Recognition and Prevention of Computed Radiography Image Artifacts

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Initiated by complaints of image artifacts, a thorough visual and radiographic investigation of 197 Fuji, 35 Agfa, and 37 Kodak computed radiography (CR) cassettes with imaging plates (IPs) in clinical use at four radiology departments was performed. The investigation revealed that the physical deterioration of the cassettes and IPs was more extensive than previously believed. It appeared that many of the image artifacts were the direct result of premature wear of the cassettes and imaging plates. The results indicate that a quality control program for CR cassettes and IPs is essential and should include not only cleaning of the cassettes and imaging plates on a regular basis, but also visual and radiographic image inspection to limit the occurrence of image artifacts and to prolong the life cycle of the CR equipment.

KEY WORDS: Computed radiography, cassette, imaging plate, image artifact, yellowing, delamination, quality control

BACKGROUND

Twelve to 18 months after the installation of 11 Fuji FCR XG-1 readers (<http://www.fujimed.com>) at a radiology department and two more at an affiliated site, reports of clinical image artifacts became more frequent. Some of these were traced to cassettes and IPs that either required cleaning or had suffered physical damage. In total, 10 general-purpose Fuji cassettes (Type C) and IPs (ST-VI) had been removed from clinical use because of physical damage that was visible on clinical exposures, and of these, six were returned to Fuji at their request for assessment and replacement.

An investigation was launched to document the physical condition and imaging performance of the Fuji cassettes and IPs in clinical use. Initially, approximately 30 Fuji cassettes and IPs were inspected and radiographed with the findings

documented to determine the types of physical wear and radiographic artifacts that were present. From those notes, data collection spreadsheets were drafted to allow documentation of the physical and radiographic condition of 197 Fuji CR cassettes and IPs at two affiliated radiology departments. Once the data were collated, the investigation was expanded to include visual and radiographic inspections of 35 Agfa (MD 10, 30, and 40; <http://www.agfa.com>) and 37 Kodak (Ektascan GP-25; <http://www.kodak.com>) general-purpose CR cassettes and IPs at two other radiology departments.

METHODS

The cassette and IP inspections took place in rooms with similar environmental conditions. Bright overhead fluorescent lighting illuminated the work areas, and height-adjustable stretchers draped with clean linen were used as work surfaces. Nonpowdered latex gloves were worn, and vendor recommendations were followed¹⁻⁵ to ensure that handling of the cassettes and IPs during the inspection did not result in contamination of or damage to their surfaces. Only Fuji cassettes and IPs were cleaned as part of the investigation

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Fig 1. Broken Agfa cassette identification holder.

process. Digital photographs were taken of cassettes or IPs that either demonstrated characteristic wear patterns or were severely damaged. To determine the number of times that each IP was read, log files stored on each CR system were analyzed. Spreadsheets that listed a cassette's unique identifier, serial number, and size and IP serial number were used to document the observations.

The exterior and interior of all cassettes were examined for cleanliness, damage to the body, hinges, and identification holders, and properly functioning latch mechanisms. The exterior of each Fuji cassette was also dry-wiped with a lint-free tissue, and soiled areas or extraneous material, such as contrast and/or marker tape glue, was removed with a lint-free tissue moistened with IP cleaner.

With the imaging plate inside the cassette, the lid closed, and the lid end pointed downward, each Fuji cassette was subjected to a gentle "shake test" to help identify cassettes with lids that did not close properly. Cassette lid latches were inspected anytime the IP barcode was not completely visible in the cassette window.

After an IP was carefully removed from a Fuji cassette and placed in a safe location, the cassette halves were separated and the interior examined for dirt, dust, and loose felt particulates. These were removed using a low-pressure jet of medical quality air and their presence documented.

The condition of the felt inside Fuji cassettes was also examined. A scoring system ranging from 0 to 3 was used to rate the condition of the felt-to-cassette glue bond along a small ridge at the open end of the cassette. A score of 0 indicated a proper glue-bond attachment; a 1 indicated a slight release of the glue bond where a portion of the felt had lifted

less than 45° from its attached position; a 2 indicated that a portion of the felt had released to an angle roughly equal to 45°; and a 3 indicated either complete failure of the glue bond allowing an extensive portion of the felt to lift more than 45° or complete loss of felt where the relatively sharp corners of the imaging plate had come into repeated contact with the felt.

Unlike the Fuji and Agfa cassettes, the Kodak DirectView CR cassette could not be fully opened to allow inspection of the interior. The interior could only be viewed from one edge of the cassette body when the IP was removed.

Both sides of the rigid, aluminum-backed Kodak IP and the flexible Agfa and Fuji IPs were also inspected. Documented observations included accumulations of dust or particulates on the IP surfaces, phosphor yellowing, and the presence of black specks on the phosphor surface. Also noted was any physical damage such as scratches, delamination or missing portions of the surfaces, evidence of crimping or excessive bending, and the presence of wear patterns associated with components inside the cassette or the CR reader. The approximate location of findings was documented to enable correlation with the radiographic images of the cassettes and imaging plates. Both sides of the Fuji IPs were also cleaned and then reinspected to determine whether adhered particulates were removable. After inspection and/or cleaning, an IP was then carefully reinserted into the same cassette from which it had been removed, and an erasure procedure was performed on each IP to completely remove any latent image that may have remained from previous radiographic exposures or from exposure to background radiation.

Next, flat-field exposures were made. Although some experimenters⁶ have used a standard radiographic technique to expose CR cassettes and IPs from multiple vendors, the

Fig 2. Cracked Agfa cassette housing.

Fig 3. This Kodak cassette's edge unexpectedly detached from the aluminum-backed IP as the IP was removed from the cassette for inspection. The same edge was loose on several other IPs.

techniques used in this investigation were similar to those recommended by each vendor for use with their cassettes and IPs. To ensure that the whole cassette was exposed, the collimators were set to include an additional 7.5 cm around a cassette's periphery. Agfa cassettes were placed on top of two aprons and aligned with the long side parallel to the anode/cathode axis. The source-to-image distance (SID) was adjusted to 1.3 m, and the beam was filtered with 1.5 mm of copper. The cassette was exposed once with a 75-kV, 4-mAs technique, and then the cassette was rotated 180° and exposed again with the same technique to minimize any heel effect and achieve a total exposure of approximately 8.7 μ Gy (1 mR). The delay time between exposing and reading each IP was less than 1 min. Each Fuji cassette was placed on edge on a large foam bolster and rested against a lead apron draped over the wall bucky so that the long edge of the cassette was parallel to the anode/cathode axis. The SID was 3.35 m, and without the extra copper filtration, the cassette was exposed with a technique of 81 kV and 1.25 mAs to achieve an exposure of approximately 8.7 μ Gy (1 mR). A 10-min delay between the exposure and reading of the cassette was observed. Each Kodak cassette was placed on two lead aprons lying on the floor with the long edge aligned parallel to the anode/cathode axis. The X-ray tube was adjusted so the SID was 1.83 m and the cassette exposed, without filtration, with a technique of 80 kV and 8 mAs to achieve a total exposure of approximately 174 μ Gy (20 mR). Each IP was read 15 min after the exposure was made.

When the flat-field exposures were read in the CR reader, processing algorithms were applied to ensure that pixel values were linearly related to radiographic exposure. Agfa IPs were read using "QA Service," "System Diagnosis," and "Flat-field" subexam with an "Exposure Class" of 400. Fuji IPs were read using the "Sensitivity" algorithm found in the "Test" menu. Kodak IPs were read with "Pattern" selected from the "Body Part" menu and then "Black Surround Mask," "Edge Enhancement," "Black Bone," and "EVP" all deselected.

After transferring the images to a personal computer, they were viewed with an image display program (eFilm or Agfa Web1000) to allow correlation of the findings noted on the radiographic images with those from the visual inspections.

RESULTS

For the cassettes and IPs investigated, the maximum number of times any cassette and IP had been read was roughly 10,000 for Agfa, 7500 for Fuji, and 3600 for Kodak. The average number of times that Fuji cassettes and IPs were read was approximately 1560. Physical damage to the exterior of the Agfa and Fuji cassettes was

Fig 4. A failed glue bond resulted in this metal piece falling out of some Fuji cassettes when they were opened to inspect the cassette's interior.

Fig 5. A white discoloration indicated where a fracture of the plastic latch found in Fuji cassettes had occurred. Fractured latches prevented complete cassette lid closure and allowed excess IP movement within the cassette.

more extensive on those used more frequently. Therefore, 18×24 , 24×30 , and 35×35 cm cassettes were in relatively good condition compared to 35×43 cm cassettes. There was very little damage observed on the exterior of the Kodak cassettes.

Items noted during the visual inspection of the Agfa cassettes included small accumulations of dust in the groove around the edges, a broken identification holder (Fig. 1), a human hair inside a cassette, a fractured cassette (Fig. 2), and minor damage to the hinge area of some cassettes that did not appear to affect the ability of the hinge to function properly.

The inspection of the Kodak cassettes revealed a small piece of tape stuck to the inside of a cassette and another cassette that appeared to have suffered an impact that loosened the end of the IP attached to the aluminum IP backing (Fig. 3).

Loose metal clips were found inside two Fuji cassettes (Fig. 4), and 85 fractured right-side plastic latches and 90 left-side latches were

replaced. On each plastic latch, the fracture occurred at the same location (Fig. 5) and resulted in incomplete lid closure of about 1 mm (Fig. 6a).

A failure of the felt-to-cassette glue bond (Fig. 7a) as well as pilling and/or fraying of the felt, in some cases severe, was noted at specific locations along the open end of many Fuji cassettes. About 45% of the 24×30 cm cassettes and 70% of the 18×24 and 35×43 cm cassettes demonstrated a glue bond that had released (rating of 1 or more), with the most severe release (rating of 2 or 3) observed on about 30% of 35×43 cm cassettes (Table 1). As the glue-bond deterioration became more severe, the felt along the small ridge pilled or frayed to a greater degree. Friction between dust and dirt particulates trapped in both the exposed glue and the deteriorated felt and the phosphor surface of the IP resulted in very fine scratches on the phosphor surface about 3 cm from the IP edge that were oriented in the direction of IP movement during transport into and out of the cassette. The scratches resulted in

Fig 6. Fuji cassettes viewed from the lid end demonstrate (a) incomplete lid closure due to fractured plastic lid latches and (b) complete lid closure of a new cassette.

Fig 7. The interior of this Fuji cassette, viewed from the lid end, demonstrates (a) a weakened glue bond resulting in release of felt (rating of 3) from a plastic ridge and (b) a new cassette with the felt intact (rating of 0).

lines parallel to the direction of IP travel on some flat-field radiographic images (Fig. 8).

Minor bloodstains were also observed on the felt inside three Fuji cassettes, and accumulations of dust particles in the grooved edges of the cassettes varied from almost none to small clumps.

Yellowing of the phosphor edges was visually noted on 39.5% or more of each size of Fuji IP (Table 2), on approximately 30% of 35 × 35 and

35 × 43 cm Agfa IPs (Table 3), and on approximately 33% of 35 × 43 cm Kodak IPs (Table 4). Unlike Agfa IPs, where yellowing noted visually was always observed as densities on the flat-field radiographic images (Table 3), the same effect was observed on radiographic images of roughly half of the Fuji IPs (Table 2) and on approximately 66% of the Kodak IPs (Table 4 and Fig. 9) that were visibly yellowed.

Table 1. Fuji felt-to-cassette glue bond rating results (by IP size)

Cassette size

Fig 8. A radiographic image of a Fuji IP shows the effect of barely visible abrasions on the phosphor surface caused by sharp particulates embedded in either the felt, or the exposed glue, or both at the open end of the cassette.

Randomly oriented scratches were observed on the phosphor surface of 70% or more of Agfa IPs and were visible on at least half of the Agfa flat-field radiographic images (Table 3). These were most likely caused by contact of the phosphor surface with the interior components of the CR unit during manual removal of the IP from the CR unit after “jams” occurred. About half of the scratches observed on Fuji IPs were oriented in random directions with the other half oriented parallel to the direction of IP travel (Table 2). Kodak IPs more frequently had scratches oriented parallel to the direction of IP travel (Table 4 and Fig. 10). These were most likely caused by contact between the phosphor surface and the open end of the cassette when the IP was transported into and out of the cassette.

Black specks were visually noted on the phosphor surface of IPs from all vendors, and many were visible on the radiographic flat-field images. Unlike the Fuji and Kodak IPs, black specks were visible on almost all of the Agfa IPs (Table 3). Some IPs from Kodak appeared to have a fine-

Table 2. Fuji IP damage noted on visual and radiographic image inspections (by IP size)

Visual and Radiographic Image Results by IP Size

Table 3. Agfa IP damage noted on visual and radiographic image inspections (by IP size)

Visual and Radiographic Inspection Results by IP Size

grained dark-colored dust on the phosphor surface that caused the flat-field radiographic image to appear lighter than an area where the dust had been easily removed (Fig. 11)⁷. The dust most likely resulted from repeated friction between the aluminum surfaces of the rigid IP backing and the open edge of the cassette each time the IP was removed and reinserted into the cassette during the reading process. When the 35 × 43 cm Kodak IPs were removed and the cassettes inspected, it appeared that some cassettes were slightly warped. This most likely caused the IP to twist slightly during removal and reinsertion and resulted in more dust deposited along one edge of the IP where the IP's aluminum backing came into contact with the cassette.

White particulates were found on Fuji IPs used in the busiest areas of the radiology department. The particulates were more easily observed on the dark-colored IP backing material (Fig. 12) but were also present on the phosphor surface. The greatest accumulations were usually found on the larger-sized imaging plates and were oriented in strips between 1 and 4 cm from the longest edges of the IP. Most of the white particulates appeared to be fibers from the white-colored felt that lines

the inside of the cassettes. The location of the particulates also correlated with excessive wear of the felt along the inner side of a small felt-covered plastic ridge at the open end of the cassette. This wear pattern was noted most often in cassettes that had lids that did not close completely enough to prevent the IP corners from repeatedly contacting the felt-covered ridge during normal usage.

Visible lines at consistent intervals across each Agfa CR image (Fig. 13), from exposures read in the same CR unit, indicated that cleaning of the optics inside the CR unit was necessary. Also visible on 57% of Agfa radiographic images (Table 3) were single or paired marks about 1 cm in length near the corners of the 18 × 24 and 24 × 30 cm IPs (Fig. 14). Agfa confirmed that the repeated application of vacuum by the CR unit's suction cups on the phosphor surface could create microfractures that would allow moisture from the IP cleaning product to enter the phosphor and result in discoloration of the phosphor and radiographic image artifacts. However, no visible discoloration was observed during the initial visual inspection nor during a second inspection of the specific IPs that produced this radiographic image artifact.

Table 4. Kodak IP damage noted on visual and radiographic image inspections (by IP size)

Visual and Radiographic Image Inspection Results by IP Size

Several wear marks observed on the phosphor backing material of Fuji IPs correlated with components inside the cassette. Marks located up to 7 mm from the leading edges of IPs (Fig. 15) appeared to be caused by the IP repeatedly slipping past a small, sharp aluminum barrier located on the inner side of the cassette lid (Fig. 16). These marks were always present on IPs where the plastic latches had fractured and seemed to be an indicator of the extent of latch fracturing; the worse is the fracture, the more

extensive the wear is on the IP's leading edge. Another prominent wear mark observed resulted from friction between the IP backing and a plastic device inside the cassette that applied a small amount of pressure to the IP once the IP was fully inserted into the cassette (Fig. 17a). Delamination of the IP edge (Fig. 17b) often began at this location and also occurred where pressure was applied to the IP by a small, rectangular piece of dense foam located in a corner opposite the cassette opening. Delamination of the

Fig 9. A radiographic image of a Kodak IP shows the effect of yellowing of the IP surface (white area).

Fig 10. Scratches observed on the phosphor surface of a Kodak IP (a) were also apparent on the radiographic image (b) of the same IP.

backing material was noted on 36% of the IPs along the leading edges and at the IP corners on 16% of those inspected (Table 5). Before separation of the IP layers occurred, the wear marks did not directly affect image quality; however, once the wear became significant enough to result in delamination of the layers, image quality was affected in two ways. Yellowing of the phosphor layer occurred when moisture, entering through breaks in the IPs surface, caused oxidation within the phosphor resulting in apparent densities along an IP's periphery. Also, delamination of the phosphor surface edges (Fig. 17c), noted on 22% of the IPs inspected, resulted in loss of image information.

Fuji confirmed that the phosphor surface of an IP had "thinned" and resulted in an artifact on a 35×43 cm radiographic image (Fig. 18) where the plastic pressure device increased the friction between the phosphor surface and the felt. This same artifact was observed on seven other 35×43 cm Fuji IPs.

Unlike Fuji IPs, where delamination of both surfaces occurred around the IP's periphery and resulted in damage to the phosphor, or the plastic backing, or both, delamination of the Agfa IPs was limited to the periphery of the phosphor surface (Fig. 19) with no damage observed on the plastic backing. None of the Kodak IPs exhibited signs of phosphor delamination.

Barely visible but sharply defined 3.5-mm squares (Fig. 20) etched on the phosphor surface of four Agfa IPs (Table 3) and either 4-mm squares or 4-mm-wide rectangular shapes (Fig. 21a, c) etched on the phosphor surface of 26 Fuji IPs (Table 2) were also noted. The size of the squares correlated with the distance an IP could move inside a closed cassette. They were most likely caused by friction between the IP and dust or dirt particulates that had become embedded in the protective lining of the cassette with the depth of the scratched area progressing each time the IP slid in the cassette during normal usage. Of these etched areas, three were visible on radiographic images of Agfa IPs and four were visible on radiographic images of Fuji IPs (Fig. 21b). Because the design of the Kodak cassettes prevented the IP from moving inside the cassette during normal handling, no etched squares were apparent.

Two Agfa IPs (Table 3) had nonleading edges, and 69 Fuji IPs (Table 5) had leading edges that showed evidence of being crimped or bent (Fig. 19b). These appeared to be caused by the cassette lid closing tightly on the edge of an incorrectly positioned IP. Whether the IP

Fig 11. Magnifications (a and b) of the corners of a Kodak radiographic image (c) show the speckled appearance of ne-grained, dark-colored dust that evenly coated the phosphor side of some Kodak IPs. The dust was gently removed at the two locations that appear darker (a and b).

Fig 12. Fine-grained white-colored particulates observed on the black backing of Fuji IPs used in the busiest areas of the department as they appeared immediately after removal of the IP from the cassette (a) and after the particulates were gathered using a gloved finger (b).

was not inserted fully into the cassette after the reading procedure or whether a technologist attempted to remove a Fuji cassette too quickly from the CR reader causing the IP to slide partially out of the cassette prior to the lid closing could not be determined.

DISCUSSION

Optimizing the quality of CR radiographs should be a goal of every radiology department.

This goal can be achieved by combining visual inspection of CR cassettes and IPs with flat-field exposures to determine when observed damage adversely affects radiographic images. Also, documenting the physical condition and imaging performance of each cassette and IP on spreadsheets aids in monitoring the progression of wear and may allow trends to become apparent. If trends are observed, maintenance on either the

Fig 13. A line in the same location on multiple Agfa radiographic images indicated that cleaning of the CR optics was necessary.

Fig 14. The paired white marks near the corners of this Agfa radiographic image were caused by the repeated application of vacuum to the IP surface by the CR reader's IP transport mechanism. Microfractures resulted and allowed moisture to penetrate and discolor the phosphor surface.

Fig 15. Wear marks up to 7 mm wide observed on the black side leading edge of Fuji IPs occurred when one or both of the cassette plastic latches had fractured. They were caused by contact between the IP and a sharp aluminum barrier on the inside of the lid as the IP repeatedly slid past the barrier.

Fig 16. An aluminum barrier located on the inside of Fuji cassette lids caused wear marks on the black side leading edges of an IP.

Fig 17. A plastic device (a) inside the Fuji cassette that applied a small amount of pressure to the IP when it was fully inserted into the cassette caused wear marks on the black side of the IP and also delamination of the black side (b) and of the phosphor side (c).

Table 5. Occurrence of Fuji IP delamination, phosphor thinning, and crimping (by IP size)

Types of IP Damage Observed by IP size

Fig 18. Phosphor thinning resulted in the lighter-colored area (a) visible on this Fuji radiographic image (b). The thinning occurred where a plastic device inside the cassette applied pressure to the IP thus increasing the friction between the phosphor surface and the cassette's felt lining.

Fig 19. The Agfa IP in this photograph demonstrates (a) delamination of the phosphor layer with an intact plastic backing and (b) a crimped edge caused by the cassette lid closing on an incorrectly positioned IP. Crimped edges were also observed on Fuji IPs.

Fig 20. The 3.5-mm square etched onto the phosphor surface of this Agfa IP was caused by friction between the IP's phosphor surface and a sharp particulate that had become embedded in the cassette's lining. The size of the square corresponded to the amount of movement the IP had inside the cassette.

cassette or reader may prevent other cassettes and IPs from being adversely affected by maladjusted equipment. Regularly performed cassette and IP cleaning can also remove many of the dust or dirt particulates that degrade image quality.

CONCLUSION

Although the electronic components used to form, transmit, and store an image must all work in harmony to produce images that are of the highest quality, it may be the nonelectronic components of the imaging chain, such as the cassette and imaging plate, that are the greatest source of image artifacts.

From our investigation, it appeared that many of the image artifacts observed were the direct result of premature wear of the cassettes and imaging plates, some caused by flaws in their design. It was also apparent that a quality control program for computed radiography is essential⁸ and should include not only cleaning of cassettes and imaging plates on a regular basis, but also visual and radiographic image inspection to reduce the occurrence of image artifacts.

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Fig 21. Sharp particulates embedded in the cassette's felt lining etched 4-mm squares onto the phosphor surface of Fuji IPs when the cassette lid closed completely or 4-mm-wide rectangles when the cassette lid did not close completely enough to prevent excess movement of the IP within the cassette. The particulate that caused one of the etched rectangles (a) was located under the plastic pressure device inside the cassette and caused enough phosphor layer wear for the rectangle to become visible on the clinical radiograph (b). Another rectangle 2 cm from the first (c) had not yet etched the phosphor surface significantly enough to be visualized on the clinical image.

REFERENCES

1. Christie Group Ltd: Imaging Plate & Cassette Cleaning Guide, Fuji Computed Radiography, January, 2004
2. Minnigh DM, MacCutcheon DW: FUJIFILM Medical Systems FCR Quality Assurance Program. FUJIFILM Medical Systems, USA: 24–25, 28–30, 2000
3. Guidelines for Acceptance Testing and Quality Control, *Kodak DirectView* CR 800 System and *Kodak DirectView* CR 900 System. Technical and Scientific Bulletin, 2001
4. Przybyszewski J: *Kodak DirectView* CR Cassette/Screen Cleaning Instructions. Service Bulletin, Health Imaging Products, Eastman Kodak Company, Publication Number 9F7318, 2005
5. Salloum Z: AGFA ADC GUIDE CR Basics, Agfa Diagnostic Centre Professional Services, 2004
6. Samei E, Seibert JA, Willis CE, Flynn MJ, Mah E, Juncck KL: Performance evaluation of computed radiography systems, *Med Phys* 28(3):363, March 2001
7. Cesar LJ, Schueler BA, Zink FE, Daly TR, Taubel JP, Jorgenson LL: Artefacts found in computed radiography. *Br J Radiol* 195–202, February 2001
8. Willis, CE: What's new in quality assurance for computed radiography? Decisions in imaging economics. *The Journal of Imaging Technology Management*. October 2004