Assessment of Radiation Dose Creep from Computed Radiography units of Diagnostic Centres in Abuja, Nigeria

Malachy C. E[1], Samson D. Y[2], Ibrahim U[2]
[1]Nigerian Institute of Radiography, Radiographers Registration Board of Nigeria, Abuja, Nigeria.
[2]Department of Physics, Nasarawa State University, Keffi, Nasarawa State, Nigeria.
Corresponding author: emalachy@yahoo.com

Abstract

Background: The use of computed radiography (CR) in the x-ray imaging systems is displacing the conventional film screen system due to obvious advantages of the former. However, the wide dynamic range of the computed radiography system has created a lacuna for unintentional overexposure of patients called dose creep.

Objectives: This study assesses the radiation dose creep from some computed radiography units in Abuja and also assesses the knowledge of radiographers using a self-structured questionnaire.

Methods: Retrospective studies with 2156 exposure indices grouped into under exposure, optimum exposure and over exposure, based on the manufacturers recommended range of exposure index were analyzed. While, a cross-sectional study of 50 radiographers questionnaire on the knowledge of dose creep, exposure index and application of the manufacturers recommended range of exposure index were also analyzed.

Results: The overall distribution of the Exposure Index (EI) values in the CR units revealed that 9.9% of the data were associated with dose creep. This indicates that the probability of dose creep in the X-ray exams was 0.099. Only 37.9% of the exposure indices were in the manufacturers recommended range. Most of the radiographers, 92% did not know the meaning of dose creep with respect to computed radiography while 58% of them did not know the meaning of exposure index.

Conclusion: The probability of dose creep in the x-ray examinations was 0.099 with rather high dose-saving potentials. The radiographers had poor knowledge of dose creep and optimization in CR.

Keywords: Computed radiography; dose creep; exposure index; diagnostic image; radiographers.

Introduction

The medical radiation protection is essential for all radio-diagnostic examinations and measures should be in place to ensure that radiation dose is kept at a minimum [1]. To maintain best practices, the radiographers need a good knowledge and practical understanding of the equipment they are using and how to choose appropriate exposure factors [2]. The X-ray film screen system has been the universal means of recording images, since the discovery of X-rays. But, technological advances in image acquisition systems over the past three decades led to the introduction of the first Fuji 101 computed radiography (CR) system in 1983 [3]. Subsequently, other manufacturers joined the CR imaging system.

There are many advantages of CR imaging system. These includes: wide exposure latitude, ability for post processing, Digital Imaging and Communication in Medicine (DICOM) compatible, electronic transfer and digital storage options [4]. The wide dynamic range of CR means that a greater range of radiation exposures can be used to produce acceptable image quality. The film screen radiography (FSR) is associated with poor image quality and frequent repeat radiographs on account of underexposure and overexposure. On the other hand, underexposure in CR results in a high signal to noise ratio that would be moderated with some post processing, and overexposures in CR results in a low signal–noise ratio and high quality image [5][6]. The wide dynamic range in CR creates a potential for reduced repeat X-ray examinations as well as dose reduction to patient. Studies have reported that radiographers tend to use higher exposure factors to improve image quality and avoid repeat radiographs [7][8][9][10][11]. This tendency to use higher exposure factors is referred to as exposure factor creep [8].

The radiographer usually assesses the images visually for optimum exposure factors with film screen radiography but this direct visual assessment is not possible with CR systems. Therefore, to allow for control of exposure factors and to militate against exposure creep in CR, manufacturers have introduced numerical parameter called exposure indicator (index) which is a direct estimate of the entrance surface dose on the imaging plate [12]. The exposure indicator is calculated with an algorithm provided by its manufacturer and named accordingly. The manufacturers recommended range (MRR) of exposure index is provided as a feedback to radiographers for optimum detector dose. The radiographer therefore needs to have good knowledge and training of the computed radiography system they are using. The EI provided by manufacturers to assist in providing a quality image has also been proposed to be used as an indicator of patient dose levels [6]. If the amount of exposure on the imaging plate is higher than MRR, then dose creep is implied [12].

The literature reviewed in this study revealed the existence of dose creep, significant deviation of exposure index from the MRR and poor knowledge of technologists about dose creep, CR physics and exposure index. Hence the authors aimed to determine the proportion of dose creep in some selected group of X-ray examinations, compliance with MRR of exposure index and overall knowledge of radiographers about exposure index and dose creep in this environment with a view to creating awareness on the subject of dose creep. The study shall awaken the national regulatory authorities and radiographers on the need for implementation of dose optimization principles and quality control measures in CR units.

Materials and methods

The study employed a combined retrospective and cross-sectional survey designs. X-ray examination exposure data was collected retrospectively from CR units while radiographer's responses were collected by means of questionnaire. The study was carried out between April 2018 and August 2018 in Abuja Municipal Area Council, Abuja, Nigeria. Ethical approval was obtained from the Ethics Committee of Health and Human Services Secretariat, Federal Capital Development Authority, Abuja.

Seven (7) diagnostic centers with CR units were recruited for the study. Exposure data were collected from four (4) CR units following attrition of three (3) units. The CR models were FCR CAPSULA XL II by Fujifilm; CR30-XM by AGFA; CR 12- X by AGFA and iCR3600M by iCRco. An average of 500 CR data was collected from each unit giving a total of 2156 data utilized in the study. The computer component of the CR unit was accessed to collect data on skull, chest and lumbosacral X-ray examinations of adult patients. The data extracted were examination type, examination view, date of exam, gender and exposure index. The data were subjected to several statistical analyses according to CR types, examination types and gender to obtain the quartiles, percentage dose creep, P-value etc.

The second aspect of the study is the questionnaire survey. Following validation of the instrument by the experts, a pre-test questionnaire was administered to the radiographers to test the validity of the instrument. The questionnaire was collectively administered to the radiographers working in the CR units using research assistants. The radiographers that filled out the questionnaires were provided with incentives like pen, candy and key holders so as to encourage them to fill and return the questionnaires and also to improve the response rate. However, the response rate was 100 percent as all the questionnaires given out were returned with valid responses. Data obtained from the radiographers included demographics, knowledge of exposure index, dose creep, MRR and its application. A codebook and descriptive statistics were used to analyze the data.

Results

A total of 2156 exposure index data were analyzed in this study as collected from four (4) CR units (Table 4.1). Exposure index data relating to the examination types studied were outlined in Table 4.2. All the examinations in the CR units had some percentage of dose creep recorded in the procedures. On the group basis, skull X-ray examinations from AGFA CR30-XM recorded highest amount of dose creep (56.3%) and chest X-ray examinations from iCRco iCR3600M recorded the least amount of dose creep (1.4%) (Table 4.2). Exposure index variation were evident between the patient genders (Table 4.3), with female patients recording higher median EI values than male patients for majority of the manufacturers and examinations. However, the differences were not statistically significant in all cases, P-values > 0.05. Dose creep was noted in each gender at the CR units except in lumbosacral spine X-ray of iCRco iCR3600M (Table 4.3).

In the overall, the EI distribution by body parts showed that skull examination recorded highest amount of dose creep (17.6%), (Table 4.4%). It was also observed that 9.9% of all the examinations were above the manufacturers recommended range of EI constituting dose creep. Figure 4.1 was the chart representation of overall distribution of EI data.

The second aspect of the study was a cross-sectional questionnaire survey of the radiographers working with the CR units utilized in this study. Table 4.5 is the descriptive statistics of the radiographer's responses from the questionnaire. Majority of the radiographers had BSc/ B. Rad degree in radiography 96%, (n = 48) and 74% (n = 37) received application training in CR. Only 8% (n = 4) and 42% (n = 21) of the respondents knew the meaning of dose creep and exposure index respectively. None of the radiographers know the value of MRR of EI in their CR units and none ever compared the EI of X-ray images with MRR (Table 4.5).

Table 4.1: Distribution of diagnostic centres/CR Units and Number of Exposure Index Data utilized in the study

Centres	Name of centres/CR unit	No of exposure index data	Percent (%)
1	Zankili medical services/FCR CAPSULA II	498	23.1
2	Cedarcrest hospital/CR 30-XM	553	25.6
3	FMC Abuja/CR 12-X	506	23.5
4	NISA Premier/iCR 3600M	599	27.8
	Total	**2156**	**100.0**

Table 4.2: Distribution of Exposure Index values for the Manufacturer/Examination Types included in this Study

S/N	Manufacturer/Exam type	Number(N)	Median	First quartile(Q_1)	Third quartile(Q_3)	% Over exposure	% Under exposure
1	Fujifilm FCR CAPSULLA II						
	Skull	73	220	143.5	340	8.2%	17.8%
	Chest	251	592	439	960	6.8%	49.5%
	Lumbosacral spine	174	509	303	798	2.3%	59.8%
2	AGFA CR 30-XM						
	Skull	16	856	452	2000.75	56.3%	6.3%
	Chest	249	554	284	1294.5	38.6%	16.5%
	Lumbosacral	288	337.5	190.5	564.75	12.2%	26.0%
3	AGFA CR 12-X						
	Skull	21	316	143.5	419	4.8%	33.3%
	Chest	304	103	77	147	2.0%	86.5%
	Lumbosacral spine	181	280	184	403.5	7.2%	28.2%
4	iCRco iCR3600M						
	Skull	38	-0.1295	-1.5650	1.156	26.3%	36.8%
	Chest	367	-2.0290	-2.4860	-1.4740	1.4%	86.9%
	Lumbosacral spine	194	-1.1670	-1.8640	-0.4360	6.2%	57.7%

Table 4.3: Exposure Index values for each Patient based on Gender and Exam Types included in this Study (for MRR of EI Value Ranges)

Manufacturer/Exam type	**Gender**	**Number**	**Median**	**First quartile (Q_1)**	**Third Quartile (Q_2)**	**% Over exposure**	**% Under exposure**	**P-value**
Fujifilm FCR CAPSULLA II								
Skull	F	53	241	161	409.5	9.4	24.5	0.417
	M	20	175	121	271.25	5.0	0	
Chest	F	152	612.5	431.5	911	8.6	51.3	0.419
	M	99	552	439	1052	4.0	46.5	
Lumbosacral spine	F	98	565	325	836	2.0	65.3	0.602
	M	76	419	298.5	775.5	2.6	52.6	
AGFA CR 30-XM								
Skull	F	8	220	376	888	50.0	12.5	0.308
	M	8	1082	696	1778	62.5	0	
Chest	F	113	569	290	1158	38.1	16.8	0.567
	M	136	556	274.75	1349.5	39.0	16.2	
Lumbosacral spine	F	120	307	179.5	520.25	12.5	28.3	0.43.
	M	168	356	202	584.75	11.9	24.4	
AGFA CR 12-X								
Skull	F	17	316	163	415.5	5.9	29.4	0.397
	M	4	272.5	103.5	608	0	50	
Chest	F	208	101.5	76	142.5	1.0	87.0	0.339
	M	96	106.5	83	159.75	4.2	85.4	
Lumbosacral spine	F	124	300.5	193.25	426.5	6.5	25.0	0.383
	M	57	236	162	373.5	8.8	35.1	
iCRco iCR3600M								
Skull	F	28	-0.1295	-1.8808	1.0420	25	39.3	0.383
	M	10	-0.1290	-1.4563	4.9812	30	30	
Chest	F	293	-2.0080	-2.5000	-1.4475	1.4	87.4	0.501
	M	74	-2.0970	-2.4303	-1.5698	1.4	85.1	
Lumbosacral spine	F	142	-1.2015	-1.9470	-0.3880	8.5	57.0	0.377
	M	52	-1.1360	-1.7970	-0.640	0	59.6	

Table 4.4: Cross tabulation of overall distribution of exposure index according to body parts

		Exposure Category			
Body part		Under exposure	Optimum exposure	Over exposure	Total
Skull	Count	35	87	26	148
	% within body part	23.6%	58.8%	17.6%	100%
Chest	Count	747	300	124	1171
	% within body part	63.8%	25.6%	10.6%	100%
Lumbosacral	Count	342	431	64	837
	% within body part	40.9%	51.5%	7.6%	100%
Total	Count	1124	818	214	2156
	% within body part	52.1%	37.9%	9.9%	100%

Table 4.5: Distribution of Radiographers' Responses from the questionnaire in the study.

Primary characteristics	Secondary characteristics	Number	Percent (%)
Gender	Female Male	26 24	52 48
Basic qualification	DCR DIR B SC/B Rad Others	1 2 48 2	2 4 96 4
Age in practice	0-5yrs 6-10yrs 11-15yrs 16-20yrs Above 20yrs	16 18 8 4 4	32 36 16 8 8
Did you receive application training?	Yes No	37 13	74 26
Who delivered the training?	Vendor Fellow colleague Others	16 21 4	32 42 8
Have heard of dose creep wrt CR?	Yes No	4 46	8 92
Have you heard of EI wrt CR?	Yes No	21 29	42 58
What is the MRR in your CR unit?	Knows Can't remember Don't know No response	0 8 19 23	0 16 38 46
Do you compare EI of X-ray images with MRR?	Often Sometimes Rarely Never	0 0 0 50	0 0 0 100

w.r.t-with respect to

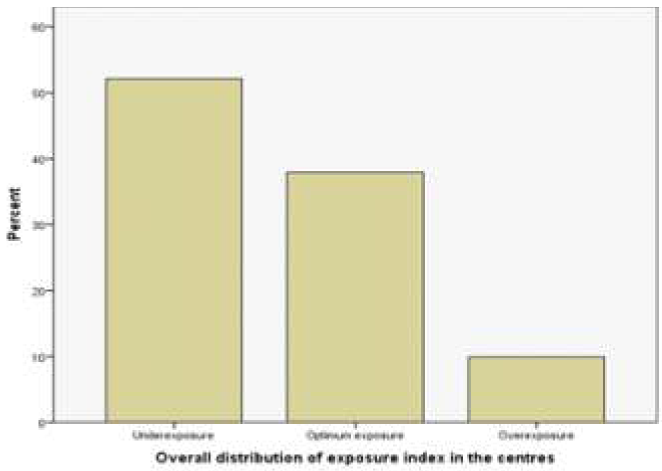

Figure 4.1: Bar chart showing the exposure index distribution in all the CR units combined.

Discussion

The purpose of this study was to investigate the phenomenon of dose creep and determine whether radiographers were complying with the MRR of EI among others, using skull, chest and lumbosacral X-ray examinations. The knowledge of radiographers about dose creep and EI was also assessed. All the examinations in the selected CR units demonstrated some proportion of EI values above MRR. AGFA CR30-XM skull X-ray exams followed by AGFA CR30-XM chest X-ray exams demonstrated the highest amount of dose creep (overexposure) rates of 56.3% and 38.6% respectively (Table 4.2). This apparent overexposure is largely in agreement with literature, which indicates that CR and other digital imaging systems can result to an increase in radiation dose to the patient [7][8][10]. The lowest overexposure rate was demonstrated by iCRco iCR3600M chest X-ray exams followed by AGFA CR12-X chest X-ray exams at 1.4% and 2.0% respectively. The high rate of overexposure in AGFA CR30-XM chest X-ray exams is a concern as it is one of the most frequently performed examinations [12] [13].

The reason for the high rate of dose creep in AGFA CR30-XM was a subject of further investigation, though the AGFA CR30-XM was installed in a specialist orthopaedic hospital unlike the other units which were in non-orthopaedic hospitals. AGFA CR12-X demonstrated the least amount of dose creep in the three selected body parts combined (Table 4.2). The perceived dose efficiency is not unconnected with the age of the CR unit as the CR12-X was the newest unit utilized in this study (installed in February 2018). No document in literature was identified to support the above observation.

The exposure index variations with patient gender were studied. In most examinations, irrespective of the manufacturer, X-rays of female patients demonstrated higher median EI values when compared with the male patients (Table 4.3). This was evident in Fujifilm FCR CAPSULA II, AGFA CR12-X skull and lumbosacral spine and iCRco lumbosacral spine. Contrary to the findings of Mothiram *et al.* [14], the gender variations in median EI values were not statistically significant (Table 4.3), as P-values remained greater than 0.05.

The overall distribution of the EI values in the CR units revealed that 9.9% of the data were overexposure (Table 4.4). This indicates that the probability of dose creep in the X-ray exams was 0.099. This result is not in agreement with Warren-Forward *et al.*[13]. The findings also showed that only 37.9% of the exams were produced within the MRR of EI. This implies that, the radiographers are not adhering to the MRR of EI. This finding is similar to the findings of Mothiram *et al.* [14]. This study also showed that 52.1% of all the examinations were below the MRR which agrees with Mothiram *et al.* [15], which had explained that the MRR of EI might be too high as images produced at lower MRR have been found to be clinically acceptable. Table 4.4 also showed that 17.6% and 58.8% of the EI were above and within MRR for the skull, 10.6% and 25.6% of the EI were above and within MRR for chest, while 7.6% and 51.5% of the EI were above and within MRR for the lumbosacral spine exams. The proportion of dose creep remained smallest in the exposure categories (Figure 4.1). This findings are contrary to the findings of Warren-Forward *et al.* [13], who used Kodak CR in Australia and found 31% and 31% of EI above and within MRR for postero-anterior chest exams at hospital A, and 25% and 69% of EI above and within MRR for postero-anterior chest exams at hospital B. For the lumbosacral spine, the authors found 52% and 27% of EI above and within MRR respectively in hospital A, and 18% and 51% of EI above and within MRR at hospital B respectively. The findings of this study are also contrary to the findings of Kheokaew *et al.* [16], who used Fuji FCR5000 model in Thailand and found 69% of the images for postero-anterior chest exams within the MRR of EI due to good knowledge of CR physics by the radiographers. A phantom based experimental study found a strong positive relationship between radiation dose and exposure index [17]. Therefore, the proportion of dose creep found in this study implied a probability of patient overexposure in every X-ray examination. There is also a potential for reduced exposure factors and radiation whilst producing acceptable image quality as was demonstrated in Nigeria and Australia respectively [18][13]. A longitudinal study in Australia by Gibson and Davidson, [9], used MRR as optimal exposure range and overexposure as dose creep. Exposure creep was observed in the study and halted after intervention.

Ma *et al.* [10] also proved the existence of dose creep using a chest phantom to assess the potential for dose creep in CR. A study in Sweden by Sanfridsson *et al.* [19], used stepwise reduction in exposure in CR to determine how far exposure creep could be reduced without losing measuring accuracy of the system.

The results from the questionnaire survey of radiographers were presented in Table 4.5. Majority of the respondents were female 52% against 48% male which is in line with Seeram *et al.* [20]. Majority of the radiographers had Bachelor's degree in radiography (96%) and were 10years or less in practice. This was due to stoppage of diploma training in Nigeria over one decade ago. The response rate in this study was high (90.9%) which is contrary to the study of Seeram *et al.* [20], where 69% response rate was documented. The present study utilized direct personal administration of the questionnaire unlike the latter which utilized online questionnaire survey with resultant high non-response rate. The backgrounds of the radiographers were similar in terms of training and qualification. The majority of the respondents (74%) agreed to have received application training on CR. However, the subsequent question indicated that majority of such training were offered by their fellow colleagues (42%) and 32% were trained by the vendors. The authors felt that such training was rather informal and lacked depth of CR physics [21][22][20]. Though the depth of training was not in the objectives of this study, a few parameters of CR imaging system were selected for the knowledge assessment which borders on EI, dose creep and MRR. When asked whether the respondents know the meaning of EI and dose creep, 42% and 8% respectively responded in affirmative. It was obvious that dose creep phenomenon was strange to the respondents, while EI was fairly understood by the respondents.

To consolidate on the responses obtained on EI and dose creep, the respondents were further asked to state MRR of their various CR units. None of them knew the values as 46% gave 'no response', 38% said 'don't know', while 16% said 'can't remember'. The responses of the participants were again captured by question 10 of the survey – 'Do you compare EI of your images with MRR?' A Likert scale was used to rate responses on a 4-point scale ranging from 'often', 'sometimes', 'rarely' and 'never'. The result of the question was obvious noting that none of the participants knew the MRR of their CR. Therefore, all the participants said 'never'.

The overall knowledge of radiographers about CR EI, dose creep and MRR was very poor considering the responses obtained in this 10 point questionnaire. The assessment of radiographer's knowledge of CR physics was in line with Seeram *et al.* [23], which considered the knowledge of participants poor in a study where 95.8% of the participants used the EI to relate with image quality and 55% compare the departmental EIs with vendors MRR. The application training received by the respondents in this study was questionable [21][22]. The findings buttressed the study recommendation by Gibson and Davidson [9] in Australia. The authors recommended comparing exposure index values with previous examinations which helped radiologic technologists to halt exposure creep. Scott *et al.* [11] also proposed EI tracking to halt exposure creep in a study done in Los Angeles, USA using automated data collection in four diagnostic centers.

It can be subjectively stated that the dose creep identified in this study had no basis of comparison with the knowledge of radiographers. Rather dose-saving potential is inferred to be responsible for reduced proportion of dose creep in the CR units [19] [24][15][17]. It is worthy of note that the objectives of this study dealt with dose creep, MRR and radiographers overall knowledge of the subject. It was not set out to compare dose saving efficiency of the different CR units or patient dose parameters like effective dose, radiation hazard indices or life time cancer risks. These subjects were beyond the scope of the present study.

Conclusion

This study has discovered that dose creep exists and 9.9% of X-ray examinations in the study locality were overexposed. The highest amount of dose creep (17.6%) was in skull X-rays and there was no significant variation of dose creep according to gender. The radiographers were not complying with the MRR of exposure index as only 37.9% of the entire exposure indexes were in the MRR. Interestingly, 52.1% of the exposure indexes were below the MRR, which highlighted the dose-saving potential of modern computed radiography.

The observed dose creep could not be attributed to the knowledge of radiographers but rather due to the inherent dose –saving potential of CR systems.

This study has also discovered that radiographers had a poor knowledge of dose creep and exposure index with respect to computed radiography. None of the radiographers ever compared the exposure index of their images with the manufacturers recommended range as a measure to optimize patient radiation dose.

Recommendations

(i) In-depth practical training of radiographers on computed radiography physics is recommended to enhance dose optimization potentials of the imaging system.

(ii) Routine quality control measures are recommended to identify computed radiography units with non-functional exposure indicators.

(iii) Following the observation of the dose-saving potentials of computed radiography imaging system, it is highly recommended for radio-diagnostic centres to further reduce the biological effects of ionizing radiations in planned exposure procedures.

(iv) Repeat of the present study in other states of the country and correlation of exposure index with entrance skin dose.

Declaration

There is no conflict of interest in connection with this study.

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