

RESEARCH ARTICLE

Evaluation of Radiographers' Practices with Paediatric Digital Radiography Based on PACS' Data

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ABSTRACT

Objective: The purpose of the study is to evaluate radiographer practice with advanced digital radiography in terms of the values of exposure indices and deviation indices between hospitals in Saudi Arabia.

Materials and Methods: The study is based on PACS' data of paediatric radiographic images limited to the chest and abdomen performed during the last year from four hospitals in Saudi Arabia. P-value was calculated to investigate any significant differences exist between the values of exposure indices and deviation indices of the images, which will be acquired from the DICOM file of image data.

Results: Most of the paediatric radiographic images (54%) were underexposed, as these images had deviation index with less than -1 from four hospitals compared to expected results. However, in one hospital, 58% of the images were overexposed. The majority of the underexposed paediatric radiographic images were chest and abdomen radiographic exam (50% and 66% separately). Results also show that most of the underexposed radiographic images were using a grid (66%); on the other hand, in the overexposed radiographic images, 59% did not use the grid.

Conclusions: The findings of the study show the need for radiographers for further knowledge and training courses to improve their performance in digital radiography and paediatric imaging.

KEYWORDS : Radiographers, Digital Radiography, PACS, Exposure Indices, Deviation Index.

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INTRODUCTION

Digital radiography (DR), including computed radiography (CR), direct and indirect digital radiography systems, have the potential to improve the image quality of radiographic images while maintaining lower radiation doses to the patients [1]. Image processing applications utilized in DR have a vital role in image quality improvement and dose reduction. For example, these applications used in a CR system can compensate for

under and over exposures by up to 100% and 500% respectively to still produce an acceptable image. This would suggest exposure factors could be reduced where appropriate. These also can adjust the overexposure images by 500 %, and still obtain diagnostically acceptable image quality [2].

If medical imaging practitioners/radiographers do not utilize digital radiography systems appropriately,

negative results in terms of image quality and increased patient radiation dose may be attained. The wide dynamic range of digital radiography systems allows radiographers to increase the radiation dose to the patient without noticing the increase in exposure factors, as radiographers still obtain good or better image quality. The other problem that is associated with digital radiography systems is the dose creep which means that the radiographers, with the time, tend to unintentionally increase the exposure factors to reduce the quantum noise and consequently produce better image quality [1, 3, 4]. Therefore, radiographers need to adjust their practices and improve their skills to obtain optimized image quality of digital radiography while maintaining lower radiation dose to patients [5-10]. Radiographers can examine the exposure level appropriateness of radiographic film of planar screen-film radiography (SFR) system. In digital radiography, this cannot be used as an indicator as the appearance of the image can be changed by computer application [11]. A measure, called exposure index (EI), has been offered to indicate the appropriateness of exposure dose levels which reach the detectors. This measure is displayed on the monitor once the exposure is taken so that the radiographer can check the exposure dose appropriateness [12, 13]. The feedback from EI helps the

radiographers to be more aware of the radiation dose imparted to the patients [4, 8]. For each manufacturer and each organ, there are predetermined reference ranges of EIs based on empirical data. These ranges must be recognized by radiographers to understand the optimal detector exposure for specific organs. For example, in the GE DR system the default detector EI range for the abdomen projection is from 0.56 to 1.68 and for the chest PA projection, 0.2 to 0.6 [14]. Table 1 demonstrates the EI ranges for the chest and abdomen projections for several DR systems of different manufacturers. EI can be used as a tool for image quality control and dose optimization, but caution should be taken as an EI value is not only influenced by exposure [15, 16]. Different factors which influence EI, include patient size and body type, implants materials in body, collimation, detector, and image processing parameters [16]. In addition to these factors, each manufacturer has its own method to calculate and interpret EI. As a result, it is difficult to compare EI among different x-ray systems of different manufacturers. Different methods of calculating EI also constrain the radiographers from greater understanding and consequently limit the usage of EI as a tool for image quality optimization [8].

Table 1: EI value ranges for chest and abdomen radiography for several DR systems of different manufacturers [14, 18]

Manufacturer/model	Exposure Indices				manufacturer-recommended exposure index MREI range	Chest PA	Abdomen
	Name	Symbol	Lin/Log	Exposure relation			
Siemens Medical VX and MX Axiom Aristos DR	Exposure Index	EXI	Linear	Direct	150–400 (Schramm H, 2012, personal communication)	Not Found	Not Found
Philips DR	Exposure Index/Kerna Area Product	EI/KAP	Linear	Inverse	200 and 800. (AAPM, 2009). 250–630 (Neitzel U, 2012, personal communication) (AAPM, 2009).	Not Found	Not Found
Carestream Health Direct View CR500 CR	Exposure Index	EI	Log	Direct	1700–1900 ^{12,13}	Not Found	Not Found
GE DR	Detector Exposure Index /Dose are Product	DEI/ DAP	Linear	Direct	(AAPM, 2009).	0.2-0.6	0.56-1.68.
Canon DR	Reached Exposure Value	REX/EXP	Linear	Direct	Not Found	(AAPM, 2009).	Not Found
Imaging Dynamics DR		SE	Linear	Inverse	Not Found	(AAPM, 2009).	Not Found
Fuji CR	sensitivity number	S	Linear	Inverse	150-250 (Carlton & Adler, 2006, p. 367).	200-600 Average 515	100-400 Average 179
Kodak CR	Exposure Index	EI		Direct	1,800-2,200 (Carlton & Adler, 2006, p. 367)	Not Found	Not Found
Agfa CR	log of medianLgM exposure		Log	Direct	1.9 and 2.5 Since it is based on a log system, an increase of 0.3 means the dose was doubled (Carlton & Adler, 2006, p. 367).	Not Found	Not Found
Konica CR	sensitivity number	S	Linear	Inverse	Not Found	Average 340	Average 211

Several studies have been conducted to overcome these limitations by standardizing EI among different manufacturers or by suggesting a new standard measure beside the current EI [10, 11, 19, 20]. Standardization of EI increases its value and expands its role in image quality control and optimization and comparing exposure techniques among different DR systems and manufacturers [16, 17]. In fact, several standardization methods of EI between different manufacturers have been developed to eliminate the confusion in monitoring and comparing exposure in digital radiography.

Three new terms, which have been established include exposure index, target exposure index, and deviation index (DI) [10, 15, 17]. Don et al. [10] proposed that DI and noise levels can be used to monitor the appropriateness of exposure factors and to avoid exposure creep. The acceptable range of DI is between -1 and +1, where the perfect DI value is 0. If the DI value is less than -1, the image is underexposed and if the value of the DI is more than +1, the image is overexposed. When the value of DI is more than + 3.0, the radiation exposure to the patient is excessive. The images should be repeated if the anatomical structure is burned out. However, if the value of DI is less than -3.0, the images should be repeated [17]. Fig. 1 explains the range of DI levels that determine whether the images are underexposed, acceptable or overexposed.

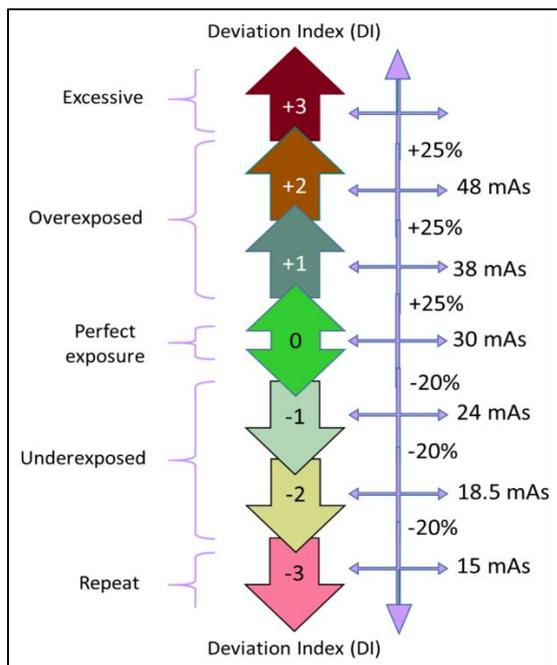


Figure 1. A schematic demonstrates the acceptance level of exposure based on the values of DI. Modified from [17].

This study aims to evaluate radiographer exposure practices in paediatric digital radiography. Picture Archive and Communication Systems (PACS) data provides information about radiographic images from chosen hospitals in Saudi Arabia. The results could improve radiographers' performance and consequently, the image quality is optimised while lower radiation dose to patients is maintained.

MATERIALS AND METHODS

The optimization of radiographer exposure practice in paediatric digital radiography was evaluated by accessing and evaluating data obtained from PACS which was made available from four hospitals in Saudi Arabia. The type of data collected is detailed in Table 2. The required ethical approvals were obtained to complete the procedures of the study. The study was approved by the Institutional Review Board of King Fahad Medical City (IRB Log Number: 15-202E), King Fahad Specialist Hospital (IRB Number: IRB00008686) and Imam Abdulrahman Bin Faisal University (IRB-2015-04-068). The chest and abdomen radiographic images were chosen from paediatric patients between the ages of 1 day old up to 10 years old for the study period.

Data collection

The PACS data collected was limited to paediatric chest and abdomen x-rays performed during the last year. It was divided into 10 groups according to patient age. The data that was acquired for the study included the following details: hospital (then identified), the patients' age, sex, exam type (chest or abdomen), exposure factors mAs and kVp, exposure indices, and deviation indices. The DICOM tags and headers are demonstrated in Table 2. Relative Exposure Indices (0018,1405) and Sensitivity (0018,6000) are old methods and no longer recommended to rely on, instead Exposure Index (0018,1411) and Deviation Index (0018,1413) are more accurate [17].

Table 2 : The DICOM data details collected and recorded and data limits

data	DICOM tag	Limits
1 Patient's age	0010,0040	1 day to 10 years
2 Patient's gender	0010,1010	
4 Manufacturer	0008,0070	Siemens, GE, Carestream, Philips, Samsung
5 Distance Source to Detector	0018,1110	100 cm to 180 cm
6 Grid	0018,1166	
7 kVp	0018,0060	
8 mAs	0018,1152	
9 Unit modality	0008,001	
10 Detector type	0018,7004	
11 Detector information	0018,7006	
12 Relative Exposure Indices/ (rEI)	0018,1405	
13 Sensitivity	0018,6000	
14 Exposure Index (EI)	0018,1411	
15 Targeted Exposure Index (EI _T)	0018,1412	
16 Deviation Index (DI)	0018,1413	

Unfortunately, not all DICOM headers included the new EI, EI_T and DI values. For the header information that did not include these values, the equivalent new EI values were calculated based on:

If the data of relative Exposure Index (rEI) (DICOM tag 0018, 1405) was available, then the new EI was calculated by converting the rEI to the new EI. For example, Siemens 400 is based on a dose of 2.5 uGy.

That value can be multiplied by 100 (no units), to get 250 which is the equivalent new EI. For GE, if the number was below 10, e.g. 1.45 then multiply by 100 to get 145. If the number is >10 then that number is used as value of EIs.

The conversion calculations were obtained from the IEC exposure indices standard [15, 17, 21]

To determine the acceptable range of DI where only values in DICOM tag 0018, 1405 were available, equivalent new DI values have been calculated based on:

- The targeted EI are typically either 157.72 or 226.22 (mainly from Carestream and Philips). These things to do are:

- a. the highest targeted EI of 226.22 will be use as to be conservative with calculating over-exposures
- b. where DICOM tag 0018, 1405 has been converted to the new relative EI, the targeted EI of 226.22 will be placed in that targeted EI values column
- c. the DI can be calculated using $DI = 10 \times (\log(\text{base } 10) (\text{new relative EI} / 226.22)) (22)$

Data analysis

The data was analysed and compared by using t-Tests and Chi-squared tests in SPSS (version 18 – SPSS Inc., Chicago, USA). P-values were calculated using a t-Test

in Microsoft Office Excel to investigate any significant differences between the EI and DI values of the images. The differences were considered significant if the P-value was less than 0.05.

RESULTS

The images were categorized as acceptable exposure, underexposed or overexposed based on the value ranges of as demonstrated in Table 3. For all age groups, the percentage of underexposed images were higher than acceptable or overexposed images and there are statistically significant differences between them ($p < 0.01$). At the same time, the percentage of overexposed images are greater than the images of appropriate exposure with significant differences ($p < 0.01$) (Figs. 2 - 9).

Most of the radiographic images of the chest and the abdomen were underexposed (50% and 67%, respectively). The percentage of appropriate exposure images were less than the percentage of overexposed images. Most of the radiographic images of the chest and abdomen examination were overexposed (68%) (Fig. 5).

Table 3. The value ranges of deviation indices for acceptable exposure, underexposed and overexposed images

	UNDEREXPOSED Mean ±SD	ACCEPTABLE EXPOSURE Mean ±SD	OVEREXPOSED Mean ±SD	P-value
Relative Exposure Index	215 ± 261	513 ± 446	1255 ± 808	0
Exposure Index	123 ± 62	653 ± 9824	1033 ± 6048	0
Targeted Exposure Index	271 ± 44	236 ± 66	221 ± 47	0
Deviation Index	-4 ± 3	.01 ± 0.6	6 ± 33	0

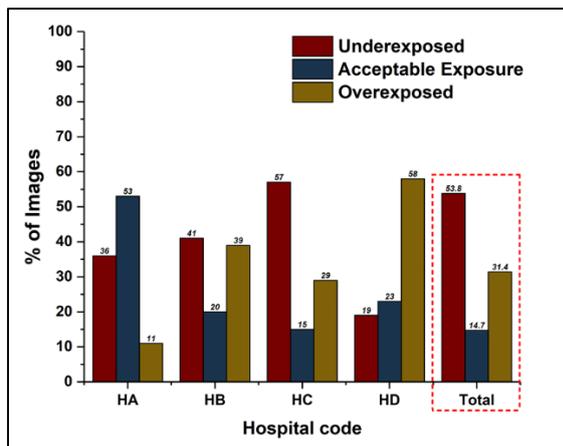


Figure 2. Line graph shows the percentage of accepted exposure of radiographic images from different hospitals.

The majority of HA images were with acceptable exposure.

While the percentage of underexposed images is high when the grid was applied (67%), the percentage of overexposed images is high when the grid wasn't applied (49%) (Fig. 6).

There is a direct relationship between the mAs and the percentage of overexposed images. The higher values of mAs correspond to a higher percentage of overexposed images as seen in Fig. 8.

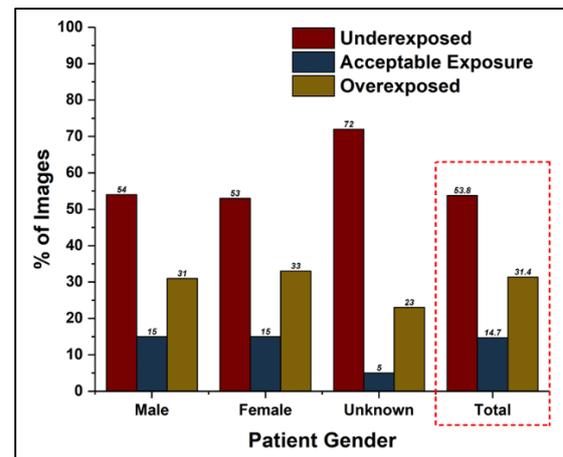


Figure 3. Line graph shows the percentage of accepted exposure of radiographic images for patients of different gender.

The majority of images of female and male are either over or underexposed, the minority of the images are with acceptable exposure.

When the images from different manufacturers were compared, Siemens has a high percentage of underexposed images, along with Philips. Even though the exposure of acceptable images in Philips is higher than Siemens. Whereas the other manufacturers, GE, Carestream, and Samsung, have a higher percentage of overexposed images (Fig. 9).

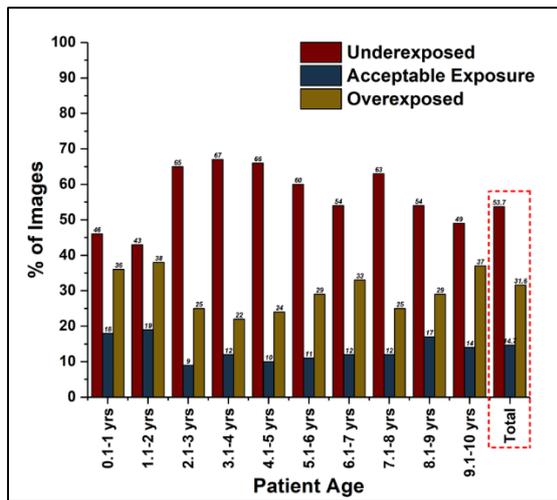


Figure 4. Line graph shows the percentage of accepted exposure of radiographic images for patients of different ages. The majority of images of different patients' ages are either over or underexposed, the minority of the images are with acceptable exposure.

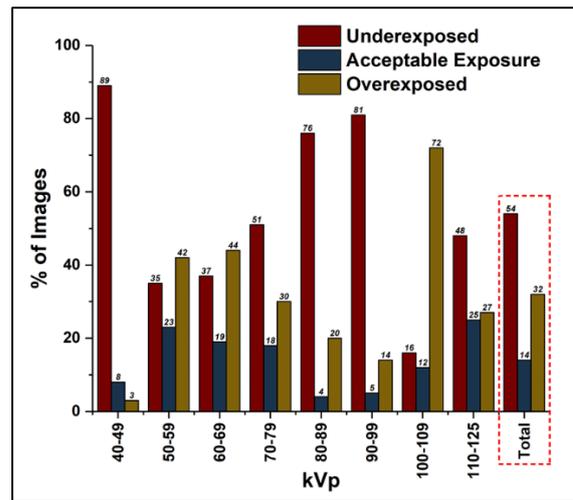


Figure 7. Line graph shows the percentage of accepted exposure of radiographic images acquired by different kVp. The majority of images obtained with different level of kVp are underexposed, however with kVp values of 50-69 and 100-109 are overexposed.

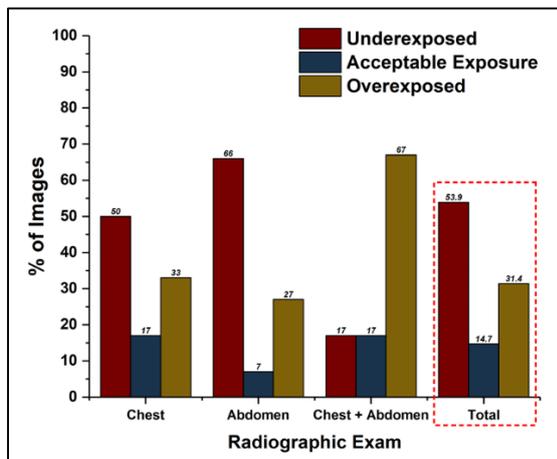


Figure 5. Line graph shows the percentage of accepted exposure of radiographic images of different examinations. The majority of chest or abdomen images are underexposed while the majority of chest and abdomen radiographic images are overexposed.

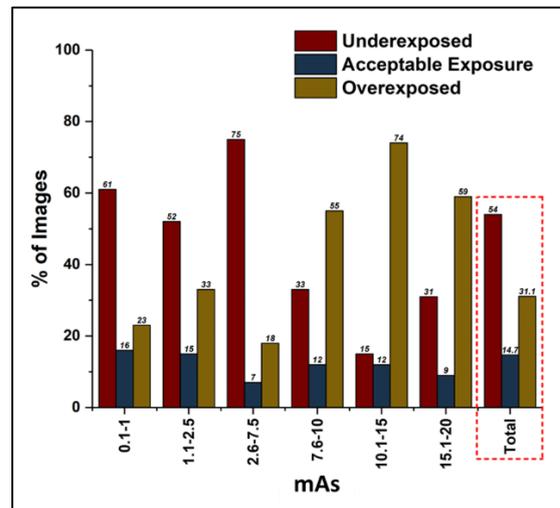


Figure 8. Line graph shows the percentage of accepted exposure of radiographic images acquired by different mAs. The majority of images obtained with lower mAs (0.1-7.5) are underexposed while the majority of images obtained with higher mAs (7.6-20) are overexposed.

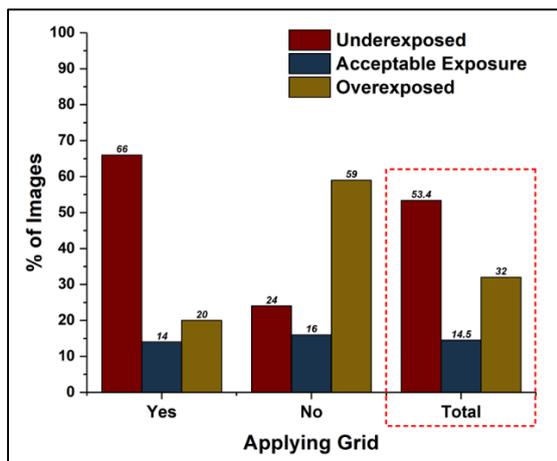


Figure 6. Line graph shows the percentage of accepted exposure of radiographic images acquired with or without applying grids. The majority of images obtained by using grids are underexposed while the majority of images obtained without using grids are overexposed.

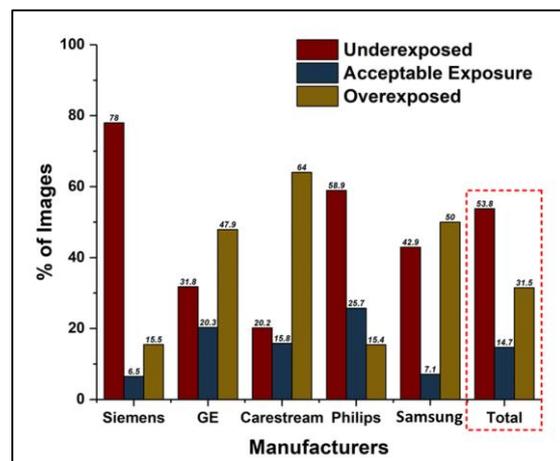


Figure 9. Line graph shows the percentage of accepted exposure of radiographic images from different x-ray unit manufacturers. The majority of images obtained from Siemens and Philips are underexposed while the majority of images obtained from GE, Carestream and Samsung are overexposed.

DISCUSSION

The purpose of this study was to evaluate the practices of radiographers with digital radiography systems by assessing the exposure index and deviation index of images from different systems and hospitals in Saudi Arabia.

The majority of the paediatric radiographic images from HA were appropriately exposed based on the exposure indices and deviation indices. Conversely, most of the images from HB, HC and HD were inappropriately exposed as the images from HB, HC were underexposed, whereas those from HD were overexposed (Fig. 2). This may show inappropriate utilization of the digital radiography systems. Unaccepted outcomes arise, for example, underexposed images could lead to inaccurate diagnosis. On the other hand, with overexposed images unnecessary radiation dose is delivered to patients [22]. Most examinations demonstrated that the number of the underexposed images was higher than that of other images in terms of gender, whether male or female (Fig. 3).

According to the radiographic exam, the separate chest and abdomen radiographs showed a higher percentage of the underexposed images. Meanwhile, the overexposed images were higher than those images with acceptable exposure. Alternatively, the majority of the radiographic images of the chest and abdomen examination were overexposed. Due to the larger area used to examine, radiographers might feel the need to use high radiation doses to cover the area of both chest and abdomen together (Fig. 5). The larger coverage area of exposure, the higher radiation dose delivered [23]. The collimation and field size influences the value of EI considerably, as it increases with larger field coverage area [24]. Loose collimation results in the inclusion of extra areas of air, indicating overexposed images but in fact the images are underexposed [25]. The radiographers might use unjustified exposure factors to include larger coverage area (Fig. 5).

In terms of applying a grid, results show that when the grid is applied, a high proportion of radiographic images were underexposed whereas a great number of radiographic images were overexposed when the grid was not in place. Some might reasonably argue that exposure levels should be reduced when not applying a grid. However, this disregards that the EI is based on pixel values and that these values should be relatively constant whether a grid has been used or not [14]. Similar exposure factors might be used in images with or without applying grid. The exposure factors should be reduced if the grid isn't applied [26]. In addition, the images with no grid applied are exposed to scatter radiation and x-ray photons with low energy, which might be completely absorbed by the detector (Fig. 6).

Radiographic images show a direct relationship between the mAs and the exposure of these images. As the values of mAs increase, the percentage of overexposed images rise and the percentage of underexposed images decreases. At the same time, as the mAs value decreases, the percentage of underexposed images increases (Fig. 8),

while the images with acceptable exposure are the nearly constant for all mAs values. This could be explained by the inverse relationship between mAs and image noise. As the value of mAs is increased, the image noise is decreased. This shows that radiographers tend to increase the radiation dose to improve image quality [27]. Rattan and Cohen [28] stated that mAs influences the value of EIs as they linearly increase with increasing mAs. Hayre [29] reported that radiographers usually rely on the pre-set exposure factors of the installed protocols in the system and they do not manipulate the exposure according to the patient size and they just "bump up" the exposure to obtain a diagnostic image.

Exposure status of radiographic images differs from the different x-ray unit manufacturers. Some shows a high percentage of underexposed images like, Siemens and Philips despite the fact that the acceptable exposure of the image in Philips is higher than Siemens. On the other side, other manufacturers such as, GE, Carestream, and Samsung show a higher percentage of overexposed images. It is hard to compare between the manufacturers because each has its own method of calculating the EI, which means these values and ranges differ from one manufacturer to another. The variety of EIs ranges used by different manufacturers of digital radiography systems causes misperception and confusion among radiographers [27]. This limits the radiographers' understanding of the EI in order to optimize image quality [8].

The differences between the manufacturers occur as each manufacturer usually sets its own protocols of exposure factors for each radiographic examination, with radiographers barely involved in this process. This is why the radiographers used the installed protocols without modifying them. One of the main responsibilities of the radiographers is to check the EI and the DI to assess the appropriateness of the used exposure factors and delivered radiation dose. Therefore the radiographers should have sufficient knowledge, appropriate skills and adequate experiences with EIs as a tool of image quality optimization and to optimally use the DR systems [10]. In addition, radiographers should be up to date with their scientific knowledge and their practices of using these newer systems [9, 10, 14] (Fig. 9). The study was conducted to investigate if there is any variation in knowledge and radiographic practice across Europe. It was found that there is wide variation in radiographer education and training across countries. This illustrates the need of standardization of education and training to ensure selecting of appropriate exposure factors and using protocol parameters [30].

CONCLUSION

The study demonstrates the need to audit the values of EIs and DI in order to optimally use the newer DR systems and to optimize the quality of the acquired images. The awareness of radiographers should be increased about the importance of monitoring EI and DI values and the important of adherence to recommended values of EIs. This study also reveals the need to raise awareness of radiographers about the factors that

influence the values of EI and DI in digital radiography specifically paediatric imaging. Each DR system in different hospitals has its own protocols for the exposure factors and radiographic parameters which are installed by manufacturers. These protocols should be modified when required to maintain the recommended values of the exposure index and deviation index of the digital

AUTHORS' CONTRIBUTIONS

The participation of each author corresponds to the criteria of authorship and contributorship emphasized in the [Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly work in Medical Journals](#) of the [International Committee of Medical Journal Editors](#). Indeed, all the authors have actively participated in the redaction, the revision of the manuscript and provided approval for this final revised version.

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images. The variations associated with patient size, area coverage to be exposed, and the use or non-use of a secondary radiation grid should be considered to justify the selected exposure factors.

STATEMENT OF ETHICS

The authors have no ethical conflicts to disclose.

DISCLOSURE STATEMENT

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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