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Novel eHealth Trends In The Field Of Radiology: A Scoping Review

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ABSTRACT

Objective: The purpose of this paper is to identify and consolidate literature that describes eHealth tools or innovations currently existing in the field of radiology.

Methods: Due to the nature of the subject matter, this paper must be partially based on non-academic literature, such as government documents, documents describing the work of organizations, and opinion pieces or reviews by subject matter experts. A literature search was conducted using broad terms, unspecific to any subtype of informatics or radiology to achieve results as inclusive as possible. The databases PubMed, Google Scholar, and OVID Healthstar were searched using the generic terms "radiology + eHealth". Specific terms (e.g. "diagnostic imaging repositories") were used to search Google Scholar, Google, and the Canada Health Infoway and eHealth Ontario websites to retrieve information on desired topics.

Results: Seven trends are identified. Trends identified based on the literature review are related to teleradiology (n=38), mobile applications and devices (n=21), enhancements to PACS architecture (n=18), and web-based tools integrated with PACS (n=17). Trends identified based on further investigation to regional initiatives are diagnostic imaging repositories, foreign exam management, and zero footprint image viewers.

Discussion: A wide variety of research and significant efforts have been applied to these seven identified trends, and subareas of each. The theme of teleradiology has a great presence in the literature. Cloud computing has been suggested as a solution to the current needs for PACS. Completion of diagnostic imaging repositories represents great success provincially and is the gateway to further advancements, such as foreign exam management.

Conclusion: Radiology and eHealth are deeply interconnected fields of medicine. Medical imaging informatics advancements such as the seven described in this review are essential for strong clinical practice, for making patient care safer, and giving providers the best tools to work with.

INTRODUCTION

The basis of both medicine and health care is almost exclusively information [1,2,3]. Thus, systems for information gathering, storage, transfer, archiving, and analysis are essential for optimizing all practices within health care. In this age of technology, these systems must be electronic in order to offer tangible benefits and effectively enhance the delivery of care [1,2].

Medical Informatics

The science devoted to information and its use within medicine is called medical informatics. Medical informatics, or health informatics, is a broad term that refers to the management and use of information in health and biomedicine [1,2,3,4]. As a discipline, medical informatics is relatively young, and came into fruition with the introduction and widespread use of digital computers and corresponding information and communication tools[2]. These information and communication tools allowed substantial progress in information processing methodologies, which has drastically changed the way medicine and health care are delivered[2]. For example, some of the earliest work in medical informatics outlined the need for computer-based medical decision-support, functional and architectural bases for hospital information systems, development of informatics based education programs, and introduction of online access to peer-reviewed journals and other medical literature [2,4]. Within the past 50 years, other types of work include the development of robust clinical information systems, telemedicine, homecare, regional networks, clinical provider order entry (CPOE), natural language processing, and standardizing and digitizing patient records[2]. Today, significant resources are invested in the development of electronic medical records (EMRs), personal health records, secure methods of communication between patients and providers, and large scale integrations of various information systems to create bigger networks of shared patient information[2].

The benefits of medical informatics to clinical workflow and patient care have been well documented, and are generally rooted in the concept of enhanced patient safety. Information technology (IT) can be harnessed to prevent medical errors and allow for more rapid response to adverse events [3,5]. It has been shown that advancements in improving communication, providing greater access to information, computerized methods for calculations, monitoring tools, decision support, tracking of adverse events and medical errors, and medication prescribing and dispensing have all been influential in increasing patient safety in clinical settings as well as at home [3,5]. In essence, three categories exist that the efforts of medical informatics fall under: contribution to good medicine and good health for an individual, good medical and health knowledge, and well-organized health care[2].

Many definitions of eHealth are synonymous with those for medical informatics. eHealth, short for electronic health, however, is a newer term, surfacing only within the past 20 years[6]. Like medical informatics, definitions for eHealth are numerous and vary based on context. For example, eHealth can be used to refer to the ways in which information and communication technologies can be used to improve health and the healthcare system[2]. Additionally, some definitions also acknowledge that eHealth is directly related to the use of the Internet within health care [2,6]. In 2005, a systematic review of published eHealth definitions found that 51 different definitions exist, and that universal themes were health and technology, in the context of the health care industry and health services delivery, and Internet technology, respectively[6]. The themes of commerce, health outcomes, geography, stakeholders, and perspectives occurred less frequently[6].

For the purposes of this paper, eHealth and medical informatics will be considered interchangeable terms, and refer to any electronic or technologically based tool or system which has meaningful use in a clinical setting, and aims to increase quality patient care, enable care providers to deliver care more effectively, or both. Any tool or technological advancement within radiology identified to be consistent with this definition of eHealth will be considered for discussion in this review.

Radiology

Radiology is a complex science that involves medical imaging using physical principles and technology, generally for the purpose of diagnosing disease or injury[7]. Advancements in medicine have been largely dependent on progress in diagnostic imaging, and both continue to flourish as they are enabled by technology[7]. Diagnostic imaging is conducted through modalities including digital radiography, ultrasonography, computed tomography (CT), magnetic resonance imaging (MRI), radionuclide imaging, mammography, and fluoroscopy[7]. Diagnostic imaging procedures are carried out by technologists, and the resulting images interpreted by specialist physicians, most often radiologists. These images are used to make diagnoses, determine appropriate courses of treatment, and stage the progression of disease or injury states [7,8]. The process includes several steps, from image production, processing, display, recording, storage, and transmission. Each aspect of radiology is based on technology, however, some, such as the development of Picture Archiving and Communication Systems (PACS) and the Digital Imaging and Communications in Medicine (DICOM) Standard are examples of technology in a medical informatics context [7,8,9]. The development of these tools has been paramount in the transition of radiological imaging from film to digital methods[9]. This paper aims to uncover tools like these, which have potential to change the way radiology is practiced on some scale.

Medical Imaging Informatics

The influence of medical informatics on diagnostic imaging can be observed in many different ways; the two disciplines are deeply interconnected. For example, integration between a Hospital Information System (HIS), Radiology Information System (RIS), PACS, and EMR has provided greater access to radiology reports, images, and correlating clinical information[10]. Advancements to technology used for teleradiology have allowed medical diagnoses to be made across regions, and in collaboration with multiple physicians, reducing the need for provider or patient travel[11]. Other IT tools have allowed computerized notification systems to be implemented in physician offices to flag abnormal imaging results and send an alert for required intervention or follow-up[12]. Electronic systems have allowed improved operational efficiency, facilitated access to imaging studies, and provided mechanisms to track, stores, analyze and report quality performance indicators within radiology[8]. The magnum of data captured within these systems holds greats value in terms of data mining; they can be used to develop superior imaging protocols, build computer-aided diagnosis tools, and determine radiation dose reduction

techniques[8]. Another example of informatics in radiology, which has proven to be effective in multiple ways, is the complete integration of a RIS, HIS, PACS, EMR, and voice dictation system, essentially merging enterprise information systems on a large scale[10]. The value of an information and communication technology project like this lies in generation of revenue, faster turnaround times, greater referring physician satisfaction and greater radiology staff satisfaction[10].
With respect to practices such as these, the term medical imaging informatics can be defined as technologies or tools developed for the purpose of enhancing efficiency and/or quality to medical imaging services and practices[8, 10].

This scoping review aims to identify and consolidate literature that describes eHealth tools or innovations currently existing in the field of radiology. It is especially important to define and analyze the eHealth tools that have become implemented most recently since it is possible that workers in this field are unaware of tools available in their practice. Knowledge and training about these tools could enhance the care of patients or efficiency and accuracy of work. Due to the qualitative, descriptive and non-scientific nature of this subject matter, studies of various research designs as well as reviews and opinion pieces will be considered for inclusion.

METHODS

Literature Search & Selection

This scoping review attempts to identify the most current and prevalent advanced informatics tools in radiology. The nature of this subject area is such that some relevant topics have presence in peer-reviewed academic journals, but some exists predominantly in the grey literature. Since the purpose of this review is to discuss very relevant and influential work, a unique methodology is necessary and this paper must be partially based on non-academic literature, such as government documents, documents describing the work of organizations, websites, and opinion pieces or reviews by subject matter experts. This methodology employs a two-step approach.

Step 1: Literature Review

A literature search was conducted using broad terms, unspecific to any subtype of informatics or radiology to achieve results as inclusive as possible. The databases PubMed, Google Scholar, and OVID Healthstar were searched. The term “radiology + eHealth” was used in PubMed and Google Scholar; each search was limited to works published in 2010 or later. The “Sort by relevance” function was used for the literature search in Google Scholar and titles and abstracts were screened until it seemed appropriate to terminate the search and results were no longer relevant. Although relatively less credible as an academic journal database, Google Scholar was leveraged for this literature search because it is likely a more fruitful search engine for the second part of the search strategy. The terms “radiology” and “eHealth” were used in the OVID Healthstar search as well. To narrow the results, the term “radiology” was focused to searching “radiology” or “radiology information systems” as key terms, and the term “eHealth” was focused to searching “medical informatics” or “Internet” or “eHealth” as key terms. These terms were then combined with AND. All titles and some abstracts were screened of these papers from PubMed, Google Scholar, and OVID Healthstar. Articles were categorized based on subject matter and major themes identified. Duplicates were then removed, and some re-categorization was done as results from each of the three databases were merged.

Step 2: Review of Government-Funded Initiatives

Current work of Canada Health Infoway (CHI) [13] and eHealth Ontario[14] in regard to Diagnostic Imaging Programs was reviewed to identify potential trends in advanced informatics tools in radiology. This information was combined with professional and educational experiences within each field, radiology and eHealth, to identify additional topics for discussion.

The Diagnostic Imaging Solution outlined by CHI describes the certification requirements for the diagnostic imaging component of the client Electronic Health Record (EHR) [13]. The work supported and funded by CHI focuses strongly on interoperability between PACS and the Diagnostic Imaging Repository, and between PACS and the Radiology Information System (RIS) [13]. The CHI Diagnostic Imaging Systems investment program also supports projects working to enable care providers to access imaging studies at locations beyond the site where the imaging study was acquired. These projects manifest as initiatives that implement a fully functioning PACS to hospitals or other imaging sites, and the development of centralized PACS repositories for multiple small facilities to use where independent PACS are not financially viable[13].

The Diagnostic Imaging Program at eHealth Ontario supports diagnostic imaging initiatives and systems such as PACS and regional Diagnostic Imaging Repositories (DI-rs). The primary goal of the agency and this program is to improve patient care, safety and access, and to do so by stabilizing the technical infrastructure required for strong information systems. eHealth Ontario is instrumental in the continuing development of the four DI-rs of the province by providing funding and hosting the ONE Network that allows clinical use of the systems[14]. Further, eHealth Ontario reports on a recently completed project called the Emergency Neuro Image Transfer System (ENITS), which exemplifies a large-scale regional imaging network for neurological imaging to facilitate consultation and necessary patient transfers[14].

Based on the current work and experiences of Canada Health Infoway and eHealth Ontario, DI-rs as an example of a regional imaging network will be discussed as novel eHealth trends in the field of radiology. Other topics selected for discussion based on LHIN initiatives[15] and consultations with subject matter experts include Foreign Exam Management (FEM), and Zero Footprint viewer technology. To obtain information on these topics, a search was conducted using the terms “diagnostic imaging repository”, “regional diagnostic imaging networks”, “foreign exam management” and “zero footprint image viewers” in Google Scholar, Google, and in the CHI and eHealth Ontario websites.

Inclusion & Exclusion Criteria

Essentially, the only inclusion criterion applied to the literature search was that articles describe some aspect or example of eHealth and radiology symbiosis. Since the inclusion criteria were not very restrictive, some results are of studies that were unlike any others found throughout the literature search. These were not excluded because the presence of these studies in the recent literature speaks to the volume and variety of work underway at the crux of both fields, and therefore their existence alone adds value to this review. In part two of the literature search which employed Google Scholar, Google, and the Canada Health Infoway and eHealth Ontario websites, the materials returned on searches were selected for inclusion based on perceived relevance to this paper.

As previously mentioned, very few exclusion criteria were applied to the literature search due to the limited amount of information available on these topics. Literature describing technology used for imaging itself (e.g. a new model of CT scanner) was excluded based on emphasis on technology of a non-informatics based nature. Articles were excluded if the full text or text in English were not available. In part two of the literature search no rigorous exclusion criteria were applied.

In both parts of the literature search, material published from 2010 and on was considered for contribution to this review. The year 2010 was selected as an appropriate limit since it allowed more results to be included in more recent years and therefore a more robust review to be conducted. Simultaneously, this restriction eliminated work from being included which is now outdated or irrelevant.

RESULTS

Literature Review

The results of the first section of the literature search are categorized based on subject matter focused on most heavily. Though much of the included literature embodies multiple themes, for example, a study describing a mobile application for teleradiology of a pediatric pathology, the best efforts have been made to categorize appropriately. This significant crossover in subject matter clearly demonstrates how radiology and eHealth are so interconnected.

The PubMed database search using the term "radiology + eHealth" yielded 221 results, from the year 2010 to the present. After screening titles and some abstracts, 63 were selected to be included in this review. Several overarching topics revealed themselves throughout this process, and the following themes were identified as the most prevalent: teleradiology, mobile devices and applications, and PACS architecture or other enhancements. The majority of results focused on teleradiology (n=35), mobile devices and applications (n=17), or PACS architecture or PACS enhancements (n=9). Some identified groups were further categorized to more specific topic areas. Within the 36 articles that focused on teleradiology, there were papers that described teleradiology for education (n=2), cost analysis (n=1), international initiatives (n=7), privacy and security of a teleradiology system (n=1), pediatric teleradiology (n=4), a teleradiology project or system for a specific patient type or disease (n=6), teleradiology in emergency care scenarios (n=3), a quality assessment study (n=1) and various general reviews (n=10).

Of the 17 articles focusing on mobile devices and applications, there were descriptions of the technical architecture of an application (n=5) and reports on various aspects of mobile devices themselves such as user acceptance, image quality, and general performance as clinical aids (n=12). The 9 articles relating to PACS architecture or enhancements were subdivided into a group pertaining to cloud computing (n=3), descriptions of an integration of PACS into other information systems (n=2), a review on system security (n=), teleradiology (n=1) and web-based technologies in PACS (n=2). Finally, there was one article categorized as "other" that focused on a radiological decision support system. These results are summarized in Table 1.

The Google Scholar literature search using the term "radiology + eHealth" yielded 2, 180 results. The "sort by relevance" function was applied and titles and abstracts were screened until results became irrelevant to this paper. Ultimately, a total of 270 articles were screened and 19 were selected for inclusion in this review. The themes that emerged among these results were teleradiology (n=7), mobile devices and applications (n=3), enhancements to PACS (n=5) and regional imaging networks (n=2). One article focused on voice recognition software for radiology reporting, and one was a general review of the role of informatics in diagnostic imaging. The 7 articles relating to teleradiology were further categorized as relating to privacy and security (n=1), international teleradiology (n=1), education programs (n=1), cost analysis (n=1) and general reviews of teleradiology practices (n=3). All 3 papers focusing on mobile technologies were reports on pilot studies for mobile applications. Finally the 5 papers on PACS enhancements included the topics cloud computing (n=3), user acceptance (n=1), and PACS within a patient portal (n=1). These results are summarized in Table 2.

The OVID Healthstar literature search using the term "radiology" focused to include "radiology information systems" as a key term, combined with the term "eHealth" focused to include "medical informatics" or "Internet" as additional key terms yielded 167 results. After screening titles and some abstracts, 64 articles were selected for inclusion in this review. The most significant themes among these articles were teleradiology (n=7), integration of web-based tools to PACS (n=16), education (n=13) and PACS architecture (n=7). Themes occurring less frequently included mobile applications and devices (n=3), regional imaging networks (n=1), data mining (n=2) and voice recognition software (n=1). The 7 articles focusing on teleradiology were further categorized into quality audits (n=1), privacy and security (n=1), educational tools or programs (n=2), and general reviews (n=3). The 16 articles focusing on web-based tools integrated with PACS included descriptions of tools designed for study, quality assurance, or audit reporting (n=8), tools designed for research (n=1), types of viewers or tools for visualization (n=3), tools for annotation (n=2), a patient portal (n=1) and a tool designed for improving workflow and efficiency (n=1). The 7 articles focusing on PACS architecture included cloud computing (n=3), research (n=3) and a client-server PACS design (n=1). There was minimal variation within the 13 articles related to education and so they were not categorized any further. Finally, there were 14 articles that fell under the category of general/other, and were either broad reviews of diagnostic imaging informatics or described a technology unique from any other discovered through this literature review. These results are summarized in Table 3.

Duplicates were left to emphasize the presence of particular topics in each database. Upon merging the results of searches in each of the three databases the duplicates were subtracted, and final results of the literature search are shown in Table 4.

Table 1: PubMed Search Results

Category	Sub-Category	Total
TELERADIOLOGY		**35**
	Education	2
	Cost Analysis	1
	International	7
	Privacy and Security	1
	Pediatric	4
	Use for Specific Patient Type/Disease	6
	Emergency Care	3
	Quality Assessment	1
	General Reviews	10
MOBILE DEVICES & APPLICATIONS		**17**
	Application Architecture	5
	Device Performance	12
PACS ARCHITECTURE		**9**
	Cloud Computing	3
	Leveraging PACS in other information systems	2
	Security	1
	Teleradiology	1
	Web-Based Technology	2
OTHER		**1**
TOTAL ARTICLES INCLUDED		**62**

Table 2: Google Scholar Search Results

Category	Sub-Category	Total
TELERADIOLOGY		**7**
	Privacy and Security	1
	International	1
	Education	1
	Cost Analysis	1
	General	3
MOBILE APPLICATIONS		**3**
PACS ENHANCEMENTS		**5**
	Cloud Computing	3
	User Acceptance	1
	PACS in a Patient Portal	1
REGIONAL IMAGING NETWORKS		**2**
VOICE RECOGNITION SOFTWARE		**1**
GENERAL		**1**
TOTAL ARTICLES INCLUDED		**19**

Table 3: OVID Healthstar Search Results

Category	Sub-Category	Total
TELERADIOLOGY		**7**
	Quality Audit	1
	Privacy and Security	1
	Education	2
	General	3
MOBILE DEVICES & APPLICATIONS		**3**
	Application Architecture	1
	Device Acceptability	2
INTEGRATION OF WEB-BASED TOOLS TO PACS		**16**
	Reporting (e.g. Radiologist reports, quality assurance, auditing)	8
	Research	1
	Viewers and Visualization	3
	Annotation	2
	Patient Portal	1
	Workflow and Efficiency	1
REGIONAL IMAGING NETWORKS		**1**
DATA MINING		**2**
EDUCATION		**14**
PACS ARCHITECTURE		**7**
	Cloud Computing	3
	Research	3
	Client-Server	1
VOICE RECOGNITION SOFTWARE		**1**
GENERAL/OTHER		**14**
TOTAL ARTICLES INCLUDED		**65**

Table 4: Literature review results sorted by category

Category	Sub-Category	Total
TELERADIOLOGY		**38**
	Education	2 [16, 17]
	Cost Analysis	2 [18, 19]
	International	5 [20, 21, 22, 23, 24]
	Privacy and Security	2 [25, 26]
	Pediatric Population	4 [27, 28, 29, 30]
	Use for Specific Patient Type/Disease	5 [31, 32, 33, 34, 35]
	Emergency Care	3 [36, 37, 38]
	Quality Assurance/Assessment	2 [39, 40]
	General	13 [41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53]
MOBILE DEVICES & APPLICATIONS		**21**
	Application	6 [54, 55, 56, 57, 58, 59]
	Device	15 [60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74]

PACS ARCHITECTURE & ENHANCEMENTS		**18**
	Cloud Computing	8 [75, 76, 77, 78, 79, 80, 81, 82]
	Integrating PACS and other Information Systems	3 [83, 84, 85]
	Security	1 [86]
	Teleradiology	1 [87]
	User Acceptance	1 [88]
	Research	3 [89, 90, 91]
	Client-Server	1 [92]
REGIONAL IMAGING NETWORKS		**3** [93, 94, 95]
VOICE RECOGNITION SOFTWARE		**2** [96, 97]
WEB-BASED TOOLS IN PACS		**17**
	Reporting	7 [98, 99, 100, 101, 102, 103, 104]
	Research	1 [105]
	Viewers and Visualization	3 [106, 107, 108]
	Annotation	2 [109, 110]
	Patient Portal	1 [111]
	Workflow and Efficiency	2 [112, 113]
	General	1 [114]
DATA MINING		**2** [115, 116]
EDUCATION		**14** [117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130]
GENERAL/OTHER		**15** [131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145]
DUPLICATES		**20**
TOTAL ARTICLES INCLUDED		**130**

DISCUSSION

Identified Trends

Based on the literature search, review of current work by organizations in Ontario, and consultation with subject matter experts, the topics selected for discussion in this paper as novel eHealth trends in the field of radiology are: teleradiology; mobile applications and devices; enhancements to PACS architectures; integrations of web-based tools to PACS or other stages in the radiological process; diagnostic imaging repositories; foreign exam management; and zero footprint image viewers. In this discussion the existing literature is summarized and project status reported for each of the identified trends or tools.

Teleradiology

Teleradiology refers to the transmission of diagnostic images from the location they were acquired to another location for interpretation or consultation [41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53]. Teleradiology became necessary in response to three main issues: the transition from film to digital imaging, an increase in radiology workload but decrease in number of radiologists, and the need for access to subspecialty consultations [43, 44, 47]. Its implementation has been instrumental in shortening waiting lists, optimizing resources, and enabling productivity gains [20, 26, 41]. Historically, teleradiology could be in the form of a couriered package containing film images being delivered to the office of a specialist physician; today, teleradiology is done almost exclusively with digital images over the Internet [44, 45]. In the early 1990s, with the implementation of PACS, digital imaging, and increased Internet bandwidth, teleradiology became the solution to consultations with subspecialists and access to radiologists during off hours [44, 45]. It was observed that access to subspecialty radiologists and other physicians was increasing the quality of image interpretations, and this was improving patient care and safety [44, 45].

In current medical practice, teleradiology has become ubiquitous, and the practice continues to evolve. Benefits are numerous, and generally rooted in the concepts of enhanced access to clinicians such as subspecialists for more accurate diagnoses reached collaboratively, resulting in improved patient care and enhanced efficiency as volumes of radiological studies performed increases, and radiologist resources decrease. However, concerns such as clinical governance, medico-legal issues, reimbursement, quality assessments of interpretations, interoperability of systems, storage capacity, privacy and security, etc. are related to teleradiology. For example, a US study analyzing the results of the American College of Radiology's Survey of Radiologists found that the most common methods of payment for reading outside studies were direct billing for the professional component or receiving a flat fee per study. The survey also found that 40% of radiology practices in the US routinely perform outside readings[49]. A quality assessment of out sourced after-hours CT teleradiology reports in a Central London University hospital found that the rate of serious misinterpretations by the teleradiology service provider was very small (0.8%), and was smaller than the discrepancy observed in the preliminary in house reports[39].

Teleradiology is at a similar status in Canada, the US, Australia, and Europe. Technical and interoperability barriers are being overcome, and drivers for increasing teleradiology practices remain increasing workloads and decreasing resources [23, 41, 42, 43, 44]. As with any part of healthcare, cost of teleradiology must be considered. One cost analysis from Germany described the perspective of the provider (a mid-size university hospital) [19]. The results of the analysis were complex, and stated that analyzing the scenarios in which teleradiology is most often used allows hospital management to enhance efficiency and implement realistic reimbursement fees. In many cases, costs associated with teleradiology are unavoidable, but can be expended in an optimized fashion[19].

International cross-border teleradiology has been idealized to make radiology available universally, improve the quality of radiology services with more access to specialists and consultations, and consolidate a community of international radiologists[20]. However, in practice, international teleradiology faces several serious barriers. Issues of disconnected structured reporting processes, poor language and semantic interoperability, and lack of trust with complicated legal implications are substantial [20]. More issues are identified and discussed in the Report of the American College of Radiology (ACR) Task Force on International Radiology [146], a paper not included in this literature review. The Task Force describes cases of non-licensed physicians reading reports across jurisdictions. Generally, state licensure is required for physicians in the state who diagnose and treat patients in any capacity, for regulating practice and safeguarding the public. This is problematic in teleradiology, especially when it is international. To address these issues, the ACR requires that the reading teleradiologist must have equivalent training to the ordering physician, and must be able to demonstrate lifelong learning to maintain imaging skills [146]. Finally, the ACR suggests that the best method of determining the quality of an interpreting radiologist is whether they are ABR certified [146]. The reach of liability insurance is another cause for concern. It is possible that physicians' insurers may not provider malpractice insurance where jurisdiction is questionable, and it may be impossible to force an out-of-country provider to participate in legal proceedings or respond to a subpoena issued in the US[146].

With these issues in mind, there have been several successful international teleradiology projects to date. One article included in this review describes the feasibility of using teleradiology to improve tuberculosis screening and case management in Malawi, where tuberculosis, a condition diagnosed by chest radiography, is extremely common, but there are no radiologists. This study reported positive results, as teleradiology changed patient management in 23.5% of the reviewed cases, and two cases of pulmonary tuberculosis were diagnosed in cases not suspected by the clinical staff [24].

Further success has been observed with teleradiology in emergency care. One study described positive results in a teleradiology system of neurological imaging used prior to the time of request for patient transfer[34]. It was found that with review of imaging, 44% of patient transfers were deemed unnecessary and prevented. This is a significant finding since transferring patients with acute injuries is dangerous, and costs for patient transfers are high[34].

Ultimately, teleradiology has proven to be a significant advancement in radiology, and later in eHealth, invaluable to medicine. Multiple use cases exist that demonstrate the benefits, which are likely to increase with evolving technology.

Mobile Applications and Devices

The mobile health movement in medicine has been very influential in recent years, and refers to the practice of medicine supported by mobile devices such as laptops, tablets, and smart phones [54, 55, 58]. Since diagnostic imaging is a vital component to patient health information, it is expected that a desire to access images on mobile devices exists as well. However, high quality image viewing software and devices, for example, a dedicated radiologist workstation, are required for highly confident and reliable exam reporting and diagnosis.

There has been some skepticism that mobile devices can offer acceptable image quality for preliminary exam interpretations to be made [72]. A 2012 study examined the performance of the iPad in terms of image quality and diagnostic performance for preliminary interpretations of emergency CT scans of the brain, compared to a desktop LCD monitor [61]. It was found that without a zoom function, the iPad performed inferiorly to the larger monitor, and did not offer diagnostic quality. However, with the ability to zoom there were no discrepancies between interpretations of exams on the iPad compared to the LCD monitor, and the tablet allowed satisfactory identification of acute CT brain findings [61]. In another study, auditing discrepancies in CT and MRI reporting with an iPad for on-call radiology diagnosis were analyzed[62]. The interpretations of multi-image CT and MRI studies on tablets were compared to those made with PACS and it was found that major discrepancies (3.4%) and minor discrepancies (5.6%) among the 8 studies reviewed by three separate radiologists were both of an acceptable level. Other feedback included that the tablet offered a favorable user experience, but there was some experience with software stability issues and limitations in image manipulation tools. Overall, there was good agreement between diagnoses made using the iPad with diagnoses made on dedicated PACS workstations[62].

To date, it seems that tablets are the most acceptable mobile devices in use for viewing diagnostic images as they offer a larger format, touch screen interface, and improved graphic display resolution[55]. Additionally, mobile devices are generally acceptable only for preliminary image interpretation or review, not for diagnosis [55, 56].

Some mobile radiological applications have been developed for use on mobile devices; there have been reports of mobile DICOM controllers that can query PACS archives and retrieve JPEG or PNG images for display [60]. Within the last 3 years, a mobile version of the open-source PACS software OsiriX has been released, which has provided a commercial off the shelf solution for viewing diagnostic images in full resolution on mobile devices [60]. OsiriX Mobile has been able to offer an enhanced user experience by allowing retrieval of DICOM images, rather than JPEG or PGN image formats. This is significant as this image format allows for more advanced and familiar image manipulations, such as zooming, panning, rotating, windowing and leveling, calibrated distance measurement, region of interest measurements, annotation, and key image capture [60].

The use of radiological mobile applications has some limitations and future considerations. At this time, there are no applications approved by the US Food and Drug Administration. Furthermore, privacy and security concerns exist related to imaging information being viewed and possibly stored on many mobile devices, which may not be auditable. Finally, the performance of an image viewing application on a mobile device may be affected by limitations in virtual private network (VPN) speed, mobile device memory and storage abilities, and cellular networks [56, 60].

Enhancements to PACS Architectures

Technology is ever changing to meet new requirements and incorporate new abilities. As the cornerstone to modern radiology, PACS is the focus of significant technological efforts and research. Some drivers for change in PACS architecture are the increase in teleradiology practices, the incorporation of faster and greater numbers of computers in a hospital work environment, faster in-house networks, and cheaper storage options [75, 85]. For example, lower storage costs means that more images residing in PACS can be kept on-line, and more readily available for viewing. An increase in the use of multimedia throughout the hospitals means that PACS may become vital in fields such as pathology, and no longer be exclusive to radiology and cardiology[85]. The emphasis on electronic systems and how they fit into overall workflow means that PACS needs to be integrated with different information systems. For example, PACS may grow to support a trigger for an alert to appear in a hospital EHR when new radiology results are available. One study included in this review reports the experience of the Hong Kong Hospital Authority's (HKHA) integration of their clinical management systems with PACS and an electronic patient record [83]. The results thus far have been positive, and a major feature of the system is described to be the availability of short-term and long-term lossless and lossy image archives with backup data centers [83]. This body of work has been underway for 30 years, and represents a vital component of the entirely electronic health information system planned in Hong Kong.

Of the trends within PACS architectural enhancements, cloud computing is gaining significant attention [75, 76, 77, 78, 79, 80, 81, 82]. Cloud computing can be defined as a network of computers sharing information through the Internet[75]. For health enterprises, the cloud can hold scalable resources and simultaneously reduce the in-house IT infrastructure required. Cloud providers generally offer storage and database services, among many others. The move towards PACS in the cloud is in response to the immense storage and retrieval efforts required of traditional PACS, and the need to exchange imaging information and images between institutions easily without significant IT efforts [75, 76, 77]. Solutions have been implemented that employ sets of DICOM routers connected through a public cloud infrastructure, and have been proven to work well as an augment to enterprise PACS for sharing images across institutions [75, 77, 79]. Other studies have been done that show PACS in the cloud may be more cost-effective for small centers because of the reduced need for IT infrastructure and support and a "pay as you go" business model. Finally, models of PACS in the cloud have been shown to be robust, with the functionality (i.e. storage, query, and retrieval of images) of local PACS[75].

Other themes in the literature include client-server PACS technology, security measures, support for teleradiology, PACS optimized for extracting data for research, and user acceptance. Ultimately, the need for strong, efficient PACS that can offer many uses is greater than ever, and it is likely that the most successful advancements will take advantage of the Web, and more specifically, the cloud.

Integrated Web-Based Tools

The literature thus far has proven that using the Internet for radiology holds great potential for a variety of functions [98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114]. An emerging theme seems to be the integration of web-based tools with PACS; the articles included in this review describe web-based tools for the purpose of enhancing radiology reporting, performing audits within PACS, and guiding quality assurance and assessment studies. One of the reviewed studies examined the use of a web-based tool designed to enhance resident performance while on-call[113]. This tool was a software program used to identify and track discrepancies between preliminary image interpretations by residents and final report by staff radiologists in off-hours emergency studies. The tool identified and graded findings as either major or minor discrepancies based on how much the health outcome of the patient would be affected. The information this tool provided allowed performance to be evaluated, establish benchmarks in acceptable reporting variance, and develop interventions to reduce the rate of reporting discrepancies. The analysis capabilities of the tool allowed the discrepancy rate in resident image interpretations to be measured as 2.6%, and it was found that exams that composed the majority of misinterpretations were on acromioclavicular joint separations, elbow joint effusions, and osteochondral fractures[113].

Another article described a web-based image quality assurance reporting system developed for the purpose of improving image quality[104]. This study examined the rate of three errors in imaging exams (orientation of axillary shoulder radiographs, coronal and sagittal reformats of shoulder CT scans, and acquisition plane of axial images in sacral MRI exams) before implementation of a reporting quality assurance system, 18 months after deployment of the system, and 12 months after an upgrade in the system software. For axillary shoulder radiographs, the error rates were 35.9%, 7.2%, and 10.0% for each phase of the study, respectively, suggesting that the original and upgraded system were effective in reducing the error rate, improving image quality. For CT shoulder coronal and sagittal reformatted images, the error rates were 9.8%, 2.7%, and 5.8%, also suggesting that both versions of the tool were effective in reducing error rates and improving quality. Both of these trends suggest that the first iteration of system software was more effective in reducing errors and increasing quality, as error rates increased slightly after an upgrade was made. For sacral MRI acquisition planes of axial images, the error rates were 96.5%, 32.5%, and 3.4% for each phase of the trial, respectively. These results indicate that each version of the software allowed increased image quality to occur[104].

Another purpose commonly served by web-based tools is optimizing visualization on PACS or supporting a viewer application. One study included in this review reports on a web-based tool that allows interactive visualization and the ability to correct intermediate imaging test results using new features of HTML5[106]. Another study describes a web-based image viewer designed for the visualization of multi-modality follow up studies, such as Positron Emission Tomography (PET) –CT scans[107]. The tool uses web-based client-server image streaming technology, which enables the user to navigate the images in an interactive and computationally efficient manner. Additionally, the tool is interoperable, requires no installation of software and results of an early usability survey indicate that it is fast and intuitive to use[107].

Finally, other web-based tools that have been developed and tested in recent years include ones for annotation, research, for enhancing workflow and efficiency, and to support PACS in a patient portal. Given the new popularity and functionality of these tools, along with a general trend in technology taking advantage of the Internet, web-based tools integrated with PACS have become a significant trend in radiology and eHealth with great future potential.

Diagnostic Imaging Repositories

The Diagnostic Imaging Repository (DI-r) serves as a single system that provides a shared archive of diagnostic images and reports from organizations such as hospitals or independent health facilities (IHFs, or imaging clinics) [13, 14, 147]. As an archive of digital images and reports, the DI-r eliminates the need for patients or imaging staff to transport this information between physicians, other healthcare providers, and facilities on CDs, films, or by fax [147].

To date, four DI-rs capture 100% of hospital imaging in Ontario: the Southwestern Ontario Diagnostic Imaging Network (SWODIN) houses the Southwestern Ontario (SWO) DI-r in London, Ontario, and holds imaging information from all hospitals and some independent health facilities in the Erie St. Clair, Southwest, Waterloo Wellington, and Hamilton Niagara Haldimand Brant LHINs (1, 2, 3, and 4, respectively) [148]; the Northern and Eastern Ontario Diagnostic Imaging Network (NEODIN) DI-r, located in Ottawa, includes imaging information from the Champlain, Northeast, and Northwest, LHINs (11, 13, and 14, respectively) [149]; the Greater Toronto Area West (GTA West) DI-r captures imaging from the Central West, Mississauga Halton, Toronto Central, Central, and North Muskoka LHINs (5, 6, 7, 8, and 12, respectively) [150]; and the Hospital Diagnostic Imaging Repository Services (HDIRS) DI-r provides services to multiple IHFs and hospitals in the Central East and South East LHINs (9 and 10, respectively) [151]. DI-r development and implementation is supported with funding from Canada Health Infoway ($21.7 million) and eHealth Ontario ($20 million); their existence contributes significantly to the government of Ontario's eHealth agenda and the Infoway vision for a pan-Canadian EHR system [14, 147].

The expected and realized benefits of DI-rs are significant in several ways. With respect to care providers, DI-r access has made images from facilities in a large region available in real-time, which can provide important information about a patient's medical history and therefore allows more informed decision-making [13, 14, 148]. The ability to consult specialists and other care providers with access to the same imaging is extremely valuable and encourages professional collaboration for patient care. Finally the access that DI-rs provide enhances remote reporting capabilities and easier access to imaging during off hours. Patients benefit from DI-rs as well [13, 14, 148]. It is possible that access to digital imaging from other facilities may prevent unnecessary emergency patient transfers or patient travel for consultations and treatments. In cases of visiting different facilities for treatment (e.g. two emergency departments in neighboring cities on two days in the same week) patients may be spared from undergoing duplicate exams when care providers have access to imaging that may have been performed recently. Furthermore, patients no longer carry the burden of physically transporting images on discs to their various care providers. Reducing duplicate and unnecessary exams can contribute to decreasing healthcare costs, decreasing the time patients may be left waiting for exam results and beginning treatment, and decreasing exposure to radiation [13, 14, 148]. With respect to the healthcare system, the DI-r is able to allow greater patient access to diagnostic services by the additional capacity created through improved provider efficiencies and reduced duplication. Diagnostic imaging repositories, and other health IT system advancements, are working to improve patient wait times through optimizing workflow [13].

Formal DI-r benefits evaluation results are either inaccessible or lacking, possibly due to the relatively recent completion of the four Ontario DI-rs. Some of the expected benefits of fully functioning DI-rs in Ontario are likely very similar to those that were experienced with the implementation of independent PACS in hospitals; in other words, the large scale transition of imaging in Canada from film to digital. The CHI Diagnostic Imaging Benefits Evaluation Report discusses the results of independent third-party evaluations of implemented PACS in British Columbia, Ontario, Nova Scotia, and Newfoundland and Labrador[152]. The overarching conclusion of these benefits evaluations was that Canada Health Infoway's PACS investments have allowed several significant benefits to be realized, specifically in terms of healthcare access, quality and productivity.

CHI supports PACS implementation and evaluation projects across the country as a means to achieve one of their core business strategies: to support solution adoption and benefits realization, and to measure and understand the impact that EHR investments have on healthcare access, quality, and productivity. There were several key findings to this benefits evaluation in terms of access. Access to imaging services has been improved to remote areas and populations with few healthcare providers. With PACS, between 30% and 40% of radiologists practicing in Canada are able to report exams acquired in one of these underserved locations[152]. Another benefit to PACS related efficiencies is simply more access. The improved workflow, efficiency gains, shorter lengths of stay and reduced duplication that PACS as allowed enables wait times to be decreased, and access to services be increased[152].

To measure benefits in terms of quality, CHI examined turnaround time studies. With PACS, turnaround time of radiology reports has improved by an average of 41%, in both urban and rural imaging centers. An estimated 30%-40% decrease in turnaround times may allow clinical decisions, such as those to begin a particular course of treatment, may occur 10-24 hours sooner, thereby reducing lengths of stay for patients, as well as wait times[152]. Another quality indicator examined was the number of patient transfers in both urban and rural areas. A physician survey revealed that access to PACS might eliminate 10,000-17,000 unnecessary patient transfers per year, which could reduce costs by $8 million-$14 million[152]. Another quality indicator measured through a physician survey was perceived clinician efficiency. For example, efficiency can be increased with easier access to imaging information, more collaboration, faster turnaround time, and reduced time spent searching for films. These increases in efficiency are estimated to be worth $160 million to $190 million, annually[152].

The benefits in productivity observed are arguably the most compelling from a business perspective. The CHI evaluation included interviews with experts, review of other CHI evaluations (e.g. duplicates study) and a literature review, and found that PACS implementation allowed technologist productivity to increase to 34% above the national standard, translating to a potential $122 million to $147 million value, or 8 million to 10 million exams, annually[152]. PACS allows radiologist productivity to increase by an average of 27%, translating to a potential $160 million to $203 million value, or 9 million to 10 million exams, annually[152]. Productivity is also improved through elimination of duplicate exams. The estimated 2%-3% reduction in duplicate exams that has occurred with PACS holds a value of $47 million to $71 million, and may represent as many as 1.3 million unnecessary exams, annually[152]. Finally, the elimination of film-related costs represents $350 million to $390 million annually, and in itself presents a near break-even value proposition for PACS implementation in Canada[152].

The report concludes that a comprehensive shared network of PACS (in other words, DI-rs) including hospital and independent imaging facility data will be required to optimize these benefits observed with PACS. Through the access, quality, and productivity benefits described, the opportunity to reduce costs also exists. CHI estimates that PACS across Canada will generate between $850 million and $1 billion a year in health system efficiencies, predominantly via increased clinical productivity, reduced patient transfers and elimination of unnecessary duplicate exams[152].

DI-rs are a major achievement in the worlds of eHealth and radiology today [13, 14, 147, 148, 149, 150, 151]. Their development and use clinically have proven beneficial in multiple ways already, and immense potential remains in optimizing supporting technologies (e.g. viewer applications), strengthening support systems, increasing user adoption and acceptance, awareness of benefits, and full capabilities of the system. Furthermore, as work continues with these four DI-rs in Ontario, and those in the rest of Canada, considerations must be made for the future. As each DI-r becomes complete with information from every hospital and independent health facility, it becomes clear that the next logical steps to take are towards the integration of each to create a provincial DI-r, and eventually, a national DI-R. As these visions come into fruition, considerations to privacy and security, requiring or compensating for common hardware and software components, and cost analyses must be made.

Foreign Exam Management

It is common for patients to receive healthcare services at various institutions. This can result in the need or desire of clinicians to view previous imaging acquired elsewhere for comparison to more recent imaging or to augment clinical data in the absence of additional imaging. Physicians often prefer to view and keep the exam in their local PACS to refer to easily, as opposed to use a separate system and interface, such as a DI-r viewer. Foreign Exam Management (FEM) refers to the ability of an existing hospital PACS to identify, ingest, and display exam images acquired at other hospitals, with no significant effort for the user, and displayed in a single user interface. In other words, FEM will allow radiologists and clinicians to easily view studies from other hospitals or IHFs within their own local PACS, eliminating the need to install, maintain, or manage another system to view foreign exams[153]. Managing foreign exams has been difficult to date; the physical transfer of discs between facilities can be slow and unreliable, import of foreign exams to a local PACS from a removable media device is time-consuming and labor-intensive, with challenges in user acceptance and seamless integration of multiple image viewing systems [153]. The objectives of FEM are essentially synonymous to those for other digital image sharing tools, such as diagnostic imaging repositories: to provide seamless radiology workflow where access to images is no longer a barrier[154]. The ability to access foreign studies while reporting more current exams or assisting in consultations is extremely valuable in clinical practice, and means an increase in efficiency, an increase in user satisfaction, an increase in accessibility of important imaging information, and allows radiologists to get a better sense of a patient's medical history. Each of these benefits translates into maximizing resources and safer, more informed patient care.

FEM is pertinent where local PACS are integrated with centralized diagnostic imaging repositories, as is the case in Ontario. Interoperability is essential for the success of FEM and the detailed IHE (Integrating the Healthcare Enterprise) profile describes the technical process of the Import Reconciliation Workflow Profile and how it could be updated to support FEM[154]. The proposal outlines several aspects for consideration. First, exam import can be automated with an Importer actor application which can place an order in the Radiology Information System (RIS) for an equivalent radiology study in the importing facility, send the images to the local PACS, and then update the study status on the RIS to indicate that it is complete. Second, imported foreign studies should be handled differently than local studies. For example, it is not conducive to radiologist workflow for imported images (behaving like newly acquired images) to appear on their reading list since it does not need to be reported. However, it is helpful for imported studies to appear near the study it is related to, to facilitate quick access to the images for comparison or additional information. Furthermore, it is unnecessary for imported exams to be archived within a local PACS and it is desirable for an automatic flushing mechanism to be established. In the FEM system described in the IHE detailed profile, exams that require importation to a local PACS (e.g. a patient with imaging studies from hospital A is transferred to hospital B, where further imaging studies may or may not be performed) are retrieved and imported by a FEM software from the local DI-r, and not the facility where the images were acquired[154]. Thus, FEM is heavily reliant on DI-rs.

Implementation of FEM is underway in Ontario and in the United States. In 2012, St. Joseph's Health Center in Toronto announced that their FEM connection with the GTA West DI-r was live[155]. In early 2013, the Northern and Eastern Ontario Diagnostic Imaging Network (NEODIN) DI-r announced Karos Health's product Rialto Connect as their selected FEM solution[153]. Finally, one of the earliest FEM pilots was carried out in 2011 at the Department of Veteran Affairs in Washington, DC. The system developed and tested here was a DICOM Importer application that automated the process of importing prior studies to local PACS in less than one minute[156]. As the project developed, three different testing sites were importing over one thousand foreign exams per week. The application has since become very popular, is used nationally and has proven extremely effective in reducing time consumed managing foreign exams.

Zero Footprint Image Viewers

The concept of footprint 'size' refers to the effort required on the client side, in terms of installation and download, to use a viewer[157]. Zero footprint image viewers have become a desired technology as the Web changes the way content is consumed, shared, discovered and connected. The use of multiple devices in an environment where access to information, like medical imaging, is needed quickly and easily necessitates technology that can offer a consistent interface without running burdensome or time-consuming applications. A zero footprint viewer functions without a client side install or download, and can allow viewing of documents and images in the native browser of the device (e.g. laptop, tablet), regardless of browser type, version, location, machine, device, software, or hardware, and while harnessing the capabilities of the browser, built-in plugins, and the device itself[157]. Zero footprint viewers are becoming increasingly accepted as the ideal approach to handling increasing file sizes and formats, devices, phones, tablets, and computers as they become an integral part of today's healthcare provision.

Zero footprint technology employs Asynchronous JavaScript and XML to interact with a server dynamically and load objects (document or images) in real-time[157]. This architecture allows the viewer to function independently of additional software or plugins. Additionally, no storage or other technical requirements at the user device end exist, since images are simply viewed rather than stored. Essentially, zero footprint viewers offer access to diagnostic images and related documents (e.g. radiology requisitions and reports) with all viewing functions and features of a traditional PACS without the need for equipment or software installation, no hardware requirements, no maintenance or upgrading of the tool, and virtually zero time to load and view a study[157].

A 2013 paper describing the future of image exchange elaborates on multiple aspects of medical imaging informatics, and cites the implementation of zero footprint viewers and emphasizing a framework that supports multiple zero footprint viewers as critical for optimizing radiology workflow[158]. The article describes image consolidation across the enterprise. Zero footprint (or "zero download") DICOM viewers are ideal integrations to large EHR systems in large hospitals. Zero footprint mobile applications are also ideal additions to facilities that stress the benefits of using mobile devices in the delivery of healthcare. Finally, the authors describe an effective, well received zero footprint (or "zero install") application that encrypts data and sends medical images through secure email[158].

Vendors have quickly responded to the demand for zero footprint viewers; there are products on the market created by General Electric, Claron Technology, Client Outlook, Siemens, Fuji, and many more [159, 160, 161, 162, 163]. Efforts in Ontario with zero footprint image viewers includes the integration of the GE Universal Viewer with the SWODIN DI-r and regional EHR in LHINs 1, 2, 3, and 4, currently underway, as well as the integration of Hamilton Health Sciences PACS with the Client Outlook zero footprint viewer and regional EHR, recently completed[15]. Ultimately, the demand for zero footprint viewers is significant, and based on need for image viewing with great flexibility for file types and sizes, users who require information quickly and easily, and the ability to unify browsers and devices with no hardware or software limitations.

Analysis of Results

The field of medical imaging informatics is yielding remarkable advancements; this claim is proven by the abundance of literature on topics such as sophisticated teleradiology systems and advancements to PACS, as well as the nature of the work being done by government bodies and other large organizations.

The results of the literature review conducted in this paper described a wide variety of work done in the field of medical imaging informatics since 2010. Several themes emerged from the literature review: teleradiology (n=38), mobile applications and devices (n=21), enhancements to PACS architectures (n=18), and web-based tools incorporated to PACS (n=17) out of 130 articles total. Given the large number of articles related to teleradiology, it is clear that this particular subcategory of medical imaging informatics represents significant advancements, and has given birth to a variety of technologies used for various purposes. For example, articles describing the use of teleradiology in education [16, 17] (e.g. an online environment for training, learning, and interactive discussions of pediatric radiology[16], n=2), for use in a specific patient type or disease management [31, 32, 33, 34, 35] (e.g. a teleradiology system for CT colonography screening studies in a population group of a remote island[31], n=5), for emergency care [36, 37, 38] (e.g. teleradiology interpretations of CT scans in emergency departments[38], n=3), and for pediatric care [27, 28, 29, 30] (e.g. teleradiology as a modern approach to diagnosing and researching child abuse[27], n=4) were found. There were two articles reporting cost analyses[18, 19], two investigating privacy and security of teleradiology systems [25, 26], and two articles focusing on quality assurance and auditing[39, 40]. Several articles described international teleradiology projects [20, 21, 22, 23, 24] (e.g. teleradiology in a remote part of northern India[22], n=5). Finally, a significant portion of the teleradiology articles was general reviews [41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53] (e.g. how teleradiology will impact the future of radiology and quality of care[47], n=13). The subject matter encompassed in these 38 articles is not surprising, as topics such as privacy and security, quality assurance, and cost are important for policy-makers and system developers. The use cases described, such as teleradiology for special populations or for international initiatives are also expected, as teleradiology likely holds the greatest value and is most effective in these scenarios.

Of the 21 included articles on mobile technology, the majority focused on the device [60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74] (e.g. image quality and diagnostic performance of the iPad on emergency CT scans of the brain[61], n=15) and there was less emphasis on the application [54, 55, 56, 57, 58, 59] (e.g. a medical imaging platform for Android[55], n=6). This is likely due to the need to establish that mobile devices of various types are acceptable for viewing diagnostic images in terms of image quality, resolution, size, etc. before unique applications are built.

The articles describing novel architectural designs or enhancements to PACS (n=18) most often focused on cloud computing [75, 76, 77, 78, 79, 80, 81, 82] (e.g. a cloud scalable platform for analyzing DICOM images remotely[79], n=8), integrations of PACS with other information systems [83, 84, 85] (e.g. image distribution with PACS through an electronic patient record system across the enterprise[83], n=3), and research [89, 90, 91] (e.g. development of a research PACS for analyzing functional imaging data used in clinical research and clinical trials[89], n=3). Topics that appeared less often included a potential method of security for DICOM images in PACS[86] (n=1), a PACS design for optimizing teleradiology[87] (n=1), a user acceptance study[92] (n=1), and a review of a client-server PACS[89] (n=1). Given the distribution of topics areas among these articles, it appears that shifting PACS to the cloud is of particular interest, integrating PACS with other systems such as an electronic patient record is considered a benefit for care providers, and significant value lies in utilizing PACS as a tool to perform research.

Articles focused specifically on the use of web-based tools in PACS were abundant (n=17) and described tools for a variety of purposes. Most notably, web-based tools for enhanced radiologist reporting or for analyzing reports such as audits [98, 99, 100, 101, 102, 103, 104] (e.g. a web-based preliminary reporting system for radiology residents[98], n=7) are of great interest, as are tools for optimizing visualization or viewing [106, 107, 108] (e.g. a web-based image viewer designed for viewing multiple PET-CT follow up studies[107], n=3). Other articles included described tools designed for extracting and analyzing PACS data for research[105] (n=1), for annotation of images [109, 110] (n=2), for integration with a patient portal[111] (n=1), and for encouraging and tracking improved workflow and efficiency [112, 113] (n=2). The functions within PACS that these tools were designed to aid in suggest that traditional PACS lack the desired functionality, or needs from the system are evolving. To expand, perhaps the volumes of studies radiologists must report today necessitate tools to perform tasks, such as annotation, more quickly, or perhaps PACS has been realized as a valuable data source for research, and therefore tailored research tools to utilize the data are now in demand.

Of these four trends discussed in this review, it appears that teleradiology has been emphasized the most (n=38), and also has the greatest variety within its category, with nine subcategories. Some of the work falling under the categories PACS architecture and enhancements and integration of web-based tools to PACS is extremely similar, and if considered as one topic includes 35 articles (n=18 and n=17, respectively), nearly as large a category as teleradiology. This implies that many aspects of PACS technology are evolving, most consistently utilizing the Web and moving towards PACS in the cloud. Finally the articles describing mobile devices and applications (n=21) are focused mainly on devices, suggesting little demand for independent apps to be created, and more interest in accessing an existing PACS viewer on mobile devices, specifically tablets and smart phones.

Topics such as DI-rs, FEM, and zero footprint viewer technology have virtually no presence in the literature. It is more feasible to learn about the nature and status of these initiatives through announcements and other documents posted by large organizations such as eHealth Ontario and Canada Health Infoway, and smaller hospital organizations. The relatively publicized nature of this information, specifically that pertaining to DI-rs, suggests that there are many stakeholders in the development of this work, and that governing bodies view these projects' completion as great success in eHealth. Compared to some of the medical imaging informatics topics identified through the literature review, such as the use of radiological apps for mobile devices, it is clear that implementations of DI-rs, FEM, and zero footprint viewers will have a more significant impact on healthcare and radiology practice in the future. This work supports interoperability, sustainability, will affect nearly every patient and care provider in some aspect, is funded by various government organizations, and creates a system that effectively utilizes each component. For example, the proposed mechanism for large-scale FEM requires access to the imaging retained in diagnostic imaging repositories, and so on. Although academic literature on these advancements is lacking, it is likely that their completions are comparatively the most significant eHealth trends in radiology in the recent past, currently, and in the near future.

Ultimately, the field of medical imaging informatics is yielding remarkable advancements; this claim is proven by the abundance of literature on topics such as sophisticated teleradiology systems and advancements to PACS, as well as the nature of the work being done by government bodies and other large organizations.

Limitations

There were some limitations to this review. The nature of the literature and other data sources on the desired topics for discussion was such that there was virtually no strong, randomized evidence on which to base the information presented. Furthermore, time and resource (e.g. only one reviewer) constraints prevented this review from being systematic, and it is not of a scientific nature. Therefore, the results of this review cannot conclusively be shown as robust or reliable.

Finally, with the primary intention of identifying the most relevant, novel trends in eHealth and radiology, and discovering eight, it was not feasible to conduct very deep analysis on each topic. Therefore, the resulting review is broad rather than deep.

Future Directions

The objective of this review was to identify and discuss trends emerging at the crossroads of eHealth and radiology. An extension of this work is deeper analysis of each aspect in each tool or technology identified, as they are complex and have significant implications individually. Further analysis would make this review or a future review more robust and meaningful, potentially revealing deeper relationships between each of these technologies and their abilities. For example, a cloud-based PACS architecture could be analyzed technically, and compared to other PACS architectures or cloud-based technologies. In another example, structured interviews or surveys could be conducted with care providers to identify barriers to adoption of DI-r viewers or perhaps a needs assessment for related tools or educational and training materials. Finally, could this analysis conjure the idea that perhaps a cloud-based PACS viewer for the DI-r could increase user acceptance and performance of the system?

Other critical components to future work in radiology and eHealth are general evaluations of large-scale initiatives post implementation. For example, a benefits evaluation of the Ontario DI-rs should be conducted and next steps determined based on results and feedback. From this type of evaluation benefits observed could be quantified, interpreted, and extrapolated to support the initiation of related future projects, and user feedback could be consolidated and analyzed to make improvements to various system components. Lessons learned from the implementation and rollout should be documented and referred to as work continues.

In the future of radiology and eHealth, advancements such as the eight described in this review will continue to evolve. It is likely that PACS architecture will take greater advantage of web-based technologies and performance and reliability will increase. Teleradiology will become ubiquitous and geography will no longer be a barrier to patients undergoing necessary tests or being treated by specialists. Imaging data sharing between facilities, LHINs, provinces, or even countries will be possible and help care providers to have the information they required for better informed clinical decision making.

CONCLUSION

This scoping review sought to identify novel eHealth trends in the field of radiology through searching and summarizing the literature and to describe the status of major medical imaging informatics initiatives underway. The seven specific trends discovered and discussed were: teleradiology; mobile applications and devices; enhancements to PACS architectures; integrations of web-based tools to various stages in the radiological process; diagnostic imaging repositories; foreign exam management; and zero footprint image viewers. The presence and nature of topics related to teleradiology, mobile applications and devices, PACS enhancements and web-based tools used within PACS in the literature indicate that significant work is being conducted in this area, with some measurable results. The recent efforts made by provincial and federal government agencies such as eHealth Ontario and Canada Health Infoway, carried out by various LHIN and hospital organizations, such as Diagnostic Imaging Repositories, Foreign Exam Management and Zero Footprint image viewer development are likely to impact many stakeholders and influence clinical practice workflow significantly. Medical imaging informatics advancements like the seven described in this review are essential for strong clinical practice, for making patient care safer, and giving providers the best tools to work with.

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