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The Enterprise Imaging Value Proposition

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Abstract
As resources in the healthcare environment continue to wane, leaders are seeking ways to continue to provide quality care bounded by the constraints of a reduced budget. This manuscript synthesizes the experience from a number of institutions to provide the healthcare leadership with an understanding of the value of an enterprise imaging program. The value of such a program extends across the entire health system. It leads to operational efficiencies through infrastructure and application consolidation and the creation of focused support capabilities with increased depth of skill. An enterprise imaging program provides a centralized foundation for all phases of image management from every image-producing specialty. Through centralization, standardized image exchange functions can be provided to all image producers. Telehealth services can be more tightly integrated into the electronic medical record. Mobile platforms can be utilized for image viewing and sharing by patients and providers. Mobile tools can also be utilized for image upload directly into the centralized image repository. Governance and data standards are more easily distributed, setting the stage for artificial intelligence and data analytics. Increased exposure to all image producers provides opportunities for cybersecurity optimization and increased awareness.

Keywords Enterprise imaging · Strategy · Digital transformation · Value-based care · Operational effectiveness · Cybersecurity

Introduction

Every healthcare executive should include enterprise imaging (EI) as a key component of their strategy for addressing current healthcare challenges. An EI initiative drives towards consolidation of imaging resources in a manner similar to the recent move from distributed subspecialty electronic medical records (EMR) to a single EMR which supports the needs of multiple specialties. The consolidated imaging record can then be accessed through a single-entry point in the EMR maintaining an efficient provider workflow.

As described by *Becker's Healthcare* and *Modern Healthcare Executive*, current healthcare challenges include value-based care, the digital healthcare organization, operational effectiveness, data and analytics, and cybersecurity [1, 2]. The Institute for Healthcare Improvement's quadruple aim further focuses attention on the patient experience, population health, care team well-being, as well as cost [3]. The value equation is a universal representation of the interaction between forces in healthcare today. In its simplest form, value equals quality divided by cost. EI offers benefits that favorably affect both sides of the value equation; quality of care is improved while cost is decreased. Enterprise imaging is a comprehensive approach to unite and coordinate all image-producing services in a way that—first and foremost—enhances clinical care, improves operational efficiency, strengthens cybersecurity, advances digital transformation by enabling mobile tools, and supports data analytics and artificial intelligence endeavors (Table 1). Many healthcare organizations may not pursue an EI initiative due to financial concerns, an issue that plagues the entire healthcare digital transformation. A compelling event, such as the need to replace a major imaging system, may be the trigger that necessitates exploration and development of an enterprise imaging strategy and roadmap. This manuscript presents an in-depth review of the value proposition of enterprise imaging.

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Enterprise Imaging Overview

The concept of EI has been evolving. Initially, EI focused on the consolidation of radiology infrastructure and services across numerous geographic sites. EI has now expanded to encompass all forms of medical media ranging from photographs to videos. Almost every specialty engages in creating

Table 1 A summary of the impact of an enterprise imaging strategy on each of the key operational priorities in the current healthcare environment

Priority	Impact
Clinical care	• Increases access to imaging information
	• Maintains provider workflow
	• Promotes patient engagement
Improved operational efficiency	• Streamlines infrastructure
	• Improves provider access to information
	• Standardizes workflows
	• Consolidates teams
Improved data utilization and analytics including artificial intelligence	• Enables shared data governance and data hygiene principles
	• Improves accuracy of diagnostic imaging
	• Increases operational insights which leads to improved process efficiency
Telehealth and mobile platform utilization	• Supports optimized mobile platform deployment for image viewing
	• Enables mobile patient, provider photograph acquisition and upload
	• Integrates telehealth platforms and image archive
Health information exchange and patient access	• Creates single point of image import and export between enterprises
	• Provides foundation for patient access to images and for patient directed image sharing
	• Eliminates media such as CDs
Cybersecurity	• Helps expose points of weakness
	• Raises awareness of risks
	• Provides opportunities for education

some form of visual media. Radiology and cardiology are the most mature and prolific of the image-producing specialties. Ultrasound services are fully integrated into obstetric and gynecologic practices. Plastic surgery and dermatology have well-developed photodocumentation programs. Ophthalmology practices are dependent on optical coherence tomography and color fundus photography. Emergency Departments have point-of-care ultrasounds and are increasingly adding photographs to their documentation. Family practitioners and pediatricians employ photographs for documentation, as well as for consultation with specialists. Intensive care units rely on point-of-care ultrasounds for a number of different indications. Videos are being utilized for multiple purposes, including gait analysis, assessment of seizures, and documentation of procedures—such as laryngoscopy. Pathology departments are looking to digitization to bring savings in manpower through increased productivity [4–6]. Digital imaging is well established in dental practices. A solid universal foundation for imaging data is essential to prevent continued fragmentation of a patient's electronic health information. In the past, many of these image-producing services have resided within physicians' offices in disconnected silos without image distribution, viewing or sharing capabilities. As more physicians are employed by hospitals and health systems, these other image-producing services will become the responsibility of these organizations. It is in the best interest of the organizations to understand the opportunities and challenges that come with managing these other image-producing services.

The introduction of the vendor neutral archive (VNA) sparked the EI evolution. A VNA provides the capability of storing images from any vendor picture archiving and communication system (PACS). However, EI is much more than a storage initiative. As defined by the HIMSS-SIIM (Healthcare Information and Management Systems Society-Society for Imaging Informatics in Medicine) Enterprise Imaging Community, enterprise imaging is "a set of strategies, initiatives, and workflows implemented across a healthcare enterprise to consistently and optimally capture, index, manage, store, distribute, view, exchange, and analyze all clinical imaging and multimedia content to enhance the electronic health record" [7]. Enterprise imaging unifies all image-producing services with these shared functions, and it is guided by enterprise governance [8]. HIMSS Analytics has also developed the Digital Imaging Adoption Model (DIAM) to provide the industry with a benchmarking tool [9]. This tool emphasizes the comprehensive nature of an EI program, including engaging multiple imaging departments, the integration of a universal viewer with the electronic medical record, inclusion of multiple imaging departments, implementation of an image exchange program and mobile tools, use of artificial intelligence, and analytics for diagnosis and business analytics. While the EI definition and maturity model are well established, implementation of enterprise imaging is in its infancy. Only a few enterprises have moved into the advanced stages of adoption as defined by the DIAM. Part of this slow evolution is related to a lack of awareness of the value proposition of an EI initiative.

Clinical Care

Streamlining the imaging ecosystem sets the stage for improving the quality of care, as well as the experience of providers and patients. In today's environment, providers often need to make decisions without access to all medical information about their patients. The electronic health record is designed to overcome this obstacle. As stated by the Office of the National Coordinator for Health Information Technology (ONC), electronic health records (EHR) are "real-time, patient-centered records that make information available instantly and securely to authorized users." [10] According to the ONC, access to information improves patient care and enhances care coordination [11]. The ONC indicates that the EHR will contain medical images. Viewing images is critical to many specialists—especially surgeons, pulmonologists, neurologists, orthopedic surgeons [12]. Access to other specialty imaging, such as in the case of correlating radiologic, pathologic, and genomic data, will improve diagnoses. Such sharing is best achieved through a shared infrastructure and single interface contextually embedded in their workflow [13].

Currently, many medical images reside in siloed systems. Access to these images often requires physical travel to the geographic location where the images are stored, and a provider may not have a required password to access a specific imaging system. In many cases, the provider may not even be aware of the existence of certain forms of medical imaging. This lack of awareness is especially true if the only reference to said images is contained within a progress note. The desired shared infrastructure and single interface are achieved through integration of universal viewer with the electronic medical record [14]. The universal viewer provides a single point of access to all images in the central image repository. This integration ensures that medical images are available in the standard EMR-based workflow and that information is available at the point of care. The combination of the visual information and the textual information significantly advances efforts to create a comprehensive electronic health record.

Providers do not need to rely on a report of another providers' description of a finding; as they say, "a picture is worth a thousand words." When patients and providers travel between different geographic sites, access to images is maintained. Providers at different points along the care continuum now have a more comprehensive view of the patient. Medical decision-making occurs in the context of a more complete understanding of the patient.

A simple wound care use case highlights these benefits. Photographs are now a key component of wound documentation. These photographs allow caregivers to assess healing at follow-up visits and can help reduce variation in wound measurement [15]. Patients recognize the importance of photographs in the continuity of their care [16]. In this example, a patient develops a decubitus ulcer on a heel during a hospital admission. At the time of discharge, a photograph is taken to document the wound's appearance. The patient is referred to a chronic wound clinic for follow-up. Photographs are taken at predetermined intervals. The patient then presents to the emergency room of the same health system with concerns that the wound has been getting worse. If the photographs from the wound clinic are stored in a siloed wound PACS or in a peripheral paper chart, those photographs would not be available. The emergency physician has incomplete information about the wound, which will impact the quality of the visit. If the baseline photograph and all subsequent photographs are stored in a single system that is accessible through the EMR, a more complete assessment is possible. Definitive care can be rendered. Communication along the care continuum and decision-making is optimized.

Patient engagement is a primary consideration in a value-based system. It is considered crucial to have patients become active participants in their own care [17]. One strategy for enhancing patient engagement is to provide them with access to their healthcare data [18]. They should have access to their medical images in addition to provider notes, laboratory results, and upcoming visits. Wang et al. demonstrated that a patient's ability to see their wound and track its healing increases their engagement in their disease process [16]. Similar results were reported for patients who were shown their radiologic studies [19]. In their study, Carlin et al. concluded that viewing images leads to an increased understanding of one's condition, creates an emotional effect, and influences the interaction between the patient and the physician [19]. Carlin et al. also recognized that, for this interaction between provider and patient to occur, images need to be available at the point of care [19]. Similar conclusions were reached by those who studied patients' perceptions of the RSNA image-sharing network [20]. Patients enjoyed the ability to control their images, including sharing with persons outside of the healthcare environment. Through the distribution and viewing functions, an EI initiative can have a profound impact on patient engagement. Image distribution and viewing are not solely aimed at providers. Patients are also consumers of these services. Patients' access to their images can be achieved through a variety of mechanisms. The universal viewer can be accessed in a standalone format or, optimally, it can be integrated into the EMR patient portal. Certain image exchange programs also provide mechanisms for patients to access their images from the centralized image repository. When patients are able to directly share their images with providers, efforts spent on release of information activities are eliminated and time to treat can be reduced. Duplicate studies can be eliminated.

Improving Operational Efficiency

Operational efficiency can best be defined as high-quality output, such as products or services for the least amount of input of which cost is a major factor, similar to the value equation. Every healthcare system is striving to achieve operational efficiency. The strategies to address these challenges used by IT departments in other industries are applicable to the healthcare sector. As summarized in one McKinsey report, these strategies center around "standardize, simplify and automate processes." [21] Activities include optimizing assets currently in place, consolidating systems that do similar things, creating a single point of entry into disparate systems, reducing human intervention, integrating data models, and having a data dictionary [22–24].

Assessment of the imaging ecosystem is a first step in the simplification process. This assessment will likely reveal a multitude of different imaging archives, all with variable end-of-life or end-of-contract timelines. In some departments, images may be stored locally on the acquisition devices without any long-term archiving. Even more worrisome is to find that images are stored on personal devices, such as mobile phones, laptops or computers, or portable media such as USB drives. In these situations, the devices and thus the images are siloed from the rest of the health record and have limited to no security. In those departments where archives are utilized, they may be supported by different, and oftentimes redundant, personnel with varying levels of technical knowledge and ability. This scenario results in duplication of storage resources and support personnel.

A centralized image repository, typically a vendor neutral archive (VNA), is the core component of EI. By consolidating imaging data storage into a single archive, multiple benefits can be realized (Figs. 1, 2, and 3). The massive purchasing power of the large imaging departments can be extended to other smaller image-producing departments. Overall image storage costs can be reduced. Implementation of an EI program in one large academic medical system resulted in an estimated 10–15% cost savings by consolidation of radiology, cardiology, and pediatric cardiology PACS into a single VNA [25]. Cost savings were attributed to a reduction in service contracts, maintenance, and support resources. Actual storage costs were decreased by 30% [25]. Other realized benefits included improved disaster recovery support, a decrease in unscheduled outages, enhanced monitoring, and auditing capabilities. The anticipate time to recoup implementation costs was 2.5 years [25]. A single archive enables the enterprise to take advantage of newer storage technologies, and it reduces the number of different replacement timelines that must be managed. Anytime equipment can be eliminated, savings are realized through the reduction in the number of software licenses, servers, maintenance, and other vendor costs [26]. Each subspecialty can, if desired, maintain its own image diagnostic and post-processing software. However, as imaging vendors shift the focus of their diagnostic capabilities from subspecialty systems to the global needs of EI, the potential for further consolidation is on the horizon.

Simplification is not limited to infrastructure. Simplification of support teams will also have a positive impact on operational efficiency. Current workforce challenges in IT include the need for appropriately skilled individuals as well as the need to continue to grow the skills of existing resources. For the past several years, a future shortage of workers skilled in informatics, including healthcare, has been recognized [27–29]. This shortage impacts the numerator of the operational efficiency equation: high-quality output. On the other side of the operational efficiency equation is the need to reduce input, primarily cost. Healthcare is a labor-intensive business and any opportunity to reduce personnel cost is greeted with excitement. With consolidated image archiving, the required support team can be streamlined. Through consolidation of support teams valuable, skilled personnel can be optimally utilized and the number of individuals can be reduced. Through cross-training, individuals can support multiple different image management systems better utilizing existing resources, improving consistency of support, and reducing reliance on vendors. These types of saving have been recognized in other industries where reductions in the IT staff have been achieved through combining, consolidating, and rationalizing disparate IT systems [30].

Standardization helps reduce costs and increase reliability, and it is a common theme for improving operational efficiency. Standardization is a must-do for information technology departments [23, 30]. It can be applied to people, process, and technology. In addition to the infrastructure simplification already described, EI will lead to standardization of workflows and metadata. In the healthcare imaging space, standardization of metadata is a key factor to future success. This metadata serves to guide indexing of studies and aids image retrieval and viewing and will be useful for clinical and business analytics. Metadata is used to identify comparison studies, and for establishing and utilizing hanging protocols during diagnostic interpretation. The EI industry is still evolving with regard to standardization for metadata. Decisions need to be made on which fields to standardize, such as body part or procedure performed, and which standards should be utilized in those fields [31]. Radiology, while a mature imaging specialty, still

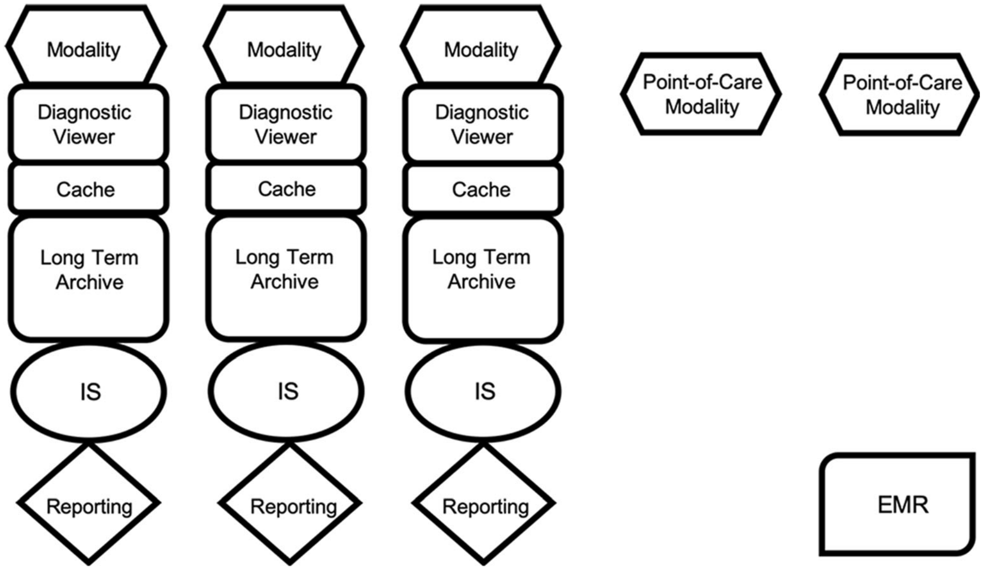

Fig. 1 Imaging past and include the information after 1a. **a** In the pre-EI era, the typical subspecialty imaging ecosystem consisted of siloed diagnostic systems. Those systems included acquisition modalities, the associated picture archiving and communication system composed of a short-term cache, a diagnostic viewer, and a long-term archive. Additional components include an information system (IS) to associate metadata and provide context for the examination, and a reporting system. For each specialty such as radiology, cardiology, ophthalmology, these systems are separated both functionally and physically. Point-of-care modalities such as ultrasound and photography have no infrastructure. These images lack metadata, long-term storage. They are also siloed from the electronic health record. There is no connection between imaging systems and the (EMR). **b** A central image repository, often a VNA, is the center of an EI program. One VNA serves as the long-term archive for multiple modalities and multiple specialties. In this example, three archives and support teams have been consolidated into one. Workflow management tools (WF) provide point-of care modalities with the ability to create worklists and to associate with images with metadata. A universal viewer provides a single point of access to all images through the EMR. Image exchange functions are supported by a single point of import and export. **c** As functionality continues to evolve the possibility of a single diagnostic viewer for all imaging services is on the horizon. All orders-based image-producing departments may share a single information system and a single reporting system

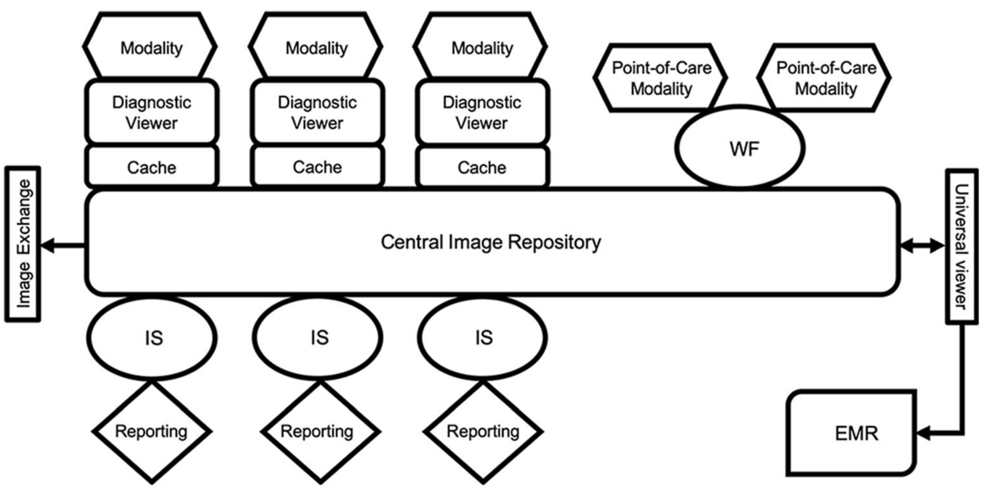

Fig. 2 Imaging present and include the information after 1b. **a** In the pre-EI era, the typical subspecialty imaging ecosystem consisted of siloed diagnostic systems. Those systems included acquisition modalities, the associated picture archiving and communication system composed of a short-term cache, a diagnostic viewer, and a long-term archive. Additional components include an information system (IS) to associate metadata and provide context for the examination, and a reporting system. For each specialty such as radiology, cardiology, ophthalmology, these systems are separated both functionally and physically. Point-of-care modalities such as ultrasound and photography have no infrastructure. These images lack metadata, long-term storage. They are also siloed from the electronic health record. There is no connection between imaging systems and the (EMR). **b** A central image repository, often a VNA, is the center of an EI program. One VNA serves as the long-term archive for multiple modalities and multiple specialties. In this example, three archives and support teams have been consolidated into one. Workflow management tools (WF) provide point-of care modalities with the ability to create worklists and to associate with images with metadata. A universal viewer provides a single point of access to all images through the EMR. Image exchange functions are supported by a single point of import and export. **c** As functionality continues to evolve, the possibility of a single diagnostic viewer for all imaging services is on the horizon. All orders-based image-producing departments may share a single information system and a single reporting system

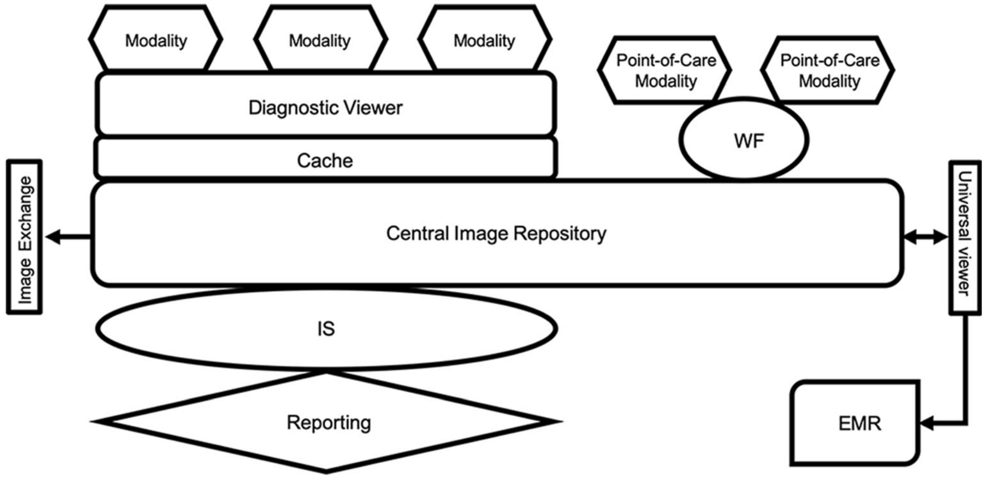

Fig. 3 Imaging future and include the information after 1c. **a** In the pre-EI era, the typical subspecialty imaging ecosystem consisted of siloed diagnostic systems. Those systems included acquisition modalities, the associated picture archiving and communication system composed of a short-term cache, a diagnostic viewer, and a long-term archive. Additional components include an information system (IS) to associate metadata and provide context for the examination, and a reporting system. For each specialty such as radiology, cardiology, ophthalmology, these systems are separated both functionally and physically. Point-of-care modalities such as ultrasound and photography have no infrastructure. These images lack metadata, long-term storage. They are also siloed from the electronic health record. There is no connection between imaging systems and the (EMR). **b** A central image repository, often a VNA, is the center of an EI program. One VNA serves as the long-term archive for multiple modalities and multiple specialties. In this example, three archives and support teams have been consolidated into one. Workflow management tools (WF) provide point-of care modalities with the ability to create worklists and to associate with images with metadata. A universal viewer provides a single point of access to all images through the EMR. Image exchange functions are supported by a single point of import and export. **c** As functionality continues to evolve, the possibility of a single diagnostic viewer for all imaging services is on the horizon. All orders-based image-producing departments may share a single information system and a single reporting system

does not have a single universally adopted standard for indexing and retrieval of studies. Photodocumentation is in its infancy as an enterprise service and has very little metadata standardization. While the overall EI industry may be lagging, each institution should attempt to standardize its imaging metadata to achieve internal efficiencies in indexing, retrieving, and viewing. For example, in our chronic wound scenario, if a photograph is labeled as "photograph" or "wound," the exact anatomic site is unknown without opening the imaging study. If it is identified as "wound, heel" or "heel wound," then the photograph's relevance to an imaging study of the foot to evaluate for osteomyelitis is more apparent. In another example, if an ultrasound of the gallbladder is consistently identified as "US gallbladder" or "US right upper quadrant," regardless of the service performing the examination, the study is readily identified as a relevant comparison examination. This internal metadata standardization enables digital imaging assets to be stored in a way that sets up the organization for future gains delivered through advanced analytics and AI. Industry efforts are currently underway to select a single anatomic standard to deliver a universally adopted body part ontology.

At the most basic level, all interfaces and communication protocols utilized should be industry standards, such as DICOM and HL7 [7, 32]. These standards then dictate requirements for all devices within the ecosystem. They ensure that new devices can successfully join the ecosystem. The DIAM stage 4 reinforces the need to employ internationally recognized standards [9].

Workflow standardization is well established for orders-based image-producing departments. In the standard order-based workflow information, most importantly patient name, other demographic information, and encounter information flows seamlessly between the EMR to the RIS, imaging modality, and PACS [33]. The Integrating the Healthcare Enterprise (IHE) Scheduled Workflow profile has been developed to support this workflow [32, 34]. Challenges arise in the encounters-based workflows. In these workflows, the need for an imaging study is not recognized prior to the patient visit. These workflows cross multiple different specialties, often using the same modality—such as point-of-care ultrasound or photography. In their siloed environments, each of these specialties built their own workflow to meet their unique needs. With enterprise imaging, an organization has the ability to establish standard workflows. New IHE profiles, such as the Encounters-Based Imaging Workflow (EBIW), have been developed to support these workflows [35]. This encounters-based workflow will create a unique study identifier, such as an accession number [31]. The EMR will be notified of the study's existence in a uniform fashion. The identification of the imaging study in the EMR will be the same regardless of modality or image-producing service. Ideally, all imaging studies will be represented on a single tab, analogous to the way laboratory results, orders, and medications are grouped. If a separate report is generated, then that report should contain a link to the imaging study in the same fashion as a radiology report. If no report is generated, then a consistent means of describing the findings of the study should exist. Depending on the EMR capabilities, there should ideally be a link between the images and this description of findings. Where appropriate, standard billing workflows can be implemented. Through consistent billing practices, reimbursement is optimized. For example, point-of-care ultrasound workflow would be the same for the physician in the emergency department and the sports medicine physician in the clinic. If rheumatology decides to offer point-of-care ultrasound, the overall implementation burden is reduced. With these standard workflows, new service lines can be added with lower investment than if new workflows were created each time.

The introduction of modality worklists enables automation of the imaging workflow. This process protects the integrity of the patient demographic data and eliminates the time-consuming manual entry. These automated worklists generate more reliable demographics and fewer verification failures, which must be manually processed. The IHE profiles support this automation. Similar automation can be achieved for encounters-based workflows through the creation of patients' lists on the modality. These lists are based on the patients scheduled to be seen in the care environment where the modality resides. The use of barcoded patient identification bands, which are then scanned to identify the patients, further automates workflow and reduces error. EI's focus on workflows will drive all imaging producing departments to the highest level of performance.

As image archives become more sophisticated, automated lifecycle management tools are being incorporated. If imaging archiving is centralized and these tools are available, a comprehensive lifecycle program for all digital images can be established. Image lifecycle management, primarily through the moving of older exams in storage tiers that are less costly, helps to reduce overall cost to the organization.

Reducing complexity and establishing a solid foundation for the imaging ecosystem through established infrastructure and standardized metadata and workflows helps support mergers and acquisition. As new hospitals, provider groups, and other healthcare delivery entities with image-producing capabilities join the organization, incorporation of their imaging systems is streamlined, and economies of scale and desired efficiencies can be achieved. The imaging component of a merger or acquisition can now be quantified.

Data Analytics and Artificial Intelligence

Artificial intelligence and machine learning are impacting industries across the globe, including healthcare. Overall, AI is predicted to bring $150 billion dollars in annual savings for the US healthcare economy by 2026 [36]. AI can be utilized to improve patient care through improved diagnostic capabilities and improve operations through improved productivity [37]. Clinical decision support tools for imaging can be effectively utilized to improve the overall health of the patient population [38, 39].

Governance and data integration, as well as elimination of silos, are critical steps in preparing an organization for machine learning [40]. Governance helps an organization meet the requirement that data is "clean, accurate, standardized and comprehensive before it can be combined with additional data sources to produce actionable insights." [41]. Even basic demographic data, such as patient name, can produce significant challenges if it does not follow a uniform format throughout an organization. Strict data governance will have a positive impact on most analytics programs, including population health and numerous other programs where data are aggregated [41]. The ability to deploy artificial intelligence algorithms and neural networks will be aided or hampered by the underlying quality of the data. Governance is critical to EI success; its importance is recognized by inclusion in the DIAM at an early stage, stage 3 [9]. EI governance and enterprise data governance need to work in concert to achieve the highest-quality imaging data.

AI efforts are well underway in the digital imaging space. In radiology, AI is being utilized to improve medical image reconstruction, noise reduction, quality assurance, triage, segmentation, computer-aided detection, and computer-aided classification [42]. Developments in evaluation of photographs for identifying melanoma have proven successful [43]. Software to aid in the evaluation of retinal scans is in development [44]. Promising results are being experienced in the evaluation of pathology slides [45]. Radiomics is an exciting new field. Radiomics combines the imaging data that is not perceptible to the human eye, with data from pathology, with the response to therapy. This combination of information is a critical component of the drive to individualized treatments, aka precision medicine [46]. While currently isolated to single imaging modalities, AI is expanding to involve multiorgan-multimodality datasets [47–49]. The centralization and standardization of imaging data provided by the structure of EI help the healthcare industry meet the critical requirements of eliminating silos and establishing standards to meet the complex AI use cases of today and the future.

The healthcare industry is early in its adoption of business analytics tools. All image-generating departments will benefit from the operational insights. Business analytics have already been employed to help radiology examine past performance and to use predictive analytics to examine operational steps and develop efficiencies [50]. BI can improve real-time dashboarding, perform workflow analysis to drive improvement, and many other operational metrics guided by machine learning [37]. For the more traditional orders-based imaging departments metrics, such as time to image, modality utilization and report turnaround time are just a few of the metrics being utilized. In addition to operational metrics, analytics can be used to assess and improve quality of radiologic care [51]. In the encounters-based imaging department, these types of metrics will be new, and they can be quite valuable. Utilization of point-of-care ultrasound machines can be analyzed to determine whether there is a need for replacement or not. Billing can be optimized across all similar image-producing services, such as point of care ultrasound [52]. Data about who is entering photographs into the archive can be used to provide benchmarking against peers and prevent overuse. An overall assessment of who is viewing images can be performed to analyze the effectiveness of EI. Through the standardization of workflows and metadata, comparisons can be made within and between image-producing departments. As healthcare progresses from volume to value, this enterprise view of imaging-producing departments will be useful to maintain the highest-quality services at the lowest cost.

Telehealth and Mobile Platforms

Telehealth and mobile platforms are two important topics in any discussion about the digital transformation of healthcare. Although they are distinct concepts, they are intertwined. Mobile tools, such as smartphones and tablets, will be utilized by patients and providers to access information, enter information, and to acquire and upload photographs of medical conditions. Mobile tools will be used for patient-to-provider and provider-to-provider communications. With the widespread use of smartphones as image acquisition tools, if providers and patients do not have access to appropriate workflows, they will develop their own. Provider ad hoc workflows are likely not a health insurance portability and accountability act (HIPAA) compliant. The storage of patient photographs in a provider's local camera where they might intermingle with personal photos is of great concern. This scenario also carries with it a risk of inadvertent exposure of protected health information. Selecting appropriate workflows for smartphone image acquisition and upload is a core component of EI. Appropriate security must be implemented [53]. These workflows provide HIPAA-compliant pathways to capture, index, manage, and store these photographs. A single, standardized workflow can be deployed to all providers independent of their specialty or department. The same workflows and metadata standards implemented for provider workflows should also be followed for patient-uploaded photographs.

In the typical store and forward model of telemedicine, patients will be sending their providers photographs of a variety of conditions, ranging from rashes to follow-up of acne or a surgical incision. New CPT codes were introduced in 2019 to reimburse providers for evaluation of these submitted photographs [54, 55]. Initially, these photographs might be stored in the telehealth vendor's cloud; however, like all other medical images, they need to be stored in the central image repository. The photographs should be captured and indexed using established workflows and agreed upon metadata. These images need to be subject to the same metadata standards as other images, so that they can be identified by future providers, are searchable and filterable, and are shareable with other organizations. If these images are not stored in the central image repository, the basic tenet of creating a single comprehensive patient record is violated. As clearly stated by one telehealth leader, "the biggest issues regarding telehealth adoption is the integration into core operations of a healthcare business." "If are a payer, provider or consumer focused organization, how you envision telehealth as an integral part of your work is crucial. Approaching it as an added layer or 'good to have' is not sufficient." [56]

Distribute and view functions for EI also need to be available via mobile technology. Most EMRs today also have a mobile application for provider access. Doctors are increasingly relying on their mobile EMR access especially during morning rounds and in evening hours [57]. Imaging information also needs to be available in a mobile format. The universal viewer will be the vehicle for this access. The viewer may be accessed independently of the EMR, or more optimally through integration with the EMR mobile version. The use of mobile tools for viewing images has been shown to be beneficial to orthopedic surgeons and traumatologists. The mobile tools were felt to ease access as they were always available, unlike desktop PCs [58]. Mobile tools were also useful for bedside image sharing with patients [58].

Health Information Exchange and Patient Access

Vertical and horizontal integrations are widespread as organizations seek to: access more resources, achieve economies of scales, expand their geographic footprint, increase market share, and provide new services [5]. These new relationships create challenges for information sharing as patients move from point to point in the healthcare delivery system. Image exchange is a key component of this information sharing. Image exchange is an integral component of an advanced EI initiative [59]. Patients expect their imaging information to move freely and securely from one healthcare institution to another, just like their banking data [60]. They are unwilling to accept failure of access to information as a reason to delay care and are unwilling to accept repeat imaging to keep care moving forward unimpeded [19, 60]. As the healthcare industry moves from volume to value, elimination of redundancy is critical. There is strong evidence to suggest that having an image exchange mechanism in place will reduce the degree of redundant imaging [61, 62]. Electronic information exchange allows images produced outside of an organization to be available during a patient visit. When exchanged prior to the patient visit, these images can be viewed through the universal viewer/EMR integration as part of the provider's routine EMR workflow. Precious minutes of the visit are not wasted trying to open a CD that refuses to share its images, or worse yet, the visit is incomplete because the patient forgot to bring the media on which their images are stored. The goal of image exchange is to present the right information at the right time in the right workflow. In their recent rule, the Office of the National Coordinator for Health Information Technology is signaling that the electronic exchange of imaging data is on the radar [63]. The exact nature of what must be exchanged and how is yet to be determined.

In many image-producing departments, the typical process for exchanging images is manual and expensive. Someone needs to find the images, create a CD, and then send that CD out. The estimated cost of creating a CD is approximately $15 to $40 [64]. Converting this manual workflow to an electronic one offers savings in materials and manpower. Supplying all providers, even those outside of an enterprise, with access to imaging data improves the overall quality of care. A single image archive, coupled with appropriate image exchange software, creates a single point of image import and export and allows the institution to enjoy the benefits of a single workflow. Through the centralization of this process, the smaller image-producing departments can benefit from this electronic process. These smaller departments are unlikely to be able to bear the full cost of image exchange software.

Patients must also be able to participate in accessing and controlling the distribution of their medical information, including their medical images. Ease of access will influence the overall patient experience. Patients want to be able to access all aspects of their health record and desire to do so from the palm of their hand [36]. Patients favor use of the Internet over CDs, especially when they have complex medical conditions and multiple imaging studies [60]. As patients desire greater control of their medical information, new functionality needs to be developed. A desired function is for patients to have the ability to electronically direct the sharing of their medical images.

Cybersecurity

Cybersecurity is a major area of concern within any healthcare digital environment. Healthcare information is some of the most valuable digital information that exists [65]. In addition to privacy concerns, cybersecurity is increasingly being considered a patient safety issue, as well as a financial issue [66]. Current estimates place that cybersecurity financial burden at over five billion dollars annually [67]. Cyberattacks not only lead to theft of protected health information but can also have significant operational repercussions with ransomware attacks limiting access to medical records [68–70]. In addition to the risk of medical information theft, nefarious individuals can create software that is able to alter the findings on imaging studies [71]. It is the organization's responsibility to ensure that its network and the devices on that network are as secure as possible and that the integrity of the imaging studies is maintained.

Imaging devices are a target-rich environment for intrusion. Network intrusions are second only to phishing attacks as sources of a breach [72]. The security risk increases as imaging equipment, which previously operated as a standalone system, joins the network [42, 68]. While medical devices, such as IV pumps, may service a handful of patients per day, radiology systems contain information on just about every patient seen at a health system. Similarly, ophthalmology systems and point-of-care ultrasounds image numerous patients per day. These imaging devices need to be securely connected to the network and to the Internet with appropriate intrusion detection systems in place [73].

Until recently, very little attention has been given to cybersecurity of medical imaging devices [73]. Research has shown that even the sophisticated specialty of radiology may lack awareness of the cybersecurity threat of networked devices [69]. For many of the image-producing systems, vendor support may occur via remote access and this access poses a potential site of breach. Embedded web services for system or device administration are a leading vulnerability threat [66]. Often, these services are left on or password defaults are not changed at the time of installation and these services may not require authentication for access [69, 74]. Aging of many legacy systems leads to software that is not current and usually not sufficiently protected against today's threats [66]. The mismatch between lifespan of computer operating systems and the longer lifespan of imaging equipment amplifies the risk [69]. Many other unnecessary programs have also been found on these systems [69].

An EI initiative helps reduce these risks through a number of ways. First, it creates increased visibility to all hardware and software within the imaging ecosystem. By increasing visibility, all devices and systems can be evaluated to determine whether or not they are compliant with the institution's security policies. Noncompliant systems can be decommissioned or brought into compliance. Secondly, EI helps increase awareness among all personnel in the imaging ecosystem. Greater than 50% of healthcare data breaches are due to internal human error and the greatest way to mitigate this risk is through the development of a security minded culture [72, 74, 75]. The heightened awareness, increased collaboration, and communication generated via enterprise governance bodies will be a strong factor in building this culture.

The addition of mobile devices to the imaging ecosystem poses two risks: the potential for inadvertent access to protected health information and the risk of physical loss of the device and the information contained within. As these devices are utilized for image acquisition, ensuring that an appropriate HIPAA compliant workflow is followed is essential.

The ability to download data onto unauthorized unencrypted devices (USB sticks, CDs, DVDs) poses another threat. In the absence of other options, providers store data on these types of devices to ensure that they have access to the imaging data they need. Yet, these methods of storage are both not secure and they are isolated from the electronic medical record. These devices pose the greatest threats to healthcare data [69, 76]. Loss of unencrypted devices can lead to hefty penalties [77]. When EI has been implemented, providers are assured that the images they desire will be appropriately archived and indexed, so that they will easily be retrieved in the future. With these assurances, providers should be less motivated to store images on portable or unsecured media. Safeguards can be put in place within the viewing software so that images can only be downloaded in a de-identified format.

Summary

In conclusion, an enterprise imaging strategy is an essential component of the healthcare digital transformation. Often overlooked, management of digital imaging assets can bring clinical value through efficient delivery of medical information. Overall costs can be reduced via infrastructure and support team consolidation. Financial and clinical risks are minimized through increased cybersecurity awareness.

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