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Workflow Efficiency Comparison of a New CR System with Traditional CR and DR Systems in an Orthopedic Setting

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Workflow efficiency is a crucial factor in selecting computed radiography (CR) versus digital radiography (DR) systems for digital projection radiography operations. DR systems can be more efficient, but present higher costs and limitations in performing some radiographic exams. A newly developed CR system presents a good alternative with its faster line-by-line instead of pixel-by-pixel image plate-scanning technology and a more efficient workstation. To evaluate workflow characteristics, a time–motion study was conducted to compare radiographic exam times of the new CR system with traditional CR and DR systems in a high-volume orthopedic operation. Approximately 200 exams for each modality were documented from the moment when a patient entered the X-ray room to the moment when all images were sent to the PACS archive using a timer and speech-recognition software. Applying Welch ANOVA and Tamhane's T2 tests, average exam times for the new CR system were significantly faster (18–42%; $P \leq 0.025$) than for the traditional CR system. Average exam times for the DR system were also faster than for the new CR system by 22–36% ($P < 0.001$) with one exception. In the case where the new CR system was located outside the X-ray room, using a one-technologist workflow model, average single-study exam times were not significantly different from those found when using DR. Therefore, the new CR system may be comparable in efficiency with the DR system for this particular setting and operation.

KEY WORDS: Computed radiography, digital radiography, workflow, time and motion studies

INTRODUCTION

In digital projection radiography, one of the key factors in considering computed radiography (CR) versus digital radiography (DR) is workflow. Workflow plays a crucial role as hospitals and clinics must meet the strict demands of higher patient volumes and constrained costs. DR systems have been marketed by vendors and reported by authors as being more volume efficient than CR systems.[1] Some authors have stated that DR systems can be at least twice as efficient as CR systems,[2] but for low patient-volume centers, the increased efficiency of DR systems will typically not yield financial benefits due to the higher purchase cost of these systems.[3] However, these articles focus on one or two types of radiographic exams (i.e., routine chest exams) restricting the application of these studies to more varied clinical settings.[1,3] This is an important factor as some DR systems do limit the ability to perform certain radiographic exams. For example, cross-table views cannot be captured with an undertable DR detector. Therefore, choosing a digital projection modality is quite a complex task and one solution is not applicable for all situations.

Recently, a new CR system with improved plate-scanning technology has been developed with the promise of being more efficient than traditional CR systems. This CR system is capable of scanning the phosphor imaging plate line by line instead of pixel by pixel, thus reducing the waiting time to preview the acquired image. In addition, cassette identification takes place in the scanning device eliminating the need for a separate

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and required step in some CR systems. To improve workflow, workstation software can be customized as provided by the manufacturer to automatically populate pre-programmed views for all studies. Also, the new CR system is compact in size allowing the unit to be placed in a location best suited for optimal workflow.

Thus, the objective of this study was to compare the workflow efficiencies of the new CR system to traditional CR and DR systems. For this purpose, a time–motion study was conducted objectively at a high-volume orthopedic clinic which operates a combination of traditional CR and DR systems in two X-ray rooms. For this study, the workflow efficiency of the new CR system was assessed in two different situations, according to the location of the plate reader; both inside and outside the X-ray room locations were used to evaluate the options of flexible workflow. Various types of clinical exams were selected to determine the overall average exam times for an outpatient orthopedic institution. This article presents the results of a new workflow evaluation for such new fast-scanning CR system compared with that of traditional CR and DR systems for a diverse range of exams in a clinical setting.

MATERIALS AND METHODS

Radiographic Modalities

As explained above, two different CR systems and a DR system were evaluated in this study. The Agfa ADC Compact Plus (Agfa-Gevaert, Belgium) system utilizes BaSrFBrI:Eu, powder-based imaging plates, scanning in a pixel-by-pixel fashion but presents the advantage of an unattended processing queue of up to ten cassettes at the plate scanner. Cassettes are identified in a dedicated station separate from the Viewing Image Processing Station (VIPS), where images can be viewed, modified, and sent to PACS. In this paper, this system was only located outside of the X-ray room and is referred to as the "traditional CR system."

The Agfa DX-S (Agfa-Gevaert) system operates using CsBr:Eu needle-based imaging plates, scanning in a line-by-line fashion. Cassettes are identified in the plate reader itself and processed one at a time. The NX 2.0 processing software allows pre-programming of the site's clinical protocols into the user interface so that the views pertinent to each particular study are displayed on the screen for pre-selection by the user prior to scanning a plate. For instance, if a two-view humerus exam is selected for a patient, blank thumbnail images for both the AP and LAT views are immediately displayed, thus omitting the step of manually identifying all views for each exam. In this study, the DX-S system is referred to as the "new CR system."

The compact size of the DX-S system allows flexibility in the siting and placement of the unit. Consequently, the new CR system was first installed inside the X-ray room. The unit was placed in a corner of the room as to not disturb the normal routine of patient preparation and image acquisition. Once the workflow evaluation of the unit was completed for this location, the new CR system was relocated outside the X-ray room in the more traditional manner of CR systems. Thus, workflow was evaluated with the new CR system both inside and outside the X-ray room; these two situations are referenced in this document as "new CR-In" and "new CR-Out," respectively.

The Siemens Aristos (Siemens, Germany) DR system employs two cesium iodide scintillator+a-Si TFT array detectors permanently installed both under the X-ray table and at the chestboard. The integrated generator and workstation was located outside of the X-ray room and automatically displays pre-programmed radiographic techniques for selected exams and views. This system is labeled as the "DR system" in this article.

Radiographic Exam Times

A time–motion study was conducted to compare radiographic exams performed with a new CR system to the traditional CR and DR systems at the University of Florida & Shands Orthopaedics and Sports Medicine Institute (UFSOSMI), a high-volume outpatient radiology operation. Relevant steps in the performance of radiographic exams were recorded by an independent observer via a laptop using XNote Stopwatch 1.4 (dnSoft Research Group, Russia), a timer software application, in conjunction with Dragon Naturally Speaking 9.5 (Nuance, USA), a speech-recognition software. The speech-recognition software allowed the use of voice commands generated simultaneously with the occurrence of an event during the process, thus making the recording of the time extremely accurate. Because the numerous steps in an exam occurred very quickly, it was necessary to use speech-recognition software to immediately describe and distinguish these steps. Although this type of documentation may have affected the technologists' performance, this factor was constant among all the modalities recorded.

The following pertinent steps of a radiographic exam were recorded to compare the workflow efficiency of each modality:

- *Start Time.* Recorded at the moment when a patient entered the X-ray room.
- *Exposure Time.* Documented at the instant when a technologist pressed the trigger button to activate the X-ray beam and acquire an image.
- *Cassette Identification Time.* Recorded at the stage when a technologist selected the "ID" command button in order to identify the cassette with corresponding patient and view information in CR systems.
- *Image Presentation Time.* Noted at the moment when the preview image was automatically displayed on the CR or DR workstation for review by the technologist.
- *Image Sent Time.* Observed at the moment when a technologist pressed the "send" command button to electronically submit the image to the PACS archive for evaluation by the radiologist.
- *End Time.* Documented at the time when a technologist electronically submitted the last image in the exam to the PACS archive.

Of the radiographic steps described above, it was decided that the significant exam times were the *start* and *end times* which together encompass the total time of the exam performed. Also, due to the clinical variability in the performance and workflow of radiographic exams particularly between modalities, other recorded steps such as *exposure time*, *cassette identification time*, and *image presentation time* were deemed to provide inconclusive information and were not included in the results.

Approximately 200 radiographic exams for each modality were timed and analyzed with Welch analysis of variance (ANOVA) and Tamhane's T2 post hoc test for unequal variance using SPSS (SPSS Inc., USA).

Clinical Radiographic Exams

To obtain overall clinical exam times, numerous types of orthopedic radiographic exams were recorded. These include, among others: shoulder, humerus, elbow, forearm, wrist, hand, finger, femur, knee, lower leg, ankle, heel, foot, toe, and pelvis. For this study, an exam was defined as the overall radiographic procedure for a given patient and which can be categorized as comprising either single or multiple studies. In a single-study (SS) exam, a technologist may acquire two views of the right femur or three views of the left wrist, but not both. In a multiple-study (MS) exam, more than one study may be performed for the patient such as a two-view right femur and three-view left wrist.

An attempt to eliminate bias in terms of patient types and conditions was made; all types of patients were included: pediatric and elderly, ambulatory and non-ambulatory, with hardware and casts, and both with limited and full mobility, representing the diverse clinical setting of this outpatient orthopedic clinic. In addition, exams with additional views due to radiologists' requests, presence of hardware, and repeated views due to improper positioning and technique were not excluded from the study. A notable difference in workflow between CR and DR systems is that, with DR, only one view at a time can be acquired on the detector, while CR systems on the other hand allow acquisition of multiple views (two to four) on one cassette. Both cases were incorporated in the assessment of workflow.

At the UFSOSMI, technologists practice a flexible one- or two-technologist type of workflow model. In the one-technologist workflow (1-TW) model, a single technologist performs all of the steps required in the exam. For the two-technologist workflow (2-TW) model, one technologist performs patient preparation and positioning in the X-ray room, while the second operates the control panel and workstation, performs QC, and sends studies to the PACS archive. For CR systems, the second technologist may also perform cassette identification and place the cassette in the plate reader. The clinic also employs technologist assistants who support the technologist in CR systems by performing those two functions in a 2-TW model. A 1-TW or 2-TW model is primarily chosen based on availability of a second technologist or assistant and secondarily in the demand for support during complicated exams. Longer exams which may require the acquisition of extra views or those performed for patients who are limited or slower in movement may strictly require two technologists to properly complete.

It is important to mention that user variability was eliminated from this study because all recorded exams were performed by a core group of three to four technologists. These technologists are highly skilled in orthopedic exams with a combined experience of about 80 years in orthopedic imaging. Also, the technologists were well trained and proficient in using the new CR system, while having 20 and 10 years of combined experience using the traditional CR and DR systems, respectively. Nevertheless, the technologists were aware that exams were being timed and this fact may have indeed influenced the results of the time–motion study.

RESULTS

The total number of exams grouped by modality, workflow model, and single and multiple types are illustrated in Figure 1. Out of about 200 exams for each modality, more than 75% were acquired as SS exams. The numbers of SS exams for both workflow models varied for each modality. For example, the 2-TW model was used in approximately 68% and 74% of SS exams, using the traditional CR and the new CR-Out system, respectively. On the other hand, for the new CR-In system, about 67% of SS exams were acquired using a 1-TW model. For the DR system, only 52% of SS exams were executed using a 2-TW model, showing that the numbers of exams were somewhat evenly distributed between both workflow models.

For MS exams, more exams were performed using a 2-TW model especially for the traditional CR and the new CR-Out systems. For instance, with a 2-TW model about 93% and 86% of MS exams were executed using the traditional CR and new CR-Out system, respectively, whereas for the new CR-In and DR systems only 64% and 58%, respectively, were performed.

Figures 2 and 3 present average exam times for both SS and MS exams, respectively. Average exam times for MS exams were about twice as long as SS exams. For both workflow models, average exam times decreased in the following order by modality: traditional CR, new CR-In, new CR-Out, and DR systems. In SS exams using a 1-TW model for traditional CR, new CR-In, new CR-Out, and DR systems, average exam times were 6:31, 4:50, 3:48, and 3:47 min, respectively. The average exam time for the new CR-Out system was only 1 s longer than that for the DR system. On the other hand, average exam times

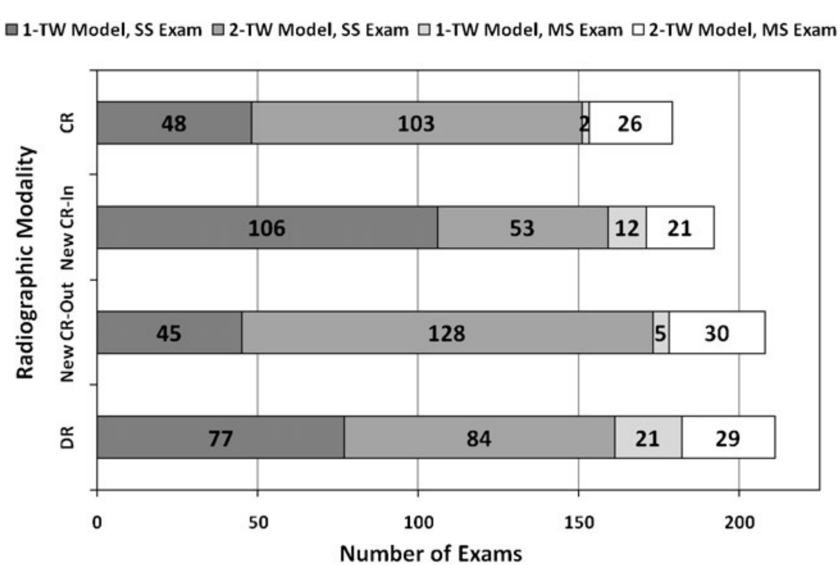

Fig. 1. Number of exams recorded for each modality, workflow models, and single- and multiple-study exams.

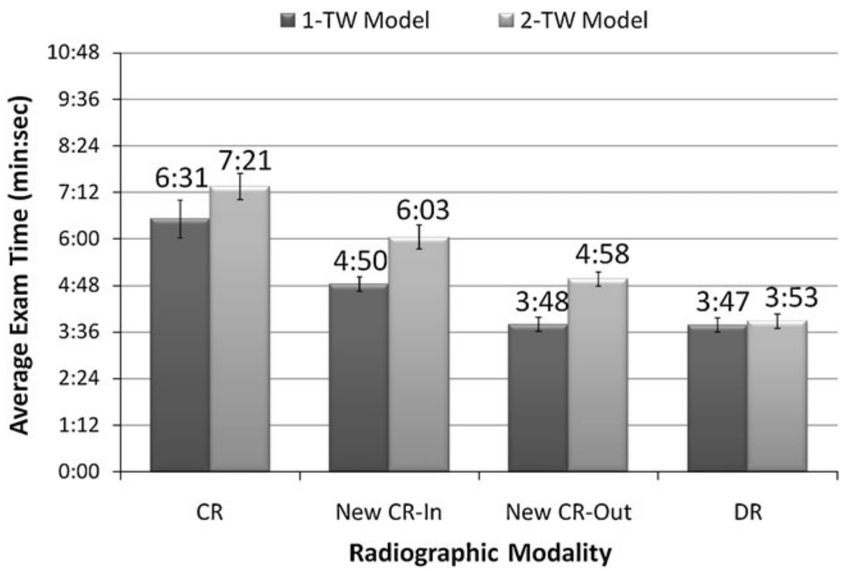

Fig. 2. Average exam times for single-study exams with *error bars* representing ± 1 standard error.

using a 2-TW model were always longer than using a 1-TW model.

The Welch ANOVA revealed that the average exams times were statistically significant between the modalities for both workflow models ($P<0.001$). Tables 1 and 2 display the outcome of Tamhane's T2 tests comparing results from the new CR-In and new CR-Out systems, respectively, with traditional CR and DR systems for SS exams. In Table 1, the new CR-In system was considerably more efficient than the traditional CR system and the DR system was also substantially more efficient than the new CR-In system for both workflow models ($P\leq0.025$). Likewise, Table 2 shows that average exams times for the new CR-Out system were appreciably faster than the traditional CR system for both workflow models ($P<0.001$). Exams with the DR system were slightly faster than the new CR-Out system for only the 2-TW model ($P<0.001$). Using a 1-TW model, average exam times with the new CR-Out system were not significantly different from the

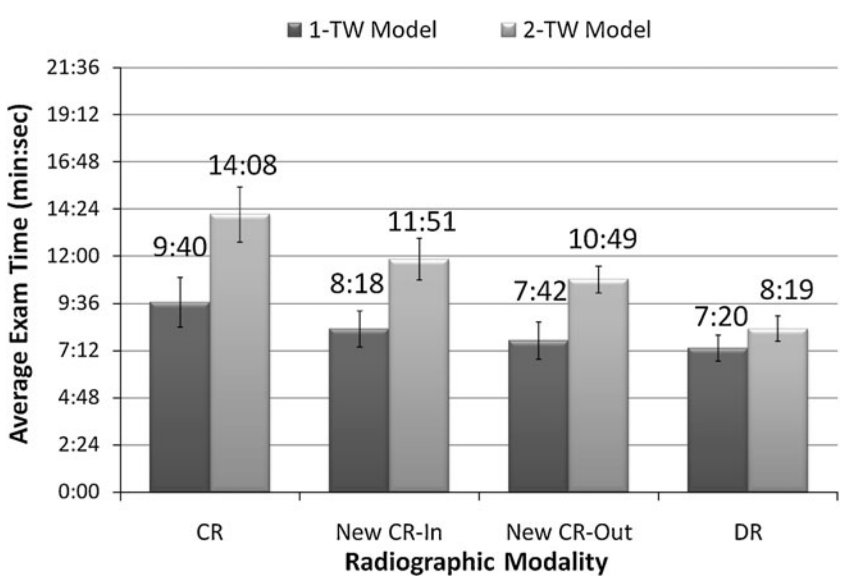

Fig. 3. Average exam times for multiple-study exams with *error bars* representing ± 1 standard error.

Table 1. Comparison of New CR-In with Traditional CR and DR Systems

	1-TW model		2-TW model	
	New CR-In vs. trad. CR	New CR-In vs. DR	New CR-In vs. trad. CR	New CR-In vs. DR
Average exam time difference (min:s)	1:41	1:03	1:18	2:10
Average exam time difference (%)	26	22	18	36
P value (Tamhane's T2 test)	0.008	<0.001	0.025	<0.001

DR system. Table 3 compares the efficiency of the new CR-Out and new CR-In systems. As indicated, the new CR-Out (i.e., located outside the X-ray room) system was significantly more efficient than the new CR-In (i.e., located inside the X-ray room) system for both workflow models ($P \leq 0.025$).

DISCUSSION

The nature of the study introduced variability which is common in a clinical study. All types of typical orthopedic exams were recorded: shoulder, humerus, elbow, forearm, wrist, hand, finger, femur, knee, lower leg, ankle, heel, foot, toe, and pelvis. Exams with additional views, difficult patients, and multiple images on one imaging plate for CR systems were included in the study to produce true, unbiased clinical average exam times. On the other hand, the following events during the exam which were not expected in a regular clinical setting were excluded from the study: incorrect exam orders, interruptions during exams, and equipment-related errors.

One- vs. Two-Technologist Workflow Model

As shown in Figure 1, the proportion of exams recorded for each workflow model varied significantly among modalities reflecting a modality-dependent preference by the technologists for either a 1-TW or 2-TW model. For example, for traditional CR systems, technologists favored the 2-TW model 72% of the time, possibly to facilitate with identifying and processing imaging plates. However, for the case of the new CR-In system, more exams (61%) were performed using a 1-TW model. Most likely this was due to the location of the plate scanner in the X-ray room, which could hinder a supporting technologist from providing efficient cassette identification assistance because of the necessary inconvenience of leaving the X-ray room when exposures are made. On the other hand, for exams executed with the new CR-Out system, the 2-TW model was performed more often (76%) than the 1-TW model as a result of the improved accessibility of the new CR system for the other technologist or assistant. For DR systems, the relatively equal distribution of exams between both workflow models (54% 2-TW, 46% 1-TW) demonstrated that there was no preference for a particular workflow model most likely due to the absence of cassette handling. For MS exams alone, more exams were performed using a 2-TW than a 1-TW model. Technologists and assistants may have chosen a 2-TW model to provide additional support for longer exams.

The longer average exam times using a 2-TW model compared with a 1-TW model in Figures 2 and 3 may be attributed to the tendency of technologists to ask for assistance for those exams predicted to be more time consuming, such as exams with several views or non-ambulatory patients. Therefore, these challenging exams required extra time and two technologists to complete effectively. However, a 2-TW model also demanded more time for clear communication between the two technologists to acquire images

Table 2. Comparison of New CR-Out with Traditional CR and DR Systems

	1-TW model		2-TW model	
	New CR-Out vs. trad. CR	New CR-Out vs. DR	New CR-Out vs. trad. CR	New CR-Out vs. DR
Average exam time difference (min:s)	2:43	0:01	2:23	1:05
Average exam time difference (%)	42	0.4	33	22
P value (Tamhane's T2 test)	<0.001	Not significant	<0.001	<0.001

Table 3. Comparison of New CR-Out with New CR-In Systems

	1-TW model	2-TW model
Average exam time difference (min:s)	1:02	1:05
Average exam time difference (%)	21	18
P value (Tamhane's T2 test)	$<$0.001	0.025

and handle cassettes efficiently while preventing errors when using a CR system. In any case, using a 1-TW model was more efficient than a 2-TW model especially in CR systems. The reader must understand that the authors do not advocate or recommend a reduction of staff stemming from these results. Technologists' roles nowadays extend beyond simple patient positioning and image acquisition and this must be taken always into account. A 2-TW model may also be beneficial and desirable for the technologists in alleviating fatigue especially for high-throughput centers.

In contrast, the average exam time in Figure 2 for the DR system using a 2-TW model was only slightly longer by 6 s than for a 1-TW model due to the lack of cassette handling in DR systems, allowing exams to be comparatively efficient even for the 2-TW model.

New CR vs. Traditional CR System

Average exam times for traditional CR, new CR-In, new CR-Out, and DR systems were decreasingly shorter for both workflow models and exam types as depicted in Figures 2 and 3. Tables 1 and 2 establish that the new CR workstation located inside or outside the X-ray room, respectively, substantially present a more efficient scenario than that of the traditional CR system ($P \leq 0.025$). The new CR system produced shorter average exam times than the traditional CR system mainly because of the faster scanning method and a more user-friendly workstation. The line-by-line scanning technology featured in the new CR system offered a preview image in about 20 to 30 s, whereas the traditional CR system utilizing a pixel-by-pixel scanning process resulted in a preview waiting time of approximately 60 s. The line-by-line scanning method displayed preview images in about half the time while still maintaining excellent image quality. In addition, the new CR workstation allowed for a more efficient workflow due to the automatic population of image views corresponding to the exam selected which effectively eliminates the time needed to separately perform patient, exam, and view selections.

New CR System: Inside vs. Outside the X-Ray Room

Because of the compact size of the new CR system, the unit can be placed in different locations for best workflow implementation. The new CR system was first placed inside and later on outside the X-ray room to evaluate its workflow possibilities. As demonstrated in Table 3, average exam times were shorter for the new CR-Out system than the new CR-In system ($P<0.025$), which explains that workflow was more efficient when the new CR system was located outside the X-ray room. Although placing the new CR unit inside the X-ray room allowed technologists to interact with the patient more actively and execute tasks on the workstation simultaneously with less travel distance, exams were often interrupted by various actions of the patient distracting the technologists, resulting in longer exam times. Also, the new CR system placed inside the X-ray room limited the accessibility of the unit to other technologists and assistants.

DR vs. New CR System

With one exception, the DR system was more efficient than the new CR system, as seen in Tables 1 and 2. This was not true when compared to the new CR-Out system using a 1-TW model. In principle, the DR system can be more efficient because there are no cassette/imaging plates to handle and process which requires the performance of several steps: cassette insertion into the table or chest bucky, cassette identification with patient and exam information, and image plate scanning. As a result, the preview image for the DR system was displayed within 5 s of the exposure. The workstation of this DR system was also integrated with the generator so that pre-programmed radiographic techniques were used for each view selected. Therefore, DR systems generated exam times with minimal delay from the modality and with more dependence on the clinical features of the exam itself such as patient positioning, exposure, and image review.

Nonetheless, as shown in Table 2, average exam time for the new CR-Out system was not significantly different from those of the DR system in a 1-TW model showing that the new CR can also operate to the very efficient limits established by the DR system. In CR systems, more than one view can be obtained on a CR imaging plate and this is practiced frequently at this facility reducing the total plate-scanning times and allowing the exams to be as efficient as possible. Average exam times may appear to be comparatively similar (difference of 1 s), because a larger number of easier exams may have been performed with the new CR-Out system than with the DR system. However, the new CR-Out system has demonstrated the potential to be as efficient as the DR system in a 1-TW model. In addition, DR systems limit the ability to perform some radiographic exams such as cross-table exams occasionally necessary in an orthopedic institution. Therefore, the best modality for a given site is not only dependent on workflow, but the capability to perform certain exams, the type of workflow (one or two technologists), and cost.

CONCLUSIONS

A time–motion study was conducted to compare the workflow efficiencies for a new CR system located either inside or outside the X-ray room with a traditional CR and a DR system in an orthopedic radiology operation. Results of the study show that the new CR (new CR-Out) system placed outside the X-ray room presents a better workflow choice than when located inside the X-ray room. For single-study (SS) exams, average exam times with the new CR placed outside the X-ray room were significantly faster than with the traditional CR system by about 2.7 min or 42% for a one-technologist workflow (1-TW) model and 2.4 min or 32% for a two-technologist workflow (2-TW) model. The new CR system may substantially increase the average number of exams performed in a facility by as many as 35 and 24 per day in a 50-exam-per-day average throughput operation for both workflow models, respectively. The DR system was also slightly more efficient than the new CR system placed outside the X-ray room but only for the two-technologist workflow model. Using the two-technologist workflow model, the DR system was slightly faster by about 1.1 min or 22% and can increase patient throughput by up to 13 exams per day in a 50-exam-per-day average throughput operation. For the one-technologist workflow model, the DR system and the new CR system located outside the X-ray room may be comparable. With its lower cost and flexibility to permit the performance of all radiographic exams, the new CR system may be an attractive alternative to a DR system. Although the study results were specific to the site, operation, and specialty, it may provide a helpful insight in evaluating the workflow possibilities and models available with CR and DR systems when choosing a digital projection radiography modality.

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