THE EFFECT OF THE IMPLEMENTATION OF THE QUALITY CONTROL PROGRAM OF THE COMPUTED RADIOGRAPHY SYSTEM

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ABSTRACT

Objectives: To study the relationship between the patient radiation doses, the image quality and the repeated and rejected rates both before and after the implementation of the quality control (QC) program to the computed radiography (CR) system at the Outpatient Division, Department of Radiology of King Chulalongkorn Memorial Hospital, Thai Red Cross Society.

Materials: Two systems of single-phase x-ray machine (Hitachi model DR-155HM), and another system of the CR system (Fuji model FCR 5000) with standard type of imaging plates, QC accessories, CR workstation with high resolution display system were compared.

Methods: Experimental prospective study, before and after QC program to the CR system were designed; 1,384 examinations of the adult patients, eight projections of CR images, skull PA, lateral cephalometry, cervical spine AP, chest PA, abdomen AP, lumbo-sacral spine AP and lateral and pelvis AP were performed under patient consent form and calculated the entrance skin dose (ESD). The radiographic patient dose was defined as the comparison of the rejected and retaken rates for the before and after QC of equipment. CR image quality evaluation had been done by two of the equivalent experienced radiologists.

Results: There were the significantly differences ($P < 0.05$) for the decreasing of the rejected and retaken rate and the decreasing of average of ESD after the implementation of the QC program of the CR system.

Conclusion: After the implementation of quality control program for the computed radiography system, the reduction of the rejected and retaken rate was 55 percent and the reduction of the entrance skin dose was 18 percent in PA chest and 16 percent in the lumbo-sacral spines while maintaining optimum image quality. The QC program of the CR system shows the useful parameters benefited for the optimization of the patient doses and the image quality.

Key words: Quality control program, computed radiography.

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INTRODUCTION

With two passing decades since the computed radiography (CR) worldwide introduction, it has become a mainstay technology for acquiring ordinary radiographic projections in digital form that produces images equivalent or better than conventional screen -film (S-F) systems. The success of CR leads to the misconception that quality assurance (QA) and quality control (QC) processes are no longer necessary. As a matter of fact, QA and QC processes for CR are no less important than they are for conventional radiography, and must be modified to take into consideration the unique characteristics of CR technology.[1] A good QC program utilizes tests that are sensitive and can be utilized frequent enough to detect degradation in equipment performance before diagnostic information is lost, with a special focus on potential dose reduction.[2] The radiation dose reduction and the diagnostic information are the output of quality control tests to assess the efficiency of computed radiographic system.[3] QA represents a comprehensive, ongoing program to evaluate all aspects of medical imaging.

ESD = Entrance Skin Dose

The ultimate goal of a QA program is to optimize image quality and patient safety. QC typically refers to the performance of periodic monitoring of imaging performance. Some authors[4] showed that the reduced retaken rate due to exposure factors by using CR led to a reduction in the overall retaken rate. Despite 50 percent dosage reduction, films were of better or equal quality when compared to conventional radiography. Several authors[5-8] suggested that the dose reduction can be achieved by means of a reduction in the number of examinations that must be repeated owing to incorrect exposure factors. In addition, it is often suggested that the computed radiography could be used with lower radiation doses than the conventional systems and thus reduce the patient doses.[9] Though the artifacts on radiographic images are distracting and may compromise accurate diagnosis, users' understanding the potential sources of CR artifacts will aid in identifying and resolving problems quickly and help to prevent future occurrences.[10] The first CR system (Fuji FCR 5000) was installed in the year 2000 in the department of radiology, King Chulalongkorn Memorial Hospital, Thai Red Cross Society, with standard resolution phosphor imaging plates (ST-V_N), Fuji Photo Film Co., Ltd..In clinical practice, several problems have been found such as Moiré patterns, too dark, too bright, too noisy images, superimposed appearances, post-processing parameter mismatch, rejected and retaken rate over 9 percents for 6 examinations (84 cases from total 934 cases in 6 months), incorrect imaging plate handle, lack of QC protocol for routine job, etc. For the long term, it is expected that the rejected and retaken rate should be reduced to 5 percent or less, the unnecessary patient radiation doses could be reduced, with the costs reduction. The goal of CR acceptance testing is to establish the CR reader and phosphor screen baseline performance. Quality control testing then detects changes in the CR system that could affect radiographic image quality. In this study, two main parameters are identified as influencing diagnostic reference levels (DRL)[11,12] and entrance skin dose (ESD) for determining which had been affected to the reduction of whether there was any statistically significant difference between before and after QC implementation of the rejected and retaken rates (and thus, reduction of radiation doses to the patient), and thus improve the image quality.

MATERIALS AND METHODS

This work has been designed as a prospective experimental study comparing the patient doses and image qualities between before (controls group) and after (experimental group) implementation of QC of the CR system (Table 1-2), and performed on the routine clinical examinations that the ethical approval by the Ethics Committee of Faculty of Medicine, Chulalongkorn University had been determined the patient information and informed consent had to be processed. All data was collected under the criteria developed by the senior technologist (Table 3). The

entrance skin dose (ESD) was calculated and the comparable images quality evaluated by two radiologists of the same experience.

Patient data was collected at the general x-ray room (Room number 4 and 5), section of outpatient Department of Radiology, (Por Por Ror Building 4th floor), King Chulalongkorn Memorial Hospital, Bangkok, Thailand. Two systems of single-phase x-ray machine (Hitachi DR-155HM, Hitachi, Japan, 1989) with bucky table, non -automatic exposure control (non-AEC) were used. Another system of the CR system was a Fuji computed radiography (Fuji, FCR 5000, Fuji Photo Film Co. Ltd., Tokyo, Japan, 2000). Imaging phosphors were Europium doped barium fluoro -bromide. Imaging plate size for skull PA from paranasal sinuses series, lateral cephalometry, and cervical spine AP was 24 x 30 cm, and 35 x 43 cm for chest PA, abdomen AP, lumbo-sacral spine AP, lumbo-sacral spine lateral and pelvis AP. Soft copies were obtained by Totoku high resolution monochrome LCD display model ME 201L using Fuji CR Workstation model HI-C 655. Hard copies were obtained from Fuji computed radiography film type 780-H (25.7 x 36.4 cm) and type LI-LM (35 x 43 cm), Fuji wet laser imager model FL-IM D containing a helium neon laser (633 nm) with developer (RD-20) and Fixer (RF-15).

Sample random technique

The selected randomly of the target patients had been done by the preliminary survey of 8 given radiographic projections and 4 age groups (16-30, 31-45, 46-60 and 61-75 years old) for 33 working days. Select 692 sample cases of "Before QC program" (control group) and meet the criteria; collect, complete and analyze the patient data for the period of 1.5 months. Calibrate the x-ray using AAPM protocol[13] in table 1 and the CR systems using AAPM protocol Task Group No.10[14] and KCARE CR QA Protocol Draft 4.0 by Kings College Hospital[15] in table 2 for 1 month. Select 692 sample cases of "After QC program" (experimental group) and meet the criteria; collect, complete and analyze the patient data for the period of 1.5 months. Calculate ESD for each examination and compare the radiation dose and image quality of the control group to the experimental group.

Data Analysis

The retaken data, the patient dose and image quality score were analyzed by using the SPSS version 11.5 for Windows software package to test for statistical significance before and after implementation of the QC program. The analysis was performed first according to the actual modality that was used for each examination. This was of interest because, if the patient underwent imaging with the different x-ray machine; the quantity of the entrance surface air kerma (ESAK, mGy/mAs), the back scatter factor and the entrance skin dose (mGy) would be different.

RESULTS

The results can be concluded into 2 groups, the first was the equipment performance (table 4 and table 5) and the second was the assessment of image quality and radiation dose before and after QC implementation in term of the percentage rejected and retaken radiographs (table 6) including the exposure factors (table 7), the mean entrance skin dose and the image quality comparing (table 8 to table 10).

The Computed Radiography System Quality control

Both of the x-ray machine and the computed radiography performances were in the acceptable range. The QC results were shown in table 4 - 5.

Table 1. The items of x-ray machine QC and list of test tools which were used.

QC items (AAPM Protocol)	**Test tools**
1. General mechanical conditions	1. Ionization chamber (Victoreen 4000M+)
2. All indicator lamps and "beam ON indicator"	2. Pure Aluminum plates (0.1, 0.5 and 1.0 mm in thickness)
3. Dead man switch	3. Beam alignment test tool
4. Source image distance (SID)indicator	4. Collimator test tool
5. Mechanical motion test	5. Sensitometer
6. Field size indication	6. Densitometer
7. Light versus radiation congruence	7. Tape measure
8. Cross-hair centering	
9. Automatic collimation or Positive beam limit (PBL)	
10. Photo timer reproducibility and density compensation	
11. Exposure reproducibility	
12. Linearity of exposure with mR/mAs	
13. Timer accuracy	
14. Beam quality (HVL)	
15. kVp accuracy	
16. Entrance skin exposure (ESE)	

Table 2. The items of CR machine QC and list of test tools which were used

QC items (AAPM Task Group 10 Protocol and	**Test tools**
1. Monitor & laser printer	1. TO20 threshold contrast test object or equivalent
2. Dark Noise	2. Small lead or Copper block (~5 x 5 cm)
3. Erasure cycle efficiency	3. 1.5 mm Copper filtration (>10 x 10 cm)
4. Sensitivity Index calibration	4. Farmer Ionization chamber 0.6 cc.
5. Sensitivity Index consistency	5. Huttner test object or equivalent
6. Uniformity	6. M1 geometry test object or lead ruler
7. Scaling errors	7. Contact mesh
8. Blurring	8. Steel ruler
9. Limiting Spatial Resolution	9. Adhesive tape
10. Threshold Contrast Detail Detectability (TCDD)	10. Tape measure
11. Laser beam function	
12. Moiré Patterns	
In all tests, the QC CR imaging plate number A 09234079 was selected for all procedures.	

Table 3. Details of patient characteristic were colleted for each examination.

Variable	Description	Method
Data group	Before or after QC group	Obtained from collected data period
Patient identification	Hospital number, age, sex and date of examination	Notes from patient identification
Exposure conditions:		
Examination type	1.skull PA 2.lateral cephalometry 3.cervical spine AP 4.chest PA 5.abdomen AP 6.lumbo-sacral spine AP 7.lumbo-sacral spine lateral 8. pelvis AP	Examination and position during exposure
Wt, Ht	body weight (kg) and height (cm)	Measured by technologist
BMI	Body mass index for each patient	Calculate by formula; $BMI = \frac{Weight(kg)}{Height\ (m)^2}$
Thickness	Patient body part of thickness (cm) in the central field for each examination	Measured by technologist
kVp	kilovoltage peak across x-ray tube	Record from control panel
mAs	milliampere second product	Record from control panel
SID	Source-image receptor distance (cm)	Measured by technologist
SSD	Source -skin distance (cm)	*SSD = SID – (Patient thickness + table to image receptor distance)*
Room ID	No. 4 or No. 5	X-ray machine (Hitachi model DR-155HM)
S-value	Sensitivity value of each image	Record from CR reader panel
ESD (mGy)	Entrance Skin Dose in milliGray unit	Calculated by formula; $ESD = mAs \times ESD_M \times (SSD/100)^2$
Image Quality	Image quality grading for chest PA, abdomen AP, L-S spine AP and lateral view	Grading by senior radiologists using criteria from European guideline forms by 0, 0.5 and 1 scale; *0 - Not fulfill, 0.5 - Partial fulfill* *1 – Fulfill, P - Pathology/Excluded*
Repeat image	Yes or No	Mark by qualified technologist
Causes of reject or retake image	1. position 2. motion 3. technical error 4. selected menu 5. high "S" value 6. low "S" value 7. artifacts	Mark by qualified technologist

Note. Some data are missing in subsequence tables of the results for one of the three reasons: not recorded, unavailable, mismatch.

Table 4. Main report of x-ray machine performance room number 4 and 5 had been done.

LOCATION:	PPR 4F King Chulalongkorn Memorial Hospital			
DATE:	9/10/2004		15/10/2004	
ROOM NUMBER:	**4**		**5**	
MANUFACTURE:	Hitachi, Japan; April 1989			
MODEL NUMBER	DR-155HM (Tube unit; U-6GE-55T)		DR-155HM (Tube unit; U-6GE-55T)	
SERIAL NUMBER	KC12808904		KC 17714403	
General mechanical conditions		**P**		**P**
All indication lamps and "Beam on indicator"		**P**		**P**
Dead man switch	-	**N/A**	-	**N/A**
Source image distance indicator	0.5% SID	**P**	1.0% SID	**P**
Mechanical motion test		**P**		**P**
Field size indication	A-C =1.19%, perpend. = 0.19%	**P**	A-C = 0.5%, Perpend. = 1.0%	**P**
Light VS Radiation congruence	A-C =0.31%, perpend. = 0.63%	**P**	A-C =1.0%, Perpend. = 1.19%	**P**
Cross hair centering	0.31%	**P**	1.31%)	**P**
Automatic collimation (PBL)	-	**N/A**	-	**N/A**
Photo timer reproducibility and density compensation	-	**N/A**	-	**N/A**
Exposure reproducibility	CV = 0.016	**P**	CV = 0.010	**P**
Linearity of exposure with mR/mAs	0.030	**P**	0.036	**P**
Timer accuracy	5.00%	**P**	5.00%	**P**
Beam quality (HVL)	3.02 mmAl at 80 kVp	**P**	2.83 mmAl at 80 kVp	**P**
kVp accuracy	4.00 – 8.92%	**P**	1.80 – 4.82%	**P**
Entrance skin exposure (ESE)		**P**		**P**

Table 5. Main report of CR system performance had been done.

CR system Calibration Test	Tolerance -The Established Criteria	Result
1. Monitor & laser printer set-up	The 5% on 0% and 95% on 100% details were clearly visible. The horizontal and vertical resolutions differ by lesser than 20%.	P
2. Dark Noise	Many artifacts were found on the images of 4 years IP used but were not on the new one.	P
3. Erasure cycle efficiency	Absence of a ghost image of the lead block from the first exposure in the re-exposed image.	P
4. Sensitivity Index calibration	The indicated exposure should agree with the measured exposure within 20%.	P
5. Sensitivity Index consistency	The variation in the calculated indicated exposures should not differ by greater than 20% between plates.	P
6. Uniformity	The images do not have obvious artifacts. The maximum variations in pixel values were within a range of 10% of each other.	P
7. Scaling errors	The measured distances x and y should agree within 3% of the actual distances. All calculated aspect ratios were within 1.00 ± 0.03.	P
8. Blurring	No blurring was present.	P
9. Limiting Spatial Resolution	For the 45^{o} angled test object the resolved line pairs per mm should be $>1.2/2p$ where p is the pixel dimension in mm. In the scan and subscan directions the limiting resolution should be >0.85/2p.	P
10. Threshold Contrast Detail Detectability (TCDD)	The results of this test are used to set a baseline for future QA tests. Results could be compared to those from other similar systems if available.	P
11. Laser beam function	Ruler edges were straight and continuous without any under- or overshoot of the scan lines in light to dark transitions.	P
12. Moiré Patterns	Moiré patterns had been visible with the routine stationary grid using.	F

P = Pass **N/P = Not performed**

F = Fail **NOTE = Recommendation suggested**

N/A = Not applicable

Patient Data

The 1,384 examinations were met the criteria and included in the study. Two groups of study were well matched for number, age, sex, the body weight and the body height.

The rejected-retaken data

The difference of rejected-retaken rate before, 22 from 692 examinations and after, 10 from 692 examinations, is statistically significant (Pearson Chi-square Test, $P < 0.05$) as shown in table 6.

Table 6. Shown the percentage of the rejected and retaken by different causes.

Types of reject and retake examination	Before group		After group		Total		*P- value*
	Retake number	%	Retake number	%	Retake number	%	
Positioning error	8	1.16	6	0.87	14	1.01	**0.591**
Motion	2	0.29	0	0.00	2	0.14	**0.157**
Technical error	2	0.29	1	0.14	3	0.22	**0.350**
Selected menu	0	0.00	0	0.00	0	0.00	-
High "S" value	7	1.01	0	0.00	7	0.51	**0.008**
Low "S" value	0	0.00	0	0.00	0	0.00	-
Artifacts	3	0.43	3	0.43	6	0.43	**1.000**
Total	22	3.18	10	1.45	32	2.31	**0.032**
Pearson Chi-square Test (χ^2) for association							

Exposure Conditions

The comparison of body part thickness (cm) and BMI that effected to the patient entrance skin doses of both groups were not different. The exposure factors (kVp and mAs) had been compared as shown in table 7.

Table 7. Shown the exposure factor data were compared between before and after QC program of examinations.

Types of exam.	Before QC group				After QC group			
	kVp		mAs		kVp		mAs	
	Mean	SD (min-max)	Mean	SD (min-max)	Mean	SD (min-max)	Mean	SD (min-max)
Skull PA	69.77	2.20 (65-75)	42.38	4.54 (40-51)	70.77	1.88 (70-75)	34.62	5.50 (32-50)
Ceph. lat	77.00	1.73 (75-78)	21.67	5.77 (15-25)	75.33	2.31 (74-78)	8.00	2.00 (6-10)
C sp. AP	69.00	5.06 (58-79)	16.90	6.86 (8-40)	67.67	4.14 (66-85)	16.52	19.20 (7-100)
Chest PA	73.65	3.51 (66-85)	13.13	2.71 (6-20)	71.22	2.71 (63-80)	11.11	2.25 (5-16)
Abd. AP	76.43	1.97 (75-82)	59.49	12.20 (50-100)	75.45	1.99 (70-80)	55.82	10.50 (40-100)
L-S AP	76.91	2.89 (70-82)	61.73	15.21 (40-104)	75.42	1.66 (70-80)	53.00	12.25 (40-100)
L-S lat	82.70	2.77 (77-89)	112.40	19.12 (80-165)	85.65	3.18 (80-93)	104.38	19.01 (64-158)
Pelvis AP	74.81	4.79 (70-85)	45.88	7.54 (32-64)	72.47	2.90 (67-75)	45.80	5.02 (40-52)

Patient doses and image quality

Most of the entrance skin dose (ESD) between two groups of the study were higher in the before QC group (compared median) as shown in table 8 and the bar graph figure 1.

Table 8. Shown the entrance skin dose (mGy) data were compared between before and after QC program of 8 examinations.

Types of exam.	ESD, mGy (IAEA)	ESD (mGy) Before QC group			ESD (mGy) After QC group			*P* ***
		Mean	Median	SD (min-max)	Mean	Median	SD (min-max)	
PNS PA	5	1.90	2.00	0.21 (1.62 – 2.27)	1.46	1.29	0.38 (1.23-2.44)	**0.001**
Ceph. Lat.	0.25	0.29	0.34	0.10 (0.18 - 0.35)	0.15	0.17	0.03 (0.11-0.17)	-
C sp. AP	0.25	0.18	0.17	0.09 (0.08 - 0.53)	0.12	0.11	0.03 (0.06-0.20)	**0.000**
Chest PA	0.4	0.17	0.18	0.04 (0.06 - 0.37)	0.14	0.12	0.09 (0.06-1.84)	**0.000**
Abd. AP	10	4.39	4.02	1.42 (2.67 - 8.91)	3.82	3.48	1.23 (2.02-8.81)	**0.010**
L-S AP	10	4.37	3.9	1.66 (1.86-10.41)	3.49	3.21	1.26 (2.08-7.91)	**0.001**
L-S lat.	30	11.09	10.39	3.59 (5.47-24.39)	11.15	10.39	3.68 (5.02-22.64)	**0.485**
Pelvis AP	10	3.12	2.4	1.37 (1.86 - 6.44)	2.90	3.06	0.84 (1.8 - 4.14)	**0.326**

*** ***Mann-Whitney Test*** **(1-tailed)**

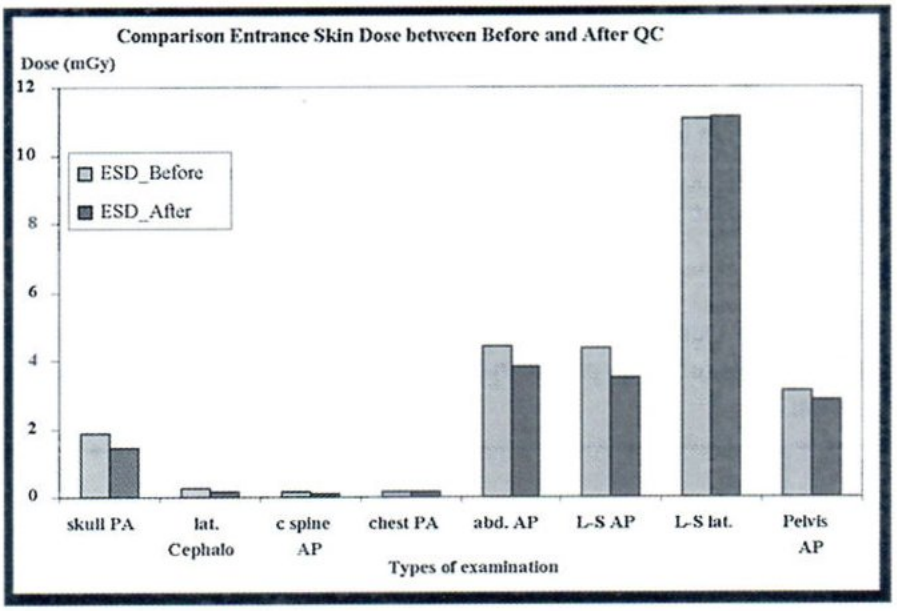

Fig.1 Bar graphs of the average entrance skin dose (mGy) were compared between before and after QC group.

Table 9. Shown the image quality data which was compared between before and after QC program of 4 examinations.

Types of exam.	Total scores	Before QC group			After QC group			
		Mean	Median	SD (min-max)	Mean	Median	SD (min-max)	*P-value*
Chest PA	12	9.81	10.00	1.19 (7.25 -11.75)	9.74	10.00	1.21 (7.00 - 11.50)	**0.976**
Abd. AP	14	11.84	12.25	1.46 (8.50 - 13.50)	11.34	11.75	1.35 (9.00 - 13.75)	**0.197**
L-S AP	8	5.75	6.125	1.64 (3.00 - 7.75)	5.34	5.125	1.73 (3.00 – 7.50)	**0.710**
L-S lat.	7	4.93	5.125	0.87 (3.50 - 6.25)	5.00	5.25	0.97 (3.50 - 6.50)	**0.790**
Mann-Whitney *Test* (2-tailed)								

Statistical significant of the 4 main examinations (chest PA, abdomen AP, lumbo-sacral spine AP and lateral view) were compared, the mean of image quality between two groups was shown in table 9.

Matching the major parameters of the 4 main examinations that effect to the null and alternative hypotheses which chest PA, abdomen AP and lumbo-sacral spine AP are accepted null hypotheses except lumbo-sacral spine lateral is rejected null hypotheses is shown in table 10.

Table 10 Shown the relationship between the body part thickness (cm) and BMI to the entrance skin dose (mGy) and the image quality of 4 main examinations in both groups were matched by using P value presentation.

Type of examinations	*P- value*			
	Thickness (cm)	**BMI (kg/m^2)**	**ESD (mGy)**	**Image Quality**
Chest PA	0.093	0.822	0.000	0.976
Abd. AP	0.064	0.367	0.010	0.197
L-S AP	0.065	0.243	0.001	0.710
L-S lat.	0.087	0.751	0.485	0.790

Result Comparison

A statistically significant decrease in the entrance skin dose and repeated exposures were obtained using Mann-Whitney analysis, $P < 0.05$. The recommended exposure chart was followed in the routine work. More than 95 percent of examinations for both groups did not need to be repeated, but there was less than 2 percent (10 of 692 examinations) of repeated after the quality control program applied.

Median ESD of the group data collected after implementation of QC was significant lower than the Dose Reference Level (DRL) by IAEA and NPRB.

Median ESDs of the group after implementation of QC are statistically significant lower than for the data before QC except L-S spine lateral, pelvis AP view (not significant) and cephalometry lateral view (data not consistent due to use of different technique).

ESD of room number 4 (35.9 μGy/mAs) is lower than room number 5 (41.2 μGy/mAs) at 80 kVp, large focus, at 100 cm FSD for the same exposure factors and the same condition.

There was no significant difference between the two groups ($P > 0.05$) in the image quality by the meaning of the effort to reduce the ESD.

DISCUSSION AND CONCLUSION

Two groups of patients in this study were well matched. 10 of 692 examinations were retaken when the quality control of the computed radiography system was initiated and the reject and retake rate was reduced to 1.45 percent from 3.18 percent (differentiate reduction 54.55 percent, $P < 0.05$). The entrance skin doses is reduced to 17.65 percent in chest PA view (mean, 0.17 mGy for before QC group and 0.14 mGy for after QC group) and 16.22 % for lumbo-sacral spine AP (mean, 4.37 mGy for before QC group and 3.49 mGy for after QC group) while maintaining optimum image quality. The exposure chart is implemented and applied for every examination in case of manual setting of the x-ray system. The performance of the x-ray system shows lower ESD from the system of room number 4 than the system of room number 5 for the same exposure factors and the same condition. The quality control program is used to inspect the system performance to keep it in optimal condition.

The quality control program is effective to assess the quality of the machine and predict the image quality. In order to practice the QC procedures, the phantom, the testing device, and operators are most important.

Both of the x-ray machine performances were the manual exposure factor setting that still in the acceptable range. Room number 4 x-ray machine had given the lower the entrance surface air kerma (ESAK) which correlated to the ESD than room number 5.

The computed radiography system performance was also quite good condition. The only one item that must be improved is the Moiré pattern testing because the recommended grid ratio for the bucky grid or the stationary grid should be 12:1 with lead strips at least 103 lines per inches.

RECOMMENDATION

In order to establish the first computed radiography system, the test device must be provided for the quality control program. X-ray machines with automatic exposure control (AEC) are strongly recommended to optimize radiation dose to the patient. For the manual setting x-ray machine, the detailed exposure factor chart must be strictly used in order to keep the ALARA (As Low As Reasonably Achievable) rule. Continuous training is scheduled for the quality improvement for the new technology in order to improve and increase the competence of the radiological technologists working with the digital modalities.

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