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Impact of Digital Imaging and Communications in Medicine Workflow on the Integration of Patient Demographics and Ophthalmic Test Data

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Abstract

Purpose—To determine the impact of a Digital Imaging and Communications in Medicine (DICOM) workflow on the linkage of demographic information to ophthalmic testing data.

Design—Evaluation of technology

Participants—699 visual field testing encounters performed by 6 ophthalmic technicians and the transfer error queue of 37,442 ophthalmic test results.

Methods—At 3 months prior to, and 6 and 16 months after implementation of a DICOM workflow, technicians recorded the work required to enter, confirm, or edit patient demographics at each visual field device. We also determined the proportion of imaging tests sent to an error queue for manual reconciliation because of incorrect demographic information before and 3, 6, and 18 months after the DICOM workflow was established.

Main Outcome Measures—The proportion of testing encounters for which staff had to enter, edit, or merge patient demographics and proportion of misfiled images.

Results—Staff entered, edited, or merged data for 48% of patients prior to implementation (n=237). This fell to 24% within 6 months and 20% within 16 months of implementing the DICOM archive (n=230 and 232, respectively). Staff could locate a patient in a DICOM worklist for 97% of encounters at 3 months and 99% at 16 months. Prior to the implementation, 9.2% of the images required additional intervention to be associated with the correct patient (n=3581). This fell by 85% over 6 months to 1.4% (n=9979; p<0.01). There was an increase in misfiled

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images between 6 and 18 months from 1.4% to 2.2% ($n=24,549$; $p<0.01$), representing an overall a 76% decrease over 18 months relative to the pre-DICOM period.

Conclusions—Implementation of a DICOM-compatible workflow in an ophthalmology clinic reduced the need to enter or edit patient demographic information into imaging/testing devices by more than 50% and reduced the need to manage misfiled images by 76%. In a clinical environment that demands both efficiency and patient safety, DICOM workflow is an important update to current practice.

The importance of ophthalmic imaging was recognized as early as 1886, when an article in the *Philadelphia Photographer* described a technique by which to photograph the “retina of the living eye.”¹ Today, the modern ophthalmologist can count upon dozens of digital imaging and testing modalities to glean high quality information about ocular disease, monitor disease course, and document treatment effects.² However, the rapid expansion of digital imaging is not without its problems. Quickly and accurately collecting, transmitting, storing, and retrieving results for all of the patients seen in a clinic—each undergoing different combination of testing—represents a true informatics challenge.²

Currently, most ophthalmic testing modalities store data into proprietary databases or formats that cannot be readily imported into an electronic health record (EHR) or a third party image archive. Often, this necessitates either printing of images for review by the ophthalmologist or implementation of proprietary interfaces to extract printed reports in digital format. Consequently, ophthalmologists cannot take full advantage of the digital paradigm, either in streamlining data management or in using software to analyze the raw testing data.^{2,3}

A single ophthalmology encounter may involve medical records personnel, front desk staff, technicians, photographers, and multiple physicians. Given the complexity of this workflow, there is great potential for losing or misfiling paper-based patient data. The field of radiology came to realize that physical film workflows resulted in limited ability to make longitudinal comparisons between studies, unnecessary repeat examinations, delayed clinical decision making due to missing exams, or diagnoses applied to incorrect patients.^{4,5} In response to growing evidence about the role that misidentification plays in iatrogenic errors, The Joint Commission named “improving the accuracy of patient identification” as the single most important National Patient Safety Goal for 2014.⁶ Thus, a key issue for the modern ophthalmologist is developing a system to easily access all the right information, for the right patient, every time.

In response to their data management challenge, radiologists developed the Digital Imaging and Communication in Medicine (DICOM) standard, which has since been extended for use in ophthalmology.^{2,3} First developed in 1985, DICOM is a mature, universal, and non-proprietary standard that “provides all the necessary tools for diagnostically accurate representation and processing of medical imaging data.”⁷ Because DICOM was designed with digital data transfer, storage, and processing in mind, the standard confers several advantages over printed images or, in fact, non-DICOM digital images. DICOM image files contain a “header” section that includes data about the image itself—acquisition parameters, filters, image dimensions—as well as more than 2000 demographic and medical attributes

including patient's name, date of birth, diagnosis, and provider. Images and their context are linked and are far less prone to identification errors and more amenable to further processing and analysis.^{7, 8}

Acquired images are then sent to and stored in a central server known as an archive, and can be viewed via networked workstations. This combination of imaging modalities, a DICOM archive, and review stations is known as a Picture Archiving and Communication System, or PACS⁸. The utility of this standard in ophthalmology was heretofore limited by slow adoption of electronic health records (EHR) and a lack of ophthalmology-specific DICOM standards. Given the recent and rapid increase in the adoption of electronic health records² and the growing trend toward DICOM compatible ophthalmic imaging, we set out to explore the impact of DICOM workflow on staff efficiency and the rate of misfiled images in an academic ophthalmology practice.

Methods

This study was determined to be non-human subject research by the Johns Hopkins University School of Medicine Institutional Review Board and was therefore exempt from review. Prior to the implementation of DICOM-based workflow for in-office testing, ophthalmic technicians manually entered patient demographic data into each machine. So, if a patient required both a visual field test and optical coherence tomography, the technician entered the patient's name, birth date, and/or medical record number separately into each modality. After testing, each machine then generated separate reports in both paper and digital formats. Digital images were then sent to an image management system (Oculab, Digital Healthcare, Cambridge, UK) that double-checked final demographic data associated with the image against the patient registration system (Cadence, Epic Systems, Verona WI) before finally serving the images to the physician upon request. These mixed paper and electronic reports arrived to the physician at different times, with the paper reports arriving with the physical patient charts and the digital reports available within seconds after capture (Figure 1).

In late November 2011, the Wilmer Eye Institute deployed a DICOM-based archive (Forum version 2.6, Carl Zeiss Meditec, Dublin, CA) to accommodate data from several testing devices distributed across both subspecialty clinics at our primary location at Johns Hopkins Hospital and our geographically distributed satellite clinics. The server software was installed on a single central server managed jointly by existing institutional and departmental IT staff. No additional staff were added to accommodate this project. It was also necessary to install new DICOM licenses on some of the devices that were integrated with the archive. Licenses for existing devices cost approximately \$1000 per device and the new devices added during the evaluation were specified to include DICOM capability at the time of delivery. Licensing of the archive software itself was included in an overall agreement between Carl Zeiss Meditec and Johns Hopkins University so the incremental cost of the new software is not available. Also at the time of implementation, all existing visual field data were uploaded from each of our HFAs to the DICOM archive so that prior studies could be available for progression analysis.

At the time of the initial deployment, 9 Humphrey Field Analyzers (HFA - Carl Zeiss Meditec, Dublin CA) and 3 Cirrus Optical Coherence Tomographers (OCT - Carl Zeiss Meditec) were integrated with the DICOM archive. In March 2012, an additional 3 HFAs and 2 IOL Masters (Carl Zeiss Meditec) were connected to the archive. In March 2013, an additional 3 Spectralis OCTs (Heidelberg Engineering, Heidelberg, Germany), 5 HFAs, 4 IOL Masters, 4 Cirrus OCTs, and 1 Visante anterior segment OCT (Carl Zeiss Meditec) were connected to the archive.

The DICOM archive was, in turn, linked to our central patient registration system via a Health Level 7 (HL7) interface. The goal of this approach was to have demographics flow from the registration system to the DICOM archive, then from the archive to the individual devices as a DICOM modality worklist. Technicians would then select the appropriate patient from the list (rather than entering demographics manually). Once testing was complete, the testing data would then flow back to the DICOM archive for storage and forwarding. As with the pre-DICOM workflow, test data were sent to the image management software (Oculab), and then available for review by clinicians. This workflow is described in Figure 2.

Survey of Ophthalmic Technicians

To determine the impact of DICOM-based workflow on ancillary clinic staff, we assessed the work done by 6 technicians in the Wilmer Eye Institute Glaucoma Center for Excellence during 3 time periods: 3 months before the implementation of the new workflow (June-Sept 2011), 3 months after (Sept-Dec 2011) and again at 16 months after implementation (Dec 2012-March 2013). At each of the evaluation periods, we asked each technician to complete a paper form indicating the work required during each encounter. These surveys are provided in Appendix A (available at <http://aaojournal.org>) and have been modified to include definitions that will be used throughout this manuscript.

Misfiled Images

Another source of inefficiency in the pre-DICOM workflow was the requirement that information technology staff had to actively work through a queue in our digital image management software containing those images and reports that could not be linked to a “real” patient based on the demographic data. This situation would arise each time a technician mistyped a patient's name, birth date, or medical record number.

To measure this phenomenon, we analyzed the log files of our image management system (Oculab) to count the number of tests that ended up in this queue. This was performed concurrently with the surveys of ophthalmic technicians 3 months prior to, 3 months after and again at 18 months after implementation of the DICOM workflow. Accordingly, the log files reflect data from the additional devices that were networked to the DICOM archive in March 2012 and March 2013.

Statistical Analysis

Differences between individual categorical variables were assessed using 2 proportion t-tests and differences in overall work distribution were assessed using Fisher's exact test.

Statistical analyses were performed using Stata/IC statistical software package (version 12.1). Differences were considered statistically significant if the p -value < 0.05 . Statistically significant values in the results tables are also highlighted in bold font.

Results

Survey of Ophthalmic Technicians

Prior to implementation of the DICOM workflow, 48% of testing encounters required some level of intervention to add or edit demographic information. Technicians were more frequently editing/merging records of existing patients than entering the demographics of new ones (29% vs. 19% - Table 1). At 3 months, only 24% of testing encounters required merging or entry of patient data. This percentage remained similar at 16 months (20%, – Table 2). Compared to the 3 month evaluation, at 16 months, a greater proportion of encounters trended towards having correct demographics available to the technician, although this was not statistically significant (80% vs. 73%, $p=0.08$). The two time periods were statistically identical in the overall distribution of tasks at the DICOM archive interface ($p=0.36$). At both the 3 and 16 month evaluations, the vast majority of encounters did not require any data entry by technicians. Relative to the 3 month post-DICOM period, technicians were at 16 months utilizing the worklist less (95% vs. 90%, $p = .04$) and were instead using the DICOM archive more to select specific patients and “push” their records down to the HFA (2% vs. 9%, $p < 0.01$). The two time periods were statistically identical in the overall distribution of HFA-related work ($p=1$ –Table 3).

Misfiled Images

Over the 24 months of evaluation, the misfiled image rate fell by 76% (9.2% to 2.2%, $p < 0.01$ Table 4).

Discussion

We believe this is the first assessment of using DICOM workflows to address the growing challenge of managing electronically stored ophthalmic testing data. Use of workflow enabled by DICOM enabled our clinic to reduce the number of patients requiring technicians to manipulate their demographics by 50% while also enabling those technicians to access the correct patient demographic data at the HFA more than 95% of the time. Consequently, the rate of misfiled images dropped by more than 50% over 3 months and 85% over 6 months. These findings have implications both for clinic efficiency and for patient safety.

Any new technology, of course, has unexpected effects, and the DICOM archive was no exception. Due to the pre-population of the archive with existing HFA data, technicians were required to merge existing, incorrect demographics with those received from the clinic registration system. They did so for approximately every 1 in 6 encounters. If each duplicate patient record was appropriately merged, we would have expected the proportion of duplicate records to decrease over time, further reducing the time required by technicians at the archive interface. However, the proportion remained the same at the 16 month follow up. One possible explanation is that patients did not have just one record prior to the DICOM archive forum but multiple versions of their demographics in multiple devices. This theory

is further supported by the increase in misfiled images observed between 6 and 18 months post-implementation, coinciding with the addition of 14 additional devices to the DICOM network; an influx of new records to the network will cause spikes in merging and misfiled images that will eventually be reconciled. Avoiding all merging of patient data in the clinic would require a likely costly and time intensive initiative to merge each machine's records *prior* to adding it to the network.

In the context of the system we evaluated, there were three ways to associate a patient with a particular test: 1) select the demographics from a worklist in the device, 2) push a patient record from the DICOM archive to the device, or 3) enter demographics de novo. At both 3 and 16 months, technicians chose the first two options more than 97% of the time. However, we note that there was a statistically significant decrease in the number of patient records selected on the HFA worklist over time and a statistically significant increase in patient encounters pushed from the DICOM archive. One possible explanation is that technicians were overwhelmed with the size of the worklist presented at the HFA, as it listed not just glaucoma patients, but every patient registered across the department that day. Based on conversations with staff, we found that it became a nuisance to scroll through hundreds of names to find the particular patient they were testing. During this initial implementation, we did not filter patient records based on clinic or device, though DICOM offers the ability to do so and this would likely make the worklists more usable.

Technicians were now working at two interfaces - the DICOM archive and the testing device - instead of one, and an argument could be posited that this complicated their workflow. It was our experience that by installing the DICOM archive software on the technicians' computers right next to HFA, and by virtue of having to only click names instead of type out full demographic data, the workflow was greatly simplified. Alternatively, there are potential risks to making things "too easy." That is, if now all that is required is clicking on a name, couldn't someone quickly and accidentally click on the wrong patient record? Could two completely separate patient records be accidentally merged? This is a legitimate concern that certainly merits investigation.

Although the rate of misfiled images decreased by more than 75% over 24 months, despite a near 8 fold increase in image volume (3200 to 24,000), the rate did not fall to zero. After consulting with our information technology staff, we discovered several possible explanations. By design, patient demographics from our satellite clinics also flows into our central clinic registration system and subsequently, into the image management software. However, one satellite clinic uses different medical record numbers and some patients are seen on both campuses (e.g. oculoplastics at one campus and glaucoma at another). In such situations, two medical record numbers for otherwise identical patient forced their images into the error queue. We also noted that our medical records department - also unable to find specific patients due to demographic errors - would occasionally issue new medical record numbers to existing patients, resulting in duplicate patient information. These issues may be unique to large institutions and may therefore not apply to a typical ophthalmology practice.

It is important to note that DICOM is a complicated standard and that there are differing levels of vendor compliance with it. For example, it is possible for a device to transmit an

image that is the equivalent of a printed report as a DICOM object. While this permits improved interoperability, it does not take advantage of storing actual data that could be re-analyzed outside of the originating device. These distinctions are not relevant to the workflow we describe here but are important in the overall design of an image management system. We used a commercial DICOM product that offers additional visualization capabilities if interfaced with same-brand testing modalities. In general, commercial solutions can be costly and full benefits may not be realized with some software packages if they are “mixed and matched” with devices from another vendor. As an alternative, the non-proprietary nature of the DICOM standard means that there are many, fully functional free DICOM packages and plugins available for download. DCM4CHE is one popular “collection of open source [DICOM] applications and utilities for the healthcare enterprise,” and others can be found using the IDoImaging website^{9, 10}. Many of these projects also offer tutorials and instructions for the motivated learner.

One limitation of this study is its observational nature; to preserve the natural behavior of patients and technicians during the testing process, encounters were not directly observed. Accordingly, we could not record information about the percentage of encounters that generated a completed survey nor whether a particular patient was new to the practice. With regard to the latter, however, overall clinic visit data did not demonstrate changes in the distribution of new and return patients during the study period. We also recognize that each clinic uses different software and approaches to workflow, so these results may not be directly generalizable to all practice settings. Another limitation of this study is that it does not include a formal cost-benefit analysis of a DICOM implementation. It was our experience that the process of installing the DICOM software on a central server and clinic workstations, transferring visual fields onto the server, and integration with the clinic registration system proved to be straightforward and the conversion did not require hiring of additional personnel. However, we acknowledge designing and deploying such a system may be beyond the comfort range of ophthalmology practices lacking expert IT staff.

Ophthalmology is a data-driven and increasingly technology-driven specialty. The key to improving efficiency and enhancing patient outcomes relies on ophthalmologists' ability to organize and utilize that data. From a clinical perspective, DICOM integration promotes a “patient centric” vs. “modality centric” approach to ophthalmic imaging. Accordingly, such a workflow affords ophthalmologists the opportunity to more easily integrate and review all of the relevant data for a given patient. Moreover, access to raw testing data, with the ability to zoom, apply filters, perform 3D transformations, or view as video, may extract enhanced clinical value from the same exact test. From a patient safety perspective, clinical images and their context are now inseparable, reducing the risk of misidentification. We describe here a solution by which we can use the DICOM workflow - an open and proven technology - to achieve these critical goals.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix A

Pre-implementation technician survey

Are the:

- ☐ Demographics present, complete, and accurate? (Work = “none”)
- ☐ Demographics present, but require editing for completeness or accuracy? (Work = “edit”)
- ☐ Demographics present, but multiple copies exist and must be merged? (Work = “merge”)
- ☐ Demographics absent, and require everything to be entered from scratch? (“Work = “enter”)

Post-implementation technician survey at Digital Imaging and Communication in Medicine (DICOM) archive*

Are the:

- ☐ Demographics present, complete, and accurate? (Work = “none”)
- ☐ Demographics present, but require editing for completeness or accuracy? (Work = “edit”)
- ☐ Demographics absent, and require everything to be entered from scratch? (“Work = “enter”)

Post-implementation technician survey at the Humphrey Field Analyzer (HFA)

Are the:

- ☐ Demographics present? (Work= “none”)
- ☐ Demographics missing, but can be “pushed” from the DICOM archive? (Work= “push”)
- ☐ Demographics missing from HFA and archive and required to be entered from scratch? (Work= “enter”)

*Interaction with the DICOM archive was important as patient records with previously inaccurate demographic information had to be merged with the correct information by the clinic registration system. Also note that post-DICOM surveys did not include an “edit” response: demographics flowed from the main clinic registration and were presumed accurate; discrepancies between demographics generated prior to DICOM and after DICOM required a merge.

A non-proprietary digital imaging standard was used to manage ophthalmic imaging data. This reduced the work of ophthalmic technicians and the rate of misfiled images immediately and during long-term (>1 year) follow-up.

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Figure 1. Pre-DICOM* workflow

*DICOM = Digital Imaging and Communications in Medicine

Figure 2. DICOM* Workflow

*DICOM = Digital Imaging and Communications in Medicine

Table 1

Work required by technicians at the Humphrey Field Analyzer (HFA) interface prior to the deployment of the Digital Imaging and Communications in Medicine (DICOM) workflow. Values are expressed as a proportion of all recorded testing encounters.

Work at HFA interface	pre-DICOM % (n) N=237
None (record correct)	50 (119)
Edit (record incorrect/incomplete)	22 (51)
Merge (duplicate record)	7 (17)
Enter (no record)	19 (46)
No response	2 (4)

Table 2

Work required by technicians at the Digital Imaging and Communications in Medicine (DICOM) archive interface at 3 and 16 months after deployment of DICOM workflow. Values are expressed as a proportion of all recorded testing encounters.

Work at DICOM interface	3 months post-DICOM % (n) N=230	16 months post-DICOM % (n) N=232	p-value
None (record complete)	73 (167)	80 (185)	0.08
Merge (duplicate record)	17 (38)	16 (36)	0.77
Enter (no record)	7 (16)	4 (10)	0.16
No response	4 (9)	0 (0)	<0.01
Other	0 (0)	0 (1)	-

Table 3

Work required by technicians at the Humphrey Field Analyzer (HFA) interface at 3 and 16 months after deployment of the Digital Imaging and Communications in Medicine (DICOM) workflow. Values are expressed as a proportion of all recorded testing encounters.

Work at HFA interface	3 months post-DICOM % (n) N=230	16 months post-DICOM % (n) N=232	p-value
None (record complete)	95 (218)	90 (209)	0.04
Find in DICOM archive (record complete, not in worklist)	2 (4)	9 (20)	<0.01
Enter (no record in worklist or archive)	0 (0)	0 (1)	-
No response	3 (6)	1 (2)	0.12
Other	1 (2)	0 (0)	0.13

Table 4

Misfiled images in image management software by stage of implementation. Note that the absolute number of images increased because of the additional machines linked to the Digital Imaging and Communications in Medicine (DICOM) archive.

Implementation Period	Misfiled % (n)	p-value (vs. prior phase)
3 months pre-DICOM N=3581	9.2 (329)	-
3 months post-DICOM N=8675	4.3 (374)	<0.01
6 months post-DICOM N=9979	1.4 (138)	<0.01
18 months post-DICOM N=24549	2.2 (529)	<0.01

The overall difference at 18 months post-DICOM compared to 3 months pre-DICOM was also statistically significant (**p<0.01**).