three main areas that were assess included: improved access to health records, improved data integration, and the use of secure standards. Improved access to health records were seen by patients, researchers and physicians based on the reviewed studies. The use of an API either enabled of simplified the process for users to view EHRs on a mobile device or computer. Improved data integration was also seen in some of the papers. Genomic data, imaging data and other EHRs were able to be integrated into one viewing portal or one source. A

secure standard, FHIR, was frequently utilized to send data securely. FHIR uses HTTP, XML, JSON, CSS and other web-based standards. Adopting FHIR standards or other related protocols like SMART on FHIR allowed different devices with diverse coding and structures to share information. SMART on FHIR is unique as it has more of a delineated guide of how to authenticate and connect EHRs and health data to different sources. It works similarly to how an individual can use their Facebook account to log in to different sites or apps like Pinterest, The New York Times or Buzzfeed. They are all different sites but when you log-in through Facebook an API provides authentication and allows you to access certain pieces of information that is stored on Facebook.

1.1.20 Limitations

The methods and results mentioned above were used to clearly delineate the search strategy, literature selected, sources search, inclusion and exclusion criteria for the review. The 27 step PRISMA guide was not exactly followed due to time constrains and the number of researchers involved in the study.

Three main limitations in this study included the lack of multiple reviewers, quantity of resources searched, and length of time spent on the process. Typically, a systematic review has between 2-4 individuals checking and analyzing materials whereas this study only had one reviewer. Since there is one reviewer there is the potential of bias. Other reviewers help provide additional checks and evaluations. Another limitation is the quantity and sources of resources. Only 5 databases were looked at but there is a plethora of other databases that could have been used to find relevant articles. The grey literature found is believed to be reputable as it is retrieved from well-established sources. Another limitation is the length of time. A systematic review typically takes 1 year while this one

only lasted a few months. The analysis performed during this systematic review strived to be diligent and accurate, but it can't compare to the work of 3 professional reviewers with more time and funds.

Conclusion

Overall, the systematic review demonstrated that APIs can be used as a viable option to improve the interoperability of EHRs. Particularly in the areas of increased access, data integration and secure data transfer methods. Access to EHRs is important for both physicians and patients. If patients have more access to their health records this would also empower them as well. For example, Apple's Health Records is a great tool allowing patients to view, culminate and share their health data with a variety of hospitals who have partnered with Apple. Apple's Health Records App uses a FHIR API that allows it to be so easily accessible and updated on iPhones and web devices. Data integration is a key component of increasing interoperability of EHRs. Having data from medical devices, lab results, pharmacies and more will help physicians generate informed decisions. Having a wide array of information available is important to evidence-based decision making. An API allows data to be shared and aggregated from multiple sources. It acts as a middle man that allows data to be transferred and shared from different sources that agree to the same secure standards.

These findings are exciting as this is only the preliminary stages of exploring how APIs can improve health information exchanges and electronic health records. APIs are only now being applied to the healthcare field. Conversely, APIs have been used in other areas –such as social media, online maps, online payment systems, video sites and more—to

seamlessly integrate data through the usage of an open API. In some cases APIs are publicized so that end users can improve data “mashups” between different sites. The goal of these “mashups” are to make sites more informative and to bring “disparate applications together, enhancing existing data with extra information.” (He & Zha, 2014). Having user input increases transparency and offer a collective source of inputs from others who want to improve the system.

Health Information Exchanges can be improved greatly if this promising trend continues based on the results found in the selected readings. Nevertheless, health information is still fragmented due to the “ad hoc implementation of clinical systems” and distinct concentrations in medicine (Kasthurirathne, Mamlin, Kumara, Grieve, & Biondich, 2015). Goals to exchange this data are highly attractive. Using APIs to do so is continuously being explored and developed through research in academia and research in industry. Having widely known regulations for APIs like FHIR is extremely useful. There is a push for it to become the universal standard but this yet to be determined.

One day we may be able to achieve seamless data transfers between similar and dissimilar healthcare devices and EHRs. Health care workers would be able to provide higher quality of care if all relevant information is available in a timely and useful manner.

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