The Evaluation of Collimator Alignment of Diagnostic X-ray Tube Using Computed Radiography System

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Abstract

The purpose of this study was to evaluate the use of computed radiography system (CR) for collimator alignment test. Images were acquired following the NCRP No.99. The screen-film images were analyzed using visual interpretation. The CR images were analyzed using digital profile. In screen-film method, the process of measurement is dependent on exposure level in order to identify the boundaries of image of x-ray field on the processed film clearly. The optimal optical density for collimator alignment test in screen-film method is in the range between 1.5 and 2.0 OD. On the other hand, the results of collimator alignment in CR method using imaging plate are independent on exposure level. CR images permit digital profile analysis; there by reducing observer error in determining the boundary of image of x-ray field. However, CR may produce longer observed distance between the x-ray field and light field, which may lead to NCRP No.99 standard violation. The variation of coefficient (CV) using CR method is less than 5% at any exposure. Thus, we concluded that the results of collimator alignment using CR method are more reliable and consistent than visual interpretations.

Keywords: *Quality Control, Collimator Alignment Test, Diagnostic X-ray Tube, CR*

1. Introduction

Nowadays, Computed Radiography (CR) system can be use in conventional x-ray equipment. It needs the same manipulations as conventional radiography and the technology is well established. CR was initially used for portable chest radiography, overcoming inconsistent image quality from inappropriate exposure. With manufacturers' ongoing improvement in ease of system use and image quality, CR use has expanded to chest, musculoskeletal, abdominal, pediatric examination and mammography[1].

The fundamental innovation in the development of CR was originated from Kodak. However, the significant technical steps and conceptualization of the application were introduced by Fuji (FCR101) who produced the first medical x-ray image in 1983[2]. Fuji, the main developer of CR in the eighties, used $BaFBr:Eu^{2+}$ phosphor and a cassette based approach[1-3]. CR systems operate with a workflow pattern very similar to screen-film radiography. CR cassettes are exposed just like screen-film cassettes, and they are then brought to a reader unit, just as film-screen cassettes are brought to the film processor (Figure 1).

The similarity in handling of CR and screen-film cassettes contributed to the initial success of CR. One of the advantages of the CR over screen-film radiography is its much larger dynamic range (Figure 2); in other words, the exposure latitude with CR is much wider than with screen-film systems.

The digital image that is generated by CR reader is stored temporarily on a local hard disk. Many CR systems are joined directly to laser printers that make film hard copies of the digital images. CR systems often serve as entry points into a PACS, for interpretation by the radiologist and long-term archiving.

The impression that CR images can always be adjusted after exposing the CR with x-rays is not necessarily true. There are several factors affecting the quality of CR images and Radiographers or technologists are the key persons who are responsible in delivering good quality radiographs, with reasonable radiation dose given to the patients. As a result, the quality control of the technical parameters and radiographic positioning of images acquired from CR systems are therefore critical and should be systematically investigated [5].

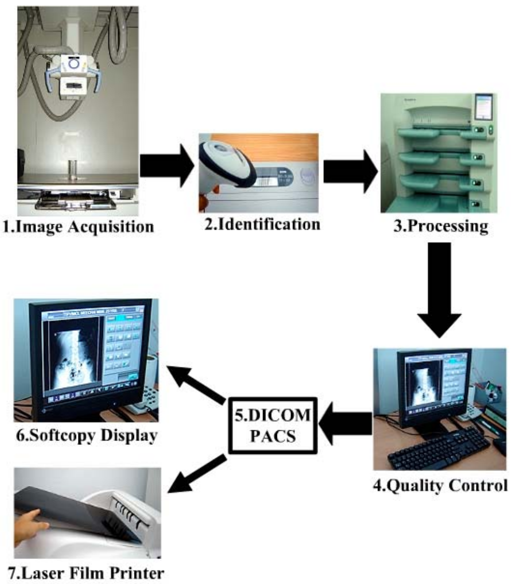


Figure 1. Representation of CR image acquisition and dataflow: 1.Image acquisition, 2.Identification, 3.Processing, 4.Quality control, 5.Electronic transfer, 6.Soft copy display and digital archiving, and 7.Laser film printer (option).

In this paper, the researchers acquired comparison of beam and collimator alignment measurement with screen-film (S/F)system[6] and imaging plate (IP) of a selected CR system. The S/F and IP were exposed at various exposure levels in order to obtain various optical densities (1.0-2.5 OD above base plus fog). The processed films were analyzed using the NCRP No.99 standard[7]. Digital images obtained from IP were analyzed accordingly. Both reading results were compared during the data analysis. The observer's reading reliability and variations were also taking into consideration.

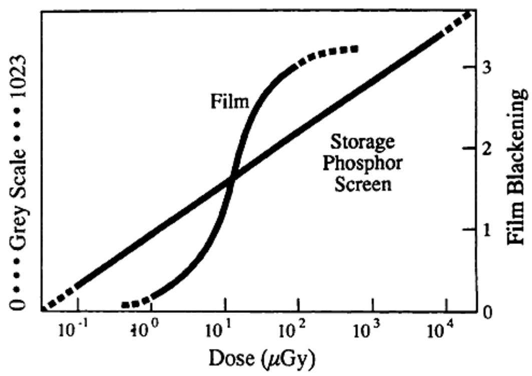


Figure 2. One of the principal advantages of CR over screen-film detector systems is the greater dynamic range that CR provides. The usable exposure range for the CR system is much greater. [4]

2. Materials and Methods

2.1 Imaging Systems

The S/F system used in this study was consisted of Kodak X-OMAT cassette sized 8"×10" and a regular screen in combination with general purpose KODAK Medical x-ray film. The exposed films were processed using a calibrated KODAK X-OMAT multiloader 7000 processor with clinical setting at 35ºC temperature. An X-rite 301 densitometer with the aperture size of 1 mm was used for film optical density measurement. The Computed Radiography (CR) system, used in the experiment was a FUJI-FILM FCR XG5000 imaging reader with imaging plate sized 20.3× 25.4 cm^2 corresponding to 100.0 µm in pixel size. The X-ray machine was Siemens's Quantum Medical Imaging.

2.2 Image Acquisition and Processing

All images were acquired using the same x-ray tube and generator at various exposure to investigate effects due to varying optical densities. During the image acquisition process, the beam and collimator alignment test tool (RMI model 161B) was carefully positioned and taped securely on the exit window of the x-ray tube collimator, so that the test tool was parallel to the anode-cathode direction. The laser line of light field was set at the same lead line of the test tool. The image receptor was placed at 100 cm from the focal spot and located in the bucky tray. A good alignment shall ensure an accurate result suitable for analysis. (Figure 3)

CR images were acquired using 8"×10"

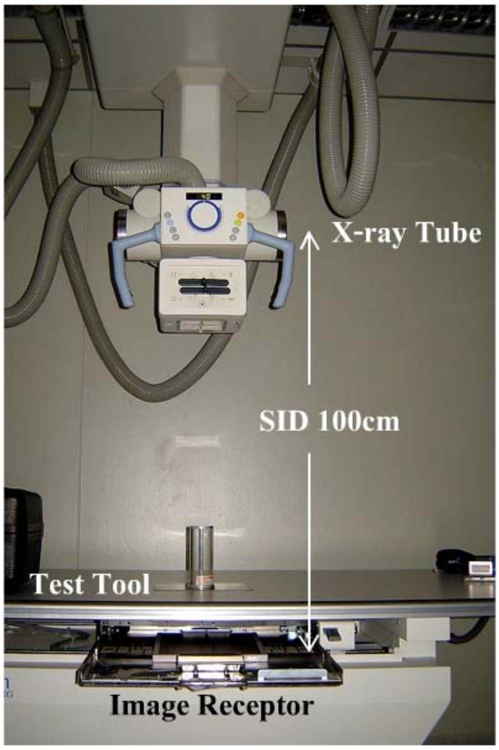


Figure 3. Setting of beam and collimator alignment test tool.

imaging plate placed at the same location as of the S/F system. To evaluate the effect of different exposure levels, the CR image plates were also exposed at similar exposures with S/F. By default, CR's raw image data were automatically mapped logarithmically in the plate reader system. To obtain linear CR profile, the data were converted to into linear data before performing calculations. The linear data mode must be set before image acquisitions by using appropriated CR reader program.

The exposure setting was varied to investigate effects of exposure varying. Table 1 shows the exposure technique used in both conventional radiography system and computed radiography system.

Table 1. The selected exposure techniques for both conventional radiography system and computed radiography system.

Conventional Radiography System	Computed Radiography System
55kVp, 5.0mAs	55kVp, 5.0mAs
55kVp, 6.4mAs	55kVp, 6.4mAs
55kVp, 7.5mAs	55kVp, 8.0mAs
60kVp, 5.0mAs	60kVp, 5.0mAs
60kVp, 6.4mAs	60kVp, 6.4mAs
60kVp, 7.5mAs	60kVp, 8.0mAs
70kVp, 1.6mAs	70kVp, 2.4mAs
70kVp, 2.0mAs	70kVp, 3.2mAs
70kVp, 2.4mAs	70kVp, 4.0mAs
70kVp, 5.0mAs	70kVp, 5.0mAs
70kVp ,6.4mAs	70kVp, 6.4mAs
70kVp, 7.5mAs	70kVp, 8.0mAs

2.3 Consistency Measurement

The standard deviation (SD) and variation of coefficient (CV) have been investigated for consistency measurement. There were 35 samples for calculated the accuracy of the test procedure. The images of each test were measured repeat 35 times for data collection and then SD and CV were calculated. The SD and CV were used to compare the accuracy of the method between Conventional Radiography system and Computed Radiography system.

2.4 Film Reading

The beam and collimator alignment on films were evaluated by one observer on a light box where its brightness levels were calibrated within the NEMA's standard range (700 and 2000 cd/m^2). The films were placed on the light box one at a time. Then the observer measured the collimator alignment, beam alignment, and centering using the NCRP No.99 standard. The results were compared to those obtained from difference exposure variations.

2.5 Data Analysis

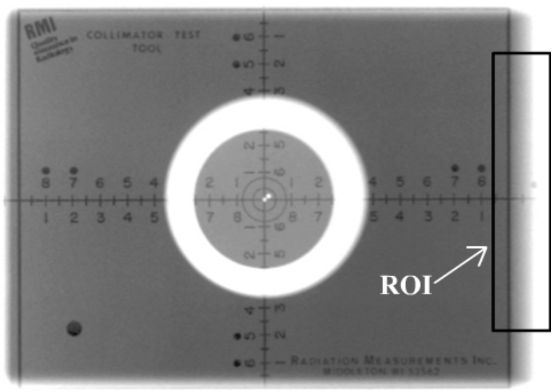


Figure 4. The appropriate region of interest used in the profile plot. The profile plot can be created using the ImageJ program shown in Figure 5.

A computer program used to analyze CR image was a public domain Java program ImageJ[8], version 1.37V. The program was selected because it can handle raw image data from CR and freely available. The image files were in DICOM format with 8 bits depth. Figure 4 shows beam and collimator alignment images from the CR system.

The procedures for data analysis are as following: The computer program was used to create the profile plot for accurately acquiring the collimator alignment. The rectangular regions of interest were automatically defined covering a large portion of the selected edge (Figure 4).

Figure 5 show an example of a collimator profile obtained from a CR image. The highest peak (the maximum point) was the region of the dark line, which was the border of the test tool or light field (see figure 4), while the minimum point is the outermost region of the x-ray field. The distance X, the distance between the x-ray field and light field obtained using digital profile plot method, was measured. The interpretation was based on NCRP No.99 criteria corresponding to the film methods.

In S/F system, the distance Y, the observable distance between x-ray field and light field, was visually observed. In this study, observed distance Y was shorter than X due to human inability to observe the distance Z, which is very low OD. Hence, the digital profile plot method may yield greater observed distance between the x-ray field and the light filed comparing to S/F.

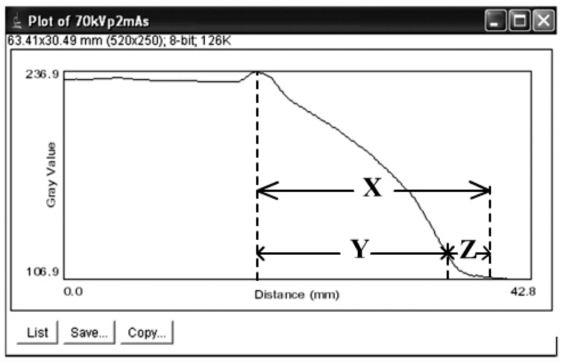


Figure 5. The profile plot of one side of collimator alignment test image.

3. Results and Discussions

3.1 Effect of X-ray Exposure

To investigate the effect of x-ray exposure on the measurement of collimator alignment, a series of small CR image plates (8"×10") and screen-film combination were exposed over a wide range of exposures and were evaluated. Table 2 lists collimator alignment measurement of S/F system, SD, and CV. The results are also illustrated in Figure 6 and 8.

The results clearly indicated that the variations among the measured collimator alignment length were very small at optical density less than 2.0 OD. In case of the optical density higher than 2.0 OD, films were overexposed to analyze the collimator alignment since there was very difficult to locate where the correct line of x-ray beam was. Hence, the optical density greater than 2.0 OD are not appropriate in practical use. For the optical density lower than 1.0 OD, there were easy to identify where the correct line of x-ray beam was. However, this is not appropriate in actual practice since the films would be underexposed. Thus, based upon the results, researcher would recommend the optical density value between 1.5-2.0 OD, which is optimal in practical use for collimator alignment test.

Table 2. Collimator alignment measurement performed by conventional radiography method.

kVp	mAs	OD	%Variance		SD		CV	
			Long Axis (cm)	Short Axis (cm)	Long Axis	Short Axis	Long Axis	Short Axis
55	5.0	1.04	1.48	1.53	0.03	0.06	0.02	0.04
	6.4	1.18	1.49	1.45	0.08	0.04	0.05	0.03
	7.5	1.28	1.47	1.55	0.06	0.05	0.04	0.03
60	5.0	1.53	1.32	1.38	0.05	0.05	0.04	0.03
	6.4	1.90	1.40	1.30	0.05	0.06	0.04	0.05
	7.5	2.10	1.33	1.13	0.04	0.05	0.03	0.04
70	1.6	1.00	1.46	1.48	0.05	0.03	0.03	0.02
	2.0	1.69	1.38	1.35	0.04	0.05	0.03	0.04
	2.4	2.01	1.34	1.33	0.04	0.07	0.03	0.05
	5.0	2.24	0.96	0.84	0.05	0.08	0.05	0.10
	6.4	2.44	0.98	0.70	0.04	0.09	0.04	0.13
	7.5	2.50	1.02	0.76	0.05	0.12	0.05	0.16
		$\overline{X}_{SF}$	1.30	1.23				

Table 3. Collimator alignment measurement performed by computed radiography method.

kVp	mAs	Pixel Value	%Variance		SD		CV	
			Long Axis (cm)	Short Axis (cm)	Long Axis	Short Axis	Long Axis	Short Axis
55	**5.0**	147	1.79	1.83	0.02	0.01	0.01	0.01
	6.4	152	1.81	1.89	0.03	0.03	0.02	0.02
	8.0	167	1.75	1.82	0.03	0.04	0.02	0.02
60	**5.0**	174	1.72	1.90	0.05	0.04	0.03	0.02
	6.4	185	1.81	1.86	0.05	0.05	0.03	0.05
	8.0	200	1.80	1.90	0.04	0.03	0.02	0.02
70	**2.4**	182	1.75	1.88	0.03	0.05	0.02	0.03
	3.2	198	1.72	1.89	0.03	0.03	0.02	0.02
	4.0	209	1.78	1.90	0.04	0.03	0.02	0.02
	5.0	202	1.75	1.84	0.04	0.03	0.02	0.02
	6.4	220	1.82	1.80	0.05	0.04	0.03	0.03
	8.0	262	1.78	1.87	0.04	0.03	0.02	0.02
		$\overline{X}_{CR}$	1.77	1.87				

For CR images, the results of collimator alignment measurement, (SD, and CV) is shown in table 3 and also illustrated in Figure 7 and 8.

The results indicated that variations among the measured collimator alignment from CR image are almost constant at every exposure. In sum, the collimator alignment using profile plot is independent of the exposure level.

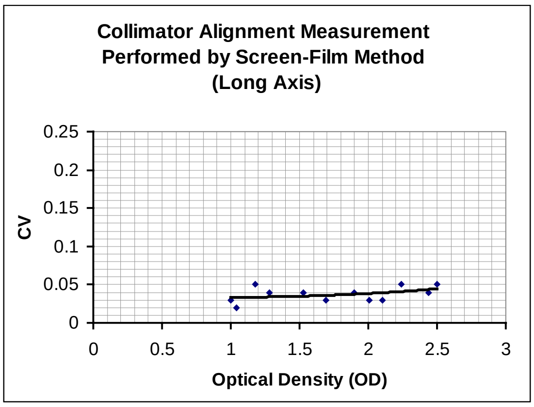
3.2 Consistency of Measurements

The evaluation of collimator alignment for the S/F system at optical density range between 1.5-2.0 OD shows the CV less than 5.0%. On the other hand, the collimator alignment films with the optical density greater than 2.0 OD had CV values between 10% and 16%, as shown in Table 2 and Figure 6(b). Hence the optical density greater than 2.0 OD is considered inconsistency and inappropriate for collimator alignment testing.

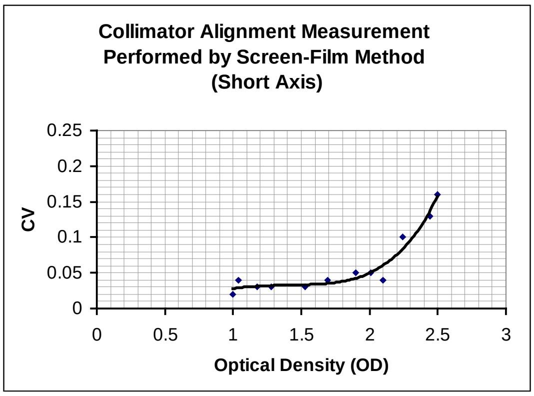
All of CR images maintained a coefficient of variation (CV) less than 5.0% at any exposure. It can also be summarized that the results of computed radiography system agree very well, showing no effects due to varying exposure combinations.

3.3 Profile Plot VS Visual Interpretation

The S/F with an optical density ranging between 1.5 OD and 2.0 OD was selected as the “Gold Standard” to compare to the CR system. The Table 2 and Table 3 show the results from S/F and CR accordingly. When comparing the results, the value reading obtained from the CR system (distance X shown in figure 5) were greater than value reading from the S/F system (distance Y shown in figure 5) because the CR values were measured from the profile plot representing the real distance between the x-ray field and light field or the border line of the test tool. However, the S/F value readings

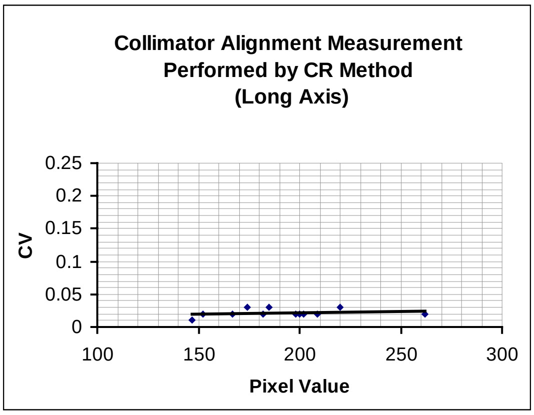


(a)

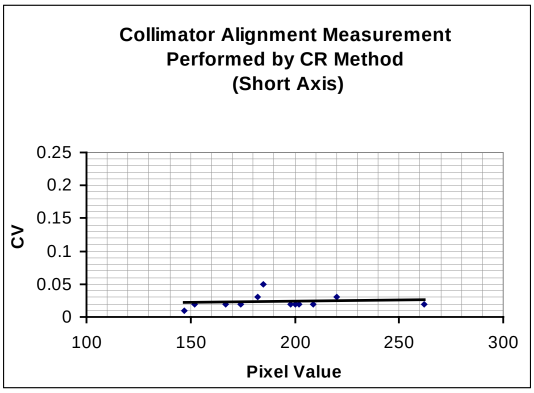


(b)

Figure 6. The CV of collimator alignment performed by screen-film method: (a) Long axis, (b) Short axis.



(a)



(b)

Figure 7. The CV of collimator alignment performed by CR method: (a) Long axis, (b) Short axis.

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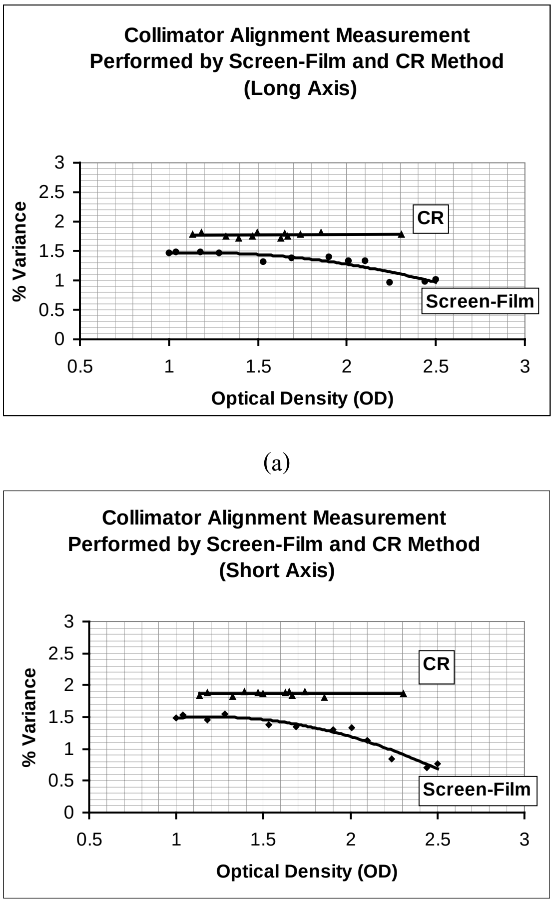
are obtained from the visual interpretation which may not represent the actual x-ray field. Although the researcher measures them carefully, errors from visual reading the distance between x-ray field and the border line of the test tool measurement may still occur.



(a)

(b)

Figure 8. The percentage variance of collimator alignment performed by conventional radiography and computed radiography method: (a) Long axis, (b) Short axis.

The researcher found that the long and short axis distance obtained from the S/F system depends on exposure level (Figure 8). Hence, the test that uses S/F should be controlled and should use appropriate exposure to improve consistency and reproducibility in measurement. The results obtained from the CR system were independent of the exposure level because the use of the profile plot helps eliminating the potential errors resulted by visual interpretation of the actual boundaries of x-ray field when images were not produced with appropriate optical density.

The long and short axis obtained using CR is greater than that of visual interpretation. The $\Delta\overline{X}$ $(\Delta\overline{X} = \overline{X}_{CR} - \overline{X}_{SF})$ of the long axis is equal to 0.47; and short axis is 0.63, respectively. (see Table 2 and 3)

4. Conclusion

Using digital image receptors, CR system, for evaluation of collimator alignment is practically applicable and convenient. It saves cost and resources because CR does not require film printing. The measured distance of x-ray field and light field using CR were more reliable and consistent than that of visual interpretations in S/F. The CR method is especially useful for those radiology departments that are in transition to a filmless operation.

Noted that the CR method using digital profile plot allows us to measure actual the distance between the x-ray filed and light field (distance X in figure 5.) which include the distance Z that may be unobservable in S/F system. The distance X is usually greater than the distance Y (using visual interpretation) in S/F (average 0.47 cm. and 0.63 cm, for long axis and short axis respectively). Thus, using CR method may produce the results that violate the 2% variance of SID (source-to-image distance) suggested by the film-based gold standard, NCRP No.99.

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