Radiography 25 (2019) e58–e62

Contents lists available at ScienceDirect

Radiography

journal homepage: www.elsevier.com/locate/radi

Evaluating the use of exposure indicators in digital x-ray imaging system: Gauteng South Africa

S. Lewis*, T. Pieterse, H. Lawrence

University of Johannesburg, South Africa

ARTICLE INFO

Article history:
Received 16 June 2018
Received in revised form
5 January 2019
Accepted 11 January 2019
Available online 30 January 2019

Keywords:
Exposure indicators
Detector dose indicator
Exposure indices/index
Exposure creep

ABSTRACT

Introduction: Exposure indicators (EIs) are the only indicator of correct exposure technique in digital x-ray imaging systems but the use of such indicators remains largely unexplored in a South African setting. With exposure creep in the digital radiography age being a worldwide phenomenon, the study investigated radiographers' familiarity and use of EIs, providing insight into current exposure technique practices in this setting.
Methods: An explorative and descriptive quantitative study was conducted at 10 randomly selected radiography clinical training facilities in Gauteng, South Africa. The study used a questionnaire consisting of 26 questions based on familiarity with and use of EIs and radiographers' attitude to ionising radiation.
Results: A response of rate of 49.3% was achieved. Results show a low number of respondents (54.3%) had a perfectly correct understanding of the exposure indicator (EI) and only 55.7% of respondents made correct use of the EI.
Conclusion: Observable lack of familiarity and use of the EI suggests that improvements could be made to the training radiographers receive on digital imaging systems. Moreover radiographers need to be vigilant against making decisions in digital radiography using knowledge that may relate exclusively to analogue radiography.

Introduction

X-ray equipment has evolved steadily since Roentgens' discovery in 1895, most recently the transition from analogue to digital radiography.[1] Resultant images in analogue radiography unequivocally provided discernible appreciation of exposure technique. On the other hand, the wide dynamic exposure latitude in digital radiography created a dearth in observable cues of exposure technique. High quality x-ray images may be obtained at 500 times the exposure technique necessary to obtain an optimum quality image.[2] Therefore knowledge learnt about exposure technique from analogue radiography can no longer be applied to digital radiography. Looking at the x-ray image alone will not provide information about exposure technique.[3–5]

While the wide dynamic exposure latitude is heralded in literature as an advantage of digital radiography, there has also been evidence to its augmentation of exposure creep.[6,7] Manufacturers therefore include an indicator of exposure in digital radiography. The indicator has diverse nomenclature and has been cited as detector dose indicators, exposure indicators, exposure index, air kerma indicator or sensitivity.[8,9] Hereafter the term exposure indicators (EI) will be used.

EI are numerical parameters of the relative receptor exposure or the estimated absorbed dose to the detector and is dependent on the receptor efficiency and sensitivity to incident x-rays.[10–14] EI are procured from the mean detector entrance exposure, which is derived from the mean pixel value within the anatomical region of interest in the acquired image. It depends on the tube current, the total detector area irradiated, the beam attenuation and patients composite attributes.[15,16] EI are proportional to the signal to noise ratio squared (SNR^2) and stipulates acceptable noise levels. Noise results from insufficient photons reaching the imaging receptor and acceptable noise levels are indicative of the image quality.[8–19]

The purpose of the EI is to determine if the optimum exposure technique was used to acquire the x-ray image in digital

* Corresponding author. Corner Siemert & Beit, University of Johannesburg, Department of Medical Imaging & Radiation Sciences, John Orr Building, 6th Floor Office, 6304A, Doornfontein, Johannesburg, 2000, South Africa.
E-mail addresses: shantell@uj.ac.za (S. Lewis), traceyp@uj.ac.za (T. Pieterse), heatherl@uj.ac.za (H. Lawrence).

https://doi.org/10.1016/j.radi.2019.01.003
1078-8174/

radiography and also acts as a safeguard against overexposure in digital radiography.[20–22] Overexposure may be curtailed if exposure techniques used produce a EI within a predetermined EI range for a specific projection. The predetermined range will be recommended by the equipment manufacturer, however, the range, may be further tailored by the radiology department, according to their image quality needs for specific projections.[23]

Without the EI, verification of the appropriate exposure factor selected by the radiographer is impossible.[2] In fact the ECRI institute[24] states that the EI is the only objective indicator of optimum exposure technique because digital radiography has the ability to disguise overexposure. Consideration of EI obtained, any presence of quantum mottle or saturation on the x-ray image and the various factors that influence the EI will be needed to make informed exposure technique decisions that uphold the ALARA principle in digital radiography.[22]

The American Association of Physicists in Medicine (AAPM)[25] notes that the name and calculation of the EI varies among manufacturers and recommends that these be standardised. The International Electrotechnical Commission (IEC) and the AAPM introduced three standardised terms with regards to digital imaging, namely, exposure index, target exposure index and deviation index.[25,26] Currently in SA the standardised terms for EI is not a legislated requirement resulting in radiographers still working with EI of varied nomenclature and calculations.[8]

Radiographers are seen as patient champions for radiation protection and optimisation of exposure technique is a vital radiation protection measure.[4,5] Therefore better understanding of exposure indicators (EIs) can increase the reliability of the EI as an indicator of exposure technique in digital radiography.[10,21] This understanding will translate into optimisation of exposure technique, a vital tenet of radiation protection.[5] Hence investigating radiographers' familiarity with EIs will provide much needed information about radiation exposure in SA digital imaging x-ray systems and address the gap in the literature as to radiographers' familiarity of EIs. The information obtained will inform effective strategies to ensure optimisation, one of the cardinal principles of radiation protection.

Materials and methods

Ethical clearance for the study was received from the relevant bodies. A self-formulated data collection tool consisting of a study information letter, research consent form, 19 closed questions and 7 open-ended questions on the demographics, professional and equipment profile, radiographers' familiarity with and use of EI and attitude to radiation exposure was distributed to 10 randomly selected public and private sector clinical sites. The randomly selected clinical sites are all accredited by Health Professions Council of South Africa (HPCSA) for training diagnostic radiography students and use equipment from various manufacturers.

The questionnaire was reviewed by experts to ensure content validity and then piloted to 13 radiographers from a non-selected clinical site, in order, to assess reliability. Thereafter a total of 213 revised questionnaires were distributed personally by the researcher to all randomly selected research sites, in order to improve the response rate. The number of questionnaires distributed at each research site varied according to the number of qualified radiographers employed at each of these sites. Student radiographers were excluded from the study. The researcher discussed the purpose of the study and the research information letter with all qualified radiographers working at clinical sites. Participation in the study was voluntary and anonymous.

Qualified radiographers who choose to participate in the study could complete one of the questionnaires left at the research sites, at their convenience and at their own pace, without influence from the researcher, thereby reducing social desirability bias. However, if the participant required any clarity or had a query regarding the questionnaire, the researcher's contact number and email address were available to the participants. Completed questionnaires could be placed in a sealed box that was left at each of the research sites. The sealed boxes were collected three weeks later from each of the research sites. Open ended questions on the familiarity and use of the EI were coded as perfectly correct, partially correct and incorrect and as incorrect use and correct use as derived from current literature on EI (Table 1).[4,11–15,27]

Statistical analysis

Data collected was coded and then analysed using IBM SSPS V.23. The majority of the data was analysed in terms of frequency, except for the experience section where central tendency in terms of the mean was used to describe the data. Independent −samples t-tests were conducted to compare the mean and the Pearson chi square test for independence was used to determine any significance between answers to various questions in the three main sections of the questionnaire. Significance for both independent −sample t-tests and Pearson chi-square test for independence was accepted if the significance value was .05 or smaller ($p < .05$).

Results

At 49.3% response, 105 completed questionnaires were received.

Demographic, professional and equipment profile

Most respondents were between the ages of 25–29 years with more than three quarter of respondents being below the age of 44. Respondents had a mean of 5 years (SD = 2.75) of experience in digital radiography and 9 years (SD = 10.53) of experience in analogue radiography. The largest percentage of respondents received informal on the job training. When respondents were asked to name the EI used for the equipment at their facilities, only 2 equipment manufacturers received 100% correct EI names from the respondents.

Familiarity and use of EI

11.8% respondents declared having not heard of EIs and 54.3% had a perfectly correct understanding of EIs. 62.7% the participants indicated using EI in practice of which more respondents used EIs correctly than incorrectly in practice.

33 respondents answered that they did not use EIs in practice. Reasons provided for their non-usage of EIs in practice showed that the majority of respondents indicated a lack of understanding and not knowing how to use EIs. A few indicated that EI is not reported therefore not necessary to note, it is not department protocol/policy, increased workload and lack of time as reasons for not using EIs.

41.3% of respondents declare that they do not know the manufacturer recommended EIs even though 45.8% acknowledge that manufacturer recommended values are available in their department. In addition 32.4% of respondents have no understanding why the EI may differ from manufacturer recommended value with 30.5% having no knowledge of the corrective measures to take if the EI may differ from what the manufacturer has recommended.

Independent−sample t-tests were conducted to compare respondents' age with having heard of EI, and their years of experience in digital radiography with having heard of EI. No significant difference was found with age of the respondents and having heard

Table 1
Coding of open-ended questions.

A: Open-ended question	B: Correct answer derived from literature[4,11–15,27]	C: Participants answers coded as
13. What is your understanding of Exposure Indicator (EI)/[a] Detector Dose Indicator (DDI)?	Any answer: • EI are the amount of photons incident on the image receptor • EI are proportional to the signal-to-noise ratio squared and are concomitant to image quality	• **Perfectly correct**: if all aspects similar or had a similar understanding as answer in column B • **Partially correct**: some aspects correct • **Incorrect**: no aspects correct
15. If you answered YES, how do you use EI/DDI in practice?	Any answer: • EI is used to determine if optimum exposure technique was used. • The EI also indicates noise levels on the image. However factors affecting EI must be considered	• **Incorrect use**: No aspects as per column B • **Correct Use**: participants used EI as expressed in literature stated in column B • Does not understand/does not know/Does not use (captured as is)

[a] Questions in the questionnaire always used both Exposure Indicator (EI)/Detector Dose Indicator (DDI) because DDI is used by the South African Directorate for Radiation Control.[8]

Table 2
Chi-square tests for answers to various questions in the three main sections of the questionnaire.

Comparing questions from three main sections in the questionnaire	Df	N	Pearson Chi-square value	Asymptotic significance (2-sided)	Phi
Understanding of differing Exposure Indicator (EI)/[a]Detector Dose (DDI) values from manufacturer recommended (MR) standards *And* Corrective measures for differing EI/DDI	4	102	110.00	$p < .001$	1.03
Use of EI/DDI in practice *And* I don't take note of the EI/DDI long as I get a X-ray image that looks acceptable. (Likert scale statement)	4	100	27.17	$p < .001$	0.50
Use of EI/DDI in practice *And* I always compare the EI/DDI I receive for a X-ray image to MR values. (Likert scale statement)	4	100	20.00	$p < .001$	0.44
Knowing the MR EI/DDI *And* I always compare the EI/DDI to the MR values. (Likert scale statement)	8	103	26.97	$p < .001$	0.51
Understanding differing EI/DDI from MR standards *And* I always compare the EI/DDI I receive to the MR values.(Likert scale statement)	8	101	29.95	$p < .001$	0.54
Corrective measures for differing EI/DDI *And* I always compare the EI/DDI to the MR values. (Likert scale statement)	8	103	41.65	$p < .001$	0.636
Corrective measures for differing EI/DDI *And* Changing exposure technique for subsequent images if EI/DDI varies	8	104	43.85	$p < .001$	0.65

[a] Questions in the questionnaire always used both Exposure Indicator (EI)/Detector Dose Indicator (DDI) because DDI is used by the South African Directorate for Radiation Control.[8]

of EI, with a mean score of 3.44 (SD 2.25) indicating yes to having heard of EI and 3.08 (SD = 2.23) indicating no to having heard of EI. However, there was a significant difference with years of experience in digital radiography and having heard of EI with a mean score of 5.15 (SD = 2.91) indicating yes and 4.29 (SD = 1.32) indicating no. There was no significant association between knowing and using EI ($p = .62$) however there was a significant correlation between use and understanding of EI ($p < .001$).

Table 2 shows that respondents that know the optimal EIs for their equipment are more likely to compare this value to those recommended by the manufacturer. Furthermore, respondents that have a greater understanding of why EI vary from manufacturer recommended standards are more likely to compare the EI received to that recommended by the manufacturer and are more likely to know the corrective action to take. Additionally, they are more likely to change exposure techniques on subsequent exposures. Respondents that indicated making use of EI also are more likely to disagree that they don't take note of the EI as long as the image they receive is acceptable and agree that they always compare the EI received to the MR standard.

Attitude to ionising radiation

Digital radiography has shown evidence of exposure creep,[9,10] therefore it was vital to describe the attitude of the radiographers to ionising radiation. Participants needed to rate five statements from strongly disagree to strongly agree on a 5-point Likert rating scale. 34.9% of respondents agreed that they did not take note of the EI as long as they received an X-ray image that looked acceptable, 35% disagreed that they always compared the actual EI to the MR standard and 71.2% agreed that they would change subsequent exposures if the actual EI differed from the MR standards. 84.6% of respondents agreed that they aimed to use the lowest possible exposure to obtain a diagnostically acceptable X-ray image. 31.4% collectively agreed and strongly agreed that the danger to patients from radiation over exposure was grossly overstated.

Discussion

Demographic, professional and training profiling of this study was congruent with literature.[27] With respondents having more experience in analogue film screen radiography than in digital radiography they would probably be using digital equipment with a knowledge base founded in analogue film screen radiography. With the AAPM[25] dubbing digital radiography as new and confusing, radiographers can no longer wholly rely on the inherited film screen analogue knowledge. Radiographers have to be reeducated to expand their understanding of the physics and theory of a multitude of new equipment.[28,2] Results show no significant difference with years of experience in digital radiography and having heard of EI. Therefore, radiographers have to amplify their current comprehension to include digital image acquisition, processing, and display practice and the decoupling of exposure technique cause and effect.[17]

54.3% of participants surveyed in the study were correctly familiar with the EI. 55.7% of participants surveyed in the study

used the EI correctly. At the onset it is important to note that no other studies have been found that have determined whether radiographers have heard of, used or understand the EI therefore these questions are difficult to contextualise within literature.

The results show that despite the majority of participants having heard of EI, upon further questioning of understanding and use of the EI only half of the participants surveyed had a perfectly correct understanding of it and made correct use of it. When considering that just under half of the participants did not know the manufacturer recommended (MR) EI, about a third did not understand the reasons for the EI differing from the MR standards and did not know the corrective actions to take if this was the case, it would be reasonable to infer that a lack of knowledge of the EI contributes to incorrect EI use. That being said, the results also indicate no significant association between knowing and using the EI but there is significance between use and understanding of the EI.

Additional contributing factors identified from literature for just over half the participants surveyed being familiar with and using EIs correctly may include participants having varying skills, needing to learn a rapidly evolving fairly “new” digital technology and participants receiving conflicting, confusing and scattered resources.[2,20,25,29]

Participants' reasons for not using the EI align with reasons provided in literature. Varying skills based on training on digital X-ray imaging systems and lack of EI knowledge and resources explain participants' reasons for not using the EI. However, EIs are not protocol or do not need to be reported which aligns with observations of radiographers being followers and protocol directed, a disposition which inhibits radiographers’ ability and willingness to learn.[30,31]

When participants were asked to name the EI of the equipment they used, they could correctly name the EI of only two manufacturers. If half the participants surveyed understand and use EI correctly surely this number should be higher. Participants worked in departments with equipment from various manufacturers and the non-implementation of the standardized EI may make remembering the various EIs difficult.[19,20,32,33] In addition, with just under half of the participants noting that MR EIs were available in the departments, the need to be able to recall the name may be negated.

Of concern is the finding that, despite 91.3% of participants having had training in digital radiography, this number does not translate into a congruent percentage of correct understanding and use of the EI. More concerning is that were participants that did not know the reasons why the EI may differed from the MR standards and had no knowledge of the corrective measures to take if the EI differs from what the manufacturer recommended. This finding indicates that perhaps the training given to participants is not presented in a way that facilitates authentic learning opportunities, which results in a theory practice gap and impacts on the clinical practice of the participants post training.[34–36]

Open-ended questionnaire responses pointed to respondents indicating inadequate training as the main reason for the lack of understanding of EI. A limitation of the current study may be that application specialists responsible for training participants on digital equipment were not asked to comment on the structure of the training programmes presented. The current study cannot therefore directly link a lack of training to the participants’ lack of understanding but can infer that the training given is not translating into acceptable application of digital theory into clinical practice.

Furthermore, the theory practice gap may be exacerbated because current radiology practices do not require legislated auditing or monitoring of EIs. Respondents, therefore, justified non-usage of the EI since these values did not have to be reported and were not part of departmental protocol, and were therefore deemed unimportant. Evidence suggests that documenting of EIs has halted dose creep[30] which makes the findings of this study concerning as it may be inferred that non-reporting of EI's may result in dose creep. Scrutiny must be afforded to the results showing that if optimal EIs are available for participants, participants are more likely to use, compare and understand EIs. Results have shown significant association between use and understanding of EIs. Ultimately this translates into observing the ALARA principle.

Attitude to radiation exposure

The majority of radiographers agree that they strive to use the lowest possible exposure to achieve optimal images yet a third of the radiographers do not pay attention to EI and only half of the radiographers surveyed correctly understand and use EI. With EI considered as the only objective indicator of optimum exposure technique in digital radiography, are the majority of radiographers really striving to adhere to the ALARA principle?[24] In the era of digital radiography following the ALARA principal means paying attention to EI, understanding EI, knowing the MR EI standards, the factors affecting EI and corrective measures to take in the event that EI differs from the MR standard. The paucity of EI use and understanding infers non adherence of the ALARA principle and violates the code of good practice for health care professions and code of practice for users of medical x-ray equipment.[37]

Most surprisingly is that 31.4% of radiographers agree that the danger to patients from radiation over exposure is grossly overstated. With a third of the respondents from research sites expressing this agreement, the disseminated narrative is disquieting. Studies indicate that radiographers require more training in radiation protection because educational level was found to be proportional to attitude and awareness of radiation protection.[38,39] Suboptimal EI understanding and use coupled with flagrant disregard for the detrimental effects of ionising radiation all violate the ethical principles of non-maleficence and a moral obligation to patients.[38,40,41]

Conclusion

With only half of the participants surveyed having a correct understanding and use of the EI, the training of radiography students in work place learning is concerning. More extreme is the third of the participants agreeing that the danger to patients from radiation overexposure is grossly overstated. Custodians of work place learning conveying such information to future generations of radiographers may mean further exposure creep and ultimately increasing radiation dose to patients. To halt this, it must be made clear that inherited film screen knowledge cannot be applied to digital radiography. Re-education in digital radiography will increase the correct understanding and use of the EI, translating into a congruent decrease in overexposure of patients to ionising X-radiation.

Conflict of interest statement

None.

Acknowledgement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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