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Implementation of Enterprise Imaging Strategy at a Chinese Tertiary Hospital

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Abstract

Medical images have become increasingly important in clinical practice and medical research, and the need to manage images at the hospital level has become urgent in China. To unify patient identification in examinations from different medical specialties, increase convenient access to medical images under authentication, and make medical images suitable for further artificial intelligence investigations, we implemented an enterprise imaging strategy by adopting an image integration platform as the main tool at Xuanwu Hospital. Workflow re-engineering and business system transformation was also performed to ensure the quality and content of the imaging data. More than 54 million medical images and approximately 1 million medical reports were integrated, and uniform patient identification, images, and report integration were made available to the medical staff and were accessible via a mobile application, which were achieved by implementing the enterprise imaging strategy. However, to integrate all medical images of different specialties at a hospital and ensure that the images and reports are qualified for data mining, some further policy and management measures are still needed.

Keywords Medical image · Enterprise imaging · Image integration platform · Clinical needs · Workflow re-engineering

Background

The need to build a comprehensive electronic health record system based on an integration platform has been recognized, particularly at tertiary hospitals in China, since 2010. However, most of these integration platforms are limited to handling information messages in text format, and images cannot be included [1]. Even according to the standards published by healthcare management organizations, image integration has seldom been mentioned [2–5]. This is mostly because of the following two reasons:

1. The common text format mostly consists of subjective healthcare information, such as admission, progress, and discharge notes, which are considered to represent the clinicians' work and value and thus are worthy of integration and exploration.

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2. Images, of course, are also useful for clinicians, but the need for integration is not very critical from a healthcare management point of view. Medical images are more related to medical devices, and the diversity of imaging formats has made the collection and processing of images more complicated. It is also more difficult to define standards, implement integration, and exchange information about images in and among departments and healthcare organizations.

However, with the breakthrough of artificial intelligence (AI) and machine learning algorithms based on images in recent years, objective healthcare information, including images and waveforms of different specialties, play an increasingly important role in medical data mining. Physicians have high enthusiasm regarding the application of AI based on medical imaging. Currently, AI applications mainly contain two aspects. One is an automatic report of a specific type of medical image of a certain disease, such as the diagnosis of pulmonary nodules based on CT images [6–8], which can be used to improve the efficiency of diagnostic reports in radiology departments. The other application scenario is providing physicians with alert therapy suggestions or other clinical decision support (CDS) based on integrating multiple types of medical images and other structured data, such as medical records and laboratory tests. Algorithms used in this scenario would be more difficult and complicated to develop. The requirement of data integration and labeling would also be higher. However, the need for the second application scenario is more urgent in healthcare organizations, especially in rural hospitals.

Xuanwu Hospital is a tertiary hospital with the well-known disciplines of neurology and clinical engineering in China. We understand the importance of medical imaging data (including waveforms). However, the completeness, validity, and timeliness of patients' image data were not adequate. To enhance the image data quality, increase the data content and encourage more data access, we set the following goals to manage medical images at the hospital level as part of the data governance strategy [9, 10] of Xuanwu Hospital:

1. Integrating the image view of medical images from different medical specialties
2. Integrating the historical view of the emergency department and inpatient and outpatient records at Xuanwu Hospital
3. Allowing medical staff (including clinicians, nurses, radiologist, and laboratory technicians) to conveniently view clinical information (including images) under authentication
4. Standardizing the imaging format and storing medical images from different medical specialties as much as possible for further research and machine learning

Methods

Basic Condition of Information Systems Related to Medical Images

Most of the imaging-related specialties at Xuanwu Hospital have built their own information systems as well as generated their own reports and images that can be viewed and shared within each specialty electronically. The vendors of the information systems as well as the image file formats and report formats stored in the information systems are listed in Tables 1, 2, and 3. The formats of the medical images and reports of each specialty information system are different, and the images can only be viewed within its own system.

Design Approach

According to Table 1, most of the specialized information systems related to medical images have been installed and used at Xuanwu Hospital. However, to manage images/waveforms at the hospital level, we still need to implement a project to index, exchange, and integrate images. Thus, a medical image integration platform was designed and implemented.

Overall Framework

To ensure that the textual data exchange speed would not be affected by the large volume of image data, we designed a framework with a two-layered integration platform for information systems at Xuanwu Hospital (Fig. 1). The service bus for the upper layer only exchanges text data using the IBM integration Bus 10 built by EWELL, Inc., Zhejiang, China, and the service bus for the lower layer uses DJ ESB 3.3.1, built by DJ HealthUnion, Shanghai, China, to exchange both

Table 1 List of the vendors of the information systems of medical images

Specialty	Vendor	Specialty	Vendor
Radiology	DJ HealthUnion	Electrophysiology	Goodwill
Ultrasound	DJ HealthUnion	Pathology	LOGENE
Nuclear medicine	DJ HealthUnion	Gastroenterology endoscopy	Medicom
Ophthalmology	Helijianxin	Vascular intervention	BJ Sichuang

Table 2 Image file format stored in each medical image information system

Specialty	Radiology/ultrasound/nuclear medicine	Gastroenterology endoscopy	Pathology	EEG	Ophthalmology
Image file format	DICOM	DICOM	JPG	Private format	JPG

images and image-related text messages, such as patient name, modality, and examination date/time. The data exchanged between the lower and upper layers are only textual; thus, the system pressure that might be caused by a large volume of images would only occur within the lower layer of the integration platform. Therefore, the risk of image exchange and storage affecting the exchange speed of the main business can be largely minimized.

In this paper, the lower layer of the integration platform, which was designed to exchange images/waveforms and image-related text data, is called the image integration platform for simplicity.

Hardware of the Image Integration Platform

Five IBM 3850 servers, each with an Intel Xeon Quad-core Processor, 64 GB of memory and 8 TB of storage capacity, were used to build the image integration platform. The hardware architecture is shown in Fig. 2.

Function Components

Enterprise Master Patient Index

The Enterprise Master Patient Index (EMPI) component of the image integration platform was built by following the "Integrating the Healthcare Enterprise" (IHE) Patient Identifier Cross-Referencing (PIX) Integration Profile [11], communicates with the PIX/PDQ servers through the EMPI adapter and provides the following services:

1. Patient information registration: registered patient information needs to be sent to the cross index, the main elements of which include the following: system ID, patient ID of the business system (patient's local ID, LID), patient name, gender, date of birth, place of birth, nationality, marital status, guardian's name, ID number, address, telephone number, and so on. Whether there is a patient index in the cross index system will be checked by matching rules, and then, further processing (creating or updating the index) will be performed accordingly. The master index will also be updated if the cross index is updated or inserted.
2. Patient information matching: When receiving the request information from the external system to register a patient, the cross index system is first searched using the system ID+LID. If there has already been an exact match, only a simple update of the original index is needed. If no exact match can be found with the required index, an additional match is needed according to the other information of the patient in the system records based on the EMPI matching rules (Fig. 3).

Other services include a master index update, potential duplicate records, master index publishing, operation log, cross index of the patient, and master index of the patient.

Cross-System Image Data Integration and Sharing

Cross-system image data integration is performed by following the IHE Cross-enterprise Document Sharing for Imaging (XDS-I) profile [14]. The image data of each heterogeneous business system are processed with technical standardization for storage. Adopting both the distributed and centralized storage architectures at the same time, centralized management of image data is realized only using the existing hardware and software.

For PACS that fully complies with the DICOM standard, the DICOM manifest document [14] is used to collect image information, followed by sharing it on the integration platform. For image information systems that do not comply with the DICOM standard, a gateway can be used to support all of the functions related to XDS-I. Images in those systems can be aggregated to the gateway and are then forwarded to the integration platform, indicating that the gateway is responsible for the interaction between those non-DICOM systems and image integration platform.

Table 3 Report format of the medical image information systems

Specialty	Radiology ultrasound/nuclear medicine	Gastroenterology endoscopy	Pathology	EEG	Ophthalmology
Report storage format	Database	Database	Database	WinWord	Database

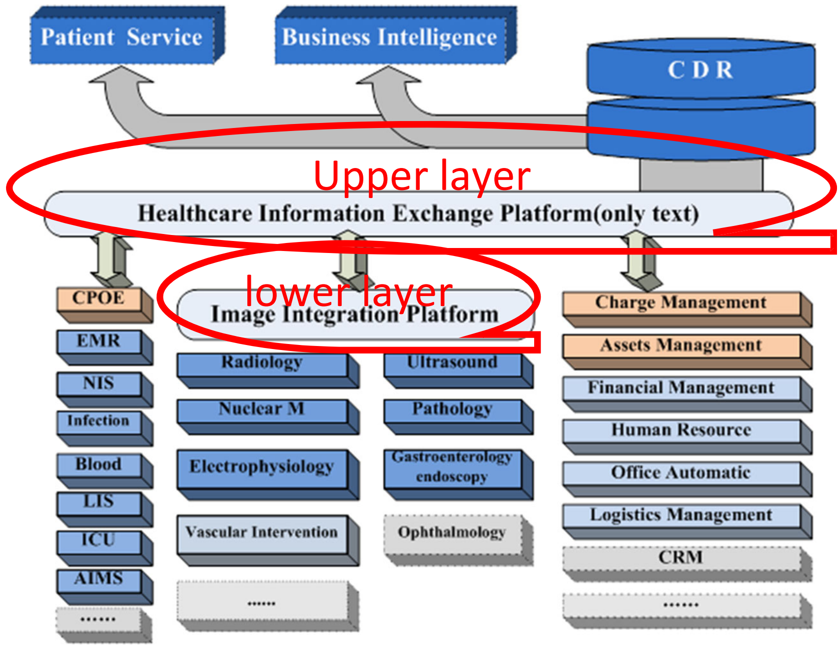


Fig. 1 A two-layered platform designed for data exchange and integration among information systems. In the healthcare information exchange platform (the upper layer), textual messages were exchanged among information systems. In the image integration platform (the lower layer), both images/waveforms and image-related text messages, such as examination reports, were exchanged and integrated

Cross-System Report Data Integration

A report data center is constructed to meet the need for centralized storage and unified interface presentation of medical reports. It also follows the IHE XDS profile. The medical imaging report data were converted to the clinical document architecture (CDA) format first and were then uploaded to the image integration platform to form the report data center.

Results

The image integration platform was constructed from 2015, and most of the medical images were integrated in this platform. Xuanwu Hospital was recognized by HIMSS Analytics as successfully achieving stage 6 on the EMR Adoption Model (EMRAM) in 2015, and it was the seventh hospital in China to achieve this stage, for which full PACS implementation and image integration were essential factors.

The detailed number of integrated images and reports grouped by patient resource, year, and examination type are shown in Tables 4 and 5.

Workflow Reform

Most of the workflows were left unaltered; however, some of the details were changed to improve the data accuracy and timeliness. For example, originally, before performing CT, the technician validated the patient's reservation information by checking his reservation document on paper, followed by confirmation in the radiology information system (RIS) without modality assignment information for that examination. Thereafter, the patient's information was input manually into the registration software of the CT scanner to start a new study. In the new workflow, the technician validated the patient's reservation by scanning the barcode on his reservation document. Once the information can be matched, the reservation is confirmed, and the patient's information is sent to the target modality automatically via the DICOM Worklist, and then, a new study with the correct patient's information can be created accordingly. Using this electronic close-looped workflow in the CT scan, the modality information can be linked correctly with the reservation information, the study, and even the report. At the same time, the risk of manual input errors can be avoided.

Patient Identification

The EMPI service is provided in the reservation function of each business system of medical images, including the CT examination reservation, MR examination reservation, and ultrasound examination reservation. The EMPI of this image integration platform also retrieves the cross index and master index information from the upper layer of the integration platform to ensure that the image data can be integrated correctly with the text data, such as medical records or laboratory results.

Integration View Available for EMR

The image integration platform provides a uniform image view based on HTML5 that can be conveniently recalled using medical software, such as EMR, the nursing record

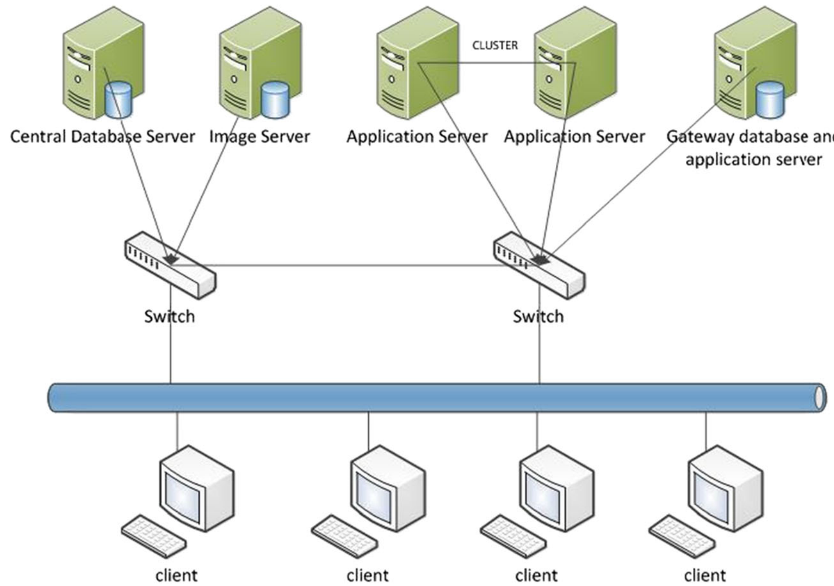


Fig. 2 Hardware architecture used in the image integration platform. Five servers, one for the database, one for image management, two clustered servers for applications, and one for the gateway, were set up and used for imaging data exchange

system using proper patient identification information, and user authentication.

We found that patient reports from different sources (ED, inpatient and outpatient) with different business system IDs could be integrated on one Web page (Fig. 4).

Mobile Application

Integrated image and report data can also be used in an APP for clinicians. Most of the clinical information, including the images and medical records of patients, can be viewed on an IPAD with proper authentication.

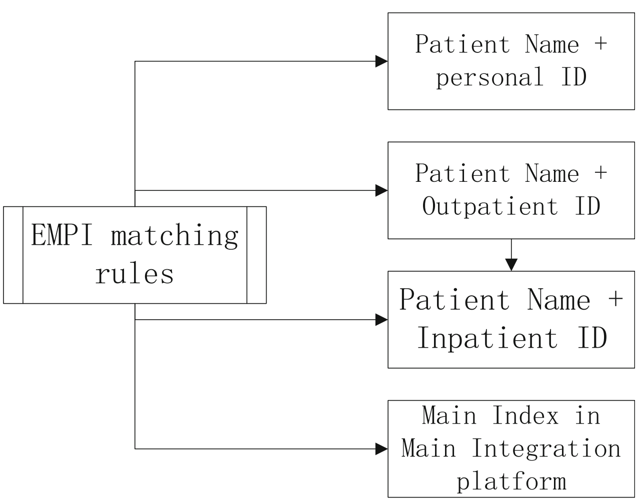


Fig. 3 Other matching rules of the EMPI to exactly match the patient's information besides using the system ID+LID. If no record can be exactly matched by searching the patient information table using the index (System ID+LID), an additional search will be performed based on the EMPI matching rules that use the other patient information from the patient information table to uncover any records that might be able to be matched with the external request

Figure 5a and b shows the view with all of the patient's examinations listed. By selecting one examination in the list, its report and medical image thumbnail are shown in the right panel; c and d shows whole medical images that can be viewed by double clicking the medical image thumbnail.

Discussion

Like most Chinese tertiary hospitals, the medical imaging information systems at Xuanwu Hospital were built separately for different specialties and in different years because of the diversity of the original needs and purposes. Due to the lack of an overall design plan, the business workflow and data structure in each business system were independent from each other. The workflow of the medical workup was not a closed loop at the hospital level, and the data completeness at each workflow node was not sufficient to trace the examination process. This is the general condition of medical imaging

Table 4 Number of integrated image files from different image sources in 2015 and 2016

Image source	Y2015	Y2016
CR	259,310	233,136
CT	14,505,568	16,289,163
MR	8,452,027	10,278,707
NM	238,421	359,102
US	1,444,786	1,819,084
Pathology	44,902	38,872
Gastroenterology endoscopy	12,082	130,542
SUM	24,957,096	29,148,606

Table 5 Number of integrated report files from different report sources and patient sources (emergency department, outpatient and inpatient departments) in 2015 and 2016

Report source	Emergency department (ED)		Outpatient		Inpatient	
	Y2015	Y2016	Y2015	Y2016	Y2015	Y2016
Radiology	30,303	58,348	70,618	115,216	49,285	85,404
Ultrasound	9941	20,323	110,576	200,618	34,716	65,309
Nuclear medicine	9	34	1198	1748	1659	3122
Pathology			31,796	25,836	13,106	12,936
Gastroenterology			4961	52,828	1080	12,443
EEG			291	1861	22	266
SUM	40,253	78,705	219,440	398,107	99,868	179,480

information systems in China. Given this condition, developing an enterprise imaging strategy [12–15] as part of the data governance plan is important and critical at most Chinese tertiary hospitals.

According to the strategy of "governance," Xuanwu Hospital has formulated the policies and rules of a system design choice evaluation and change management (see Fig. 6). In particular, in the need collection phase, three roles are involved—end user, IT staff, and needs management team. The needs management team, which includes members of the related management departments, delegates of the user departments involved in the workflow that are affected by the need, and IT management staff, works as an interface between the clinical user and IT staff in the need collection phase to evaluate the need's rationality and feasibility at the whole hospital level as well as whether the need is consistent with the hospital's vision and development objectives. If the need is confirmed to be implemented in the information system, it will be assigned a priority order by the needs management team and will then be transferred to the IT staff for follow-up. After implementing the new workflow, a dynamic report of data generated in the new workflow will be presented to the relevant management departments to evaluate the efficiency and efficacy of the change.

In this work, we found that the image integration platform is a useful tool to manage images at the hospital level. For example, for patient identification, before implementation of the enterprise imaging system, independent ID management must be adopted in each business system and the master index of patient identification at the hospital level cannot be formed,

Fig. 4 Medical images are placed in a uniform interface order by patient and study for the convenience of the clinical staff to review. Most medical images of the patients examined at Xuanwu Hospital are listed in this uniform view. The clinical staff can find the target images easily by date, time, imaging type, and application department

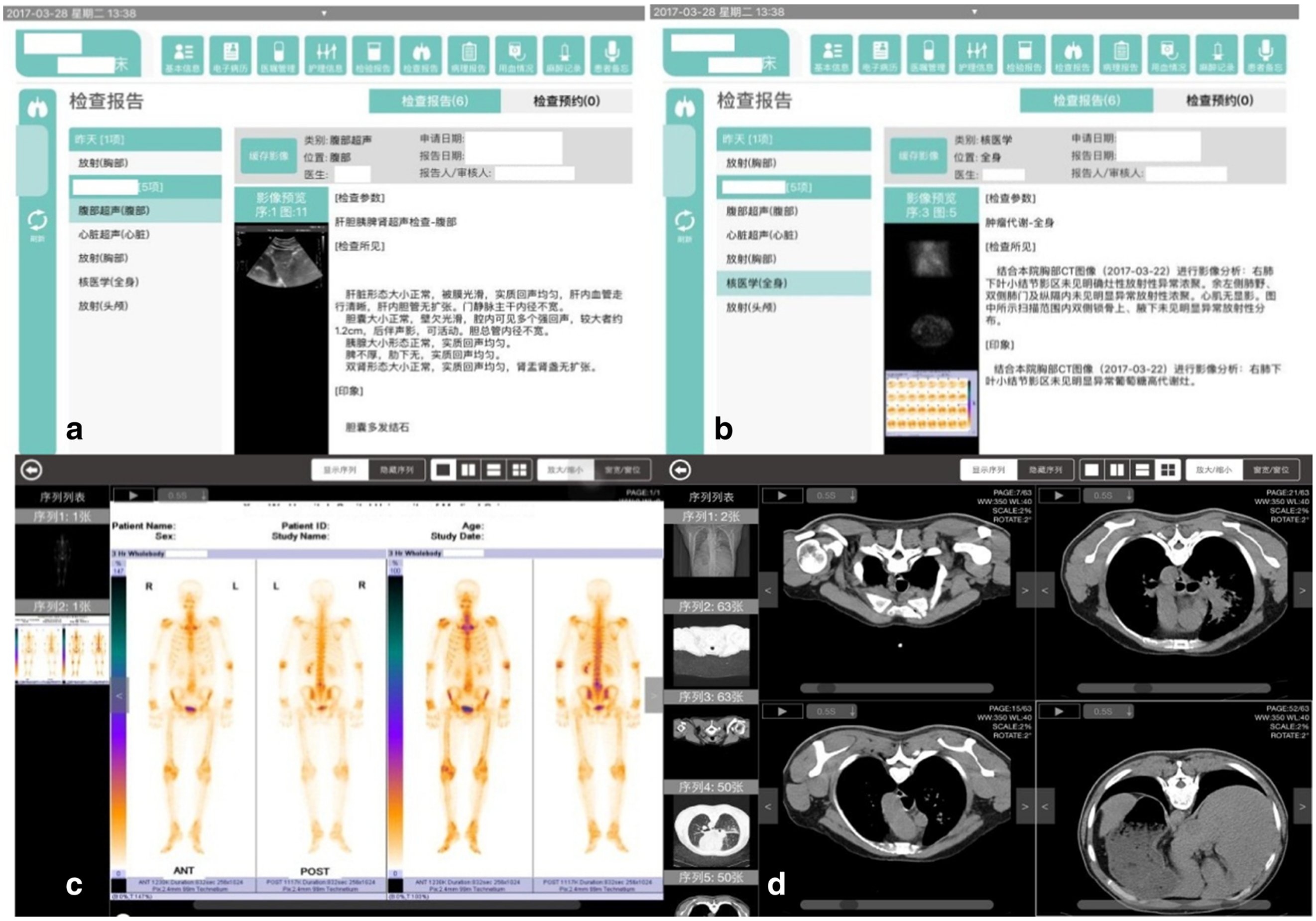
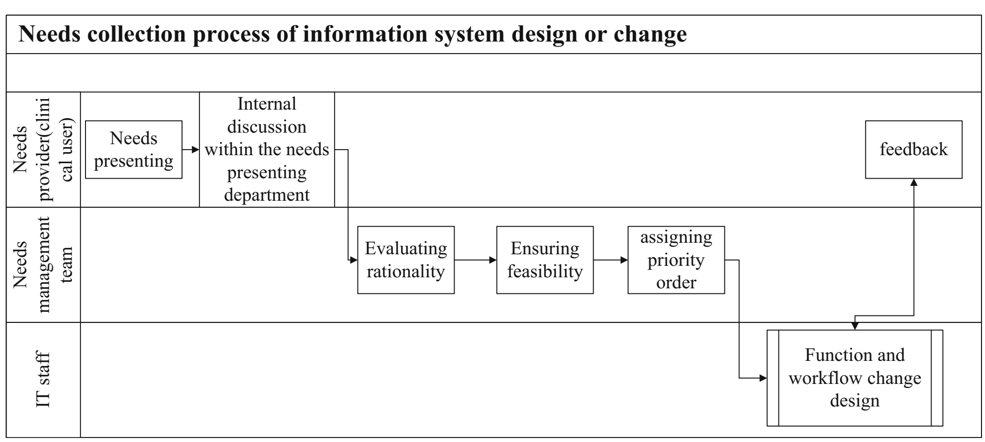


Fig. 5 The patients' reports and related medical images can be viewed in the clinical information app of Xuanwu Hospital. A list of all of the examinations for a patient can be pulled up and reviewed (**a** and **b**). By selecting one examination in the list, its report and medical image thumbnail are shown in the right panel. The medical images can be viewed by double clicking the medical image thumbnail (**c** and **d**)

leading to one patient being assigned to more than five business system IDs and having to show the exact ID of that business system to hospital staff to register the correct examination. Otherwise, their information cannot be traced. Because of the weak correlation among the business system IDs, the historical data matching ability is low and numerous historical clinical data cannot be accessed or used by clinicians. The EMPI service of the image integration platform helps to match patients at registration and communicate with up-layer hospital-level EMPI services so that patients can use one ID to go through most of the examinations at our hospital and so that the historical clinical data of one patient can be

Fig. 6 Needs collection process of information system design or change



integrated in EMR and the nurse document concurrently. By implementing the en image integration platform, more than 54 million medical images and approximately 1 million reports were integrated. Furthermore, based on uniform patient identification in most imaging systems, images and report integration views were able to be made available to the staff and mobile application.

The image integration platform can provide support to clinicians in various situations. In the first scenario, physicians can view images of the same patients from the same examination type in different clinical departments (e.g., outpatient, ED, and ICU) throughout the timeline to observe disease progress over time. In the second scenario, physicians can view most of the examination images and reports (including radiology, endoscopy, and pathology reports) of a patient during a hospital stay to observe the lesion comprehensively. In the third scenario, the image integration platform supports mobile devices, and physicians can browse the latest medical images and reports of patients on a mobile device at the bedside or outside the examination room, providing timely and convenient information support for physicians. In the fourth scenario, the platform supports authenticated users' access to patients' images and reports at any work site, providing convenience for a wide range of case discussions in multidisciplinary team (MDT) care. There are many such application scenarios of the image integration platform at Xuanwu Hospital. Implementation of the image integration platform not only brings benefits to information management but also meets clinical needs.

However, the technical solutions are not omnipotent. During the construction of the image integration platform, we encountered major challenges related to some nontechnical problems, the toughest of which was the historical data quality. For example, the patient index data stored in some specialized systems is incomplete or inaccurate; thus, such patients cannot be indexed correctly, and their images cannot be integrated with clinical data in other medical services until they visit the hospital again and provide sufficient information. To ensure the patient index quality after image integration implementation, further business system transformations requiring complete patient basic information at the patient registration function are still necessary, although such business system transformations may lead to more information input work for staff at registration offices and their possible dissatisfaction.

Examination workflow re-engineering for closed-loop patient examination control is also needed in image data governance. For example, although the image data volume in the Vascular Intervention (VI) Department is huge, it cannot be integrated in this platform because there is no electronic patient registration and reservation function in the VI examination workflow. The technicians only input the patient's name, age, and gender in the DSA modality, which are insufficient for patient identification matching; thus, the images cannot be matched with other medical records, although the image format of VI complies with DICOM. A good solution is to add the registration function node in the examination workflow, similar to that performed in the radiology examination workflow, to collect sufficient patient information for cross-system referencing. When physicians place an order for a vascular intervention operation, a new examination application is created automatically at the same time. The information on this examination application form is transmitted electronically to the VI registration model, and the patient and operation information is validated before the patients undergo the operation. Unfortunately, under some conditions, the management staffs may hesitate to change the current clinical workflow, and workflow re-engineering cannot be carried out as planned.

Additionally, besides technical solutions, policies and rules are still required to ensure that medical images generated at a hospital can be accessed, managed, and analyzed at the hospital level. For example, although the integrity of the data and quality of the image integration platform is better than that before image integration platform construction, it is still not sufficient for further data mining or to perform other studies. The lack of good labeling is common for medical images. An examination report may include more than three possible diagnoses, and then, medical staff still need to classify and label the respective images manually if they want to perform further data mining. A policy concerning medical image labeling and sharing in the business process (not research process) should be issued to the medical staff, vendors of modalities, and image information systems in a future enterprise imaging strategy to promote more convenient use of real-world clinical data.

Conclusion

The enterprise imaging strategy was developed to improve image data quality, and an image integration platform was adopted as a tool at Xuanwu Hospital, a tertiary hospital in Beijing, China. Images generated in most of the current medical workups can be integrated on the platform after examination workflow re-engineering and some function transformation in information systems. However, for the data to meet the requirements of machine learning or other AI studies, further policies and management measures are still needed.

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