Research Article

Barriers and facilitators to adoption of soft copy interpretation from the user perspective: Lessons learned from filmless radiology for slideless pathology

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Abstract

Background: Adoption of digital images for pathological specimens has been slower than adoption of digital images in radiology, despite a number of anticipated advantages for digital images in pathology. In this paper, we explore the factors that might explain this slower rate of adoption. **Materials and Method:** Semi-structured interviews on barriers and facilitators to the adoption of digital images were conducted with two radiologists, three pathologists, and one pathologist's assistant. **Results:** Barriers and facilitators to adoption of digital images were reported in the areas of performance, workflow-efficiency, infrastructure, integration with other software, and exposure to digital images. The primary difference between the settings was that performance with the use of digital images as compared to the traditional method was perceived to be higher in radiology and lower in pathology. Additionally, exposure to digital images was higher in radiology than pathology, with some radiologists exclusively having been trained and/or practicing with digital images. The integration of digital images both improved and reduced efficiency in routine and non-routine workflow patterns in both settings, and was variable across the different organizations. A comparison of these findings with prior research on adoption of other health information technologies suggests that the barriers to adoption of digital images in pathology are relatively tractable. **Conclusions:** Improving performance using digital images in pathology would likely accelerate adoption of innovative technologies that are facilitated by the use of digital images, such as electronic imaging databases, electronic health records, double reading for challenging cases, and computer-aided diagnostic systems.

Key words: Computer-aided diagnostic, electronic health records, informatics, pathology, soft copy

INTRODUCTION

Digital imaging has been accepted as the standard for clinical care for most of the current radiology practice in the United States for most modalities.[1] At some institutions, radiologists are trained exclusively using digital images and several radiology departments are completely digital. In comparison, the use of digital images for pathological specimens is still relatively rare in current practice. Nevertheless, many pathologists predict that

digital images will eventually become standard practice. Anticipated advantages of digital slides over glass slides include easier long-term storage, access to historical images, comparison with alternative images of the same specimen with different stains or immunoreagents, collaborations with colleagues for challenging cases, and use of computer-aided diagnostic (CAD) support.[2]

In this work, we explored the factors that might explain the slower adoption rate of digital images in pathology as compared to radiology. We have identified possible lessons learned from radiology for pathology, and compared our insights with findings from prior research on adoption of innovative health information technologies.

MATERIALS AND METHOD

We conducted fix 1 hour semi-structured interviewson barriers and facilitators to the use of digital images in clinical practicebetween February and September 2010. The interviewees were selected as a convenience sample from personal networks and represent four different healthcare organizations in the Midwest and one in the United Kingdom. They were as follows.

- Radiology MD who specializes in mammography and was in charge of implementing digital imaging over the last 3years; shehas exclusively used digital images in her practice for a year,
- Radiology RN who specializes in lung disorders and has used digital imaging exclusively in her practice for over 3 years,
- Pathology MD who specializes in hematopathology, practices with glass slides, and has conducted research on digital pathology for 3 years,
- Pathology MD/PhD who specializes in veterinary medicine, practices with glass slides, andhas taught residents using both glass slides and digital images for the last 2 years,
- Pathology MD/MS researcher who specializes in gastrointestinal cancer and conducts research on digital pathology, and Pathologist's Assistant/PhD who specializes in breast cancer and has created an online curriculum for medical and dental students.

Barriers and facilitators to adoption of digital images were identified via standard qualitative techniques that iteratively identify patterns bottom up from the interview data while also being guided top-down by a conceptual framework.[3] During analysis, investigators highlighted areas of disagreement, which were then resolved via group discussion. Data collection and analysis was guided by a theoretical framework of human factors concepts[4] developed for research on barriers and facilitators to the use of computerized clinical reminders for physicians treating patients with infectious diseases in the outpatient setting [Figure 1]. During analysis, the primary themes that emerged were performance, workflow-efficiency,
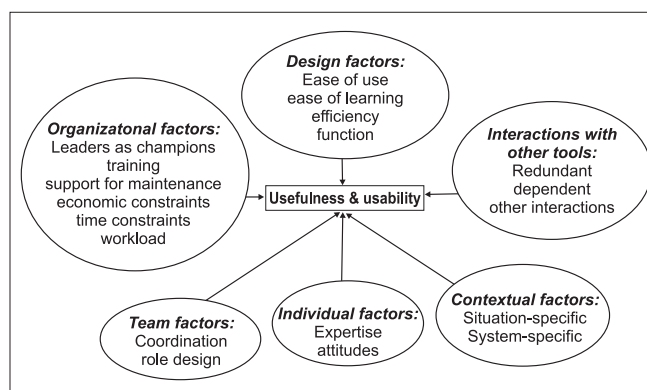

Figure 1: Theoretical framework of factors impacting the usefulness and usability of new technologies

infrastructure, integration with other software, and exposure to digital images.

After analysis was completed, one final iteration on the analytic findings was conducted following an explicitcomparison with findings from prior research. Specifically, the categories, barriers, and facilitatorswere compared with prior categories, barriers, and facilitators to adoption of three other health information technologies: the electronic Intensive Care Unit,[5,6] Bar Code Medication Administration,[7] and computerized clinical reminders.[8]

RESULTS

Table 1 details the findings regarding barriers and facilitators to the use of digital images in radiology and pathology, respectively. The most striking difference is the perception of relative performance using digital images as compared to the traditional approaches: a hard film copy of an x-ray image in radiology, and glass slides and a microscope in pathology. The two practitioners in radiology felt that performance was improved using the digital images. The improvement was largely attributed to the higher resolution quality of the images, as well as easier manipulation of the image. These perceptions are corroborated by the findings of a large study funded by the National Cancer Institute, the Digital Mammographic Imaging Screening Trial (DMIST), for particularly challenging populations: women with extremely dense breasts, women under 50 years old, and in premenopausal or perimenopausal women.[9] In contrast, the threepathologists, but not the pathologist's assistant,felt that diagnostic performance was inferior using digital images. Although no rigorous, large-scalestudies have been conductedin pathology regarding performance, one publication suggests that the common perception among pathologists is that performance is reduced using a digital image.[10] Note that these findings do not include the use of CAD support, which require the use of digital images and are anticipated to improve

Table 1: Barriers and facilitators to digital images in radiology and pathology

Factor	Radiology MD	Radiology RN	Pathology MD	Pathology MD/PhD	Pathology MD/MS	Pathologist's Assistant/PhD
Performance	Facilitator: Higher resolution images, easier zoom, toggle, annotating, contrast control, multimodal capabilities Barrier: Hard copy backup images have low resolution	Facilitator: Higher resolution images, easier zoom, can change background color	Barrier: Harder to see cell size and nucleus elements Facilitator: Use more color stains Facilitator: See more cells	Barrier: Change magnification less often Facilitator: Use more color stains	Facilitator: With bar coding, reduces risk of wrong patient diagnoses Barrier: Magnification and image scale not what pathologists are used to now Barrier: Worse performance on a small percentage of cases matters for high-risk diagnoses	Facilitator: Performance is comparable with digital slides Facilitator: Students can see what the instructor and other students are looking at Barrier: Unfocused areas from folds in tissue or warped slide cannot be brought into focus
Workflow/ efficiency	Barrier: Longer to access historical images Barrier: Upgrades disrupt workflow Barrier: Poor interface design for image search Facilitator: Barcodes	Barrier: Learning curve to use automation Facilitator: Fewer overexposed or lost films Facilitator: Do not need to find space to view images, do not need to turn off lights	Barrier: Longer to get cases Facilitator: Less recounting using marks Facilitator: Get a double reading more quickly	Barrier: Longer to change magnification Facilitator: Access off-site Facilitator: Avoid starting over when bump slide Facilitator: Can move image by microns	Barrier: ~ 60% slower with digital slides Facilitator: Optimizing workflow Facilitator: Larger viewing screen Facilitator: Better human-computer interaction design	Facilitator: Quicker to show student groups digital slides than with multi-headed microscopes Facilitator: On-line education modules can be done without the instructor present
Infrastructure	Barrier: Large file sizes required new cables, specialized workstations	Barrier: Cost, specialized workstations	Facilitator: Can display image to groups	Barrier: Large file sizes	Barrier: Large file sizes	Barrier: Large file sizes
Integration with other software	Barrier: Poor integration with hospital systems	N/A: Issues during transition 3-4 years ago have been worked out	Facilitator: Automatic cell counting Facilitator: Remote access to electronic health records during double reading	Barrier: Digital scanner different file type Barrier: File size too large for automated results notification Facilitator: Barcodes	N/A: Unclear whether primary workstation will be integrated with hospital system, lab system, or scanner	Barrier: Need to integrate with academic institution's online learning management system Facilitator: Students are already familiar with laptops and mice
Exposure to digital slides	Facilitator: Exclusively trained on digital slides	N/A: Everyone used to it now	Barrier: Many pathologists have no exposure	Barrier: Many pathologists have no exposure Facilitator: Most pathologists in training have exposure	Facilitator: Once they get exposed to it and used to it, they will want to do it the same way every time Facilitator: Most pathologists in training have exposure	N/A: All students trained with both microscopes and digital slides

diagnostic performance.

In both radiology and pathology, there seems to be the potential for both efficiency gains and losses following a transition to soft copy reading. With soft copies, there is the potential for a workflow transition from batch processing of multiple images to 'just in time' availability of individual soft copy images. Two studies from radiology support these impressions. The first, an observational time motion study,[11] found that soft copy interpretation takes longer to read primarily due to longer computer manipulation times (bringing up the images, enlarging them to 100% resolution, and panning through the image) and increased time gazing at the image. The second study[12] found that the overall productivity of the radiologists increased 10-30% after the conversion,

likely due to more rapid access to old images and reports, elimination of interruptions by personnel looking for films, better ability to distribute the workload across all radiologists, and constant displays of unread examinations making remaining workload more observable. While the overall efficiency was increased, some efficiency losses were identified in one paper following the transition due to a longer time reading each case, slower image retrieval time from the database, and needing breaks every 40-50 min rather than every 1-2 h. The fatigue was presumed to be higher with the digital slides due to relatively decreased brightness of the monitors (true at that time, but not with newer hardware), monitor flicker, small cursor, and active role in image manipulation. On the other hand, as sharing radiologic images has now become feasible via direct electronic exchange even with large files,[13] there appears to be a greater use of radiology services.[14]

Most of the other findings from Table 1 were similar in radiology and pathology, with the exception of more widespread exposure to digital images in radiology as compared to pathology. The finding that trainees are more exposed to digital images in pathology is supported by the results of a recent survey; of those using a digital system, 72% are using it for education and/or training.[15]

The findings from Table 1, and particularly the groupings and factor labels, were informed by a comparison with barriers and facilitators to adoption of other health information technologies. The methodologies and detailed findings from studies are detailed elsewhere for the electronic Intensive Care Unit (e-ICU),[5,6] Bar Code Medication Administration (BCMA),[7] and computerized clinical reminders (CCRs).[8] An overview of the findings from these prior studies is provided in Table 2.

There are some interesting differences between Tables 1 and 2, including that none of these technologies had definitive evidence of improving performance in the published literature, all of them incurred efficiency costs, were perceived as having poor usability, and were perceived to reduce the authority for making clinical decisions. Overall, these summary findings suggest that if the use of digital images in pathology could be clearly demonstrated to improve diagnostic performance, overall there might be fewer, or at least more tractable, barriers to adoption than for these three other health information technologies.

Table 2: Barriers and facilitators to health information technologies

Factor	e-ICU	BCMA	Clinical reminders
Performance	Facilitator: Demonstrable improvement at the site Facilitator: Disseminate evidence-based protocols	Barrier: Unclear impact on medication errors, outcomes Facilitator: Nursing satisfaction	Barrier: Unclear impact on outcomes Facilitator: Improved hospital quality measures, reminder completion rates
Workflow/efficiency	Barrier: ICU nurses interrupted by e-ICU calls	Barrier: Routine slower; first time and upgrades slower; more documentation; backup systems slower; exception handling slower	Barrier: Routine slower; first time and upgrades slower; more documentation; too many clinical reminders at most sites
Usability	Barrier: Navigation across multiple screens difficult	Barrier: Challenging to change medication administration times	Barrier: Few resident physicians know how to remove clinical reminders from the overview screen
Infrastructure	Barrier: Equipment, Electronic Health Records	Barrier: Wireless network, outlets, batteries, carts, scanners	N/A
Integration with other software	Barrier	Barrier: Electronic Health Record, Medsure, PYXIS	Facilitator: Integrated with Electronic Health Record
Exposure to new technology/training	N/A	Barrier: How to use a mouse, scanner, barcodes	Barrier: No required training for residents on clinical reminders
Authority	Barrier: ICU physicians want sole authority to write orders Barrier: ICU nurses do not want behavior monitored Facilitator: e-ICU and ICU staff have trusting relationships	Barrier: Nurses do not want administration times monitored	Barrier: Unclear who is responsible for using clinical reminders Facilitator: Label with N and P clinical reminders for nurses and physicians to use
Compliance	Barrier: Must be credentialed in multiple states	N/A	Facilitator: Hospitalquality measures, medical director salary bonus
Coordination	Barrier: Between healthcare providers Facilitator: With patients and families	Facilitator: Nurses can easily request that pharmacists dispense missing medications	Barrier: Physicians and nurses
Access to specialized expertise	Facilitator: Intensivist physicians and senior ICU nurses	N/A	N/A

An important limitation of this work is that the pathologists who were interviewed had no personal experience implementing or using digital images in a clinical setting, unlike the radiology practitioners and users of the other health information technologies. Although, to our knowledge, there are few pathologists with extensive and long-term experience using soft copies for clinical purposes, the findings are likely to be biased. First, it is possible that the pathologists might be relatively poorly calibrated to the relative importance of the reported barriers and facilitators during adoption. Similarly, the informatics systems, scanning technologies, image repository software products, connectivity speed, and hardware are rapidly changing, and therefore perceptions of barriers and facilitators may quickly become outdated, particularly in relation to identifying lessons learned from the practice of radiology for pathology from a decade ago. In addition, there are likely barriers and facilitators to adoption about which they are unaware. For example, additional barriers which were not mentioned likely include: (1) infrastructure barrier: access to digital scanners to create the digital images is limited and mostly for research or quality assessment purposes in many institutions, (2) software integration barrier: although a supplement tothe Digital Imaging and Communications in Medicine (DICOM) standard has recently been approvedfor whole-slide images (Supplement 145), it hasnot yet been widely adopted for distributing and viewing any kind of medical image regardless of the origin, although a working group (DICOM WG-26) has been working to increase the potential for widespread adoption, and (3) regulatory barrier: digital-based systems will likely need to receive Food and Drug Administration (FDA) approval prior to use in anyUnited States clinical setting. Similar, prior research in transitioning to soft copy reading in radiology identified factors that did not emerge as themes during analysis, but they might be important. Factors that were identified on a survey as important for improving the effectiveness of soft copy reading room designs in radiology included room lighting, number of monitorsand their resolution, size and brightness, chair design (lumbar support, wheels, swivel, frequent height adjustment), compartmentalization of the reading room, and availability of the hospital/radiology information system at the workstation.[16] Finally, the pathologists represent a wide variety of clinical domains, and therefore likely have different needs, particularly with respect to the scale and dimensionality of the abnormalities that they are detecting.

Finally, another limitation of this study is that the interviewees represent a small, convenience sample of participants from three organizations. The pathologists and the pathologist's assistant are likely biased toward the adoption of digital images since they have some

experience using them, which is not representative of pathologists in general. We believe that we have partially addressed this limitation by comparing the findings with barriers and facilitators to adoption of other transformative health information technologies that are farther along the adoption curve. In future research, we intend to further triangulate these findings with a survey from a larger, more representative group of pathologists.In Table 3, we have provided the survey items that we have piloted with five pathologists recruited during a recent pathology informatics conference. Most responses are on the same 1-7 Likert scale from "strongly disagree" to "strongly agree." In addition to demographic questions about experience in general and with the use of digital images, the questions represent (1) barriers and facilitators to the use of digital slides, and (2) perceived usefulness of new features using digital capabilities.

CONCLUSIONS

This work represents findings from an initial exploration of the factors that might be important for adopting digital imaging in pathology as it becomes more widespread. Future research is planned regarding how to increase the effectiveness of the technology and accelerate adoption based upon these findings and additional studies.

Overall, the primary insights from this exploratory study are that the performance factor on challenging high-risk diagnostic cases might be the most important barrier to the adoption of digital slides in clinical settings, that digital slides are being adopted more quickly in educational than clinical settings, and that barriers to adoption of digital slides are anticipated to be easier to address than forthree other transformative health information technologies. These insights resonate with the findings from prior research detailed in Table 2 in that demonstrable benefits to performance at either an individual or organizational level or unique access to specialized expertise likely increase the willingness to adopt a new technology. It is possible that the performance barrier could be addressed in pathology by providing more images at more magnification levels, thereby more closelymatching what is possibleby using the fine focus adjustment on a microscope. Doing this would require interaction features to easily allow this as well as significantly larger digital storage space. Alternatively, new technologies such as iPad applications that magnify digital images with high resolutions or computer-aided diagnostic (CAD) support might dramatically increase performance.[17-23]

Interestingly, after our first interview with the first pathologist, we had identified potential barriers to adoption that we thought might be difficult to address that appeared more tractable after the other interviews.

Table 3: Survey questions

Category	Question
Demographic	Years since board certification in pathology
	Years practicing as a pathologist
	Experience using digital slides
	Training: exclusively on microscopes or both microscope and digital slides
Barriers and facilitators to using digital slides	Openness to change
	It would be too hard to change how I do my work now
	It will be easier to recruit talented pathologists if we use digital technology
	If I used digital slides, I would still want to keep my microscope
	Performance
	I believe my performance would be worse using digital slides
	I am concerned that parts of digital slides would be poorly focused
	It takes more time for me to use a digital slide than a glass slide
	It is harder to visualize in three dimensions with a digital slide
	It is harder to get an overall (gist) assessment of a tumor using digital slides
	It is easier to remember what areas I have reviewed with a microscope
	A computer does a better job recognizing multiple stains at once than I could
	I would be more willing to use digital slides if they were a higher resolution
	Having easier access to historical slides would improve my performance
	Being able to quickly adjust lighting would improve my performance
	Efficiency
	I might have to wait longer for digital slides than glass slides
	I might need to take breaks more frequently using digital slides
	I might have to adjust room lighting more frequently using digital slides
	My turnaround times would be faster using digital slides
	Backup system:
	I worry about what I would do if my computer crashed
	Cost
	I am not certain of the return on investment for purchasing digital equipment
	There is scant budget for upgrading equipment or infrastructure
	Environment
	It is harder to interrupt me when I am using a microscope than when I am infront of a computer screen
	It is hard to find time for training during my work day
	I am distracted by e-mail when I view digital slides on my computer
	It is easier to concentrate with a microscope than with a computer
Perceived usefulness of new features using digital capabilities	Bar coding to identify patients
	Viewing the magnified area in relation to the entire slide region
	Default settings for common magnification levels
	Displaying slides from before and after a patient's surgery/treatment
	Displaying slides at the same time with normal and abnormal tissue
	Comparing two different regions of the slide at the same time
	Writing comments on the slide
	Two pathologists seeing the same slide manipulated at the same time
	Multiple layers of annotations
	Two pathologists accessing the same slide at the same time
	Circling regions of interest
	Automated marking of what has been viewed already
	Support for requesting a specialist consult through the interface
	A large dedicated screen for viewing digital slides
	A touchscreen
	A dedicated workstation
	Multiple screens
	User-friendly controls for selecting, zooming, annotating slides
	Automated counting tools based on what is marked on the slide
	Multiple infrared stains to identify specialized cell types

For example, supporting task immersion by having a dark surrounding field and reducing interruptions seemed less important based on the other interviews. Similarly, keeping roles the same before and after the technology and using the same workflow strategies such as hanging protocols seemed to be less critical.

As many have pointed out, there is often a first-time adoption cost that is higher than after a system has been implemented. Our findings provide support for this pattern, particularly with relation to infrastructure costs and integration with other software.

Finally, there seemed to be a sense of inevitability about the use of digital images for routine clinical practice in both radiology and pathology. In particular, training and recruiting talent seemed to encourage more digital image use in that trainees want to be perceived as being current on the latest technological developments when they enter the workforce.

In summary, the slower adoption rate for digital images in pathology appears to be primarily explained by a perception of decreased individual performance with their use for challenging high-risk diagnoses. On the other hand, there seems to be a sense of inevitability regarding eventual adoption of digital images as a standard for clinical practice. Improving performance using digital images in pathology would likely accelerate adoption of digital images as well as other innovative technologies that require the use of digital images, including electronic imaging databases, electronic health records, double reading as a best practice for challenging cases, and Computer-Aided Diagnostic (CAD) systems.

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