SESSION III: Radiology Reengineering in the Military

Photostimulable Storage Phosphor Image Acquisition: Evaluation of Three Commercially Available State-of-the-Art Systems

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Photostimulable storage phosphor (PSP) image acquisition systems have been available for several years. The technology has had the opportunity to mature; however, there has not been an independent comparison of recently marketed commercial systems. For this study, three computed radiography (CR) systems using PSP technology (Kodak CR System 400 with autoloader [Eastman Kodak, Rochester, NY], Fuji FCR AC-3CS [Fuji Medical Systems, Stamford, CT], and Agfa ADC Compact [Bayer Corp, Ridgefield Park, NJ]) were connected to an IBM RadWorks diagnostic radiology workstation (IBM Corp, White Plains, NY) and evaluated for conformance to their performance specifications using guidance provided in the most recent draft acceptance testing protocol from Task Group No. 10, American Association of Physicists in Medicine. In addition, the physical requirements (eg, space and power) and connectivity to another manufacturer's diagnostic workstation were examined. X-ray technologist comfort with each PSP imaging system and an assessment by our supporting biomedical equipment maintenance activity of their ability to service each PSP imaging system were also considered.

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BEGINNING EARLY IN 1999, the Digital Imaging Network–Picture Archiving and Communication System (DIN-PACS) developed for the Department of Defense will be installed in the 10 largest medical treatment facilities within the US Army's Great Plains Regional Medical Command (GPRMC). These facilities are Brooke Army Medical Center (BAMC), Fort Sam Houston, TX; Darnall Army Community Hospital, Fort Hood, TX; Reynolds Army Community Hospital, Fort Sill, OK; Bayne-Jones Army Community

Hospital, Fort Polk, LA; Evans Army Community Hospital, Fort Carson, CO; General Leonard Wood Army Community Hospital, Fort Leonard Wood, MO; Munson Army Community Hospital, Fort Leavenworth, KS; Irwin Army Community Hospital, Fort Riley, KS; William Beaumont Army Medical Center, Fort Bliss, TX; and Bliss Army Community Hospital, Fort Huachuca, AZ. Teleradiology will link all 10 facilities in a virtual radiology environment (VRE). BAMC, one of three level I trauma centers in San Antonio, TX, will serve as the hub of the GPRMC VRE.

Computed radiography (CR) using photostimulable storage phosphor (PSP) technology will be the primary mode of image acquisition at each GPRMC medical facility. Consequently, the VRE project manager had to select a CR system for the GPRMC. Based on a number of factors, such as size, cost, and throughput, three CR systems were chosen as candidates for testing. These were a Computed Radiography System 400 (CR System 400) from Eastman Kodak Company (Rochester, NY), an Agfa Diagnostic Center (ADC) Compact from Bayer Corporation's Agfa Division (Ridgefield Park, NJ), and a Fuji Computed Radiography (FCR) AC-3CS from Fuji Medical Systems USA, Inc (Stamford, CT).

We report the results of the physics testing performed on the three CR systems, to include subjective assessments of image quality by radiologists and radiologic technologists.

MATERIALS AND METHODS

BAMC was chosen as the test site based on its substantial experience with CR and PACS dating from 1993. With the exception of mammography, the Department of Radiology at BAMC is entirely digital and relies on CR as the major image acquisition system. The BAMC PACS is the Medical Diagnostic Imaging Support (MDIS) system, one of the largest PACS in the Department of Defense.

VRE project deadlines required us to complete the testing expeditiously, allowing 1 week per CR system. System installation and calibration were performed by the manufacturer on

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Monday and Tuesday, testing was performed on Wednesday and Thursday, and system removal was performed on Friday. Each manufacturer provided service engineers and applications specialists to install, maintain, and operate their respective CR systems throughout the testing period.

Each manufacturer provided a quality control (QC) workstation with its CR system. All CR systems and the IBM RadWorks diagnostic workstation (IBM Corp, White Plains, NY) to which they were connected are Digital Imaging and Communications in Medicine (DICOM) 3.0 compliant.

The tests performed on each CR system follow those described in an August 1998 draft report by Task Group No. 10, American Association of Physicists in Medicine (AAPM).¹

Phosphor Plate Dark Noise

Several PSP imaging plates (IPs) were erased using the CR system's full erasure cycle to remove all residual signals. Next, each erased IP was scanned using an automatic or fixed scaling algorithm that maximized the gain of the system. Each soft-copy image was viewed for uniform density shading and artifacts.

System Linearity, Autoranging, and Exposure Response

This test measured the response of each IP over two decades of exposure (0.1, 1.0, and 10 mR). Two IPs of each size were tested. Each IP was loaded into its cassette and placed on the floor atop a lead apron to minimize backscatter. Using a calibrated radiographic x-ray tube with reproducible output, the entire IP was exposed using 80 kVp at approximately 180-cm source-to-image distance (SID), with additional filtration inserted at the output surface of the collimator. The amount and type of added filtration employed was according to manufacturer's specifications. Actual incident exposures were verified using a calibrated Radcal Model 1515 radiation monitor with 10 × 5-6 ion chamber (Radcal Corp, Monrovia, CA). After a delay time of 10 minutes following exposure, each IP was processed using a readout algorithm specified by the manufacturer for exposure value calibration. Exposure to the IP was calculated from the IP exposure index displayed by the CR system and then compared with the actual measured exposure.

Receptor Reproducibility, Density Uniformity, and Artifact Analysis

This test was performed using the images from the 10-mR exposed IPs (see previous test). Soft-copy images were viewed on the diagnostic workstation. The region-of-interest (ROI) tool was used to compare average digital values in the center and near each of the four corners of each image. The average digital values of each ROI were compared to determine if they were within 10% of the global average. All images were examined for banding, black or white spots, streaks, and other artifacts.

Phosphor Plate/Cassette Throughput

Each CR system was equipped with an autoloader. Throughput was tested for each size IP/cassette. Each CR system's QC workstation was configured to pass each acquired image directly to the IBM RadWorks diagnostic workstation. Six loaded cassettes were processed as fast as possible. Timing began as soon as the first image was received at the diagnostic worksta-

tion, and ended with the arrival of the final image, yielding an elapsed time for five IPs/cassettes. (Note: When batch processing IPs, the Kodak CR System 400 cannot load an IP/cassette into the processor until the most recently processed IP/cassette has emerged from the autoloader. Since images from Kodak IPs consistently reached the IBM diagnostic workstation before the IP/cassette was ejected from the autoloader, timing for the Kodak CR System 400 ended when the final IP/cassette was ejected.) The number of IPs processed per hour was calculated.

Laser Beam Function

A steel ruler was placed on a 14-in × 17-in cassette and centered roughly perpendicular to the laser beam scan lines. The cassette was exposed using a radiographic technique of 80 kVp, 180 cm SID, and sufficient charge to deliver an incident exposure of roughly 5 mR. The resulting image was examined.

Spatial Resolution

A lead bar square-wave resolution test phantom was placed on each size IP/cassette. One square wave pattern was positioned parallel to the fast scan direction, the other parallel to the slow scan direction. Each cassette was exposed using 60 kVp at 180 cm SID and sufficient charge to deliver approximately 5 mR to the cassette surface. Soft-copy images were viewed on the diagnostic workstation to determine if the manufacturer-specified limiting resolution was achieved. If the limiting resolution was not readily detectable, the exposure was repeated using 2-, 1-, and 0.5-degree star patterns. Blur diameters of the resulting images were measured with the RadWorks distance-measuring tool to calculate the limiting resolution.

Wire Mesh Test and Resolution Uniformity Across the Receptor

A 14-in × 17-in IP/cassette with a wire mesh screen-film contact test tool placed in direct contact with the face of the cassette was exposed to approximately 5 mR (60 kVp, 180 cm SID, and sufficient charge). The soft-copy image was viewed for distortion and sharpness over the entire field of view.

Low-Contrast Sensitivity/Detectability

A UAB low-contrast phantom² designed to provide a measure of low-contrast sensitivity was placed on the face of a 14-in × 17-in IP/cassette and exposed at 80 kVp, 180 cm, and sufficient charge to produce exposures of 0.1, 1.0, and 10 mR to the IP. The resulting images were viewed on the RadWorks and scored to determine low-contrast sensitivity.

Distance Accuracy

Four-inch square copper sheets were placed in the center and near each corner of a 14-in × 17-in IP/cassette. Edges of the sheets were parallel with the edges of the image receptor. The cassette was exposed to approximately 1 mR using 80 kVp and 180 cm SID. The length and width of the image of each square were measured using the RadWorks distance tool.

Accuracy/Thoroughness of Erasure Cycle

One 14-in × 17-in IP/cassette was exposed to approximately 50 mR (80 kVp, 180 cm SID, sufficient charge) with a centrally placed high-contrast test object (resolution bar pattern) in

Table 1. System Linearity, Autoranging, and Exposure Response

Actual Exposure (mR)	IP Size (in)	Calculated Exposure From Exposure Index (mR)					
		Kodak CR400		Agfa ADC Compact		Fuji AC-3CS	
		Exposure (mR)	% Error	Exposure (mR)	% Error	Exposure (mR)	% Error
10	8 × 10	10.6	6%	8.6	−14%	9.1	−9%
	10 × 12	10.7	7%	7.8	−22%	9.5	−5%
	14 × 17	10.1	1%	9.3	−7%	9.3	−7%
	Average	10.5	5%	8.6	−14%	9.3	−7%
1.0	8 × 10	1.22	22%	0.88	−12%	0.91	−9%
	10 × 12	1.20	20%	0.81	−19%	0.98	−2%
	14 × 17	1.10	10%	0.96	−4%	0.98	−2%
	Average	1.17	17%	0.88	−12%	0.96	−4%
0.1	8 × 10	0.148	48%	0.097	−3%	0.117	17%
	10 × 12	0.157	57%	0.089	−11%	0.123	23%
	14 × 17	0.138	38%	0.106	6%	0.108	8%
	Average	0.148	48%	0.097	−3%	0.116	16%

contact. The IP was processed using a standard clinical algorithm and returned. The same IP was reexposed to a uniform incident exposure of approximately 1 mR with a slightly smaller collimated area, and then processed using the same readout algorithm. The second image was examined using the Rad-Works to check for the presence of a ghost image of the resolution test pattern.

Image Processing, Lookup Transforms, and Frequency Enhancement

Image processing, lookup table (LUT) transforms, and frequency enhancement were evaluated subjectively by staff radiologists and radiologic technologists. To accomplish this, images of patients and a variety of anatomical phantoms were obtained and optimized by the applications specialist.

RESULTS

Phosphor Plate Dark Noise

None of the CR systems yielded images with obvious artifacts, density shading, or nonuniformities.

System Linearity, Autoranging, and Exposure Response

The calculated exposure value for a processed IP should be within ±20% of the actual incident exposure for any single receptor and within ±10% for the average. Quantitative evaluation of the image properties on a computer workstation should verify a consistent average digital number independent of exposure, and a decrease in relative noise (increase in signal to noise) with increased exposure. Over the full range of exposures tested, the exposure indices from the Agfa ADC Compact and the Fuji AC-3CS consistently resulted in calculated exposures within 20% of actual exposures, with only one exception each (Table 1).

Receptor Reproducibility, Density Uniformity, and Artifact Analysis

All three CR systems demonstrated excellent uniformity and no significant artifacts.

Phosphor Plate/Cassette Throughput

Phosphor plate/cassette throughput differed noticeably among the three CR systems (Table 2). On the Fuji FCR AC-3CS, the cassette remains in one position during the entire IP processing cycle. The Agfa ADC Compact moves the cassette during IP processing, but allows one cassette to be unloaded or reloaded during processing of another IP. Because of the autoloader design, the Kodak CR System 400 can handle only one cassette at a time, ie, the cassette with reloaded IP must be ejected from the autoloader before another cassette can be loaded into the processor. This appears to be the primary cause of low IP/cassette throughput relative to the other CR systems tested.

Laser Beam Function

The image of the ruler should have straight and continuous edges over the full length of the image. All CR systems met this requirement.

Table 2. Phosphor Plate/Cassette Throughput

Plate/Cassette Size	Plates per Hour		
	Kodak CR400	Agfa ADC Compact	Fuji AC-3CS
8-in × 10-in IP	41	69	95
10-in × 12-in IP	40	62	80
14-in × 17-in IP	39	63	68

Table 3. Spatial Resolution

IP Size (in)	Spatial Resolution (lp/mm)					
	Kodak CR400		Agfa		Fuji	
			ADC Compact		AC-3CS	
	Fast	Slow	Fast	Slow	Fast	Slow
8 × 10	5.0	5.0	4.4	4.4	4.3	5.0
10 × 12	4.3	4.3	4.4	4.4	3.3	3.3
14 × 17 (std res)	2.9	2.9	2.9	2.9	2.5	2.5
14 × 17 (high res)	NA	NA	4.4	4.4	NA	NA

Abbreviation: NA, not applicable.

Spatial Resolution

The limiting spatial resolution should not be more than 10% less than indicated in the manufacturer’s specifications for either the vertical or horizontal directions. In all but one case, each CR system met manufacturer’s specifications for limiting resolution (Table 3). The Fuji FCR AC-3CS displayed 4.3 instead of 5 line pairs per millimeter in the fast-scan direction on images from 8-in × 10-in IPs (“fast” and “slow” scan refer to directions parallel and perpendicular to the laser scan direction, respectively.) The test was repeated several times with the same result.

Wire Mesh Test and Resolution Uniformity Across the Receptor

Each CR system produced images that were distortion free and sharp over the whole field of view.

Low-Contrast Sensitivity/Detectability

The CR systems differed little in low-contrast sensitivity (Table 4).

Distance Accuracy

Comparison of the true distance to the actual measured distance was within the acceptable measurement error of 1% to 3% in both directions (Table 5).

Accuracy/Thoroughness of Erasure Cycle

None of the CR systems produced a ghost image to indicate residual signal from the previous high exposure.

Table 4. Low-Contrast Sensitivity/Detectability

Exposure	Kodak CR400	Agfa ADC Compact	Fuji AC-3CS
0.1 mR	2.00%	2.00%	1.50%
1 mR	1.50%	1.00%	1.00%
10 mR	1.00%	0.50%	0.50%

Table 5. Distance Accuracy

Average % Error*					
Kodak CR400		Agfa ADC Compact		Fuji AC-3CS	
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
2.0%	2.2%	1.1%	0.3%	0.0%	0.4%

*Image of five 4-in rectangles, displayed in portrait mode, using a 14-in × 17-in IP.

Image Processing, LUT Transforms, and Frequency Enhancement

Each CR system was provided with an impressive array of image processing tools. Overall, the radiologists and radiologic technologists felt all three CR systems had fairly equivalent image enhancement features.

DISCUSSION

Tests in which one or more CR systems failed to meet the manufacturer’s specifications are listed in Table 6.

The short time allotted to test each CR system prevented making adjustments to any system in time for retesting. We felt that the first test listed in Table 6 could have been passed by all three CR systems if enough time had been available to make the necessary adjustments and recalibrations.

The Fuji FCR AC-3CS was the only CR system that failed to demonstrate its highest advertised limiting resolution in the fast scan direction. We repeated the test using the same cassette/IP combination in an existing Fuji FCR AC-3 installed at BAMC and obtained a similar result. The cause will be determined by further study.

Kodak IPs are solid plates as opposed to the flexible IPs used by Fuji and Agfa. Kodak IPs are not flexed during processing. Kodak representatives observing the testing reported that their IPs have remained usable for 40,000 exposures or more. At BAMC, our flexible IPs become unserviceable after 2,000 to 3,000 exposures. At several hundred dollars per IP, Kodak IPs may provide huge savings over the life of the CR system.

Radiologist and technologist satisfaction with image quality and image processing capabilities was high for each system, and they felt all three CR

Table 6. Test Failures

Test	CR System
System linearity, autoranging, and exposure response	Kodak
Spatial resolution	Fuji (5 lp/mm, fast-scan direction)

systems had fairly equivalent image enhancement features. Technologists indicated that throughput was the most important factor affecting their work efficiency.

Biomedical maintenance personnel from BAMC concluded that the supporting biomedical maintenance sections at the GPRMC medical treatment facilities could maintain each CR system with a minimum of training.

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