The objective of the study was to assess UC Davis Health System’s transition to digital radiology. The study involved pre- and post-PACS analyses of workflow and costs, physician satisfaction surveys, and self-recorded radiology interactions by on-call residents. The study revealed significant results. Before the PACS implementation, physicians spent one to three hours searching for films daily and were dissatisfied with radiology services. After implementation, images were readily available, physicians were more likely to view and interpret images themselves, and they reported increased satisfaction. From real-time reporting, residents viewed studies with radiologists 90.2 percent less often. Average image search time decreased, from 16 to 2 minutes, saving 21.5 physician years, worth $1,034,150 annually. Reductions in film printing (73.4 percent) and file clerk full-time equivalents (50.3 percent) saved $1,001,452 annually, and freed up 1,218 hospital and 8,108 warehouse square feet, worth $2,018,320. As a result, UCDHS’s digital radiology system improved clinician satisfaction and workflow, increased clinician image viewing, and decreased clinician engagement with radiologists. System implementation saved 21 physician years and $2 million annually.
benefit and cost effectiveness, and say there’s been limited acceptance by radiologists of such systems. Older generations of PACS tended to be stand-alone products, produced unclear images and suffered from slow upload times. Current systems offer better image quality and near instantaneous access time.

To assess the impact of PACS technologies on clinical users, UC Davis Health System conducted a comprehensive implementation study. The institution implemented a digital radiology system as part of a larger paperless health system project.

Researchers hypothesized that, after full digital image access was available, physicians would read radiology images themselves more often, spend less time locating films, and would take more clinical actions.

Researchers hypothesized that, after full digital image access was available, physicians would read radiology images themselves more often, spend less time locating films, and would take more clinical actions. Researchers also hypothesized that user satisfaction would increase. However, they could not hypothesize about the PACS system’s total costs or on the interactions of clinicians with radiologists. Before and after PACS implementation, researchers assessed clinician user satisfaction, directly observed physician workflow, obtained self-reported radiology use by on-call resident physicians, and analyzed system cost-effectiveness.

**Methods in the Study**

The University of California Davis Health System (UCDHS) Institutional Review Board approved this study. UCDHS implemented a digital radiology system provided by Stentor Corp. from May 2002 to April 2003 that had three components—an online image archiving PACS, a digital radiology reading system, and a clinical viewing system. The system enables clinicians to access and view digital radiology images—computerized tomography, plain films, and magnetic resonance imaging—using any PC with Internet Explorer version 5.5 or higher.

The system was made available to clinicians in August 2002; UCDHS clinicians can access images dating back to January 15, 2002. More than 1,500 new computers with high-resolution, digital-quality LCD flatscreens were deployed throughout UCDHS hospital and clinics starting in July 2002 to enable easy access to image viewing and the UCDHS electronic medical record. Installation of the digital radiology system and the workstations required 20 full-time personnel working for 18 months.

In February 2002 and again in May 2003, all UC Davis clinical faculty, fellow, and resident physicians were surveyed about their experiences with the radiology environment. In 2002, digital workstations providing access to CT and MRI images using an older offline PACS system were available in the radiology department, the emergency department, and two intensive care units.

After an introductory e-mail from the hospital chief medical officer, a 26-item paper survey was mailed in 2002. Reminder postcards and new surveys were sent to non-respondents after two weeks and one month. Respondent identity was removed before analysis of the data. The survey assessed physician demographics, such as specialty and training level, satisfaction with access to radiology images and reports, and time to availability of images.

Additionally, physicians were asked how they viewed images—whether by themselves, with their team, or with the radiologist—and on whose interpretation they relied— theirs, a team member, their attending physician, a radiology resident, or a radiology attending. They also were asked how long it took to locate hardcopy films during days, evenings, and weekends, and whether they removed films from the radiology department. If they removed films, they were asked where they stored them. After implementation, physicians were sent, by e-mail, a Web-based post-PACS implementation survey in May 2003, which reassessed global satisfaction, time spent on locating images, image usage, and decision-making patterns.

**Studying Workflow Changes**

To understand changes to physician workflow before and after PACS installation, interviews were conducted in February and March 2002 with 25 senior residents and faculty identified as process experts by the department chairs of internal medicine, general surgery, orthopedics, pediatrics, neurology, physical medicine and rehabilitation, and ophthalmology. One faculty and one to three senior resident physicians were interviewed for one hour each about their experiences with radiology services, barriers to use of images and current usage patterns.

Investigators then followed clinician teams for three to four hours each to directly observe their workflow, including how their activities interacted with radiology test ordering and image use. After PACS implementation, interviews again were conducted, and workflow observations...
were repeated. Workflow maps were created for three environments—the hard-copy only system, the digital and hard-copy system and the digital system only. The workflow maps included access of radiology images, decision-nodes used to locate films, and different scenarios for radiology image use.

Assessing Service Usage

Researchers directly assessed use of radiology services and the time intervals between image ordering, image processing, dictation, image access, and diagnostic or management decisions based on the radiology images. Three data sources were used—resident physician data entry of their workflow, radiology film ordering and processing information, and radiology transcription systems.

Some 19 on-call medicine and trauma-surgery residents (10 in June 2002 and nine in June 2003) directly recorded information related to radiology imaging during their call cycles using pre-programmed Palm-based personal digital assistants. Residents most likely to order radiology images—third-year medicine residents and second-year trauma residents—were paid $50 per call for participation. A 10-minute training session occurred before initial data recording. Data recording lasted for 24 hours while on-call (noon to noon for medicine residents, and 7 a.m. to 7 a.m. for trauma surgery).

Residents were instructed to record the medical record number of their patients on a call-night for whom radiology imaging was ordered; the time they saw the patient; the time the test was ordered; who ordered and who interpreted the test; how long it took to access the results; and how the information influenced their diagnostic and management decisions. Time-stamp buttons and other features increased ease of PDA use. Time to test completion was determined from internal radiology and transcription databases. Medical record numbers were removed after data from the separate radiology tracking and transcription data were merged. Pre-implementation tracking was performed from May to June 2002; post-implementation tracking lasted from September to October 2003.

PACS implementation occurred at the beginning of the EMR implementation, and costs were shared between the two projects. In analyzing system costs, researchers asked the question, “How much would UC Davis have had to spend to implement a stand-alone distributed digital radiology system?” Cost data were obtained from internal UC Davis financial administrative databases and from contract reports with the consulting company implementing the PACS system. One-time expenditures included those for hardware and software, consultants and training. Recurrent expenditures include those for personnel, and hardware and software support. Contract provisions preclude UCDHS from publicly disclosing the upfront and ongoing payments from UCDHS to Stentor or its consulting film. Therefore, a calculation of the return on investment or net present value of the digital radiology project could not be provided, but cost savings data is included.

At the recommendation of statistical consultants, tests for statistical significance were performed with 2-tailed T-tests, using Microsoft Excel 2000 software.

Results of the Study

Response rate, respondent characteristics and survey response data are summarized in Table 1. Responses were on a five-point Likert scale, where five represents extremely satisfied or extremely likely.

After digital film implementation, physician satisfaction increased significantly for overall radiology services and test availability. They were more satisfied with digital image availability than with film retrievability. Physicians also reported they were more likely to view images themselves or with team members, and were less likely to view with radiologists. Additionally, they were more likely to interpret images based on their own readings or the radiology faculty’s reading, and less likely to use the interpretation of radiology residents or other team members.

“Before implementation of the system, physicians reported they spent an average of one to two hours looking for hard-copy films during the day...”

Films were difficult to find before PACS implementation. Before implementation, more than 65 percent of physicians reported regularly checking films out from the library, thus making them unavailable for others. Some 34 percent of physicians reported they took the films for conference; 20 percent took them to show their attending; 19 percent for procedures; 11 percent for reading, and less likely to use the interpretation of radiology residents or other team members.

When physicians would take films from the radiology department, they would store them in multiple locations around the hospital—in their offices (43%), their call rooms (28%), conference rooms (20%), attending’s office (4%) or patients’ rooms (2%). Films were out of the radiology department for an average of more than 20 hours. Post-implementation, with radiology images online, this behavior ceased.

Before implementation of the system, physicians reported they spent an average of one to two hours looking for hard-copy films during the day..."
Internal medicine and trauma surgery residents tracked their use of radiology services for standard X-rays, CTs and MRIs for more than 35 call cycles (See Table 2). The average number of tests recorded per call cycle ranged from two to 10, for a total of 198 observations. Data was missing or nonsensical in approximately 20 percent of fields from the radiology tracking and transcription systems. For instance, in some fields, films were reported as having been dictated and transcribed before being ordered. Transcription and internal radiology system data were not usable, because non-standardized administrative processes led to idiosyncratic results, for example, when the time from test-ordering to faculty reading of an image was less than the total time to perform the test. Residents left five to 40 percent of fields blank, especially if the test result was not reported by the end of the call cycle. Results were reported in which the observations were consistent and not missing.

Emergency department physicians ordered most radiology tests before the admitting team was called. After transition to a digital radiology environment, residents reported they did not view images with radiologists as often, reporting a 28 percent decrease, viewed images themselves more often, indicating a 12 percent increase, and read radiology reports more often, a boost of 20% increase. No meaningful shifts occurred in calling radiology residents or faculty. When residents ordered films themselves, the total time from test ordering to image availability did not change significantly.

Resident diagnostic conclusions changed somewhat after PACS implementation, perhaps as a result of different image viewing behaviors by residents. After obtaining radiology studies post-PACS, residents recorded that they derived new diagnoses more often, changed their pre-image diagnoses more often, confirmed their working diagnoses less frequently, and were unclear of the diagnosis 59 percent more often (12.2 percent to 19.4 percent) than pre-PACS.

Table 1. Physician satisfaction and image utilization behaviors (from surveys)
Resident management actions also changed. After obtaining radiology studies post-PACS, residents ordered new radiology tests or procedures more frequently. They reported little change in ordering new laboratory tests, medications or consults. In both study periods, physicians were likely to continue initial therapy after image review.

PACS implementation simplified the recovery of radiology images. Based on expert physician interview and workflow observation before implementation, physicians would have to look in as many as 16 places for a hard copy of a film; these included radiology front desk, image processor, two to six radiology reading rooms, mobile X-ray machine, file room, call rooms, conference rooms and so on. Along the way, they would have to make multiple decisions about how to spend their time, and what actions to take to search the next location (See Figure 1). Physicians reported spending from one to five hours looking for films during weeknights and weekends, especially in the hours before surgical or medical conferences. Post-implementation, the number of activity and decision nodes, and the amount of time spent searching decreased dramatically (Figure 1). Physicians log on to the PACS Web site, enter the patient’s medical record number, and retrieve the images, which are immediately uploaded to the system after completion.

The on-call teams spent an average of 16 minutes searching for each radiology study pre-PACS deployment, and 88 percent less post-deployment. With 332,800 film jacket pulls in the year before system deployment, the 14.1 minutes saved per study represents 85,937 hours of physician time saved per year. With the new 80-hour resident
work week, and assuming two weeks of vacation, UCDHS residents work approximately 4,000 hours per year. Therefore, the time saved searching for radiology studies represents 21.5 physician years annually.

The Financial Impact
Table 3 details saved and avoided costs. Reductions in film printing and file room clerks saved $1,001,452 annually, while the number of radiology studies increased from 317,000 the year pre-PACS to 340,000 the year after. Assuming a 3 percent inflation rate and a discount rate of 6 percent, the 2003 present value of these savings was $33,381,733.

Film storage space requirements were substantially reduced. At UCDHS, 1,218 square feet of hospital file room space was converted to revenue-producing use, with a value net of conversion costs of $450,608 in 2003. Warehouse storage totaling 8,108 square feet and costing $54,485 in annual rent in 2003, will no longer be rented to store films after 2009. Discounting back to 2003 the avoided
rental cost from 2010 to perpetuity, the elimination of this
warehouse space had a 2003 present value of $1,567,712.
The total 2003 present value of all freed-up space totaled
$2,018,320.

Nationally mandated maximum 80-hour resident
workweeks in 2004 created a physician staffing crisis at
UCDHS, which hired 5.5 additional hospitalist physician
full-time equivalents. UCDHS may have had to hire as many
as 21.5 additional residents or hospitalists physician FTEs if
the digital radiology system not been installed the previous
year. UCDHS interns earned $48,100 in salary and benefits
in 2004, while hospitalists received $182,000. As a result,
the cost avoided by not hiring 21.5 additional physicians
was from $1,034,150 to $3,913,000 annually, with a 2003
present value of $34,471,667 to $130,433,333.

The 2003 present value of all cost savings totaled from
$69,871,720 to $165,833,386.

**Comments**

Assessing how new technologies affect users is an impor-
tant and often overlooked quality improvement step in
healthcare. In this study, researchers comprehensively
assessed how a PACS system affected film-viewing behav-
iors, workflow, film utilization and system costs. This study
differs from other studies of PACS systems by examining not
only cost and physician satisfaction, but also this
technology's effect on ordering physicians' clinical behav-
iors, including their interactions with radiologists. Also,
the UCDHS system, unlike previously studied systems, is
Web-based, which has improved image accessibility,
eliminated the need for specialized radiology workstations for clinicians and for a separate radiology image network for radiologists. UCDHS’ experience is that such a system can be implemented in less than 12 months.

There were significant changes in physician diagnostic behavior after PACS implementation. Physicians more frequently viewed and interpreted radiology images themselves. They viewed images with radiologists less frequently. Additionally, physicians indicated a trend towards greater uncertainty in clinical diagnosis, which may reflect the differences between self-interpretation and the “firmer” diagnosis suggested by dictated reports. No significant differences in therapeutic actions were found.

Speed of access to radiology images improved dramatically as the decision points needed to locate films decreased drastically, an improvement that was accompanied by improved physician satisfaction with radiology services. Physicians no longer had to hunt for films, check films out and thus making them unavailable for other clinicians, or hide films. Because radiology department workflow was not addressed during the PACS implementation project, it is not surprising that satisfaction with time from ordering to study completion did not improve. Technology projects must be paired with process improvement initiatives to achieve maximum benefits for organizations.

Hospitals and health systems across the United States face daunting financial challenges, but even so, many implement a digital radiology system while continuing to also print films. By eliminating printing and distribution of X-ray film, the digital radiology system saves UCDHS more than $2 million annually. As UCDHS moves additional modalities, such as ultrasound, to its PACS and begins producing CDs for distribution of radiology images to patients and external healthcare providers, the volume of films printed will continue to fall, as will the associated costs.

Data suggest that the relationship between clinicians and radiologists changes with the advent of widely available digital radiology images. At UCDHS, on-call physicians reported a 90 percent relative decrease (from 31 percent to 3 percent) in viewing films with radiologists, while reading staff radiologists’ reports twice as often (19 percent to 38 percent). This change in the pattern of physician communication may have important implications for the practice of radiology. If further study confirms these findings, then non-interventional radiologists’ physical location may no longer matter, and the nascent trend toward outsourcing of radiology services may accelerate.

Limitations of This Study
Survey response rates were 20 percent and 22 percent, which may have resulted in an over- or under-estimation of survey-based findings. However, physician ratings correlate with observed clinical workflow patterns and appear to have similar directionality. Many fields were left blank by self-observing clinicians, despite appropriate orientation and reminders, perhaps because of respondent burden on busy call nights.

When implemented efficiently, digital radiology imaging systems also can provide system-wide cost savings and have the potential to improve care for patients. The study demonstrates that new digital technology, when implemented with attention to the clinical user, can improve satisfaction, efficiency, cost and clinical behaviors.

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