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Productivity and Cost Assessment of Computed Radiography, Digital Radiography, and Screen-Film for Outpatient Chest Examinations

Katherine P. Andriole

An objective assessment and comparison of computed radiography (CR) versus digital radiography (DR) and screen-film for performing upright chest examinations on outpatients is presented in terms of workflow, productivity, speed of service, and potential cost justification. Perceived ease of use and workflow of each device is collected via a technologist opinion survey. Productivity is measured as the rate of patient throughput from normalized timing studies. The overall speed of service is calculated from the time of examination ordering as stamped in the radiology information system (RIS), to the time of image availability on the picture archiving and communication system (PACS), to the time of interpretation rendered (from the RIS). A cost comparison is discussed in terms of potential productivity gains and device expenditures. Comparative results of a screen-film (analog) dedicated chest unit versus a CR reader and a DR dedicated chest unit show a higher patient throughput for the digital systems. A mean of 8.2 patients were moved through the analog chest room per hour, versus 9.2 patients per hour using the CR system and 10.7 patients per hour with the DR system. This represents a 12% increase in patient throughput for CR over screen-film; a 30% increase in patient throughput for DR over screen-film, which is statistically significant; and a 16% increase in patient throughput for DR over CR, which is not statistically significant. Measured time to image availability for interpretation is much faster for both CR and DR versus screen-film, with the mean minutes to image availability calculated as 29.2 ± 14.3 min for screen-film, 6.7 ± 1.5 min for CR, and 5.7 ± 2.5 min for DR. This represents an improved time to image availability of 77% for CR over screen-film, 80% for DR over screen-film, and 15% for DR over CR. These results are statistically significant ($P < .0001$) for both CR over screen-film and DR over screen-film but not statistically significant for DR over CR. A comparison of the digital technology costs illustrates that the high cost of DR may not be justifiable unless a facility has a steady high patient volume to run the device at or near 100% productivity. Both CR and DR can improve workflow and productivity over analog screen-film in a PACS for delivery of projection radiography services in an outpatient environment. Cost justification for DR over CR appears to be tied predominantly to high patient volume and continuous rather than sporadic use patterns.

KEY WORDS: Computed radiography, digital radiography, workflow, PACS assessment

CONSIDERABLE CONFUSION surrounds the choice of a system for acquiring digital projection radiographs in a picture archiving and communication system (PACS) environment. Is an investment in computed radiography (CR) and/or digital radiography (DR) worthwhile, or is continued use of conventional screen-film methods more appropriate? This study presents an objective assessment and comparison of CR versus DR and screen-film in terms of workflow, technologist productivity, overall speed of service, and potential cost justification for imaging the chest in ambulatory patients.

At the University of California at San Francisco (UCSF) Ambulatory Care (Outpatient) Center (ACC) an outdated chest x-ray room needed to be replaced. A DR dedicated chest unit was purchased in anticipation of achieving the improved radiology workflow and speed of service reported at other institutions.[1–3] The workflow and productivity of the two types of dedicated chest imaging systems at UCSF (a

From the Department of Radiography, University of California at San Francisco, San Francisco, CA.

Correspondence to: Katherine P. Andriole, Associate Professor, Department of Radiology, University of California at San Francisco, 505 Parnassus Ave., Box 0628, San Francisco, CA 94143-0628; tel: 415-476-3924; fax: 415-502-3217; e-mail: kathy.andriole@radiology.ucsf.edu

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DR device and a conventional screen-film device) were compared for delivery of projection radiography services to ambulatory patients.[4]

A similar situation existed in our outpatient services–only community medical center at Mt Zion, where a CR reader was purchased to update projection x-ray imaging there. After installation and technologist training on the new device, an objective assessment was performed for the multipurpose CR scanner. These results were compared with those for the two types of dedicated chest units (analog versus digital).[5] This study extended our previous work to include a comparison among three projection radiography modalities, CR, DR, and screen-film.

Findings from both studies showed an improvement in workflow and productivity for the digital modalities over analog screen-film. Similar results were shown in a study by Reiner and Siegel.[6] A study by Dalla Palma et al[7] compared the operating and investment costs of a conventional radiographic system and a CR device for one year's worth of chest and skeletal x-ray examinations. They noted that although the digital radiography system had a much higher investment cost than the conventional system, the operating costs and the total costs, including the variable, technology, and labor costs of CR could be lower. Note that film was used as the output device for both the analog and digital methodologies. Therefore, the time to reach a break-even point varied depending on the size of film used. The investigators found that if 8'' × 10'' film could be used for the x-ray examinations, a break-even point would be achieved after one year accounting for 10,000 studies. However, if 11'' × 14'' film was used, a break-even point would not be reached until 30,000 examinations were performed.

Because others investigators have shown the cost benefits of digital technology over analog screen-film, the present study addresses the comparative costs of the two digital modalities, namely CR versus DR, for performing a two-view upright chest examination. In this examination of cost, image interpretation takes place in a soft-copy reading environment, which eliminates the costs associated with the printing and management film. Cost assessment is based on the productivity measures determined in the workflow experiments and on device expenditures.

MATERIALS AND METHODS

Two outpatient settings were used for comparison of the three projection radiography modalities. These included the UCSF Ambulatory Care Center, which performs an average of 50 upright chest x-ray examinations per day, and the Mt Zion Community Hospital, which performs an average of 30 such examinations per day. The Ambulatory Care Center received the DR chest unit, and the community hospital received the multipurpose CR reader.

At UCSF, and including Mt Zion, a full departmental PACS is in place, with Web-based enterprise wide distribution to specialty referring clinicians and locations outside the Department of Radiology. These outpatient environments have been one of the last areas in the UCSF health care enterprise to go to digital image acquisition and display. The investment in digital projection radiography, as well as the deployment of a Web distribution and display application, has enabled further reduction in film printing and management costs for delivery of diagnostic imaging services to clients outside the Department of Radiology.

The analog device compared in this study was the Picker International, Cleveland, OH, which is now Philips Medical System, Bothell, WA) VTX650 Chest Unit attached to a Kodak (Rochester, NY) RP X-omat processor (Fig. 1). The distribution procedure followed for the analog device for the productivity and timing experiments was as follows. Once the film was processed, the technologist delivered the study to the film library where a film librarian delivered the film jacket to the chest reading room, recording the time of delivery. Images were interpreted on a traditional film alternator.

The DR device compared in this study is a General Electric (Milwaukee, WI) Digital Radiographic XQ/I Chest System (Fig. 2). It consists of an amorphous silicon flat panel detector with a cesium iodide scintillator. The CR reader is a Fuji (Stamford, CT) SmartCR. Both systems are integrated fully with the UCSF departmental PACS (Agfa Medical, Ridgefield Park, NJ), and the radiology information system (IDXRad, Burlington, VT) giving them modality worklist link features for automatic association of patient demographic information with image data. Both also have digital imaging and communications in medicine (DICOM) autosending capabilities. Primary diagnostic interpretations were read soft-copy on dual-headed workstations with high-resolution (2.5 K × 2 K), high-brightness monitors.

All technologists were adequately trained on the new digital devices, and all had several months of experience before initiation of study measurements. The following four measurements were made for all three devices: patient throughput, image availability, workflow/ease-of-use, and reliability. Patient throughput was measured as the time a patient entered the chest procedure room subtracted from the time that patient exited the room. A measure of productivity was calculated as the rate of patient throughput expressed as the number of patients moved through the room per hour. Image availability reflecting speed of service

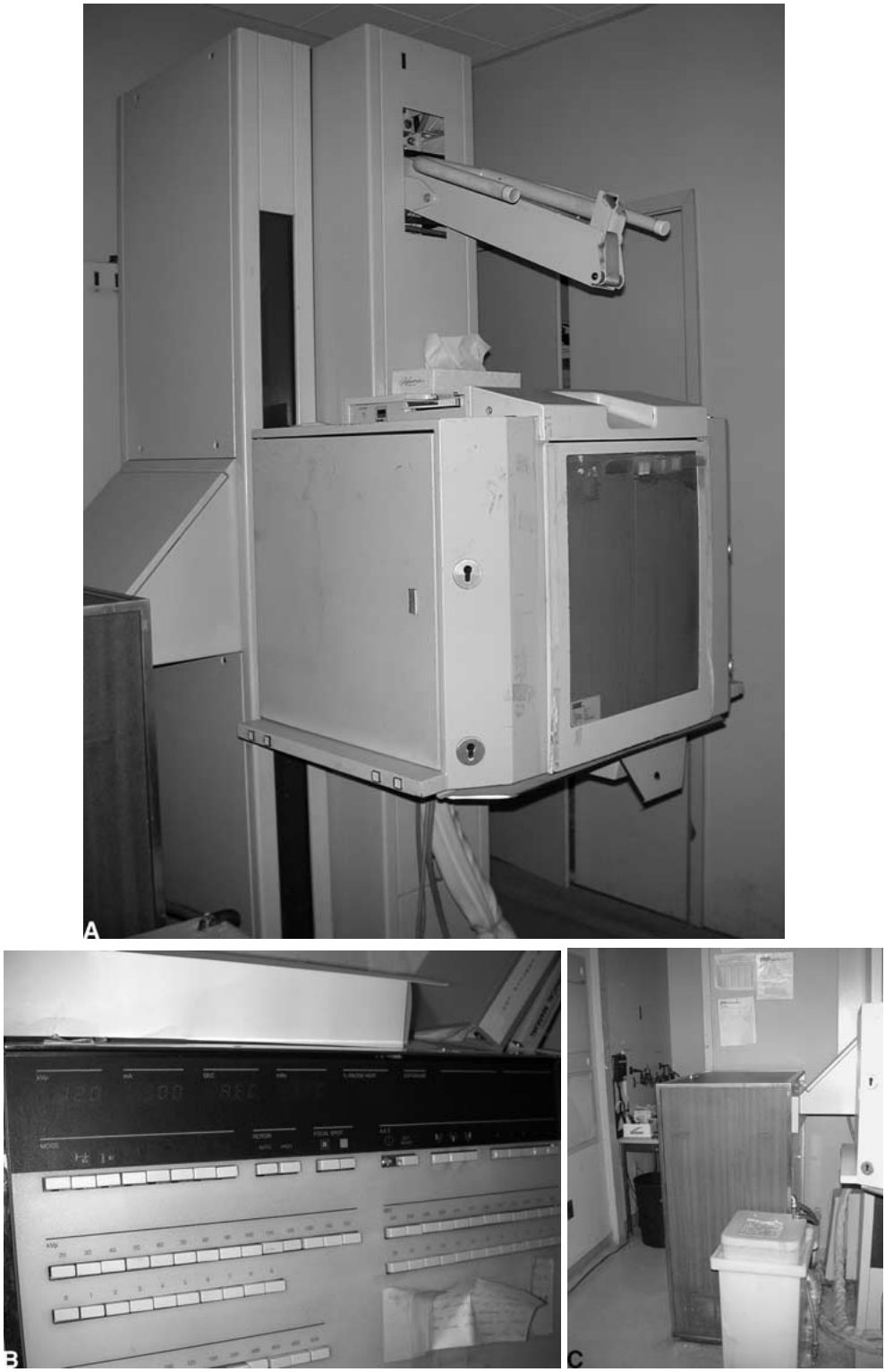

Fig 1. The analog device examined in this study including the upright chest unit, the control console, and the film processor.

Fig 2. The DR device examined in this study including the upright chest unit, the RIS-linked control console, and a dual monitor, high-resolution display workstation.

was measured as the time a patient entered the chest procedure room subtracted from the time the imaging examination was available in the reading room. For the digital devices, image availability time was measured directly from the PACS database.

Workflow, ease of use, and reliability assessments were made from a technologist opinion survey in which the technologists were asked to rate the overall speed, performance, ease of use, and reliability of either CR or DR versus screen-film, using the following scale: −2, film much better than digital; −1, film better than digital; 0, film and digital the same; +1, digital better than film; +2, digital much better than film. Any device malfunctions were noted via the technologist opinion survey.

Table 1. Comparative Results of Performance for Screen-Film (analog) and DR-Dedicated Chest Units and a CR Device in Terms of Average Patient Throughput and Average Time to Image Availability for Interpretation

				% Improvement (*P* Value)		
	Analog	CR	DR	CR *vs* Analog	DR *vs* Analog	DR *vs* CR
Patient throughput (# per hour)	8.2	9.2	10.7	12% *P* = .2296	30% **P = .0394**	16% *P* = .0615
Image Availability Average minutes ± SD	29.2 ± 14.3	6.7 ± 1.5	5.7 ± 2.5	77% **P < .0001**	80% **P < .0001**	15% *P* = .2068
Range availability (minimum, maximum)	(13, 52)	(5, 13)	(2, 10)			

NOTE. Patient throughput is expressed as the average number of patients entering and leaving the Radiology Department per hour. Statistically significant results are in bold.

Measurements were taken over 2-week periods for the analog and digital systems, spanning approximately 500 chest examinations per period. Measurements were made throughout a typical workday and workweek, covering periods of constant activity as well as sporadic activity. All studies included in the analysis were two-view upright chest examinations. Statistical analysis was performed individually, calculating two-tailed *P* values using an unpaired *t* test.

The cost comparison is done for CR versus DR only, with soft-copy image interpretation and digital delivery and archival. Thus, in this assessment, the costs associated with film printing and management are considered negligible for both modalities. The factors considered in the approximation of cost include equipment purchase, device infrastructure costs, space, power, and maintenance, balanced against device productivity and performance.

RESULTS AND DISCUSSION

Comparative results of patient throughput and time to image availability for interpretation for screen-film (analog), CR, and DR are shown in Table 1 and graphically presented in Figs. 3 and 4. Patient throughput is expressed as the average number of patients moved through the diagnostic room per hour. Time to image availability for interpretation is expressed as the mean time in minutes plus or minus the standard deviation. The range of time to image availability is also measured for each device and is expressed as the minimum and maximum times in minutes. The percent improvements in patient throughput, seen as an increase, and in time to image availability, seen as a decrease, also are given, comparing the screen-film or analog device with CR and with DR, and comparing CR with DR. The *P* values calculated for analog versus CR, analog versus DR, and CR versus DR for patient throughput and for time to image availability also are tabulated.

Note that patient throughput is higher for the digital systems. A mean of 8.2 patients were moved through the analog chest room per hour, and 9.2 patients were moved per hour using CR, versus 10.7 patients per hour for DR. This represents a 12% increase in patient throughput for CR over screen-film, a 30% increase in patient throughput for DR over screen-film, and a 16% increase in patient throughput for DR over CR. These results are only statistically significant for patient throughput measures for the DR device over analog screen-film with a *P* value less than .05 ($P = .0394$). The two-tailed *P* value calculated using an unpaired *t* test for the CR device over analog screen-film is $P = .2296$, and $P = .0615$ for DR versus CR, neither of which are statistically significant.

The measured time to image availability for interpretation was much faster for both CR and DR versus screen-film. Both CR and DR are statistically significantly faster than analog screen-film, with *P* values less than .0001. The mean minutes to image availability plus or minus the standard deviation were calculated as 29.2 ± 14.3 min for screen film, 6.7 ± 1.5 min for CR, and 5.7 ± 2.5 min for DR. This represents an improved time to image availability of 77% for CR over screen-film, 80% for DR over screen-film, and 15% for DR over CR. The two-tailed *P* value calculated using an unpaired *t* test for the DR device over CR is not statistically significant, with a *P* value of .2068.

As can be seen from the large standard deviation in image availability measurements for

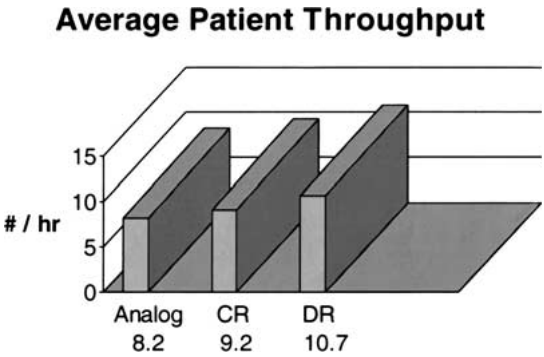

Fig 3. Graphical results of performance for screen-film (analog) and digital radiography (DR) dedicated chest units, and a computed radiography (CR) device, in terms of patient throughput. Patient throughput is expressed as average number of patients imaged per hour.

screen-film, the range of times from minimum to maximum for the analog device was 13 min–52 min. Both CR and DR exhibit much less variability, with CR ranging from 5 min to 13 min and DR ranging from 2 min to 10 min.

Fifteen x-ray technologists with experience on either CR or DR unanimously preferred the digital modalities over the film-based system. The technologists rated the DR system as "Much Better" (+2) than film for all areas (including speed, performance, and ease of use) except for reliability, for which the average rating was +1.7, or between "Better" and "Much Better" than film. Interestingly, the only reported device malfunction was with the DR system. Similarly for CR, technologists rated it "Better" to "Much Better" (+1 to +2) for all categories.

A number of broad assumptions are made in the following cost justification discussion comparing CR with DR. The first approximates the costs associated with film printing and film management to be zero (and equivalent) for the two modalities because image interpretation, delivery, and archival are all done digitally. Since file sizes are roughly the same for CR and DR and both are DICOM-compatible formats, PACS infrastructure costs for network transmission, image archival, and display will be considered equal.

Power and space also will be taken as equivalent, although one could argue that siting costs are higher for DR, particularly considering that a DR device is tied to one room and may require x-ray tube and generator replacement costs, whereas one CR reader can be used to service multiple rooms simultaneously and can be used with existing x-ray tubes and generators. Finally, an approximation of equivalence will be made in equipment maintenance for both devices even though service contracts typically are a percentage (between 8% and 14%) of the original equipment list price. It could be argued that consumable costs in terms of the imaging plates (at approximately $500 per pair of 14" × 17" plates) are higher for CR. However, DR detector "glassware" replacement, often not included in maintenance contracts, can cost between $85,000 and $145,000.

The charges for a two-view upright chest examination are the same regardless of whether the images are obtained with CR or DR. The approximate charge at UCSF is $200 per examination, including a $130 technical fee and a $70 professional fee. Based on these general approximations, a discussion of cost justification between CR and DR simplifies as follows. Cost includes only that of the individual modality equipment, and comparative revenues include only that gained in productivity and performance.

The July 2002 issue of Advance for Imaging and Oncology Administrators lists current costs for the devices examined in this study as follows. The Fuji SmartCR lists for $95,000. The GE XQ/i DR Chest System costs from $360,000 to $425,000. Other CR devices can cost more at $125,000 for a Fuji 5501 single-sided upright chest reader, $195,000 for the Fuji 5501 speed suite (which includes an x-ray tube and generator), and $275,000 to $350,000 for dual-sided reading, energy subtraction, and other capabilities. Other DR devices list in the same range as the device used in this study. For example, the Hologic CR 1000C (Bedford, MA) is priced at $375,000, the Kodak CR5100 device (Rochester, NY) is priced at $350,000, the Philips Digital Diagnost VR (Bothell, WA) is priced between $520,000 and $620,000, and the Siemens Thorax FD (Malvern, PA) is in the range of $500,000. For the purposes of this discussion, the device cost for CR will be taken as $95,000 and the cost for DR will be taken as $395,000, for a differential of $300,000.

In comparing performance, if an imaging facility had the patient volume to operate the

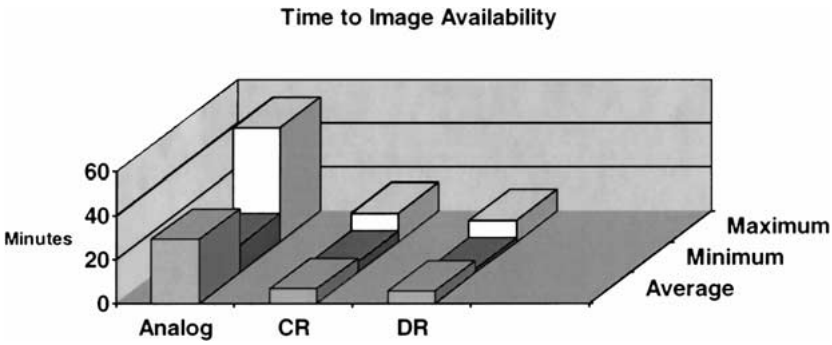

Fig 4. Graphical results for screen-film (analog) and digital radiography (DR) dedicated chest units, and a computed radiography (CR) device time to image availability for interpretation. Image availability is expressed as the mean time, with the range of times measured for each device expressed as the minimum and maximum times to image availability, all in minutes.

imaging device at 100% capacity, the following efficiencies would be possible:

- With CR
  9.2 patients/hour × 8 hours/day = **73.6 patients/day**
  × 250 workdays/year = **18,400 examinations/year**
  @ $200/examination = **$3.68 million/year.**
- With DR
  10.7 patients/hour × 8 hours/day = **85.6 patients/day**
  × 250 workdays/year = **21,400 examinations year**
  @ $200/examination = **$4.28 million/year.**

This results in a differential of $600,000 per year more with DR than with CR.

These calculations were repeated for operating each modality at 75%, 50%, and 25% device capacity. The volume of patients that could be imaged in a day, the number of examinations performed per year, the dollars generated per year, and the revenue differential per year for CR and DR at these device capacities are given in Table 2 and graphed in Fig. 5. It can be seen that to cost justify purchasing DR over CR, device capacity must approach 50% to "break even" with the cost differential of $300,000 in one year. This is equivalent to concluding that if an imaging facility has a patient volume of 42.8 patients per day, DR can be more cost effective than CR. In other words, if a facility has a continuous patient flow of at least 5.35 patients per hour, then DR may be costeffective.

Although this financial analysis is not rigorous and many assumptions have been made, the results do suggest that the increased produc-

Table 2. Performance Versus Cost Assessment

% Capacity	# Patients/h	# Patients/d	# Exams/yr	Yearly Revenues	Yearly Differential (DR over CR)
[100%.] CR	9.2	73.6	18,400	$3.68 Mil	$600,000
[100%.] DR	10.7	85.6	21,400	$4.28 Mil	
[75%.] CR	6.9	55.2	13,800	$2.76 Mil	$450,000
[75%.] DR	8.025	64.2	16,050	$3.21 Mil	
[50%.] CR	4.6	36.8	9,200	$1.84 Mil	$300,000
[50%.] DR	5.35	42.8	10,700	$2.14 Mil	
[25%.] CR	2.3	18.4	4,600	$0.92 Mil	$150,000
[25%.] DR	6.15	21.4	5,350	$1.07 Mil	

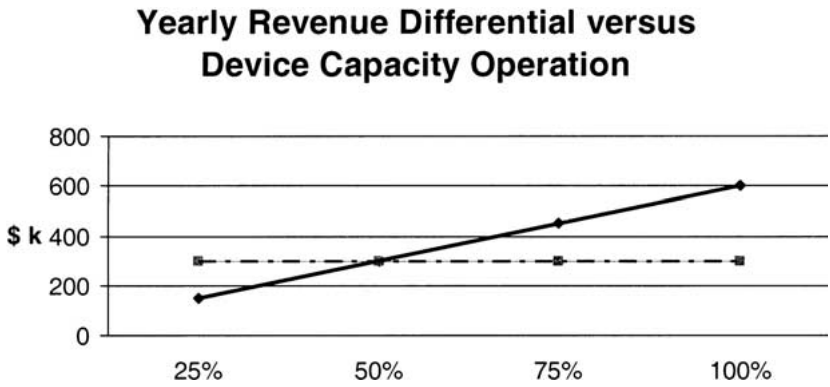

Fig 5. Performance versus revenue differential at various device capacities. The y axis has the yearly revenue differential achieved for DR over CR in thousands of dollars versus percent device capacity operation on the x axis. The dashed line shows the revenue differential at which DR is cost justified over CR. The point of intersection marks the capacity at which the yearly revenue differential cost justifies the purchase of DR over CR.

tivity in patient throughput achievable with DR over CR may not always be cost justifiable. For example, a setting with average to low volumes of roughly 40 patients per day or fewer, where the increased device capacity achievable with DR cannot be realized, there is no cost advantage. In contrast, CR may be cost justified with a relatively low volume of patients per day or a flow of 4.5 patients per hour.

CONCLUSIONS

Timing studies indicate that a DR dedicated chest device can increase patient throughput over CR in an outpatient environment performing two-view chest x-rays on approximately 50 patients per day, although the increased throughput is not statistically significant. Both CR and DR achieve higher patient throughput over screen-film. Thus, the patient can be released from the Radiology Department sooner with the digital modalities than with the screen-film system. In addition, the digital units are perceived by x-ray technologists to improve workflow, to be easier to use, and to be more reliable. In addition, the use of either CR or DR over screen-film can increase the overall speed of service from examination ordering to interpretation available in a PACS environment. Both CR and DR are comparable in this regard.

It appears that the use of DR for upright chest examinations is an excellent application of this technology. In a high-volume outpatient ambulatory care setting, DR can provide the most improved workflow and technologist productivity. The CR device also improves workflow over screen-film and can serve multiple x-ray rooms and be used for most general radiography studies, as well as the upright chest examinations.

It remains to be shown in a low-volume setting whether the increased technologist productivity can justify the high cost of DR over CR, particularly during periods of spurious rather than continuous patient flow. The time saved with DR systems may not currently justify the increased cost of DR over CR. Better service to referring colleagues by faster time to interpretation achieved with both CR and DR may be the more significant improvement in workflow. Faster release of patients from the Radiology Department achieved with DR may justify the cost for the high-volume imaging facility, however.

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