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Radiology Informatics and Work Flow Redesign

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ABSTRACT

The transformation from film-based to filmless operations has become more and more challenging as medical imaging studies expand in size and complexity. To adapt to these changes radiologists must actively develop new workflow strategies to deal with increasing work demand. This article addresses the evolutionary changes underway in the radiology interpretation process, reviews shifts that have occurred in the past years and presents our departments experience with an open source radiological information system based on IHE (Integrating Healthcare Enterprise) directives. These undergoing changes include a number of development in soft-copy interpretation, electronic decision support and learning tools such as MIRC (Medical Imaging Resource Center).

Keywords: *radiology informatics, radiological workflow, human computer interaction, PACS, RIS, MIRC.*

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1. Introduction

Technology expansion is evident throughout all medical fields, but no area is more affected than radiology, the only medical specialty that is 100% technology driven. Informatics creates a unique opportunity for radiology growth and a whole new breed of research tools. At the same time, however, new imaging and computer technologies present a whole new set of scientific, clinical and educational challenges for radiologists. As new technologies are introduced into the practice of radiology, so are expectations heightened concerning the time taken for information delivery, the accuracy of radiologic diagnosis and the overall standard of patient care.

The evolving technologies within medical images take on a variety of forms from diagnostic imaging modalities (i.e. the machines acquiring images from the patient's

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body) to information systems and picture archiving and communications systems (PACS) namely server-class computers connected to a data network and devoted to storage and retrieve operations. Radiologists, clinicians, technologists and information technology (IT) personnel are always introduced to new medical imaging and computer applications that exceed their predecessor in speed, complexity and sophistication. This creates a series of economic, educational, integration and implementation challenges. The long-term success of these professionals will be linked mostly to their ability to incorporate the changing technologies into their workplace. This article, written from the perspective of a clinical radiologist, discusses how these evolutionary pressures are changing the way radiology is being practiced and taught. We begin by analysing past and current trends, moving on to attempt to predict how future technology enhancements will change the data gathering workflow and the inherent interpretation process.

2. Filmless Radiology

The availability of digital radiographic images is no longer limited to CT, MR (Magnetic Resonance) and nuclear medicine (specialties that were born digital) and has opened a new and concrete path for informatics within the medical imaging department.

To address the justification of filmless radiology we must understand the existing factors contributing to the adoption of PACS and digital radiography. In 1998, according to the American College of Radiology’s Professional Bureau there were 1.3 job listings per job seeker (Sunshine, 2002). By 2000, this ratio of job listings to job seekers increased to 3.8, reflecting the existing crisis in the radiology workforce. Bhargavan et al. recently, in 2002, postulated that if the demand for imaging services continues to increase at its current rate and radiologists productivity is not fully achieved, then the radiologists shortage could increase by another 250%. The authors of this study stated that PACS-related productivity enhancements could decrease the demand for radiologists by 20% over the next 10 years. The hypothesis that PACS can improve radiologist productivity has also been reported in a number of other studies (Reiner, 1999). Such an increase in productivity is believed to be multi-factorial, including the automation of a manual task (e.g. image display), electronic access to patient clinical data through the integration of PACS and HIS/RIS (Hospital Information

System/Radiology Information System), prefetching of historical comparison studies, use of electronic window/level[1] visualization presets, decreased interruptions and reduced work fatigue. At the same time, studies demonstrated striking productivity gains for technologists (the professionals who acquire images at the modality) associated with film-based operation (Reiner, 2002).

In addition to the improvement of radiologist workflow, PACS has added theoretical benefit of improving interpretation accuracy. In a recent study (Reiner, 2002) a soft-copy[2] interpretation of CT exams was linked to a significant improvement in interpretation accuracy when compared with an equivalent hard-copy CT interpretation using films. This improvement is believed in a large part to be the result of more free usage of multiple window/level settings when using a computer workstation. This observation was supported also in another study (Pomerantz, 2000) which found that the repeated view through additional window/level settings using a computer workstation resulted in improved characterization of abnormalities in 67% of cases and additional findings of clinical significance in 18% of CT exams.

Although the combined effects of improving productivity and interpretation accuracy should justify the transition to filmless operations, there are also additional reasons: filmless operation with PACS has been shown to contribute to reduced report turnaround time, improved clinician access to medical images and decreased exam backlog (Flagle, 2000).

2.1. Evolutionary changes in the Image-Interpretation Process

Once adopted, PACS and digital radiology needs to be adequately used to achieve their full potential. In particular, one must realize the extent to which imaging technology for medical usage has been transformed in its short life-span. CT, for instance, has undergone a transformation from single-slice, to helical single channel, to helical multi-channel[3]. In 10 years, typical abdominal/pelvic CT exams have gone from

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1 The original concept of window and level evolved from CT imaging and has historically expressed the range of displayed data as the absolute value of the difference between the highest and lowest numerical pixel values (eg. Hounsfield Units) to be displayed (the window width) and the numerical midpoint of that range (the level). Window/level settings acquire clinical relevance allowing better visualization of free air or soft tissue.

2 Soft-copy, opposite to hard-copy film-based imaging, means displayed on computer screen.

3 Conventional single-slice CT involves an x-ray source that rotates around the patient. The housing was designed so the x-ray source rotated over the patient to obtain a single transverse image and then unwound to prepare for another rotation and scan. The advent of slip-ring technology in the 90s enabled the x-ray source to rotate without having to unwind. In addition, more powerful computers allowed a process known as helical-CT which consists of continuous activation of the x-ray source and continuous movement of the tabletop through the gantry, resulting in multiple transverse slices and volumetric data acquisition.

80 images to 1,000 images, thereby eliminating film as a practical form of image display: a 1,000-image exam printed on 12-on-1 image format, for a single window/level setting, would require 84 individual sheets of film. The need to film images with lung, liver, soft-tissue and/or osseous window/level settings may increase the estimated number of sheets of film by a factor of two to five. Conventional film display devices are equally obsolete for image interpretation. An eight-panel viewbox would require 11 separate hangings to accommodate the 84 sheets of film with a single window/level setting and this does not take into account the need to hang comparison studies. This way of displaying images will result in loss of radiologist spatial memory, highly inefficient workflow and the potential to overlook subtle pathological details when comparing serial examinations.

Radiologist workflow has undergone significant changes during the first decade of PACS with several display and interpretation strategies employed (Table 1). Initially, when hard-copy film images where replaced with soft-copy images (stage two), image display and data navigation remained relatively static. Then radiologists and PACS vendors decided to reproduce the “look and feel” of film images on the computer workstation, which typically contained four monitor with images displayed in tile[4] format. This was a logical extension when one considers the fact that these early PACS users were entirely trained in a film-based imaging environment and therefore could only reproduce what they were familiar with. As radiologists became more experienced with soft-copy interpretation, a number of workflow enhancements occurred, giving way into the next stage, dynamic soft-copy display (stage three). Radiologists could now become active players in the image interpretation process, with active use of a variety of workstation tools, including window/level adjustment, magnification, zoom and pan, and linear ROI (Region of Interest) measurements. In addition, workflow was enhanced by the ability to quickly and efficiently display comparison studies using automated and user-defined hanging protocols reviewing historical reports. It was with reference to this stage that Reiner et al. (2002) and Pomerantz et al. (2000) demonstrated improved radiologist productivity and interpretation accuracy. Even though this strategy was an improvement over conventional film display interpretation, it lacked many of the current advances in workstation functionality.

The fourth stage in the interpretation paradigm shifted from tile mode display to stacked[5] or cine[6] display. This allowed radiologists to navigate rapidly through cross-

[4] The tile format implies the arrangement of two or more images on a computer screen so that they do not overlap.
[5] The skaced display shows a set of images of a CT/RM study (slices) sorted in craniocaudal or any other axial order.

sectional imaging data sets by sequentially displaying consecutive images in the form of a cine loop. This strategy offered several advantages over the tile mode because reading a large data sets require considerable eye and head movement, which is significantly reduced with stack imaging (Beard, 1994). Stack viewing also takes better advantage of the human visual system's ability to detect motion or subtle change. Because stack viewing allows viewers to maintain their gaze on a specific spatial location as images change, the three dimensional relationship of various structures is better realized, than in the tile mode, where the gaze shifts between images (Mathie, 1997). This difference is best illustrated by the process of detecting pulmonary nodules on a chest CT. The ability to sequentially maintain a fixed gaze allows the reader to better appreciate the course of the pulmonary vessels and to differentiate a vessel against a pulmonary nodule.

The next stage in interpretation process is an advanced iteration of the stacked mode, which allows the synchronization of two or more individual stacks (stage five). This can take the form of linking two historical comparison studies or two or more individual sequences within a single examination.

1. Hard-copy film
2. Static soft-copy
3. Dynamic soft-copy (tile mode)
4. Stack Cine Mode
5. Synchronized Stack Cine Mode
6. Multi-planar Volumetric Navigation
7. 4-D Volumetric Navigation and Computerized Decision Support

Table 1. Stages in the evolution of medical image interpretation**.**

An example of synchronized stacking would be a magnetic resonance imaging exam that has separate T1 and T2 weighted sequences[7] in various planes. Synchronizing the axial T1 pre-contrast and axial T2 post-contrast allows the viewer to correlate comparable anatomic images (in the same plane) for the different technique being employed. By adding the comparison study, extremely subtle differences can be detected that may otherwise be missed.

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[6] The cine display allows the user to review a stack in motion.
[7] The relaxation process in magnetic resonance is controlled by the biological parameters T1 and T2. These parameters are tissue dependent, introducing the possibility to separate different tissue types in the human body.

The sixth and seventh stages in the CT interpretation paradigm consist of computer processing tools that rapidly reconstruct large volumetric data sets into 2-dimensional and 3-dimensional reconstructions. Use of this technology could potentially obviate the need to review each axial image, enhancing radiologist productivity and workflow. Four-dimensional (eg. 3D in time shifts environment) reconstructions along with complex image segmentation, texture and tone processing and incorporation of computer-aided detection tools (eg. software tools that can highlight mammary or pulmonary nodules in mass screening tests) now allow radiologists to review selected portions of the entire data set and rapidly sort the specific organ systems or anatomy of interest. The volumetric data from a multi-slice CT exam, for example, can be reviewed in parallel as a CT angiographic study (for detection of pulmonary embolus), CT bronchoscopy (for detection of endobronchial pathology) and high-resolution CT (for the detection of interstitial lung disease). At the same time, multi-modality overlays can be applied to enhance diagnostic accuracy. In the example of a multi-slice chest CT with a newly diagnosed pulmonary nodule, functional positron emission tomography (PET) data can be combined with the CT data set to produce physiologic information as to the likelihood of malignancy (PET fusion imaging). With this technology, areas of pathology can be easily reviewed on the computer workstation with graphic presentation displaying the likelihood of malignancy.

3. Overcoming the problems in the Human-Computer Interface.

The diagnostic interpretation of medical images is a complex task consisting of two distinct processes: perception and reasoning. Image perception, from a radiologist perspective, is the process of recognizing unique patterns in the image, whereas reasoning evaluate the relationship between perceived patterns and potential diagnosis (Tourassi, 1999). These processes depend on a radiologist’s overall medical knowledge, memory, intuition and diligence. It is interesting to note that the majority of radiology malpractice lawsuits are brought as a result of errors in perception or judgment (Berlin, 1998). This observation surely outlines the significance of the human factor. A possible good synergy can derive from combining the flexibility of the radiologist with the analytical, repetitive capabilities of a computer program. Computers offer the potential to assist radiologists by deconstructing the complex process of image perception and diagnostic reasoning into a series of well-defined tasks

(Tourassi, 1999). In addition, computers can assist radiologist by reducing the “human weakness” of bias, fatigue and inconsistency. Radiologists should use this computer-derived capability not as an independent image reader, but as an adjunct help to their own analysis. By exploiting the inherent advantages of computers (processing power, memory capacity and consistency), radiologists can improve their own diagnostic.

PACS should be an enabling technology improving the time efficiency of all the radiology activities including images and reports generation and management, consultation with referring clinicians and patient, direct patient care, teaching/education, research and technology assessment. Strategies for management change and quality improvement should begin by considering how humans interact with computers. Human-computer interaction in the radiology practice is affected by factors belonging to four distinct areas: psychology, sociology, input device characteristics and hardware visualization capabilities (Carrino, 2005). The entire chain of events from image acquisition through display to communication of a report should be re-engineered considering a whole new set of concepts from different disciplines such as Systems Engineering, Human Factors Engineering, Reliability Engineering and Operation Research.

One of the goals of radiology management should be to encompass the development of a robust practice environment that emphasizes workflow enhancements with seamless integration of decision support and task automation tools.

Despite the benefits of digital imaging and archiving, there are several key challenges that healthcare organizations should consider when planning, selecting, and implementing the information technology (IT) infrastructure to support digital imaging.

The paradigm shift that accompanies operating in an electronic environment requires alterations of the human resources infrastructure and work habits that are not trivial. The new patterns of work will impact all occupations within the radiology department. Additional operational issues that may also need re-structuring include technical support, maintenance, and an emergency course for system downtime (eg. a failover plan). A well-informed implementation plan can facilitate a seamless transition to the electronic environment and relies on the PACS building team.

4. Overcoming the problems in the institutional infrastructure: the development of standards

There have been many systems with proprietary technical implementations in use for many years. Yet there has been little enthusiasm from both the PACS vendors and the radiology community to implement any given or even well-known system. The explanation lies in the absence of a standard, such as it was in PACS before DICOM[8]. RSNA MIRC (Medical Imaging Resource Center) implementation ended the time of uncertainty and established a distributed peer-to-peer Digital Teaching File (DTF) system. However it is still mostly up to the user to develop and implement a way of capturing significant images on a specific PACS system.

One of the most time-efficient methods of data gathering in today's health care environment is surfing the Internet. With its abundant and wide array of resources readily available to any physician with a computer and an Internet service provider, the Net is an oasis of information. While searching for text-based medical information is quick and easy, yet the search for indexed medical images is not. Medical images files are most often found in clinical repositories and local teaching files that are not accessible to most Internet users. The lack of a meta-index of on-line medical image resource that organize information across these numerous resources, makes the process of reviewing and downloading medical images on an orderly fashion time-consuming and laborious for the end user. A number of technical challenges limit the ability to create such a comprehensive image index. The large size of imaging datasets (up to some Gbytes per exam) creates challenges for storage and retrieval, and the concerns with image transmission (eg. regulations about patient privacy and information security) place a series of restrictions on electronic exchange of medical images and data. Even if these technical and medico-legal challenges were satisfactorily addressed, the dilemma of how index images without any available standardization protocols would remain. This combination of factors has prohibited radiologists from incorporating these data elements (eg. key image note[9]) into the daily decision-making process and, in turn, has restricted the contents of the radiology report. On the contrary, if such information were to be available in an easy-to-use,

8 The Digital Imaging and Communications in Medicine (DICOM) is an industry standard for distributing and viewing any kind of medical image regardless of the origin.

9 The key image note technology allows a user to mark one or more images in a study as significant by attaching to them a note managed together with the study. Radiologists may attach key image notes to images for a variety of purposes: referring physician access, teaching files selection, consultation with other departments, and image quality issues, etc.

indexed format, radiologists could refer to the images and related data for image interpretation, clinical research and physician education.

In 1999, the Radiological Society of North America (RSNA) proposed the creation of a Medical Imaging Resource Center (MIRC) to establish a community of Web-based libraries of imaging information, including medical image teaching files and research data. The primary goal of this initiative included the development of an information model and technical framework for a multimodality medical image library, development of basic authoring and viewing tools, creation of a standardized repository of medical images and development and incorporation of a radiology standardized lexicon.

This concept evolved from a single, centralized library to a community of distributed libraries, each locally managed but cooperating in such way that any user can search the entire community with a single query. MIRC files are extensible markup language (XML) documents that include descriptive text information and references to images and other medical data. Although commercial PACS vendors are not involved in this early phase of development, it is expected that they will develop tools to integrate the vast growing resources of MIRC into their own commercial PACS and RIS (Radiology Information System). RSNA also anticipates that not only MIRC will become a part of the Integrating Healthcare Enterprise (IHE)[10] initiative, but also predicts the introduction of a “MIRC teaching file integration profile” which would define the transaction required to directly link a PACS workstation to MIRC.

In addition to developing a comprehensive database and indexing system, the success of the MIRC project is also dependent upon the development of a radiology lexicon that establishes standardized terms of pathology and descriptive terminology in the classification, query and retrieval of images and related data. It is interesting to see the potential synergy of this endeavour with ongoing efforts within Speech Recognition (SR) and structured reporting. As radiologists begin to introduce standards and uniformity to the reporting process, this will provide a new ability to cross reference medical images and data according to pathology. This will further the development of the MIRC community and provide all radiologist with a tool to quickly and efficiently search indexed databases with a single keystroke or a voice-activated command.

Discussions and implementation efforts are currently underway to create standard electronic presentation formats for educational and on-line journals that are consistent with the MIRC information model. In the future MIRC will be part of an integrated

[10] IHE is an ongoing effort to encourage the health care imaging and information technology industries and developers to implement standards-based methods of information sharing.

clinical and educational health care information system playing a vital role in clinical decision support, education and research. Additional information and an updated version of MIRC can be found on the RSNA Web Site http://mirc.rsna.org.

4.1. MARiS and MIRC

MARiS is a software developed according to the IHE Technical Framework. The goal of MARiS is to realize a suite of IHE actors to better understand the IHE workflow in Radiology and Nuclear Medicine domain. Our MIRC is built around an open source radiological system based on IHE we are using in our department, called O3 project. We developed it completely integrated using the IHE profiles. The system was developed with GPLed tools and is based on open source technologies such as PHP/Apache environment and java/JBoss application server. We installed the MIRC server software to realize a database of teaching file to use it during the reporting on the workstation. In a three month experience we introduced a new model of radiological reporting: not only a comparison between two different examinations of the same patient, but also the comparison between same pathology of different patients. This teaching system proved an higher efficiency in resident training, especially in CT and MR examination. During these three months we submitted about 100 cases, mainly of musculo-skeletal radiology, using the MIRC web application. The next step will be the development of a new MIRC server based on new IHE Profile called Teaching File, along with a full integration between the MARiS and DPACS (DPACS is our in-house developed open source PACS, more infos available at http://www.o3consortium.org). In this forthcoming seamless and integrated environment a radiologist will be able to create a shared teaching file or research data directly during his/her reporting work through the selection of key images and the relatives clinical facts (eg. radiological findings) from the RIS/HIS. Figure 1 shows four displays of our reporting workstation. Top left screen shows the MARiS and MIRC interface (both are web-based). MARiS is built around different IHE component/actors. The screenshot below shows the order filler, the information system that manage the radiological orders workflow and allows access to worklists (pending studies) and previous reports for comparison. The MIRC interface places submissions and permits query/retrieve of images and related data based upon a standardized query lexicon.

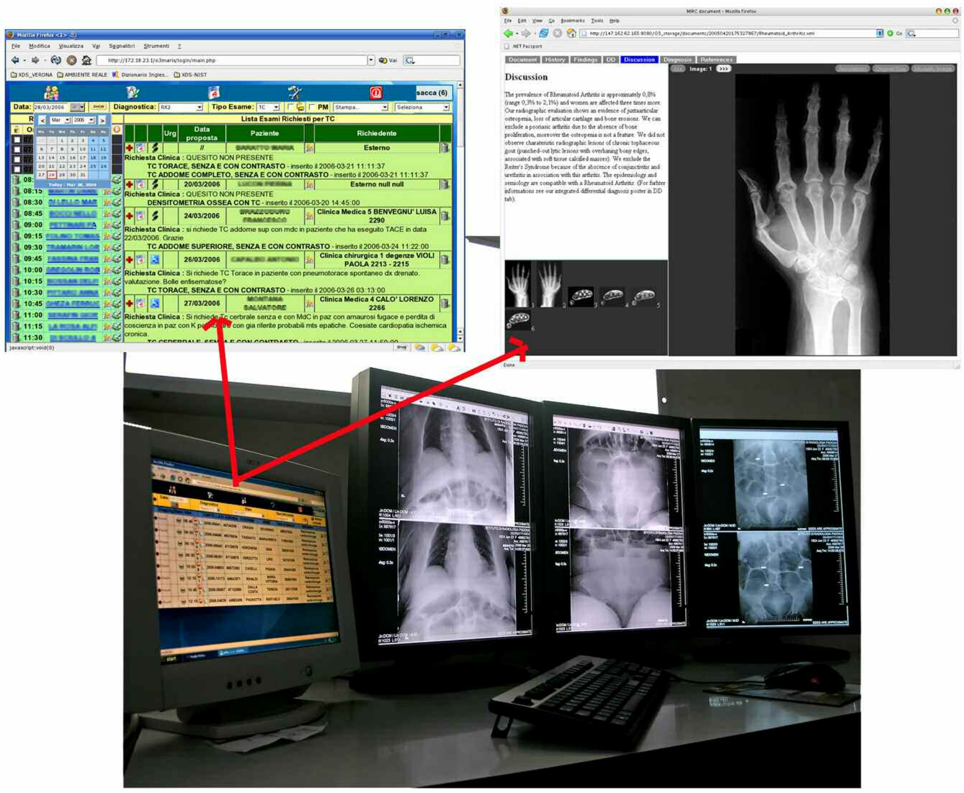

Figure 1 Our MIRC reporting workstation.

5. The Future of Radiology Reporting

Report turnaround time has great value in the radiologist's practice. It is one of the most critical factors in assessing clinicians' satisfaction with imaging services (Seltzer, 1997). Despite an understanding of the importance of report timeliness, most radiologists in hospital-based practices have little control over the process of radiology reporting. This problem is magnified when practicing in the traditional paper and film-based medical imaging department.

If a new technology is to be embraced, it must be able to prove that it positively enhances clinical outcomes and radiologists performance. Improved radiologist performance is a somewhat nebulous concept and can mean different things, depending on the perspective and the way in which performance is evaluated. For the referring clinician, radiologist performance can be improved by increasing diagnostic accuracy, improving communication of pertinent findings, or improving the content/structure of the report. Regarding radiology itself, performance is often judged in productivity measures, and improvements can take the form of an increased number of interpreted exams and improved workflow. Another subjective factor that indirectly changes performance and is often overlooked by radiologists is the subjective nature of fatigue and stress which can have adverse effects on performance. These can include reduced productivity and heightened exposure to medico-legal issues. These different perspectives must be considered when investigating the impact of a new technology on performance. Given that the radiologists population is heterogeneous, a comprehensive analysis should be considered before arriving at any sweeping decisions.

The following paragraphs briefly review tools and concepts necessary for creating the radiology report of the future.

5.1. Structured Reporting

Interest is growing in redefining the composition and structure of the radiology report. This effort is largely driven by the parallel transitions from film and paper to filmless and paperless operations. With the increasing adoption of PACS-HIS/RIS integration, digital tools are now available to redefine the way radiologists create their reports.

Structured reporting is a point-and-click reporting software that uses templates and macros, enriched with SR and standardized lexicon. Because the text of the report is captured as structured information, an underlying clinical database is created that can be used in a number of ways, previously not so easily achievable. Examples include billing/coding, quality assurance and peer reviewing, clinical follow-up, practice management (identifying clinical trends) and research (database mining).

5.2. Computer-Aided Diagnosis

The concept of using Computer-Aided Diagnosis (CAD) software tools for improving diagnostic accuracy of radiographic and mammographic images was a result of numerous studies that showed significant error rates in the screening of lung and breast cancers (Harvey, 1993). Later studies demonstrated that the use of radiologist “double reading” produced increased sensitivity when compared with single radiologist interpretation (Hendriks, 1998). If computers could be trained to serve as the source of the “second read”, radiologist productivity and diagnostic sensitivity could be improved.

The initial application of CAD was performed at the University of Chicago more than 25 years ago, using digitized film mammography images (Ishida, 1982). These early attempts at CAD were found to be impractical due to the limitations in computational capabilities. As computer processing speed increased (in accordance with Moore's law), CAD applications in a clinical setting became more feasible and now a number of forces are converging and will assist the integration of CAD into the radiology workplace. Factors contributing to CAD adoption in image interpretation are listed in Table 2.

- Increasing computer processing speeds and memory
- Decreasing cost of computer hardware
- Increasing size and complexity of imaging datasets
- Increasing adoption of PACS operation
- Increasing emphasis on productivity and diagnostic accuracy
- Routinely incorporation of CAD into digital mammography.

Table 2. Factors contributing to CAD adoption.

From a technical perspective, CAD utilized a range of techniques for quantifying specific visual features on the radiographic image and for providing metrics for the measurement of geometric, topologic, and other characteristics by which medical images are evaluated.

The novel paradigm created by CAD and PACS technologies is the creation of a new approach to image interpretation. Radiologists are no longer restricted to the "single best" image presentation state and image quality. Instead, radiologists will become limited by the psychophysical and ergonomic boundaries in human perceptual process. In fact with the added volume and size of imaging datasets, strategies will need to be developed to deal with a kind of "information overload". Multislice CT exams can now contain thousands of individual images and thereby place stress on the interpreting radiologists. At the same time, as the volume of screening studies (especially mammography and chest radiography) continues to increase, it is important to have strategies and tools that can handle this demand without sacrificing diagnostic accuracy. The radiologist is ultimately responsible for image review and interpretation, but CAD offers an efficient means to maintain productivity without sacrificing accuracy.

6. Conclusions

The transition from film-based to filmless imaging is now a foregone conclusion. The practice of diagnostic radiology should not only convert to filmless and digital work flow, but radiologists must also become active participants in this conversion. Future applications of imaging technologies will be driven in large part by research in the area of medical imaging informatics. It is therefore imperative that the radiologist collaborate with computer scientists and other new technology professionals. During the past few years, the importance of an understanding of work flow devoted to RIS and PACS environment has resulted in substantial improvements in the development of intelligent software and integration with other information systems. This will undoubtedly continue. Universal adoption of communication protocols such as the IHE initiative and standards such as DICOM and HL7 (Health Level Seven) will continue the trend toward the elimination of paper and this will result in further reductions in the number of steps in the flow of information to and from the imaging department and in the frustration associated with routine tasks. This new understanding of the radiological work operations and evolutionary potential of new technology will serve benefit quality and timeliness of care of our patients.

7. References

Beard, D.V., H.B., & Denelsbeck, K.M. (1994). How many screens does a CT workstation need? *J Digit Imaging, 7*, 69-76.

Berlin, L., H.R. (1998). Malpractice issues in radiology: perceptual errors and negligence*. AJR Am J Roentgenol, 170*, 863-867.

Bhargavan, M.S.J., & Schepps, B. (2002). Too few radiologist? *AJR Am J Roentgenol, 178,* 1075-1082.

Carrino, J.A. (2005). Organizational issues in today radiology practice. *Paper presented at PACS Revolution 2005, October 21/22, Riva del Garda, Italy.*

Flagle, C., R.B., & Siegel, E.L. (2000). Impact of filmless imaging on utilization of radiology services. *Radiology, 215*, 163-167.

Harvey, J.A., F.L., & Innis, C.A. (1993). Previous mammograms in patients with impalbable brest carcinoma: retrospective versus blinded interpretation. *AJR Am J Roentgenol , 161*, 1167-1172.

Hendriks, J.H., B.G. (1998). Automated detection of breast carcinomas not detected in a screening program. *Radiology, 207*, 465-471.

Ishida, M., K.H., & Doi, K. (1982). Mammography-computer-aided detection. *Paper presented at SPIE 1982, San Diego, California.*

Mathie, A.G., S.N. (1997). Interpretation of CT scans with PACS image display in stack mode*. Radiology, 202*, 709-711.

Pomerantz, S.M., W.C., & Krebs, T.L. (2000). Liver and bone window settings for soft-copy interpretation of chest and abdonminal CT. *AJR Am J Roentgenol, 174*, 311-314.

Reiner, B., S.E. (2002). Technologists' productivity when using PACS: comparison of film-based versus filmless radiography. *AJR Am J Roentgenol,* 179, 33-37.

Reiner, B., S.E., & Hooper, F.J. (2002). Accuracy on interpretation of CT scans: comparing PACS monitor display and hard-copy images. *AJR Am J Roentgenol, 179*, 1407-1410.

Reiner, B., S.E., & Protopapas, Z. (1999). Impact of filmless radiology on the frequency of clinician consultations with radiologists. *AJR Am J Roentgenol, 173*, 1169-1172.

Seltzer, S.E., K., & Adams, D.F. (1997). Expediting the turnaround of radiology reports in a teaching hostpital setting. *Am J Roentgenol, 168*, 889-893.

Sunshine, J.H., & L.R., & Schepps, B. (2002). Data from a professional society placement service as a measure of the employment market for physician. *Radiology, 224*, 193-198.

Tourassi, G.D. (1999). Journey toward computer-aided diagnosis: role of texture analysis. *Radiology, 213*, 317-320.