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SCAR Radiologic Technologist Survey: Analysis of the Impact of Digital Technologies on Productivity

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As medical reimbursements continue to decline, increasing financial pressures are placed upon medical imaging providers. This burden is exacerbated by the existing radiologic technologist (RT) crisis, which has caused RT salaries to trend upward. One strategy to address these trends is employing technology to improve technologist productivity. While industry-wide RT productivity benchmarks have been established for film-based operation, little to date has been published in the medical literature regarding similar productivity measures for filmless operation using PACS. This study was undertaken to document the complex relationship between technologist productivity and implementation of digital radiography and digital information technologies, including PACS and hospital/radiology information systems (HIS/RIS). A nationwide survey was conducted with 112 participating institutions, in varying degrees of digital technology implementation. Technologist productivity was defined as the number of annual exams performed per technologist full-time equivalent (FTE). Productivity analyses were performed among the different demographic and technology profile groups, with a focus on general radiography, which accounts for 65-70% of imaging department volumes. When evaluating the relationship between technologist productivity and digital technology implementation, improved productivity measures were observed for institutions implementing HIS/RIS, modality worklist, and PACS. The timing of PACS implementation was found to have a significant effect on technologist productivity measures, with an initial 10.8% drop in productivity during the first year of PACS implementation, followed by a 27.8% increase in productivity beyond year one. This suggests there is a "PACS learning curve" phenomenon, which should be considered when institutions are planning for PACS implementation.

INTRODUCTION

THE CRISIS IN RADIOLOGIC technologist (RT) staffing was outlined in the first part of the 3-article series.[1] There are numerous financial pressures on medical imaging providers including diminishing reimbursements, decreasing capital and operational budgets, and increased compensation for professional and support personnel. These combined economic and workforce constraints place an increased importance on productivity, as a means to address the increased utilization and complexity of medical imaging services despite a shrinking RT workforce. Whereas industry wide technologist productivity "norms" have been documented for film-based facilities,[2-6] there have been only a few published reports in the scientific literature evaluating technologist productivity changes after the transition to filmless operation.[7-9] These, in effect, constitute a series of individual case reports.

Information technologies (IT) within the medical imaging department include picture archival and communication systems (PACS), hospital information systems (HIS), and radiology information systems (RIS). In addition, general radiography as a modality is undergoing an evolution from film screen to digital techniques such as computed radiography (CR) and direct radiography (DR). These digital technologies have the potential to improve technologist productivity in a number of ways,

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including decreased examination times, reduction of job-related stress and fatigue, elimination of darkroom and filming functions, as well as reducing clerical responsibilities commonly placed on technologists in a paper/film-based imaging department.[10-12]

To better understand the complex relationship that exists between technologist productivity and implementation of these digital technologies, a large-scale longitudinal nationwide survey currently is being conducted with the initial results presented in this series. As more comprehensive data are collected and analyzed, we hope to better understand the impact of digital technologies on productivity. This may, in turn, allow for more accurate determination of personnel requirements, staffing allocations, and potential cost reductions as institutions successfully transition to filmless and paperless operations.

The purpose of this study was to analyze the survey data to elucidate the relationship between the use of medical imaging–related IT and technologist productivity. These information technologies are the hospital HIS, RIS, HIS-RIS interface, and the use of a PACS.

METHODOLOGY

The development of the survey instrument, data collection, and quality control were described in the first report of the 3-part series in detail.[1] Technologist productivity was defined as the annual number of examinations performed per full-time technologist equivalent (FTE), assuming 40 working hours per week, over a 50-week year. The number of procedures per FTE was calculated by modality for each site by taking the total number of annual procedures and dividing by the number of technologists for each modality. "Filmless" and "near-filmless" status was determined for each modality with facilities that performed no film printing were defined as "filmless." "Near filmless" was defined as those facilities printing less than 25% of procedures.

The technology profile analysis was as follows. The number of procedures per FTE was evaluated based on the presence or absence of a RIS, HIS, HIS-RIS interface, and modality-specific PACS and whether a facility was film based, near filmless, or filmless. Analyses were done for each of the 7 modalities separately. The significance of these differences was determined using a *t*-test. Because some categories had a small number of facilities and concern that outliers may skew the means, we also compared median values between these groups using the Mann-Whitney U test (a nonparametric procedure). The remainder of the analyses focused on general radiography procedures. The demographic profile groups were stratified according to facility type, geographic area serviced, and bed numbers (for hospitals). The mean and median procedures per FTE were calculated. Comparison also was made based on the presence of a technologist training program. The significance of these differences was determined using a *t* test. For those facilities with an operational PACS, the timing of PACS implementation also was assessed to determine whether it had any effect on technologist productivity. Facilities with PACS deployment before 2001 were compared with facilities with PACS deployment after 2001. The mean number of procedures per FTE was calculated. The significance of this difference was determined using a *t* test.

Table 1. Technologist Productivity for Diagnostic Radiography Examinations: Comparison of Demographic Profile

Facility	Mean
Type	
University hospital	3,240
Community hospital	3,022
Outpatient imaging center	2,799
Hospital size	
<100 beds	2,818
100 to 200 beds	3,070
200 to 300 beds	3,129
>300 beds	3,135
Area Serviced	
Urban	3,197
Metropolitan	3,251
Rural	2,900

RESULTS

A number of factors should be considered when trying to determine the primary and secondary variables affecting technologist productivity. Table 1 provides information about technologist productivity within a number of

Table 2. Association of Information Technologies with Technologist Productivity: Combined Data for General Radiography Examinations

	Yes		No			
Technology	Mean	Median	Mean	Median	*t* Test	*P* Value
HIS	3,108	3,000	2,608	2,434	2.27	.07
RIS	3,100	2,930	2,956	3,062	2.28	.07
HIS-RIS	3,171	3,029	2,713	2,641	1.64	.12
HIS-RIS with modality worklist	3,217	3,188	2,984	2,879	1.09	.29
PACS	3,335	3,184	2,937	2,848	1.80	.08

Note. Technologist productivity is defined as the number of examinations per year per technologist, working 40 h/wk, 50 wk/yr.

demographic profile groups including facility type, hospital bed number, and service area. Not surprisingly, technologist productivity was highest among larger (in excess of 300 beds), university, and metropolitan hospitals. There is a linear relationship between hospital bed number and technologist productivity, with mean productivity measures (annual examinations per technologist FTE) for general radiographic studies ranging from 2,818 to 3,135. A similar trend is evident when correlating facility type with technologist productivity, as one compares outpatient imaging centers with community and university hospitals. A negligible difference is observed when comparing more heavily populated urban and metropolitan service areas. However, as population density decreases, such as in rural service areas, technologist productivity decreases as well. An additional factor to consider when evaluating technologist productivity is the presence or absence of a technologist training program. In our survey population, approximately two thirds of respondents reported technologist training programs within their facility. In those facilities with a technologist training program, productivity measures were higher (3,156 examinations per FTE) than in those institutions without training programs (2,563 examinations per FTE).

When evaluating technologist productivity as a function of technology implementation, several interesting observations can be made regarding general radiography (Table 2). The implementation of an HIS and RIS alone, as well as in combination, was associated with improved measures of diagnostic technologist productivity. This association approaches statistical significance ($P = .07$). In those facilities that had an integrated HIS-RIS, the median number of examinations per technologist FTE was 14.7% higher (2,641examinations per technologist FTE without HIS-RIS to 3,029 examinations per technologist FTE with an integrated HIS-RIS). This increased diagnostic technologist productivity seems to have been enhanced further in those facilities with modality worklist capability, which was associated with an increased number of examinations per technologist FTE (3,188). Implementation of PACS interfaced to a diagnostic modality such as computed or direct radiography also was associated with improved technologist productivity, with reported productivity comparable with those facilities that reported use of a HIS-RIS and modality worklist. The increased technologist productivity observed with PACS implementation also approached statistical significance ($P = .08$)

When evaluating the relationship between technology implementation and hospital size, several interesting trends are observed. Implementation of HIS-RIS again is associated with increased technologist productivity (for general radiographic examinations) for all sized hospitals. For large, medium, and small-sized hospitals, mean technologist productivity measures (examinations per FTE) are 2,753, 2,823, and 2,541, respectively. Comparable values for institutions without HIS-RIS are 2,100, 2,747, and 2,161, respectively. Implementation of modality worklist and PACS was found to have an incremental positive effect on technologist productivity only in large hospitals. For large hospitals, mean technologist productivity measures increase from 2,753 to 3,007 to 3,149 examinations per FTE, as modality worklist and PACS are added to HIS-RIS. The addition of

Table 3. Timing of PACS Implementation: Effect on Diagnostic Radiography Technologist Productivity

Time of PACS Acquisition	Mean	Median	*t* Test	*P* Value
≥1 year PACS experience	3,411	3,245	3.61	.004
<1 year PACS experience	2,497	2,540		

modality worklist and PACS does not appear to have any synergistic effect on technologist productivity at medium-sized hospitals. In medium-sized hospitals, mean technologist productivity measures were strikingly similar for HIS-RIS alone (2,853 examinations per FTE), HIS-RIS with modality worklist (2,816 examinations per FTE), and those with a PACS (2,736 examinations per FTE). The effect of PACS implementation on general radiographic technologist productivity in small hospitals could not be assessed in the survey because of the small number of these facilities with PACS in operation ($n = 4$).

In our survey sample of facilities with PACS, significant differences were observed when correlating the time of PACS acquisition with technologist productivity measures (Table 3). The median measure for diagnostic technologist productivity in facilities without PACS was 2,848 examinations per technologist FTE. The comparable figure for facilities acquiring PACS during 2001 (ie, PACS in operation less than one year), was 2,540 examinations per technologist FTE, which represents a decrease in technologist productivity of 10.8%. This relationship between conventional and PACS-based facilities, however, was reversed when evaluating those with PACS implemented before 2001 (ie, PACS in operation in excess of one year). Those facilities had a technologist productivity level of 3,245 general radiographic examinations per technologist FTE. This latter figure represents productivity increases of 13.9% above "non-PACS" sites and 27.8% above those PACS facilities with less than one year's experience with the system. These technologist productivity differences among PACS sites with varying degrees of experience were highly significant, with $P = 0.004$.

DISCUSSION

One of the compelling questions facing medical imaging practitioners in the current digital environment is, "what impact do information systems and PACS have on overall technologist performance?" In the first report of this 3-part series,[1] we observed that implementation of these digital technologies does not appear to affect technologist staffing. Similar technologist staffing shortages exist for medical imaging departments, regardless of whether they are film based or filmless in operation. The same survey data, however, do suggest a positive association between implementation of information systems and PACS technologies on technologist productivity. One must be wary of assuming that adoption of these technologies, themselves, will translate into instantaneous productivity gains. The timing of PACS implementation as well as workflow optimization play important roles in determining changes in technologist productivity. Many facilities make the mistake of operating in a manner similar to their modus operandi with film-based operation and merely replace film with digital radiography. Redesign of departmental and enterprise-wide workflow is essential if one is to realize the full potential in productivity gains after transitioning to filmless operation. These factors have important economic implications for administrators looking to cost-justify PACS implementation.

In addition to technology adoption, a number of demographic variables contribute to technologist productivity, as illustrated in Table 1. Facility type and overall size both have an observed effect on technologist productivity in the performance of general radiographic examinations. In our survey, large university hospitals had the highest levels of technologist productivity. This correlates with recently published AHRA survey results.[6] Technologist productivity measures decrease as one moves from larger academic facilities based in the major metropolitan areas to smaller community-based hospitals and outpatient imaging centers. The relationship between demographic profile and technologist productivity is believed to be multifactorial. One of the contributing factors is the differential rate of technology implementation among the demographic profile groups. The larger academic facilities tend to be early adopters of digital technologies and have higher rates of HIS, RIS, and PACS implementation.

At the same time, these larger academic institutions have additional student and support staff to assist technologists. RT training programs tend to be more prevalent in larger hospitals, and this provides technologists with a supply of unpaid labor to assist them with many of their responsibilities. Larger facilities also have a broader array of support staff (radiology aides, nurses, transport personnel, scheduling clerks, and intravenous catheter technicians) for assistance. Technologist responsibilities are quite variable and often include a number of nontechnical functions such as scheduling, data access, patient preparation, retrieval of comparison studies, and patient transport. The addition of these support staff has the potential to enhance technologist productivity by allowing technologists to focus the majority of their time and efforts on examination performance.

Other factors are also believed to play a role in the differential productivity measure observed among the demography profile groups. Larger facilities tend to have fewer episodic fluctuations in examination volumes than smaller hospitals or outpatient imaging centers. The longer queue of patients in larger facilities often is because of larger volumes of emergency room, in-house, and clinic patients. This results in a more predictable continuous flow of patients having general radiographic studies and less technologist downtime.

Regardless of the efficiency of the technology, technologist productivity will be adversely affected by downtime, and, the ultimate goal for any administrator is to maintain continuous examination volume to minimize this phenomenon. Another potential factor that contributes to technologist productivity in a larger, academic facility is the patient population. Although these patients tend to be less ambulatory than their counterparts in community hospitals and outpatient imaging centers, they often have multiple general radiographic examinations at a single time. Because a large percentage of examination time is spent in patient preparation and transport, the ability to perform multiple examinations on a single patient has the potential to enhance a given technologist's productivity. This is especially true for technologists working in a trauma center, where patients commonly undergo 6 or more general radiographic examinations at a time (chest, abdomen, pelvis, cervical/thoracic/lumbar spine, and extremities as needed).

The impact of information technologies on technologist productivity is addressed in Table 2. A positive association between implementation of information technologies and productivity (that borders on statistical significance) was observed with implementation of HIS and RIS. The fact that these relationships do not quite fulfill standard criteria for statistical significance may be largely because of the relatively small sample size, which is one of the major limitations of the study. However, even with this limitation, the data suggest that there is only a 7% likelihood that this observed increase in technologist productivity with HIS or RIS implementation could be explained by chance alone.

The interaction effects between information technology implementation and hospital size is only partly addressed in the survey data, largely because of relatively small sample sizes among the different groups analyzed. Interestingly, hospitals *without* these information systems reported negligible differences in technologist productivity for general radiographic examinations. Mean technologist productivity measures for large and small hospitals that do *not* have HIS/RIS and PACS are nearly identical. The mean number of general radiographic examinations per technologist FTE for large and small hospitals without HIS-RIS was 2,100 and 2,161, respectively. Similar measures for large and small hospitals without PACS are 2,204 and 2,291, respectively. When comparing different-sized hospitals that have adopted these technologies, a trend is observed that correlates hospital size with technologist productivity. This trend is best illustrated when comparing technologist productivity among different-sized institutions that have implemented HIS-RIS and modality worklist. Large hospitals in this group report mean technologist productivity of 3,007 examinations per FTE versus 2,354 for similar technology implementation within small hospitals. One possibility is that observed differences in technologist productivity among different-sized hospitals may partly be a reflection of the differential rates of information technology adoption. Large hospitals may have more experience with information technology than smaller facilities with similar systems, which may explain some of the differences in their respective productivity levels. Additional data collection is necessary to better delineate the interaction effects between hospital size, technology implementation, and technologist productivity.

The highest measures of technologist productivity were observed in the group of facilities that have implemented PACS. This group was heterogeneous in nature, largely because of the study definition of PACS. We defined PACS as at least 2 modalities with a shared electronic archive and interpreted using a computer workstation. This then encompassed a wide variety of implementations, ranging from a "mini-PACS," in which 2 cross-sectional modalities were filmless, to an enterprise-wide PACS, in which 100% of imaging studies were filmless. In spite of this wide diversity of types of implementations, the presence of a PACS was shown to be positively correlated with higher levels of technologist productivity. This relationship borders on statistical significance ($P = .08$).

A critical question raised by the survey is, "why are these information technologies associated with enhanced productivity?" The answer to this question centers on workflow and the operational efficiency gains realized when transitioning from paper/film-based to paperless/filmless operation.

Data collected at the Baltimore Veterans Affairs Medical Center (BVAMC) suggest that improvements in both lost examinations and retake rates can be achieved with the transition from film to a digital environment. The lost examination rate during film-based operation was 8% and subsequently decreased to 0.3% after the transition to a digital department.[11] At the same time, retake rates for general diagnostic examinations went from 5% during film-based operation to 0.8% using a combination of computed radiography and soft-copy interpretation.[8] This is believed to be the result of the combined effects of the wider dynamic range of computed radiography, coupled with the ability of radiologists to dynamically modify window/level settings at the computer workstation.

A number of workflow optimization software enhancements are available to augment technologist productivity by increasing system functionality and operational efficiency. One of these workflow enhancers is *modality worklist*, which allows for orders residing (most typically) in the HIS to be automatically distributed to various modalities where they can be accessed readily by technologists. After images are acquired at the local modality and reviewed for quality assurance purposes, they are transferred automatically to the enterprise-wide PACS. An additional software function, referred to as *performed procedure step*, electronically notifies the hospital information system that image acquisition has been completed. This can help avoid the additional time-consuming steps required for examination verification on the part of the technologist.

Use of modality worklist has been shown to significantly reduce errors in patient and examination identification and result in automatic and rapid entry of patient information. A study by Reiner et al[13] evaluated computed tomography (CT) transmission failure rates within a filmless imaging department. Before the use of modality worklist, study profiling failure rates for CT examinations were 8%, 69% of which was because of data entry error by technologists. With the advent of modality worklist software, these failure rates decreased by 56%, resulting in enhanced operational efficiency and CT technologist productivity. The automation of these processes performed by modality worklist and performed procedure step software reduces transfer error rates, improves workflow, and minimizes technologist fatigue.

Fatigue and stress seem to play a surprisingly important role in technologist productivity, a fact that has been largely ignored in the radiology literature. Previous reports in the film-based radiology literature[15,16] have suggested that as much as 20% of a technologist's examination time is attributable to fatigue and stress. After transition to filmless operation using computed radiography and PACS, technologists at the BVAMC reported reductions in perceived levels of stress and fatigue,[11,17] despite significantly improved productivity levels. This also is believed to be caused by a number of factors including decreased interruptions by

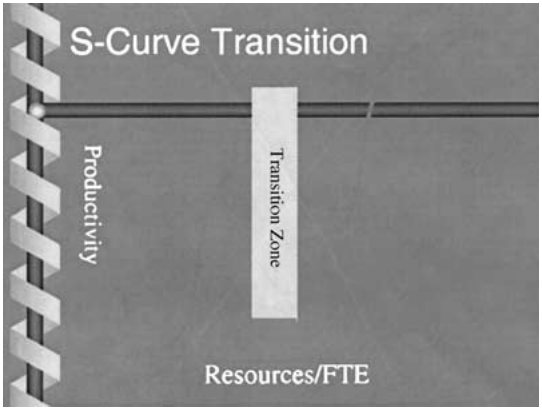

Fig 1. S-curve discontinuity. As one transitions between 2 different technologies, productivity undergoes an initial decrease during the zone of transition. Shortly thereafter, after the "learning curve" is completed, higher levels of productivity are realized for the same level of resources expended.

radiologists and clinicians, decreased retake rates, decreased requests for film copies, and elimination of film handling as well as processing and retrieval of old examinations. If filmless imaging is found consistently to reduce technologist stress levels, this would be likely to have a positive effect on productivity and staffing.

The amount of experience with PACS and soft-copy operation was found to have a significant impact on diagnostic technologist productivity in our survey as illustrated in Table 3. Productivity measures were found to decrease for the facilities that had recently acquired a PACS (less than one year of PACS experience), relative to those respondents without PACS. This trend reversed itself for those institutions with PACS in operation for greater than one year. These observations are consistent with the theory of S-curve discontinuity that explains productivity changes that occur on implementation of a new technology (Fig 1). The prior technology achieves a high steady state level of operational efficiency and productivity, after years of operation. Once a new technology is introduced (eg, PACS), a temporary decrease in productivity is observed as the facility adapts to the new technology, which equates to a learning curve. This period represents the zone of transition, and is to be expected during the initial phase of new technology implementation. Over time, with successful implementation and workflow optimization, higher levels of productivity are realized. A new steady state is reached with higher levels of productivity, surpassing those encountered previously with the prior technology. Whereas these S-curves and the zone of transition are unique for each institution, the overall trend is to be expected with any new technology implementation and can explain the observed initial drop-off in technologist productivity.

A number of other factors should be considered when explaining the interval decrease in technologist productivity immediately after PACS implementation. Most facilities implementing PACS do so in an incremental fashion, with a period of overlap between film-based and filmless operations. This creates a hybrid department, which by nature is inefficient and often duplicates technologist responsibilities. Another contributing factor has to do with the deployment and integration of digital technologies. Frequently, the information systems and PACS are purchased from 2 or 3 different vendors and can produce technical challenges in the integration. As a result, there is an appreciable delay in the interface between these technologies, resulting in a transient decrease in technologist productivity. Two major problems underlie this challenge in integrating digital information technologies. The first is the lack of implementation of information exchange functions (such as modality worklist) in most existing imaging systems along with a lack of support for this level of integration by many HIS-RIS systems in place today. The second impediment has been the lack of agreement among vendors as to the way in which existing standards are used.

The two most common standards used in this communication of patient and study information are the Digital Imaging and Communications in Medicine (DICOM) and Health Level Seven (HL-7). In spite of the near universal support for DICOM among modality vendors, many HIS-RIS vendors have provided limited DICOM support in their systems. As a result, many imaging providers (ie, technologists) have been unable to take full advantage of the workflow savings made possible by the implementation of the DICOM modality worklist function and performed procedure step. A recent initiative of the Radiological Society of North America (RSNA) and the Health Information Management Systems Society (HIMSS) has focused on increasing connectivity and systems integration, by bringing together imaging and HIS-RIS vendors. This initiative, known as Integrating the Healthcare Enterprise (IHE), already has resulted in the creation of a consensus among multiple vendors on the use of DICOM and HL-7 to communicate information between a modality, information system, and PACS.

The IHE initiative is likely also to facilitate communication between multiple PACS and HIS-RIS systems, which should allow improved collaboration and sharing of resources among multiple facilities. These ongoing efforts should provide improved system functionality and performance, resulting in improved productivity within the imaging department.

The published literature to date has been somewhat inconsistent in its assessment of how PACS implementation affects technologist productivity. Although several studies at the BVAMC have reported significant increases in technologist productivity after the transition to filmless operation,[8,9,11,17] this experience has not been universal. In fact, some studies report initial decreases in diagnostic technologist productivity after PACS implementation.[18-20] Some of the factors thought to contribute to this decrease in technologist productivity after the transition to filmless operation include (1) initial "learning period" associated with a new technology, (2) unexpected equipment downtime, (3) lack of a functional interface between PACS, RIS, and imaging modalities, (4) limited access of technologists to QA workstations.

It is interesting to note that a number of the same researchers who reported an initial decrease in diagnostic technologist productivity (after implementation of digital radiography and PACS), have subsequently reported increased technologist productivity on follow-up studies.[21,22] Many of the limitations of the systems present in the initial studies were subsequently alleviated, accounting for interval gains in operational efficiency and technologist productivity. At the same time, these published experiences may be indirect confirmation of the theory of S-curve discontinuity in the radiology domain.

CONCLUSION

This project has taken the first step in assessing the complex relationship that exists between technology implementation and technologist productivity within the imaging department. The preliminary analyses suggest that facilities that have implemented radiology or hospital information systems, digital radiography, and PACS tend to have greater technologist productivity than other facilities, especially during the first year after transition from film-based to filmless operation. There are however, numerous confounding variables that enter into this analysis, and further large-scale data collection will be needed to further understand the complex relationship that exists between the implementation of hospital and radiology information and imaging systems and productivity.

Because of the rapid changes that occur in technology development and application, this data collection will require a dynamic approach that assesses changes both within and outside of a given facility. To accomplish this, a longitudinal study should be undertaken to attract a larger sample population for analysis. Many unanswered questions remain including:

1. What is the effective "learning curve" associated with implementation of PACS?
2. What overall effect does system functionality have on workflow and productivity within the imaging department?
3. To what degree does the timing and implementation strategy of PACS affect technologist productivity?
4. Does integration of multiple facilities into a single "virtual imaging network" have an impact on technologist productivity?
5. To what extent does the transition to a filmless environment affect technologist productivity for each individual imaging modality?
6. What is the economic impact of PACS implementation on personnel costs within the imaging department?
7. Is technologist productivity a "vendor neutral" proposition?

We anticipate that many of these questions will be addressed as data collection continues for this proposed 5-year longitudinal study. We encourage your active participation in this project and look forward to sharing more information with you in future publications.

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