Saving Time, Improving Satisfaction: The Impact of a Digital Radiology System on Physician Workflow and System Efficiency

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ABSTRACT

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.

KEYWORDS

■ PACS ■ Digital image processing ■ Medical education ■ Resident education ■ Digital radiology ■ Physician workflow ■ Physician satisfaction ■ Cost-effectiveness ■ Radiology imaging

It is important to understand how new technologies affect users. Health systems and clinicians are under increasing pressure to become more efficient, while continuing to provide high-quality patient-centered care.[1,2] These pressures are intensified in academic institutions, where inefficiencies of education compound time pressures for both learners and educators.

Detractors of picture archiving and communication systems (PACS) decry it as a waste of limited financial resources. They contend there is a lack of proven clinical

benefit and cost effectiveness, and say there's been limited acceptance by radiologists of such systems.[3,4,5,6,7,8,9] Many hospitals have implemented PACS only in their radiology departments, while printing and distributing X-ray film to clinicians.

By contrast, PACS supporters point to increased user satisfaction and potential workflow improvements.[10,11,12] 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.[13] Significant questions remain about the impact of such systems on clinical users.

To assess the impact of PACS technologies on clinical users, UC Davis Health System conducted a comprehensive implementation study.[14] The institution implemented a digital radiology system as part of a larger paperless health system project.[15,16,17]

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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.[18] 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.[4,19]

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.

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Before implementation of the system, physicians reported they spent an average of one to two hours looking for hard-copy films during the day and one to three hours looking for films during nights and weekends. After PACS implementation, the total search time dropped to less than one hour for all patients.

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 surgery; 13 percent for procedures; 11 percent to show the patient; and 3 percent to hide them for other purposes.

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%), their 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.

		Pre-PACS (mean ± SD)	Post-PACS (mean ± SD)	Significance (p-value)
Respondent characteristics				
Response rate	Response rate	265/1195 (22.2%)	236/1197 (19.7%)	
Respondents	Attending physicians	144	160	
	Resident physicians	119	70	
	Did not identify role	2	6	
Specialty	Medical Specialty	61%	67%	
	Surgical Specialty	39%	33%	
Satisfaction "How satisfied were you with…" (5 = extremely satisfied)				
Overall radiology services		2.96 ± 1.03	3.39 ± 1.02	<0.0001
Time from test-ordered → test-completed		2.86 ± 1.00	2.99 ± 1.14	0.22
Time from test-completed → test-available		3.23 ± 0.96	3.98 ± 0.94	<0.0001
Film retrievability		2.39 ± 1.00	2.75 ± 1.05	<0.0002
Digital image availability		2.48 ± 1.19	3.92 ± 1.10	<0.0001
Image viewing patterns "How likely are you to.." (5= extremely likely)				
Personally view images that you ordered		3.35 ± 1.48	3.89 ± 1.34	<0.0001
View images with team members		2.89 ± 1.25	3.17 ± 1.37	0.02
View images with radiologists		2.33 ± 1.18	2.04 ±1.27	0.01
Image interpretation patterns "How likely are you to interpret images based on…" (5 = extremely likely)				
Your own reading		2.66 ± 1.40	3.19 ± 1.45	<0.0001
Radiology faculty's reading		2.58 ± 1.42	3.03 ± 1.43	0.001
Radiology resident's reading		2.63 ± 1.27	2.19 ± 1.22	0.0002
Other team member's reading		1.81 ± 1.09	1.54 ± 0.93	0.005
Average time spent searching for radiology images, per image				
Daytime		1-2 hours/film	<1 hour	
Nights and weekends		1-3 hours/film	<1 hour	

Table 1. Physician satisfaction and image utilization behaviors (from surveys)

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.

		Pre-PACS	Post-PACS
Respondent characteristics			
Call cycles		15	20
Residents	Medicine residents (2nd or 3rd year) on 5 teams	8	7
	Trauma team residents (1st year) on 2 teams	2	2
Total number of tests recorded		89	98
Tests recorded per resident, per call cycle		2-10	2-10
Test ordered by ER physician (not your team)		39%	33%
With whom did you view the image?			
Personally viewed the image		61.3%	73.7%
With team member			
With Radiologist		30.7%	3.0%
Additional information obtained about image			
Read radiology report		18.7%	38.4%
Called radiologist		4.0%	3.0%
Time from test-ordering to result-availability			
Time interval includes writing order, secretary entering order, radiology processing order, patient transport, image capture, result available			40 minutes less per image*
Diagnostic information (may select more than one)			
Derived new diagnosis (i.e. new lung mass)		6.8%	10.2%
Changed the working diagnosis		5.4%	2.0%
Confirmed working diagnosis		74.3%	66.3%
Diagnosis is unclear after test		12.2%	19.4%
Management decisions (may select more than one)			
Ordered new radiology tests		4.2%	10.0%
Ordered new procedures		5.6%	9.1%
Ordered new laboratory tests		1.4%	2.0%
Ordered new medications		4.2%	5.1%
Ordered new consults		2.8%	3.0%
Continue initial therapy		84.7%	83.8%

Table 2. On-call resident utilization of radiology services (from real-time PDA data entry)
* Not significant (p=0.70)

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

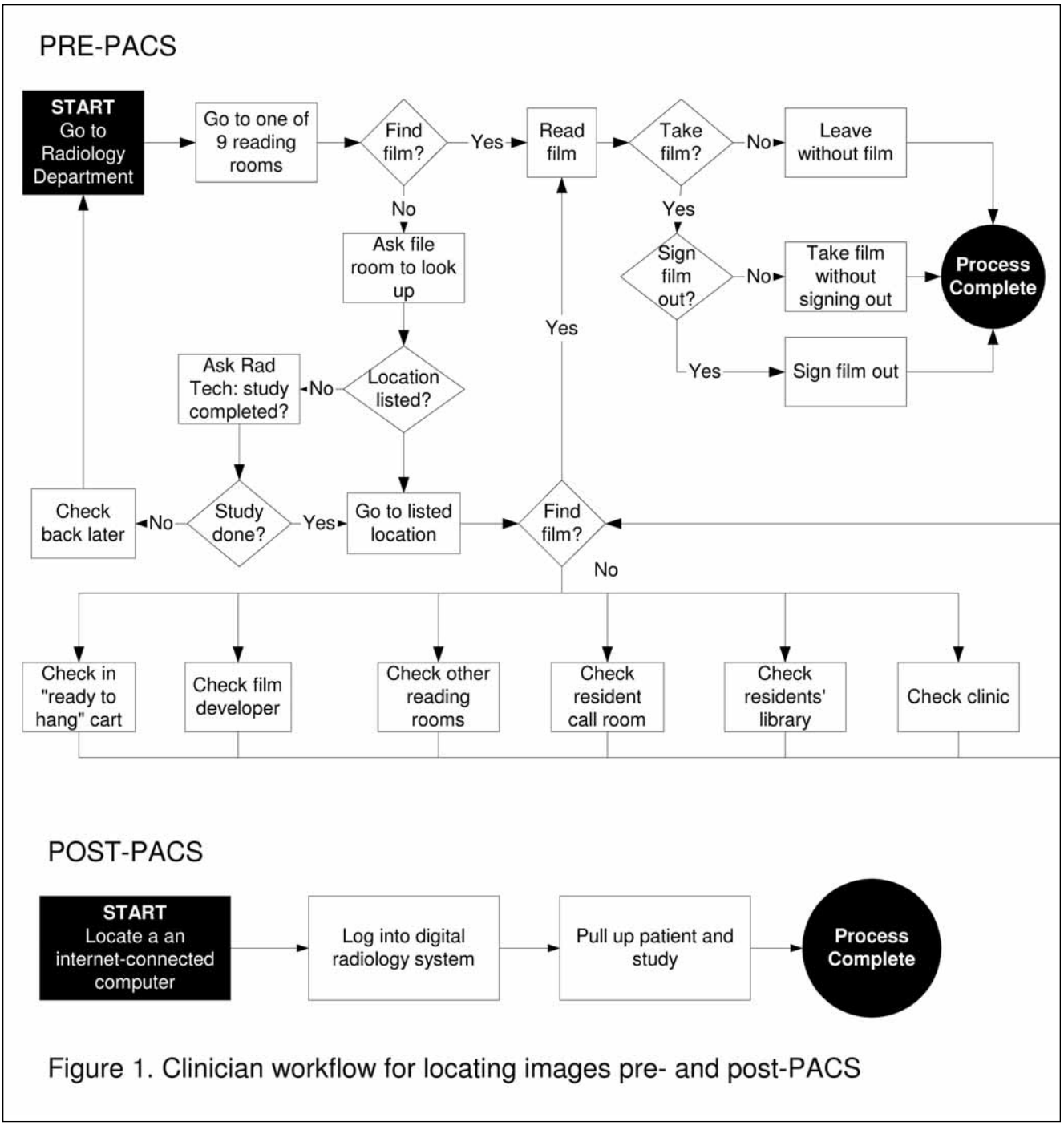

Figure 1. Clinician workflow for locating images pre- and post-PACS

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.[20] 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

Domain	Savings Source	Change Pre-Post PACS	Cost Savings	Present Value
Radiology studies	Film printing costs (including film jackets and sleeves).	$665,400/yr to $177,300/yr	$488,100/yr	$16,270,000
Radiology personnel	File room clerks (salary+ benefits= $31,494/year) staffing.	32.4 FTEs to 16.1 FTEs	$513,352/yr	$17,111,733
Film storage, on site	Hospital space converted to revenue generating activities. New hospital construction cost $484.49 sq ft in 2003. Converting space cost $139,492.	1218 hospital sq ft freed up	$450,608	$450,608
Film storage, off site	Rented warehouse space no longer needed after 2009, based on projected film recycling rate.	8108 warehouse sq ft not rented, after 2009	$1,816,867 PV (2003-perpetuity) minus $248,455 FV (2003-09) = $1,567,712	$1,567,712
Physician time	Mean 14.1 minutes saved per study, with 332,800 checked out in 2002, and assuming an 80-hour workweek.	85,937 hours per year saved, equivalent to 21.5 physician FTEs	$1,034,150 to $3,913,000/yr	$34,471,667 to $130,433,333
Total savings			$2,018,320 up front, then $2,035,602 to $4,914,452/yr	$69,871,720 to $165,833,386

Present value (PV) is the sum, which, if invested at time 0 at an interest rate (the discount rate), would be equal in value to a series of periodic payments or costs at fixed intervals (an annuity). Future value (FV) is the sum of the value of the annuity payments. Present and future values were calculated in perpetuity with the 6% discount rate used by the UCDHS finance department in 2003, and an inflation rate of 3%.

Where C = recurring payment, r = discount rate, i = inflation rate, t = # of time periods:
Present value = $C/(1+r) + C/(1+r)^2 + C/(1+r)^3 + \ldots C/(1+r)^t$
Present value (with inflation) = $C/(1+r) + C(1+i)/(1+r)^2 + C(1+i)^2/(1+r)^3 + \ldots C(1+i)^{t-1}/(1+r)^t$
Present value (in perpetuity) = C/r
Present value (in perpetuity with inflation) = $C/r-i$
Future value = $C(1+i) + C(1+i)^2 + C(1+i)^3 + \ldots C(1+i)^t$

Table 3. Financial impacts of implementation of a digital radiology system.

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 important and often overlooked quality improvement step in healthcare. In this study, researchers comprehensively assessed how a PACS system affected film-viewing behaviors, 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 behaviors, 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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