Radiology

Multi-institutional Analysis of Computed and Direct Radiography Part II. Economic Analysis[1]

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Abbreviations:
BVAMC = Baltimore Veterans Affairs Medical Center
CR = computed radiography
DR = direct radiography

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See also the other article by Reiner et al in this issue.

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PURPOSE: To compare economic aspects of equipment configurations, productivity levels, and patient waiting times in the performance of computed radiography (CR) and direct radiography (DR).

MATERIALS AND METHODS: The study received internal review board exemption status, without the need for informed patient consent. Data from four study sites were used to calculate the CR-DR crossover point (defined as the point at which the cost-effectiveness of DR equals that of CR) and CR-DR annual cost differentials. Analyzed variables included equipment and operating costs, examination volumes, and productivity. A program was developed to simulate patient arrival times, number of patient examinations, and patient waiting times on the basis of average annualized parameters for each of the four clinics. Sensitivity analyses were conducted to assess utilization rates and determine cost optimization. Utilization rates were compared with the number of excess long-stay CR patients (ie, patients who spent more than 30 minutes waiting in the radiology department prior to CR examination) and with the cost (per excess long-stay CR patient who waited more than 60 minutes) averted by using DR.

RESULTS: Excess annual costs for DR over CR at the four sites ranged from $50 757 to $75 303. At extrapolated levels of economic penalties for long waiting times, the crossover point at which the DR cost became justifiable was when CR capacity utilization rates approached or exceeded 80%.

CONCLUSION: In the current practice environment, with capacity utilization rates well below 80%, CR is likely to be a more cost-effective technology for the majority of general radiography providers.

Evolutionary forces that currently affect medical imaging are changing the nature of radiographic work more rapidly than ever before. Although technologic expansion is evident throughout the medical disciplines, no area is more affected than radiology, which from its earliest days has been technology driven (1). Over the past decade, a technologic expansion has enabled a transition from film-based to filmless operation within many imaging departments, through the implementation and integration of information systems, picture archiving and communication systems, and digital image acquisition systems. One of the last imaging modalities to undergo this digital transformation is general radiography (excluding mammography and fluoroscopy), which continues to account for 65%–70% of all imaging examinations (2). Although computed radiography (CR) was available for general radiographic use early on, most departments have taken an incremental approach to implementing the transition to filmless imaging and have addressed the cross-sectional modalities first. Two primary options for digital radiography are currently available: CR (mainly with cassette-based imaging systems) and direct radiography (DR) (with cassetteless systems). To date, most publications that have looked at productivity and economic differentials in modern radiographic practice have focused on differences between screen-film imaging and digital radiography (either CR or DR) without directly comparing CR with DR (3–6).

In the current climate of fiscal responsibility, quantitative accountability is essential both for cost justification and for the selection of new technologies (7). Health care organizations must address a number of clinical and economic issues to optimize capital expenditures and patient outcomes (8). In the end, however, each institution must make decisions about technology implementation that are based on its unique resources, challenges, and clinical expectations—with the support of available data from the experiences of others in the field. Thus, the purpose of our multi-institutional study was to compare economic aspects of equipment configurations, productivity levels, and patient waiting times in the performance of CR and DR.

MATERIALS AND METHODS

Because economic productivity was the primary subject of investigation and no patient data were collected, the external review committees at the University of Maryland Medical Center and the Baltimore Veterans Affairs Medical Center (BVAMC), Baltimore, Md, determined that the study had internal review board exemption status and that informed patient consent was not needed. Three other sites in the study also were included in this exemption.

The study was partially supported by an industry research grant from Fuji Medical Systems USA, Stamford, Conn. However, the authors monitored all data collection and analysis and prepared the results for publication.

The study was designed and coordinated by researchers from BVAMC, with the cooperation of radiologists, radiologic technologists, and technician assistants at BVAMC and three other clinical institutions in the northeastern and middle Atlantic United States. A data coordination and statistical analysis center was established at BVAMC. Data were collected over a 6-month period that varied from site to site.

Research sites included BVAMC; the Memorial Sloan-Kettering Cancer Center, New York, NY; the Lahey Clinic, Burlington, Mass; and Westchester Medical Imaging Services, Hawthorne, NY. Detailed descriptions of the study sites, the varied technologies employed, and time-motion data collection and analyses are presented in the article about the first part of our study (9).

Study Assumptions

We developed several average annual parameters for each of the four clinics. These parameters are known to vary daily, weekly, and monthly. Before incorporating these summary measures into the sensitivity analysis, it was necessary to test them for their consistency. Two random one-third subsamples were drawn from the collected data, and their means were compared. No statistically significant differences were observed. Because we were able to check for internal variability within each clinic, the annualized parameters were sufficiently consistent to be used in our simulations.

Site-specific CR and DR mean examination times from our previous study (for two-view general radiographic examinations) were subsequently used for a multi-institutional economic analysis (9). In addition to these examination time measurements, additional site-specific empirical CR and DR data were incorporated into the economic analysis, including the mean daily number of examinations per room (hereafter, referred to as the examination volume), equipment purchase price and parts replacement cost, annual operating costs, and maintenance costs. This economic analysis is based on a number of assumptions, including the following: *(a)* an equipment lifetime for both CR and DR of 10 years, based on costs associated with "new room" configurations, including purchase price and installation; *(b)* an annual interest rate of 3%, with capital costs amortized with one payment made per year, at the end of each of the 10 years of equipment life (note that the 3% interest figure is a real interest rate rather than a nominal rate because we abstracted it from price inflation; thus, if the rate of price inflation were 5%, the corresponding nominal interest rate would be 8%); *(c)* the equivalence of personnel costs for CR and DR (assuming that one technologist is working in a single CR or DR room at any point in time); *(d)* the provision of services in a single CR or DR room for patients who arrive between the hours of 7:00 AM and 5:00 PM, Monday through Friday, for 50 weeks (250 days) in any given year; *(e)* the examination of every patient on the day on which he or she arrives; *(f)* the independence of patient arrival rates from the choice of technology (ie, CR vs DR); *(g)* the examination was not scheduled ahead of time but was performed on an as-needed basis; *(h)* an economic penalty is incurred when a defined critical per-patient waiting time (eg, 30 or 60 minutes) is exceeded (such a penalty could result from patients leaving before they were served, reduced future referrals, or excess costs due to technician overtime labor to serve all patients); *(i)* equivalence of equipment downtime for CR and DR, with no effect on patient throughput; *(j)* variation in the total number of patients arriving each day, with a Poisson distribution of the daily numbers (10–12); *(k)* variation in rates of patient arrival within each day, with fractions of patients arriving in various 2-hour periods as follows: 7.64% of total daily patients between 7:00 and 9:00 AM, 27.53% between 9:01 and 11:00 AM, 23.29% between 11:01 AM and 1:00 PM, 25.28% between 1:01 and 3:00 PM, and 16.26% between 3:01 and 5:00 PM (these percentages were chosen on the basis of empirical and unpublished data about time-of-day variations in patient arrivals at BVAMC; within each 2-hour period, patients were assumed to arrive at evenly spaced intervals); *(l)* an examination retake rate of 0.8% for both CR and DR (13), with retakes accounted for with increases of 0.8% in the respective CR and DR mean examination times at each site; *(m)* the same allocation of space and staff to equipment for both CR and DR; and, as a result, *(n)* no differences in space requirements, labor requirements, and overhead costs between CR and DR.

Capacity Calculations

Individual CR and DR equipment capacities were calculated for each study site on the basis of the measured mean examination times, the assumed retake rate, and a 10-hour regular working day. These theoretical CR and DR equipment capacities were then compared with mean daily examination volumes to calculate the actual CR and DR capacity utilization rate at each site (the number of daily examinations actually performed per room, divided by the theoretical equipment capacity). Note that capacity utilization, in this definition, is abstracted from capacity constraints that may occur elsewhere in the service delivery process (eg, in patient registration). Because we focused specifically on the equipment technology choice while holding other factors constant, this definition was appropriate.

TABLE 1
CR-DR Cost Differential and Characteristics at Four Sites

Cost Parameter	Lahey Clinic	MSKCC	WMIS	BVAMC
CR				
Equipment cost	80 000	80 000	172 000	200 000
Annualized equipment cost*	9378	9378	20 164	23 446
Annual service contract cost	6400	6400	13 760	16 000
Examination time (sec)	520	258	523	348
Patient capacity per day†	69	138	68	103
DR				
Equipment cost	440 000	360 000	440 000	360 000
Annualized equipment cost*	51 581	42 203	51 581	42 203
Annual service contract cost	39 500	48 000	39 500	48 000
Examination time (sec)	272	153	347	126
Patient capacity per day†	131	233	103	283
Annual cost differential (DR − CR)	75 303	74 425	57 157	50 757

Note.—All costs are in U.S. dollars. MSKCC = Memorial Sloan-Kettering Cancer Center, WMIS = Westchester Medical Imaging Services.
* Assuming 3% interest rate and one annual end-of-year payment yearly for 10 years.
† Based on examination time (multiplied by the retake factor) and 10 hours of operation.

TABLE 2
CR and DR Utilization Rates at Four Sites

Utilization Parameter	Lahey Clinic	MSKCC	WMIS	BVAMC
Mean daily room examination volume	21	34	25	29
CR capacity	69	138	68	103
DR capacity	131	233	103	283
Implicit CR utilization rate (%)	30.4	24.6	36.8	28.2
Implicit DR utilization rate (%)	16.0	14.6	24.3	10.2

Note.—MSKCC = Memorial Sloan-Kettering Cancer Center, WMIS = Westchester Medical Imaging Services.

Arrival Rate

To describe the relationship between examination volume, theoretical capacity, and number of "long-stay" patients, assumption *k* was used, along with site-specific examination times (included the time for retakes), to generate site-specific and modality-specific listings of patient arrival and waiting times for each daily patient arrival rate between 40 and 200. Long-stay patients were defined as those who remained in the radiology department without examination for longer than an assigned acceptable waiting period (either 30 or 60 minutes). The range of 40–200 daily patient arrivals per examination room was chosen because this is the range in which long-stay patients were theoretically possible. Rates above and below the 40–200 range made a negligible contribution to the expected number of long-stay patients, either because (at fewer than 40 daily arrivals) they implied capacity utilization rates with which backlogs would be virtually impossible or because (at more than 200 daily arrivals) the probability of such a high rate was essentially zero, even when the Poisson mean was set to the level of 100% of CR capacity.

The probability that any one of these daily arrival rates (in the range of 40–200) would actually occur on a single day was then computed for specified levels of the mean daily arrival rate by using the Poisson distribution (assumption *j*). Applying this probability to the number of long-stay patients for each daily arrival rate, we then computed the mean number of long-stay patients corresponding to each mean daily arrival rate. This figure was then multiplied by 250 days to obtain the mean annual number of long-stay patients.

Comparison of Costs

The last step in our method was the calculation, for each site and each specified mean daily patient arrival rate, of the cost incurred per long-stay patient with CR that was not incurred with DR (ie, per excess long-stay CR patient). This cost was computed by dividing the difference between the annual capital and operating costs for DR and those for CR by the difference between the mean annual number of long-stay patients for CR and the mean annual number of long-stay patients for DR. The result of this calculation represents the lowest level of the economic penalty per long-stay patient that would economically justify the use of DR rather than CR. Finally, to make results more easily comparable across sites, we also computed the ratio of each specified mean daily patient arrival rate to the theoretical daily patient capacity at each site for CR units.

Statistical Analysis

Data were tabulated and basic calculations were performed by using spreadsheet software (Excel; Microsoft, Redmond, Wash). Poisson probabilities for the highest daily arrival rates were calculated by using statistical software (Stata, version 7; Stata Corporation, College Station, Tex).

RESULTS

Costs and Utilization Rate

The results of our calculations of annual (capital plus operating) costs showed that CR was less costly than DR at all four sites, with the cost differential ranging from $50 757 to $75 303 (Table 1). The large differences in equipment and operating costs at the four study sites indicate that the productivity advantages associated with DR can be obtained only at considerable expense. The actual CR and DR capacity utilization rates for the four study sites differed (Table 2). At the observed daily examination volumes per room, the range of CR capacity utilization rates was 24.6%–36.8%, compared with the implicit DR capacity utilization rate range of 10.2%–24.3%. BVAMC and the Memorial Sloan-Kettering Cancer Center, the sites with the shortest examination times, also had the lowest capacity utilization rates. The data also imply an unused CR capacity greater than 63% at all sites and an unused DR capacity equal to or greater than 75% at all sites.

Long-Stay Patients

The mean annual numbers of excess long-stay CR patients at each site were calculated on the basis of the mean daily arrival rates that corresponded to CR capacity utilization rates ranging from 58% to 98%. The mean numbers of daily patient arrivals at each site assumed for these calculations, and the corresponding CR capacity utilization rates, are shown in Table 3. By using these mean daily arrival rates and a long-stay criterion of a wait of at least 30 minutes, we calculated the mean annual excess number of CR long-stay patients at each site that corresponded to each level of CR capacity utilization (Table 4). Except at very high capacity utilization rates, the mean annual number of long-stay DR patients approached zero; thus, for most capacity utilization rates, the mean annual number of excess CR long-stay patients was equal to the mean annual number of CR long-stay patients. For all sites, the mean annual number of excess CR long-stay patients at a 58% capacity utilization rate was extremely small, ranging from 0.2 patient for the largest-capacity site (the Memorial Sloan-Kettering Cancer Center) to 17.3 patients for the smallest-capacity site (Westchester Medical Imaging Services) (Table 4). At capacity utilization rates below 58% at all sites, the mean number of CR long-stay patients rapidly approached zero and therefore was not included in the tables. As capacity utilization increased, the mean annual number of excess CR patients for whom the wait exceeded the defined 30-minute period increased gradually until the capacity utilization rate exceeded 73%. The rate of 73% represented an important point, after which the percentage of long-stay CR patients increased markedly.

When the time unit for analysis was changed from 1 year to 1 day, the CR capacity utilization rate had to reach 68%–72% before one long-stay CR patient (on average) could be expected within each working day, and an increase of 88%–194% over existing daily examination volumes was required at each of the four study sites. If the criterion for an acceptable waiting time was changed from 30 to 60 minutes, the CR capacity utilization rate had to be 74%–78% before the average of one long-stay CR patient per day was reached (see Table 5).

TABLE 3
Mean Daily Patient Arrival Rates for Various CR Utilization Rates

CR Utilization Rate (%)	Lahey Clinic	MSKCC	WMIS	BVAMC
58	40	80	40	60
63	43	87	43	65
68	47	94	46	70
73	50	101	50	75
78	54	108	53	80
83	57	115	57	85
88	61	122	60	91
93	64	129	63	96
98	68	136	67	101

Note.—Data are number of patient arrivals per day at the indicated utilization rate. MSKCC = Memorial Sloan-Kettering Cancer Center, WMIS = Westchester Medical Imaging Services.

TABLE 4
Mean Annual Number of Excess Long-Stay CR Patients (30-minute Criterion) for Various CR Utilization Rates

CR Utilization Rate (%)	Lahey Clinic	MSKCC	WMIS	BVAMC
58	13.5	0.2	17.3	2.1
63	59.8	5.1	74.3	22.5
68	293.0	66.0	245.9	148.7
73	748.3	463.9	862.9	645.4
78	1973.1	1964.4	1783.5	1968.1
83	3422.6	5479.4	3711.6	4478.0
88	5900.5	10 946.6	5564.6	8806.3
93	7921.3	16 990.7	7553.9	12 707.7
98	10 468.2	22 148.9	10 063.1	16 156.8

Note.—MSKCC = Memorial Sloan-Kettering Cancer Center, WMIS = Westchester Medical Imaging Services.

TABLE 5
Mean Annual Number of Excess Long-Stay CR Patients (60-minute Criterion) for Various CR Utilization Rates

CR Utilization Rate (%)	Lahey Clinic	MSKCC	WMIS	BVAMC
58	1.1	0.0	1.4	0.1
63	6.6	0.1	8.2	1.3
68	48.0	2.5	36.5	12.8
73	158.7	32.2	182.6	82.8
78	468.1	236.9	479.0	363.5
83	1207.6	1076.3	1321.0	1152.5
88	2638.9	3278.0	2382.6	3224.6
93	4126.1	7216.1	3805.0	5972.7
98	6455.6	12 335.9	6085.1	9311.8

Note.—MSKCC = Memorial Sloan-Kettering Cancer Center, WMIS = Westchester Medical Imaging Services.

Cost-effectiveness Crossover Point

The CR-DR crossover point for a defined 30-minute waiting time and the sensitivity of the DR-versus-CR choice to the CR utilization rates and economic penalty levels varied (Table 6). For example, if one assumes an economic penalty of $25 per long-stay patient, capacity utilization rates greater than 78% must be achieved to reach the crossover point. (Note that this economic penalty level equals the current Medicare technical reimbursement fee for a two-view chest radiographic examination.) At an economic penalty level of $50 per long-stay patient, utilization rates in excess of 73% must be achieved to reach the crossover point for cost-effectiveness.

The economic penalty level per long-stay patient would have to exceed $1000 for the DR crossover point to occur at CR capacity utilization rates below 63% for three of the four sites (Table 6). For a defined waiting time of 60 minutes (Table 7) and a $25 penalty level, the capacity utilization rate must exceed 83% before DR becomes economically preferable to CR. Here, justification of DR over CR at CR capacity utilization rates below 68%

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TABLE 6
Cost per Excess Long-Stay CR Patient (30-minute Criterion) Averted by Using DR

CR Utilization Rate (%)	Lahey Clinic	MSKCC	WMIS	BVAMC
58	5578.00	372 125.00	3303.87	24 170.00
63	1259.25	14 593.14	769.27	2255.87
68	257.01	1127.65	232.44	341.34
73	100.63	160.43	66.24	78.64
78	38.16	37.89	32.05	25.79
83	22.00	13.58	15.40	11.33
88	12.76	6.80	10.27	5.76
93	9.51	4.38	7.57	3.99
98	7.19	3.36	5.68	3.14

Note.—All costs are given in U.S. dollars. MSKCC = Memorial Sloan-Kettering Cancer Center, WMIS = Westchester Medical Imaging Services.

TABLE 7
Cost per Excess Long-Stay CR Patient (60-minute Criterion) Averted by Using DR

CR Utilization Rate (%)	Lahey Clinic	MSKCC	WMIS	BVAMC
58	68 457.27	NA	40 826.43	507 570.00
63	11 409.55	744 250.00	6970.37	39 043.85
68	1568.81	29 770.00	1565.95	3965.39
73	474.50	2311.34	313.02	613.01
78	160.87	314.16	119.33	139.63
83	62.36	69.15	43.27	44.04
88	28.54	22.70	23.99	15.74
93	18.25	10.31	15.02	8.50
98	11.66	6.03	9.39	5.45

Note.—All costs are given in U.S. dollars. MSKCC = Memorial Sloan-Kettering Cancer Center, NA = not applicable, WMIS = Westchester Medical Imaging Services.

would require economic penalties well above $1000 per long-stay patient.

DISCUSSION

Considerable confusion surrounds the digital radiography selection process, and most prospective customers must rely on unsubstantiated vendor claims as the sole source of data. The study reported by Andriole (14) is one of the few in which this controversial issue was addressed by means of a cost assessment of outpatient chest examinations with CR, DR, and screen-film radiography. The author concluded that the high cost differential between CR and DR was not outweighed by the productivity advantages inherent to DR and that cost justification of DR can be accomplished only in the setting of extremely high examination volumes with continuous work flow. In fact, patient arrival distributions within most imaging departments are episodic rather than continuous. The episodic nature of arrival distributions is not well documented in the medical literature and is frequently overlooked in economic analyses of imaging. However, we believe that it plays a critical role in the evaluation of capacity utilization rates.

Sack (15) found that a backlog of 6–10 patients was relatively common during peak hours of operation in the performance of general screen-film radiographic examinations. The primary factors were competing demands (from emergency room patients, outpatients, and inpatients) and inefficient work flow. It is noteworthy that most imaging departments (including the four participating sites in this study) do not electively schedule nonemergent general radiographic examinations. This policy can inadvertently decrease operational efficiency and increase the patient backlog. The net effect is greater variation, within the day and from day to day, in capacity utilization rates. Our data suggest that such variation may play a critical role in the economic analysis of CR and DR.

At all four sites in our study, the annual cost differential in favor of CR was more than $50 000. Over the anticipated 10-year equipment lifetime (and ignoring discounting), this represents a total cost differential ranging between $507 570 and $753 030. Although annualized equipment cost differences account for a substantial part of this disparity, a surprisingly large percentage (44.2%–63.0%) of the cost differential is accounted for by annual service and maintenance costs. (Note that the percentage would be slightly less if annual interest rates were higher. For example, an assumption of 6% rather than 3% results in a 10% increase in the overall annual cost differential, with all of this increase accounted for by the higher capital cost differential.)

Alternative assumptions can be made regarding the useful lifetime of the CR and DR units. If the expected lifetime is assumed to be less than 10 years, the annualized capital cost differential between CR and DR will increase, making DR even less cost effective. A longer equipment lifetime for both CR and DR will decrease the calculated cost differential, making DR more affordable. In the end, although capital costs for these technologies are an important consideration, service and maintenance costs are equally, if not more, important in the overall economic analysis.

Several interesting observations were made when we evaluated CR and DR capacity utilization rates. First, the existing room volume (the number of patients examined per room per day) at all study sites was low when compared with the room capacity. This is in large part a vestige of the "film bias" that plagues many departments that have undergone a transition to filmless imaging technologies. Administrators often elect to convert screen-film radiographic rooms to digital radiographic rooms on a one-to-one basis, without taking into account the improved technologist productivity afforded by digital radiography (4,5). On the basis of reported data, a film-to-digital radiographic room conversion ratio of 2:1 for CR and 3:1 for DR would be easily accommodated without increasing capacity utilization rates above 75%.

On the basis of our data and assumptions, a sharp transition point was noted when capacity utilization rates exceeded 70% for all sites. At a CR capacity utilization rate of 68%, the daily mean number of long-stay CR patients ranged from 0.3 to 1.2. At a slightly higher CR capacity utilization rate of 73%, the daily mean number of long-stay CR patients increased to 1.9–3.5. This modest 5% difference in the CR capacity utilization rate resulted in an increase of more than 190% in the number of long-stay CR patients.

These data have important consequences for technology selection. Unacceptable waiting times are likely to generate patient complaints that could result in a loss of future referrals. Some imaging centers might attempt to differentiate themselves from competitors by ensuring shorter waiting times. A busy outpatient imaging center in a major metropolitan service area could advertise "no charge" to patients who wait longer than 30 minutes. To make such an offer, the center would need to determine the existing and anticipated future capacity utilization rates. If the existing CR capacity utilization rate were 75% and the no-charge amount were $100 per long-stay patient, for example, our analysis suggests that DR would likely be the preferred technology. The same outpatient center operating at a capacity utilization rate of 35%, however, would save money by opting for CR. At the opposite end of the spectrum would be a facility that operates in a capitated environment with less economic incentive to achieve short patient waiting times. This facility might consider 60-minute patient waiting times acceptable and therefore might set a higher capacity utilization rate threshold of 90% before electing to choose DR over CR. A range of levels for economic penalty, then, are quite possible, and the form in which this penalty is incurred will vary among facilities.

The cost of averting longer waiting times with CR by switching to DR is closely related to CR capacity utilization rates. Expressed on a per-patient basis, this cost is extremely high at relatively low levels of CR capacity utilization, and the switch from CR to DR therefore could be justified only by an extremely high economic penalty level. With an illustrative penalty level of $25 (the Medicare technical reimbursement fee) for a defined waiting time of 30 minutes, the CR-DR crossover point occurs at a CR capacity utilization rate of approximately 83%. With a waiting time of 60 minutes, the crossover point occurs at an increased CR capacity utilization rate of approximately 90%.

Mayo-Smith et al (16) evaluated the financial impact of the use of general screen-film radiography in an outpatient center. The study reported an average overhead cost per examination of $49.80 compared with a Medicare global reimbursement fee of $38.69 per examination, with a resultant net average loss of $11.11 per examination, not counting physician costs. This study addressed the financial inequities that imaging providers currently face in the delivery of general radiographic services, where the two main remediative strategies are to decrease operational costs (through enhanced productivity) or to increase revenue (through increased volume and/or improved reimbursement). If reimbursement rates increased, this would have a small but favorable effect on the relative economic benefit of DR and decrease the capacity utilization rate at which the CR-DR crossover point occurs. If, for example, an increased reimbursement rate caused the economic penalty per long-stay CR patient to increase from $25 to $45, the CR-DR crossover point at the Lahey Clinic in our study would change from a capacity utilization rate of 83% to a rate just below 78%. This illustrates the fact that while multiple variables contribute to the calculated CR-DR crossover point, the capacity utilization rate is consistently one of the most important factors in the overall analysis.

A number of limitations in this study point to the need for additional research. Because of the stochastic nature of patient arrivals, additional empirical data collection is required at all study sites to quantify the relationship between variable inter- and intraday arrival rates and capacity utilization rates. Such analyses should provide additional insight into queueing, which has important implications for departmental work flow. Although attempts were made to quantify the lost-opportunity costs associated with prolonged patient waiting, these were somewhat speculative in nature and require more in-depth investigation, perhaps in the form of detailed sensitivity analyses and patient surveys. Because limited data are currently available with regard to equipment lifetime, equipment downtime, and retake rates, extrapolated figures were used for these analyses. Ideally, the availability of a combination of established manufacturer-provided and site-specific empirical data would provide a more accurate perspective on each site's experience.

As suggested by the results of the first part of our study (9), wide variations in work flow in different types of institutions form an important and integral component in the selection and successful implementation of new technologies. Although it is clear that optimized work flow will have salutary results for the cost-effectiveness of radiographic procedures, it remains to be seen whether these benefits would be greatest with CR or DR.

This study was deliberately limited in scope in that we focused only on single CR-DR rooms. Most hospital-based imaging departments have multiple general radiographic rooms and would therefore require multiple-room analyses that would consider not only the choice of CR or DR but the effects of combinations of the two. This would be particularly applicable to imaging departments with dedicated emergency or trauma radiographic rooms. It is clear that imaging departments that are planning a transition from screen-film to digital radiography should consider decreasing the number of rooms allocated to general radiography and should select technology on the basis of capacity utilization rates as well as the desired level of service to patients.

In conclusion, when performing a cost analysis of digital radiography, a number of important factors should be considered, including technologist productivity, equipment purchase and maintenance costs, examination volume, and capacity utilization. Technologist productivity advantages reported for DR are disproportionately offset by the associated higher costs of equipment purchase and maintenance. Our data suggest that the economic crossover point at which DR becomes more cost effective than CR is not reached until an extremely high capacity utilization rate (approximately 80%) is achieved. This finding does not reflect current practice in imaging departments, many of which operate at capacity utilization rates below 40%. Institutions planning to undergo a transition to filmless digital radiography should consider a range of economic and clinical variables when considering new technologies.

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