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The Effect of PACS on the Time Required for Technologists to Produce Radiographic Images in the Emergency Department Radiology Suite

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The purpose of this study was to evaluate the effect of a switch to a filmless image management system on the time required for technologists to produce radiographic images in the emergency department (ED) after controlling for exam difficulty and a variable workload. Time and motion data were collected on patients who had radiographic images taken while being treated in the emergency department over the 3½-year period from April 1997 to November 2000. Event times and demographic data were obtained from the radiology information system, from the hospital information system, from emergency department records, or by observation by research coordinators. Multiple least squares regression analysis identified several independent predictors of the time required for technologists to produce radiographic images. These variables included the level of technologist experience, the number of trauma-alert patient arrivals, and whether a filmless image management system was used (all $P < .05$). Our regression model explained 22% of the variability in technologist time (R^2 Adjusted, 0.22; $F = 24.01$; $P < .0001$). The regression model predicted a time saving of 2 to 3 minutes per patient in the elapsed time from notification of a needed examination until image availability because of the implementation of PACS, a delay of 4 to 6 minutes per patient who were imaged by technologists who spent less than 10% of their work assignments within the ED, and a delay of 18 to 27 minutes in radiology workflow because of the arrival of a trauma alert patient. A filmless system decreased the amount of time required to produce radiographs. The arrival of a trauma alert patient delayed radiology workflow in the ED. Inexperienced technologists require 4 to 6 minutes of additional time per patient to complete the same amount of work accomplished by an experienced technologist.

KEY WORDS: PACS, technologist, productivity, workload, emergency department, radiographer

THE PROJECTED SAVINGS in labor has been identified as one of the major components in the cost savings justifying the purchase of a picture archival and communication system (PACS) for radiology departments. Previous investigators have anticipated a savings of up to 10% in technologist labor costs when justifying PACS.[1] To date, PACS has been shown to improve technologists' productivity when performing computed tomography scans[2,3] and investigators have reported a potential for a 12% reduction in the time required to perform an ultrasound examination after the switch to a filmless environment.[4]

However, approximately 50% of all of the diagnostic imaging examinations performed within the radiology department are plain-film radiographic examinations. Previous studies have shown that there is substantial variability in time required for technologists to perform radiographic examinations.[5] Examination type and other factors reflecting examination difficulty contribute to this variability. Additionally, plain-film examinations typically have a small number of images taken per examination, and film processing and handling tasks for plain-film examinations are not as time consuming as

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the processing and handling tasks required for the multislice imaging modalities such as computed tomography or ultrasound. Consequently, the productivity improvements seen in multiimage modalities may not be realized in plain-film radiography, and current studies evaluating technologist productivity for plain-film radiography have had varying results.[6-12]

This study addresses the confounding factors of emergency department (ED), workload volatility, and radiographic examination difficulty. We attempt to quantify the times savings, if any, realized by technologists taking plain-film radiographs after the conversion from conventional image management to digital image management.

METHODS AND MATERIALS

Time and motion data were collected on patients who had radiographic images taken while being treated in the emergency department over the 3-year period from April 1997 to November 2000. Event times and demographic data were obtained from the radiology information system (RIS; IDXrad, IDX, Burlington, VT), from the hospital information system, from emergency department records, or by observation by research coordinators.

In the "hard-copy" environment, images were acquired by computed radiography (CR) and printed onto hard copy for interpretation. After radiographic exposure, the technologists processed the images. Technologists then evaluated the processed images for radiographic quality first on the CR image monitors and subsequently on the printed hard copy image. After this quality control procedure, all hard-copy images were hand carried to the radiographic reading room by the technologists. During these collection intervals, there was a radiographic reading room proximal to the technical control room where images were displayed on 50-panel multiviewers.

In January 1998, a General Electric (GE; Milwaukee, WI) Pathspecd PACS was installed and the ED switched to a "filmless" environment. During this period, the CR reader automatically forwarded processed images directly to the PACS where they were matched with study information from the Radiology Information System (RIS). The images then were forwarded into the GE PACS archive. The GE CR system was interfaced to the RIS via a patient terminal where technologists looked up the scheduled examination information and had it added automatically to the processed CR image. A separate CR quality control workstation then received the images, and the processing parameters were manipulated if necessary by the technologists. Finally, the images were forwarded into the PACS archive. Once images were received in the PACS, they were available for final demographic changes and some basic image manipulation. After this step, they were available to the radiologist.

There were 6 main data collection intervals that typically were 6 weeks in length. Two collection intervals were conducted while the conventional system of image management using hard copy images was in place (conventional period). Four data collection intervals were conducted after the switch to soft-copy images (filmless period). Because of limitations in research personnel, a convenience sample of all patients who underwent radiographic examinations between the hours of 8:00 AM and 4:00 PM were included in the study. Data captured during these 6 intervals included:

- The time of patient arrival in the ED.
- The patient's triage code. This 1-4 Likert scale (1-most acute, 4-least acute) rating is based on the patient's presenting symptoms and was assigned to the patient at arrival by the triage nurse and served as a severity of illness indicator. Nurses who are assigned to triage incoming patients have at least 6 months clinical experience and receive a didactic and clinical orientation with a preceptor. Guidelines established by the Emergency Nurses Association were used when assigning a triage code. If the patient's triage code had not been recorded in the ED records, it was considered "unknown."
- The time that radiology was notified of a needed examination and how notification was accomplished. Notification could be accomplished either verbally, by faxing a request to scheduling, or by telephoning the radiology scheduling clerks.
- The time that the patient's images were available for viewing. In the Conventional Period, this was considered the time that the hard-copy images were displayed on the reading room multiviewers. During the filmless period this was defined as the time that the images arrived in the PACS archive.
- The time the radiologist completed image interpretation and had dictated a report.
- The time that the ED physician first obtained information either by viewing the images or by obtaining a report.
- The time of patient disposition.

There also was one supplementary collection interval conducted within the ED at the ED control desk. Data captured during this interval included the time that the examination request form was completed by the ED physician and the time that the radiology department was notified of a needed examination via fax machine. The data from this period was used to quantify the amount of delay between the time that the ED clinician first completed a request form until the time that the radiology department was notified of the needed examination.

Statistical Analysis

Differences in proportion were tested with Pearson χ^2 Test. Differences in median values were tested with a Wilcoxon Rank Sum.

Technologist Workflow was evaluated by a multiple least squares regression model with the elapsed time from notification of the radiology department of a requested examinations until all the patient's images were verified by the technologist and available for viewing (termed *tech-*

nologist's time) as the dependent variable. To meet the assumptions of constant variance and normality of the data, we used a logarithmic transformation (ln) of technologist's time. Because ED patients occasionally require more than one radiographic examination, and to preserve independence, the unit of analysis in the model was the ED patient rather than radiographic examination. Independent variables were selected a priori for inclusion in the model because they were thought to have an impact on unit workload or on examination difficulty and therefore affect the time required for technologists to produce radiographs. Independent variables selected included:

- The type of image management system in place; either a conventional system or filmless system (variable type; binary).
- The number of radiographic examinations requested on the patient (variable type; continuous).
- The type of examinations requested categorized as either an abdominal, thoracic, skull/facial, spinal, or appendicular skeleton, or of mixed type (variable type; categorical).
- The number of trauma alert patients that arrived in the ED while the patient was waiting in queue for their radiographic examinations (variable type; continuous). A patient was considered in queue if the radiology department had been notified that the patient needed examination, and if that examination had not yet been completed. A trauma alert patient is one who, based on triage criteria, has a moderate to high risk of life-threatening injuries and could benefit from immediate resuscitative efforts or surgery. The triage criteria used included: (1) Physiologic Criteria: Glasgow coma scale of less than 13, systolic blood pressure of less than or equal to 100, respiratory rate less than 10 or greater than 29, trauma score less than 14; (2) Anatomic criteria: penetrating injuries to chest, abdomen, neck or groin; amputation proximal to ankle or wrist; flail chest; 2 or more long bone fractures; 10% body surface area burn; (3) Mechanism of injury criteria: fall of 20 feet or more, ejection of patient from motor vehicle, pedestrian hit by motor vehicle traveling at 20 mph or more.
- The average number of patients arriving in the ED per hour during the course of the patient's visit to the ED (variable type; continuous).
- The patient's triage code (variable type; categorical).
- The method used for scheduling the patient's radiographic examination categorized as either the "usual method" when the request was faxed to the radiology scheduling desk or as a "workaround method" when the technologist would be notified directly or when a request was phoned in to radiology scheduling (variable type; binary).
- Technologist's workload calculated as the number of examinations completed by the technologist in the hour preceding the patient's radiographic examination (variable type; continuous).
- Whether the patient's examinations were done in the radiographic examination room or at bedside (variable type; binary).
- The technologist's level of experience in the ED categorized as either "experienced" with frequent assignments to work in the ED or as "inexperienced" with less than 10% of their work assignments in the ED (variable type; binary).

Table 1. Sample Characteristics and Patient Demographics

	Conventional	Filmless
Image management system	Film-based	Filmless
Number of data collection days	51	93
Number of patients	307	1,085
Number of radiographic exams	377	1,384
Ratio men to women	0.84	0.81
Median age of patients	50	47
Proportion of patients admitted to hospital	0.37	0.35

RESULTS

Patient Demographics

Table 1 shows sample characteristics and patient demographics during the 2 collection periods. The differences in median patient age, ratio of men to women, and proportion of patients subsequently admitted to the hospital were not significant (all $P > .1$). Table 2 shows the distribution of study patients according to their triage code. There was a significant difference in the distribution of patients by triage code between the 2 periods ($P < .0001$).

Elapsed Time From ED Examination Request until Radiology Notification

Research coordinators observed the ED physicians while they filled out radiographic examination request forms and observed when the request forms were faxed to radiology scheduling. In this part of the study, research coordinators obtained data on a total of 49

Table 2. Distribution of Study Patients by Triage Code

	Conventional		Filmless	
Triage Code	No.	Proportion	No.	Proportion
Level 1	23	0.07	95	0.09
Level 2	119	0.39	425	0.39
Level 3	107	0.35	299	0.28
Level 4	8	0.03	166	0.15
Unknown Triage Code	50	0.16	100	0.09
Total	307		1085	

Table 3. Distribution of Radiographic Examinations Taken on Study Patients

	Conventional		Filmless	
	No.	Proportion	No.	Proportion
Abdomen	31	0.08	90	0.07
Appendicular skeleton	72	0.19	373	0.27
Chest	233	0.62	762	0.55
Skull or facial bones	4	0.01	15	0.01
Spine or pelvis	37	0.10	144	0.10
Total	377		1384	

patients. The median elapsed time from examination request generation by the ED physician until the radiology department received a faxed request was 7 minutes (interquartile range, 4,12; $n = 49$).

Technologist Workload

The median number of patients radiographed per 8-hour work shift increased from 18 patients during the conventional period to 19 during the filmless period ($P = .02$). The median number of examinations performed by the ED radiologic technologist per hour was 5 for both the conventional period and for the PACS period ($P = .4$). Table 3 shows the distribution of the radiographic examination types taken on the study patients; there was a significant difference in the distribution of radiographic examination types between the 2 periods ($P = .03$). There were no significant differences in the number of examinations taken per patient between the 2 periods ($P = .6$).

The median elapsed time from radiology notification until images were available was 34 minutes for both the filmless and the conventional periods ($P = .57$).

Emergency Department Workload

The median number of patients who arrived at the ED registration desk for treatment was 6.61 patients per hour during the conventional period and 7.74 during the filmless period. This difference in patient arrival rate was significant ($P < .0001$).

Seven percent (21 of 307) of the patients in the conventional period and 5% (53 of 1,085) of the patients in the filmless period were waiting for a radiographic examination to be taken at the time when a trauma alert patient arrived in the ED. This difference was not significant ($P = .18$).

Multivariate Model

Multiple least squares regression analysis identified several independent predictors of the time required for technologists to produce radiographic images. Overall, our regression model explained 22% of the variability in technologist time (R^2 Adjusted, 0.22; $F = 24.01$; $P < .0001$). Table 4 summarizes the results of this analysis and shows the respective coefficients and P values for each independent variable. Table 5 shows the change in the time required for technologists to produce radiographs predicted by the regression equation with respect to each independent variable and with all other variables set to their median values.

DISCUSSION

PACS are becoming more commonplace, and the costs of implementing these systems have been justified partially by the savings resulting from anticipated improvements in productivity. When comparing the film-based Philadelphia and Fort Howard Veterans Medical Centers to the filmless Baltimore Veterans' Medical Center, Reiner and Siegal reported less average time required for technologists to perform examinations in the filmless environment.[6,7] However, some of these time savings could be attributed easily to the different ages of the respective hospitals, the configuration of the radiology departments, or to differences in the imaging equipment between the hospitals. Other studies evaluating technologists in the computerized axial tomography department have shown improved productivity.[2,3] These findings, however, may not be extrapolated to plain-film radiography because of the differences in the tasks required from the technologists and in the higher volume of images that is typical of computed tomography (CT) scans.

In contrast to the findings of Reiner and Siegel, other studies have found an increase in technologist's time.[8-11] Andriole et al,[10] for ex-

Table 4. Multiple Linear Regression Analysis Technologist Time

	Coefficient	SEM	*P* Value
Hard-copy as image medium	0.06	0.03	.040
Number of radiographic exams patient needed	0.13	0.05	.007
Number of Trauma-alert patients	0.08	0.03	.002
No scheduling workaround	0.28	0.02	<.0001
Technologist's workload	0.03	0.01	.0003
Emergency department workload	0.03	0.01	.002
Exam is done portable	−0.21	0.03	<.0001
Technologist has experience in ED	−0.12	0.03	<.0001
Exam type is*			
Abdominal	0.00	0.26	.996
Appendicular skeleton	−0.31	0.11	.005
Chest	−0.39	0.10	<.0001
Spine	−0.16	0.14	.257
Skull	−0.17	0.25	.496
Triage code is†			
Level 1	0.06	0.07	.395
Level 2	0.19	0.04	<.0001
Level 3	0.06	0.04	.181
Level 4	−0.22	0.06	.0006

* Base group in analysis is the group of patients with examinations of several types.
† Base group in analysis is the group of patients with an unknown triage code.

ample, reported that the perceptions of the end users of a digital image management system were that the digital system slowed patient throughput in the emergency department. These perceptions may have originated from the fact that the study was conducted in the 9 months after the change to a digital environment, and during these initial months of implementation the investigators reported a considerable amount of down time. Another factor contributing to the perception of slowed patient throughput in this study was the lack of an interface between the radiology information system (RIS) and the imaging modalities.

Table 5. Time required for technologists to produce radiographs predicted by the regression equation with respect to each independent variable and with all other variables set to their median values for a patient with one radiographic exam ordered by the patient's triage code (Hours: Minutes)

	Triage Code				
	1	2	3	4	Unknown
Exam Type					
Abdomen	0:57	1:05	0:57	0:43	0:54
Appendicular skeleton	0:42	0:48	0:42	0:31	0:39
Chest	0:38	0:44	0:38	0:29	0:36
Skull or facial bones	0:48	0:55	0:48	0:36	0:45
Spine or pelvis	0:48	0:55	0:48	0:36	0:45
More than one type of exam	0:57	1:05	0:57	0:43	0:54
Other factors					
When digital image management used	−0:02	−0:03	−0:02	−0:02	−0:02
Scheduling workaround used	−0:09	−0:09	−0:09	−0:07	−0:09
Per unit increase in technologist workload	0:01	0:01	0:01	0:01	0:01
When technologist has little experience	0:05	0:06	0:05	0:04	0:05
Per additional exam	0:06	0:06	0:06	0:04	0:05
If exam is performed at bedside	−0:07	−0:09	−0:07	n/a	−0:07
Per trauma-alert occurence	0:24	0:27	0:24	0:18	0:22
Per average hourly patient arrivals	0:01	0:01	0:01	0:01	0:01

We also have documented a lengthening in the time required for technologists to perform imaging examinations in the emergency department after the switch to a digital system.[8,9] Similar to the study by Andriole et al,[10] our studies also were conducted shortly after the switch to the digital environment when a reduction in productivity may be caused by a learning effect or to the lack of an interface between the imaging equipment and the RIS. Another limitation in our previous studies was the absence of variables indicating the level of technologist's workload. Previous studies in the emergency department have shown that an increased patient arrival rate and a high number of patients registered for care have been associated with increased patient waiting times.[13,14] A similar circumstance may be at work in the emergency department radiology suite when there are many patients waiting for radiographic examinations, and this may affect the amount of time between examination request and image availability (technologist's time). Additionally, during this study, we documented that there was a significantly higher proportion of less acute patients treated in the ED during the filmless period, and that a higher proportion of skeletal examinations and a lower proportion of chest examinations were taken during the filmless period. These differences had an effect on technologists' workload and may have confounded the evaluation of PACS technology when measuring technologist's time.

In our initial comparison that was unadjusted for fluctuations in workload, the time from notification of a needed examination until the images were available for review did not change after the implementation of PACS. This study was undertaken well after the switch to a digital system and after controlling for workload variability and the effects of patient-related variables such as the type and number of examinations required. The model predicted a 2-minute savings per patient in technologist time after the switch to PACS. This gain is most likely from the absence of film-handling tasks and from the absence of an additional quality control session that is required when digital images are printed to hard copy. Given that the technologists in this study, on average, performed examinations on 18 patients per day, a PACS would only save about 36 minutes in technologist time per work-shift. Although these improvements in productivity may be realized, cost savings can only be realized if this time savings can be used to image an additional patient or to accomplish additional tasks.

Although we did not show a large savings in the time required for technologists to perform examinations after PACS implementation, other factors had an impact on technologist time. According to a national survey that polled the chairmen of academic emergency medicine programs, 48% of ED departments use a paper form to communicate to the radiology department, and only 36% use a computerized method for ordering examinations.[15] In this study, a paper examination request form was faxed to the radiology department when an examination was ordered by the ED physician. Fifty percent of these requests were sent to the radiology department within 7 minutes after the ED physician filled out the request; however, 25% of the requests were delayed beyond 12 minutes. Accordingly, a computerized system that allowed ED physicians to directly notify radiology would save time and would have a greater impact on patient throughput than the switch to a filmless environment.

In addition to the initial delay that occurred before the radiology department was notified, our multivariate model predicted delays of about 9 minutes per patient in the time from radiology notification until image availability when the formal method for requesting examinations was used. Typically, the ED clerk would fax the request to the radiology department where a scheduling clerk would schedule an appointment. After this, an examination notification card would print in the technical control area, and this card would serve as notification to the technologist that an examination was needed. In contrast, when an informal method of notification was used, ED personnel would directly notify the radiologic technologist who would either schedule the examination himself or herself, or they would phone the scheduling clerk to obtain an appointment for the examination. Consequently, the technologist would have known about a needed examination several minutes before a time would have been recorded in the RIS. Therefore, the actual

time savings realized by using an informal method of notification would be less than 9 minutes per patient because we could not document the amount of time that the technologist knew of a needed examination before it was scheduled in the RIS, and it could not be accounted for in our model. Nevertheless, improvements made to the method of communication between the ED and radiology may streamline the process to where an informal notification method is not used and where the technologist will not be required to perform scheduling tasks that may interfere with their imaging tasks.

Another factor that imposed an additional delay in the time from notification until image availability was the experience level of the technologists assigned to the emergency department. Our model predicted a 4- to 6-minute delay per patient in the time from notification until image availability when the technologist had little experience working within the ED. On average, the technologists radiographed 18 patients per day. At this rate, an inexperienced technologist would need 72 more minutes per day than an experienced technologist to complete the same amount of work. This indicates that experienced technologists are a more valuable resource than entry-level technologists and that efforts should be made to retain seasoned employees, particularly in the current labor market.

Similar to previous studies on patient waiting, our study found that the time required from examination request until image availability increased with the number of both ED patients and trauma alert patients that were cared for during the study patient's stay in the ED.[13,14] Typically, trauma alert patients require radiographs immediately on arrival in the ED, and the radiologic technologist on duty will image these patients before any other waiting patients. This requires that all pending radiographic examinations be delayed until the imaging of trauma alert patient has been completed. Our study indicates that patients must wait an additional 18 to 27 minutes to obtain their radiographs if a trauma alert patient arrives in the ED while they are waiting in queue to be attended to by a radiologic technologist. Fortunately, the arrival of a trauma alert patient is an infrequent event, and only 5% (74 of 1,392) of our study patients were in queue for an imaging examination when a trauma alert patient arrived.

Other factors that reflect technologist workload were controlled for in our model as well, and similar to previous investigators[5] we found that the time from notification until image availability varied depending on examination type. We also found that the time increased by 4 to 6 minutes per additional examination ordered and that images taken at bedside were available 7 to 8 minutes earlier than images taken within the x-ray room. Usually bedside images are given priority over any other pending requests because the patients who require bedside images are more acutely ill. Consequently, this decrease in delay may represent the time saved by not requiring the patient to wait in queue, or it may represent the time saved by not requiring the patient to be transported to the x-ray examination room.

Potential limitations of this study include its focus on an environment which uses CR images printed on hard copy as an image medium because the results may not generalize to the screen film–based ED department.

Future research should focus on mitigating the extreme learning curve and on technologist education as ways to decrease technologist time and to improve productivity.

In conclusion, after controlling for the variability in technologist workload, a PACS was shown to decrease the amount of time required to produce radiographs in the emergency department, but by only 2 minutes per patient. On an average working day, an inexperienced technologist requires 72 more minutes to complete the same amount of work as a technologist with experience in the emergency department. The arrival of a trauma alert patient into the emergency department delayed radiology workflow by between 18 and 27 minutes per patient.

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