Radiology Workflow and Patient Volume: Effect of Picture Archiving and Communication Systems on Technologists and Radiologists

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This study was performed to evaluate the changes in workflow and efficiency in various clinical settings in the radiology department after the introduction of a picture archiving and communication system (PACS). Time and motion data were collected when conventional image management was used, and again after the introduction of a PACS. Changes in the elapsed time from examination request until the image dispatch to the radiologist, and from dispatch until report dictation, were evaluated. The relationship between patient volume and throughput was evaluated. The time from examination request until dispatch was significantly longer after the introduction of PACS for examinations taken on patients from the emergency department (ED) (pre-PACS, 20 minutes; post-PACS, 25 minutes; $P < .0001$), and for examinations taken on patients in the medical intensive care unit (MICU) (pre-PACS, 34 minutes; post-PACS, 42 minutes; $P < .0001$). The interval from image dispatch until report dictation shortened significantly after the introduction of PACS in the ED (pre-PACS, 38 minutes; post-PACS, 23 minutes; $P < .0001$) and in the outpatient department (OPD) (pre-PACS, 38 minutes; post-PACS, 20 minutes; $P < .0001$). Simple least squares regression showed a significant relationship between daily patient volume and the daily median time until report dictation ($F = 43.42$, $P < .001$). PACS slowed technologists by prolonging the quality-control procedure. Radiologist workflow was shortened or not affected. Efficiency is dependent on patient volume, and workflow improvements are due to a shift from batch to on-line reading that is enabled by the ability of PACS to route enough examinations to keep radiologists fully occupied.

PICTURE ARCHIVING and communication systems (PACS) are becoming more widely accepted, and it expected that these systems will improve radiology department productivity and expedite consultation by radiologists. To date, PACS have been evaluated for their potential for improving throughput with varying results,[1-7] and workflow analysis with attention paid to procedure mix and number of examinations performed has been suggested as an important preparation for PACS installation.[8] In this study, we measure and evaluate the changes in radiology department workflow after the introduction of PACS for both technologists and radiologists. We look at several areas within radiology, including the emergency department (ED), the outpatient department (OPD), and the inpatient department (INPD), in order to determine if PACS expedites workflow in different clinical settings.

It is predicted that PACS will enable better utilization of resources and more time efficient reporting of radiographic results. Supporting this goal is the ability to route images to a remote workstation where an individual radiologist could interpret examinations from several clinical sites and/or hospitals. Ideally, this will enable 24-hour expert service to hospitals and to sites that would normally have to wait until a radiologist was available. However, this will result in a substantial increase in patient volume for any individual radiologist, and may have an effect on throughput. Therefore, we evaluated the relationship between patient volume and workflow for the radiologists in our department who began interpreting images from multiple clinical sites after the introduction of PACS to determine the effect of increased volume.

METHODS AND MATERIALS

Time and motion data were collected over a 5-year period in three clinical areas in the radiology department both before and

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after the transition from conventional image management to a digital PACS. More than 31,000 radiographic examinations were included in the study that were taken on patients in the ED, in the OPD, and on inpatients admitted to the medical intensive care unit (MICU).

Image Acquisition and Storage

In the conventional "film-based" environment, each clinical area had a divisional technical control room where image development and quality control took place. Images were either acquired by computed radiography, and printed onto hard copy for interpretation or were acquired on analog film. After radiographic exposure, the images were processed by the technologists or by a darkroom aide. In the INPD and in the ED, the technologists evaluated their own images for radiographic quality. In contrast, a dedicated quality-control technologist inspected all images performed in the OPD. Following the quality-control procedure, all images were dispatched to the radiographic reading room. During the conventional period, there was a radiographic reading room close to the technical control room in all three clinical areas. Current images were displayed in the reading room on 50 panel multiviewers, and historical, comparison images were brought to each reading room at the time of radiographic examination request or at examination start. During the conventional period, attending radiologists were on duty in the ED at all times. There was an attending radiologist on duty in the OPD and in the INPD reading room during the day. The OPD was closed at night, and all night cases from the MICU were first read by the resident on call with backup by the night ED attending radiologist.

A General Electric (GE) PACS system (General Electric Co, Milwaukee WI) was installed in January 1998. As of January 2000, six computed radiography (CR) readers have been installed. The GE CR system is interfaced to the radiology information system via a patient terminal where technologists can look up the scheduled examination information and have it automatically added to the processed CR image. A separate CR quality-control workstation then receives the images, where the CR processing parameters can be manipulated if necessary. Finally, the images are forwarded into the PACS archive. Once images from any of the CR readers are received at the PACS, they are available for final demographic changes and some basic image manipulations. After this step, they are dispatched to the radiologist.

Statistical Analysis

Differences in technologist workflow before and after the introduction of PACS were evaluated by comparing the elapsed time from radiographic examination request until image dispatch. Changes in radiologist workflow were evaluated by comparing the elapsed time from examination dispatch until report dictation. Event times were downloaded from the radiology information system (RIS) (IDXrad, IDX, Burlington, VT). Differences in elapsed times were tested with a Wilcoxon rank sum test.

After the adoption of PACS technology in the ED, the images from the OPD were routed to the ED radiologists, and the outpatient reading area was discontinued. This resulted in a substantial increase in patient volume for the ED radiologists. Data from both of these areas were evaluated in a simple least squares regression and a second-order polynomial regression in order to test the relationship between daily patient volume and daily median elapsed time from examination completion to report dictation. Additionally, the ED timing data were divided into night examinations (completed 11:00 PM to 7:00 AM), and day examinations (completed 8:00 AM to 6:00 PM), because there is a considerable difference in patient volume at night versus day. Daily volume was calculated as the number of patients evaluated by radiographic examination each day. In order to meet the assumptions of homoscedasticity and normality of the data, the median elapsed time at each level of patient volume was used as the dependant variable in the regression model.

Table 1. Technologist Workflow: Elapsed Time (in minutes) From Exam Request Until Image Dispatch to a Radiologist

Clinical Site	Conventional Image Management System		PACS		
	Median	n	Median	n	*P* Value
ED	20	2,734	25	4,354	.0001
MICU	34	1,254	42	373	.0001

RESULTS

Technologist Workflow

The elapsed time from examination request until image dispatch is shown in Table 1. This time was significantly longer after the introduction of PACS, for examinations taken on patients from the ED, and for examinations taken on patients from the MICU. A comparable time was not available in the OPD, because in this clinical area, the technical component of a radiographic examination is divided between an imaging technologist and a quality-control technologist.

Radiologist Workflow

The time interval from dispatch until report dictation is shown in Table 2. It was significantly shorter after the introduction of PACS in the OPD and in the ED during the day. There was no significant change in the elapsed time from dispatch until dictation for the examinations taken on

Table 2. Radiologist Workflow: Elapsed Time (in minutes) From Exam Dispatch (completion) Until Report Dictation

Clinical Site	Conventional Image Management System		PACS		
	Median	n	Median	n	*P* Value
ED daytime	38	2,734	23	4,354	<.0001
OPD	38	7,828	20	4,435	<.0001
MICU	118	1,203	111	373	.21
ED night	91	2,736	92	3,904	.91

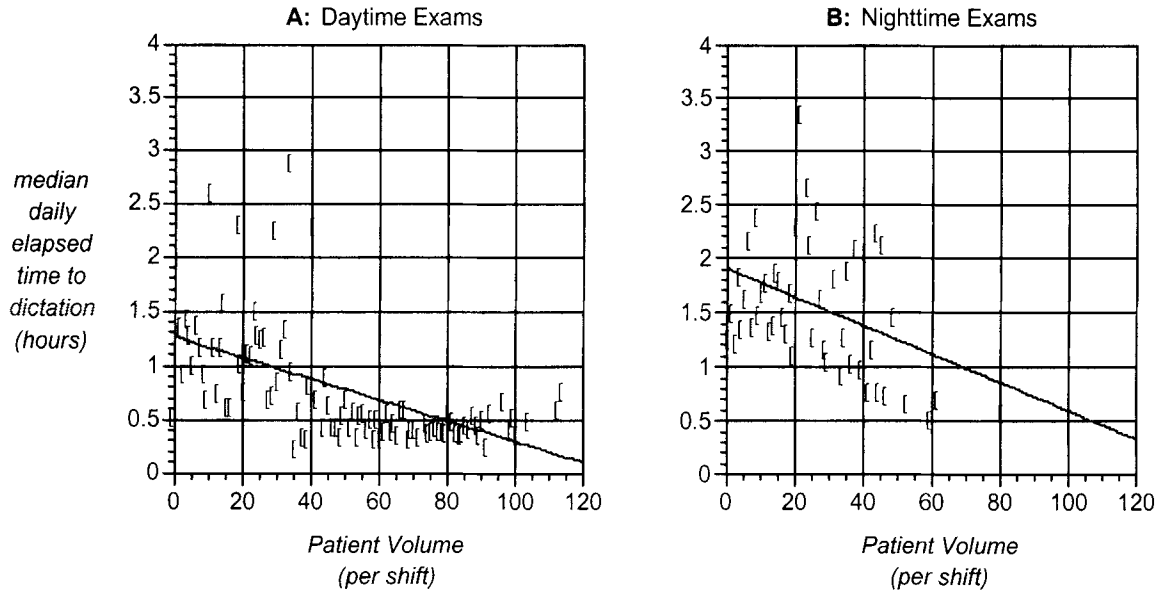

Fig 1. Linear regression lines fitted to the night and daytime data. For the daytime exams, median volume was 24 patients per shift before PACS and 62 patients per shift after PACS. At night, median volume was 12 patients per shift before PACS and 16 patients per shift after PACS.

the MICU patients, nor for examinations taken on the night ED patients.

Patient Volume and Radiologist Workflow

During the day, there was a 258% increase in daily patient volume for the radiologists reading ED images, after the introduction of PACS, due to the discontinuation of the OPD reading room and the routing of OPD images to the ED radiologists (median level of 24 patients per day before PACS to 62 patients per day after PACS). However, the median daily elapsed time until report dictation decreased from 61 minutes before PACS to 26 minutes after PACS. At night, there was only a minor increase in patient volume after the switch to PACS (median level of 12 patients per shift before PACS to 16 patients per shift after PACS), and there was not a significant change in the median daily elapsed time until report dictation (pre-PACS, 96 minutes; post-PACS, 94 minutes; $P = .47$).

Simple least square regression showed a significant linear relationship between daily patient volume and the median daily elapsed time from exam completion until report dictation for both the night examinations and the day examinations ($F = 8.48$, $P = .006$; $F = 43.42$, $P < .0001$, respectively). Figure 1 shows the linear regression lines fitted to the night and daytime data.

There was a highly significant curvilinear relationship between daily volume and median time until dictation for the daytime data shown by a second order polynomial regression model ($F = 24.72$, $P < .0001$). A significant curvilinear relationship was not found in the night data, and is possibly due to the narrower range of patient volume (2 to 82 patients at night *v* 0 to 150 patients during the day). Figure 2 shows the parabolic fit to the daytime data.

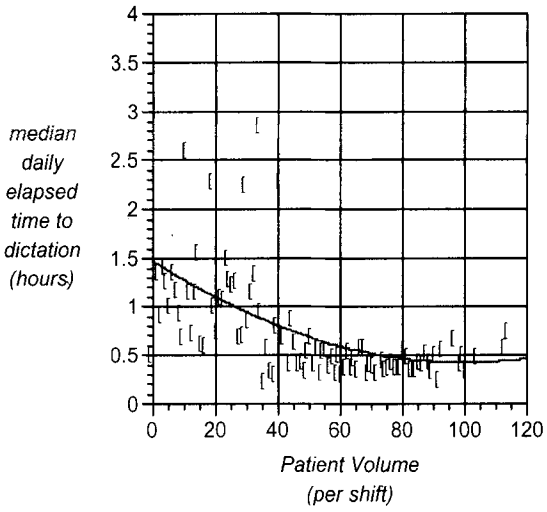

Fig 2. Curvilinear regression lines fitted to the daytime data.

DISCUSSION

The introduction of PACS slowed technologist workflow by prolonging the quality-control procedure. The radiologist workflow was decreased or not affected. The effects of the introduction of PACS may vary depending on the existing work practices at the clinical site, and the time savings seen in any particular clinical site after the introduction of a digital PACS does not indicate that there will be similar time savings in all areas of radiology.

The introduction of PACS enabled the consolidation of two separate reading rooms, the OPD and the ED. Formerly, these areas were attended by two radiologists. With PACS, all examinations were routed to one radiologist. This resulted in a substantial increase in patient volume; however, this did not result in an overall slowing of radiologist's workflow. Rather, the median daily elapsed time from exam completion until report dictation shortened significantly after the introduction of PACS. Furthermore, regression analysis showed that as patient volume increased, the elapsed time until dictation decreased. This suggests that the increased efficiency for radiologists, after the introduction of PACS, is not necessarily the result of improvements in image delivery or a result of a more facile way to interpret images. Rather, it may be due to a shift from batch to on-line reading that is enabled by the ability of PACS to route enough examinations to a radiologist and keep them fully occupied. The curvilinear model (Fig 2) indicates that as patient volume increases beyond the optimum level of operation, the elapsed time until report dictation grows longer due to increased workload.

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