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Retrospective evaluation of exposure indicators: a pilot study of exposure technique in digital radiography

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Abstract

Introduction: Digital radiography lacks visual clues of exposure techniques used to obtain radiographs, therefore manufacturers have included exposure indicators (EIs). EIs provides feedback about exposure techniques used and evaluating EIs will yield much needed information about exposure trends used in digital radiography. **Methods:** A retrospective explorative quantitative study was conducted at nine randomly selected imaging departments in Gauteng, South Africa. Data pertaining to EI was retrospectively collected using quota sampling and compared to manufacturer recommended (MR) standards. **Results:** A total of 1422 EIs were collected. 50% of these were within the MR standard. 27% of EI indicated overexposure and 23% indicated underexposure. **Conclusions:** Greater evidence of overexposure was noted in the retrospective analysis of the EI. This pilot study shows the need for further investigation into exposure technique practices in digital radiography and the need for measures to halt the evidenced overexposure.

Introduction

The chief elements of X-ray production have not changed over the past 100 years, but the process after the X-ray photons have passed through the patient has morphed progressively with the use of digital X-ray equipment.[1,2] Digital X-ray equipment has a wide dynamic exposure latitude over which optimal images may be obtained and allows the radiographer to manipulate the image after the exposure has been given. Additionally, radiographers schooled in conventional film screen radiography can no longer wholly apply the same knowledge paradigm to digital radiography.[3–6]

In digital imaging systems insufficient exposure produces higher noise levels on the X-ray image, whereas overexposure may still produce optimal images despite the excess exposure of x-radiation to the patient before saturation is evinced.[7,8] Radiographers therefore tend to rather overexpose a patient to avoid repeating the image and to produce better quality images without image noise.[9] As a result, the radiation dose to the patient will increase proportionally. This phenomenon is known as exposure creep.[6,10]

Exposure creep, as noted by Gibson and Davidson,[11] is an increase over time of manual exposure factors that are set by radiographers. Manufacturers of digital X-ray imaging systems include an indicator to alert radiographers of overexposure or underexposure of the resultant image.[9] Therefore, this study investigated the only indicator of exposure creep in digital radiography, known as the exposure indicator (EI). Investigating the EI is necessary for ensuring optimal radiation protection of patients.

The first EI dubbed 'sensitivity/s-number' made an appearance in 1980 with cassette-based digital imaging X-ray systems.[12] Here, the indicator was used to amend the gain to obtain the latent image. Later its use evolved to rescaling of digital data for increased contrast and to compensate for exposure technique dissimilitude. Eventually it became a mainstay to correlate exposure technique.[13,14]

The EI is the numerical parameter 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.[15–19] Seeram and Brennan,[5] however, indicate that the EI is not a measure of radiation levels at the detector but rather a representation of the radiation levels at the surface of the detector achieved by converting pixel values (pixel values indicate the intensity of light photons striking the pixel).

The EI is proportional to the signal to noise ratio squared and stipulates acceptable noise levels.[13] Acceptable noise levels are indicative of the image quality therefore in many practices the EI is used as a quality control tool.[20,21] As such EIs should be accurate, consistent and reproducible.[14]

The American College of Radiology (ACR), AAPM and the Society for Imaging Informatics in Medicine (SIIM)[10] advise that as part of quality control, EI data should be analysed regularly to ensure the 'as low as reasonably achievable' (ALARA) principle. The Bonn Call-for-Action[22] stresses the importance of audits to facilitate and enhance justification of ionising radiation in practice. The Center for Devices and Radiological Health[23] also notes that there is a wide variation in radiation doses for particular medical imaging exams among different imaging facilities in the United States of America (USA) and recommends standardisation and better quality assurance. Furthermore, the IAEA worldwide survey of medical radiation exposure tracking[24] found that none of the 76 countries surveyed had a national exposure tracking programme.

The purpose of the EI is to allow the radiographer to ascertain if the correct exposure technique was used to acquire the X-ray image.[4,6,25] Therefore, the EI also acts as a safeguard against overexposure in DR. Overexposure may be curtailed if radiographers use exposure techniques that correlate closely to the manufacturers' predetermined EI value for a specific projection.[26] However, studies have found that manufacturers set the EI standard too high.[27,28] It is also important to note Seibert and Morin,[29] who, along with Adler and Carlton,[30] caution that the indicators are not direct indicators of dose, but are indicators to achieve optimal images at the lowest dose possible.

Radiographers must consider the EI obtained and any presence of quantum mottle or saturation on the X-ray image to inform exposure technique. In addition, they must consider various factors (Tables 1 and 2) other than exposure technique that influence the EI to make informed decisions that follow the ALARA principle.[4]

Since the EI is obtained from the image histogram it is prone to errors related to the histogram analysis. The variations in the EI are caused by errors in the histogram analysis and not because of exposure to the imaging receptor. Therefore, radiographers need to be aware of factors that may cause the EI to vary (Table 1). If any of these factors are present, the EI no longer correlates to the exposure to the imaging receptor. Radiographers need to look for any visible quantum mottle or saturation to determine if the image would be acceptable.[7,25,31]

Table 1. Factors causing variations in the exposure indicator.[25,31,37–39]

Factor	Explanation
Extraneous exposure information, including scatter	In computed radiography (CR) it is suggested that an optimal size CR cassette be used to eliminate extraneous exposure information. If a larger CR cassette must be used, the area of interest must be centred to the CR cassette with four-sided collimation equally distributed from the cassette borders. With incorrect centring, the collimation field would have to be larger to include all the anatomy that is needed, resulting in a wider histogram
Exposure field recognition error	Occurs if collimation margins are not detected
Unexpected material in field	Widen histogram analysis due to densities that would usually not be included in look up table (LUT)
Extreme underexposure or overexposure	Histogram analysis error due to excessive quantum mottle or saturation
Delay in processing	CR cassettes must be moved away from the radiation area and be processed as soon as possible to prevent errors in the histogram analysis of the fog-altered pixel values
Part selection from workstation menu	If the anatomical part selected from the workstation menu is incorrect, the LUT used to rescale the histogram data will be incorrect. The LUT for each anatomical part has a specific optimum gray-scale and brightness level.

Additional factors affecting EI as discussed in Table 2 were identified by Mothiram et al.[13]

Another conundrum faced by radiographers when using EIs is the varied nomenclature used by manufacturers. Shepard et al.,[14] however, do note for all manufacturers this value should reflect their system's sensitivity for a given exposure. Simultaneous but independent efforts by the IEC and AAPM to standardise EIs have given rise to IEC 62494-1 standard and the AAPM report 116.[10,14,25,29,32]

This study which retrospectively evaluates EI variations from manufacturer recommended (MR) standards, was designed considering all the variables that may cause variation in the EI that are not related to the exposure to the imaging receptor. Comparing the actual EI values with the MR standard will provide much-needed information about radiation exposure in digital imaging X-ray systems.

Table 2. Additional factors affecting exposure indicators.[13]

Factor	Explanation
Patient gender	Female patients had a higher variant exposure indicator (EI) which is congruent with Lanca and Silva's[39] findings. This finding was attributed to lack of exposure technique chart optimisation in both studies.
Time/date of exposure	X-rays taken outside of normal working hours also showed an increase in the EI variations[13] similar to findings in Peters and Brennan's[28] study. The studies attributed the findings to the level of experience of radiographers working during shifts and the choice to rather overexpose the patient than to repeat the X-ray in staff-strapped busy environments[13,28]
Grid usage	When grids were used the EI obtained varied from that obtained when no grid was used for the same exam[13]
Presence of implant or prosthesis	The presence of artefacts, implants or prostheses will widen the histogram and display a varied EI value[31]

Methodology

A retrospective analysis of actual EIs was conducted at nine randomly selected imaging departments in Gauteng, South Africa (SA). Quota sampling was used to record data of adult patients, X-rayed in the imaging department, according to a predetermined anatomical area and criteria in Table 3. Excluded from the sample were any patients younger than 18 and any patients who underwent ward radiography. The sample consisted of 10 images of each for the upper limb, lower limb, chest, abdomen, spine, skull and facial bones per collection site. Retrospective analysis of the actual EIs obtained on these images was compared to the MR standards.

Table 3. Retrospective data collection criteria.

Date
Time
Age
Gender
Examination
Projection (anterior-posterior/lateral/oblique, etc)
Presence of prosthesis/artefact (Yes/No)
Effective four-sided collimation (before post-processing (Yes/No)
Grid (Yes/No)
Any noise/saturation present
Repeated (Yes/No)
kVp given (if available)
Milliamperes second given (if available)
Actual exposure indicator (EI)
The manufacturer recommended EIs that were supplied to research sites (minimum and maximum)

Ethics

Ethical clearance for the study was received from the research ethics committees of University of Johannesburg and Witwatersrand. Patients' names were not documented during the data collection; only the gender and age was documented.

Statistical analysis

Data collected were coded and then analysed using IBM SSPS V.23. The Pearson chi square test for independence was used to determine any significance between the EI collected and the factors affecting EI. At four sites the EI is represented by S-numbers. Statistical analysis accounted for the inverse relationship of the S-number and exposure.

Results

A total of 1 422 actual EIs were collected retrospectively from nine randomly selected sites.

Results as seen in Figure 1 showed that half of the actual EIs retrospectively collected were within the MR standard and therefore optimum exposures were used to obtain these images. From the remaining half, more images were overexposed than underexposed. 17% (57) of underexposed images were repeated due to the presence of quantum mottle.

The EI may not always be an absolute reflection of the exposure to the detector because it may be influenced by factors as discussed earlier. Therefore, chi-square correlations (Table 4) were done to consider associations in the data set.

Significance for the Pearson chi-square test for independence was accepted if the significance value was 0.05 or smaller ($P < 0.05$).

In Table 4 the P value shows that there is a significant correlation between whether the EIs were within, lower or greater than the MR EI and the type of examination done, which projection was being done, the presence of a prosthesis, effective four-sided collimation prior to post-processing and the use of a grid. However, whether an examination is done within normal or after hours and the gender of the patient had no significant influence on EI received. Considering phi, the type of examination and projection being done revealed the strongest correlation to the EI received while the other factors indicated a weak correlation.

EIs collected indicated that manufacturers in SA do not adhere to the IEC 62494-1 standardised terms of exposure index (EI), target exposure index (EI_T), and deviation index (DI) (IEC, 2008). In fact only one

Table 4. Factors affecting exposure indicators.

	Actual exposure indicators within, lower or greater than manufacturer recommended range				
	Chi-square				
Factor	df	*N*	Pearson chi-square value	Asymptotic significance (2-sided)	Phi
Normal or after hours	2	1421	0.431	$P = 0.80$	0.01
Gender	2	1420	1.89	$P = 0.38$	0.03
Examination	50	1419	170.71	***P* < 0.001**	0.34
Projection	36	1421	76.38	***P* < 0.001**	0.23
Presence of prosthesis	2	1420	9.79	***P* = 0.007**	0.08
Effective four sided collimation before post- processing	2	1415	12.64	***P* = 0.002**	0.09
Grid	2	1419	6.75	***P* = 0.03**	0.06

Bold values indicate Significance was accepted if $P < 0.05$.

manufacturer expressed EI according to the IEC 62494-1 standard.

Discussion

In SA, licensing of X-ray equipment does not compel manufacturers by law to provide MR standards or for MR standards to be checked, therefore radiology departments might not be provided with MR standards.[33] Radiology departments with equipment that do not have MR standards for EIs would need to obtain the MR standards from the manufacturer. Moral and ethical obligations of the manufacturers to uphold the ALARA principle should negate the need for legislation to compel them to provide the standards for the only indicator of exposure in digital X-ray imaging systems.

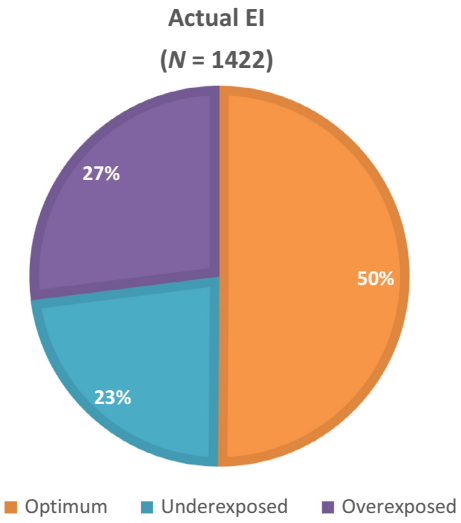

Figure 1. Actual exposure indicator compared to manufacturer recommended standards.

Half of the actual EIs collected retrospectively were found to be within the MR standards. When considering that there are studies that have found that manufacturers have set EI standards too high questions arise as to the effectiveness of the MR EI at the research sites.[27,28] Suggestions to develop facility EI standards which achieve the correct balance between exposure technique and optimum image quality while preserving the ALARA principle must be deliberated.[26,34]

Coincidently the ability to manipulate original S-number is concerning as the only indicator of exposure technique in digital radiography is no longer reliable. Manufacturers still using S-numbers as EIs are clear indication that IEC 62494-1 standard is not being adhered to. This provides a further challenge for radiographers who have to understand the various manufacturer EIs.

In this current study, more EIs were over than under the MR standard. Variations in the exposure favoured overexposure leading to exposure creep. Underexposed images were repeated, further contributing to patients' overexposure. The reason that only 57 of the underexposed images were repeated can be attributed to digital X-ray imaging systems compensating for underexposure. The exposure was probably not low enough to create noise on the image. However, the EI would probably have indicated that the image was underexposed. Mothiram et al.[13] found that a significant number of examinations for chest, abdomen and pelvis were outside the MR standards. Peters and Brennan[28] found 30% of EIs over the MR standards.

In SA, the Directorate of Radiation Control[33] stipulates that display monitors used for diagnostic reporting on images must have a 3 megapixel resolution and those not used for diagnostic reporting must have a 1 megapixel resolution. Due to the cost of a higher resolution monitor only radiologists are provided with a 3 megapixel resolution display monitor.[7] Radiographers view their resultant images on a 1-megapixel resolution display monitor and may not be able to see noise on an image that may be visible on a 3-megapixel resolution monitor. At public hospitals, due to patient volumes, not all patients receive a radiologist's report. Therefore, noise on images may be missed by radiographers and images are not repeated. Radiographers must therefore pay attention to the EI and compare the EI received for an image to the MR standard in order to rule out underexposure. In addition the magnification function may be used to access the image to rule out quantum mottle.[35]

The factors affecting whether the EI was within the manufacturers' range in this study were the type of examination, projection, presence of a prosthesis, effective four-sided collimation prior to post-processing and the use of a grid. It should be noted that grid use was not compared for the same examinations as per Mothiram et al.[13] Considering that in digital radiography the use of a grid will reduce both the signal and noise received by the detector, exposure technique adjustment must preserve the signal to noise ratio.[36]

The factors affecting the EI are similar to findings in literature except for patient gender and whether the examination was done within or out of normal working hours were found to have no influence on whether the EI was within the manufacturers' range in this study.[13,25,31,37–39] The reason provided by Mothiram et al.[13] and Lanca and Silva[39] for the variations in EIs in males and females was a lack of exposure technique chart optimisation. It is not clear whether participants in this current study could be changing their exposures between males and females to suit their patient and that is why this variant does not appear to influence the EI. As part of the licensing requirements for diagnostic X-ray equipment, the Directorate of Radiation Control, requires an updated exposure chart to be available for all equipment.

Conclusion

Retrospective evaluation of individual patient EIs at imaging departments in Gauteng, SA shows evidence of overexposure in digital radiography. Overexposure is unnoticed because evaluation of individual patient EIs is not currently mandatory. Legislating mandatory provision of MR EI, evaluation of individual EIs and standardisation of manufacturer EI may curtail overexposure in digital radiography. Authentic and lifelong learning of digital radiography will ensure a congruent shift in the current radiation protection paradigm.

Conflict of Interest

All authors declare no financial relationships with any organisations that might have an interest in the submitted work in the previous 3 years; no other relationships or activities that could appear to have influenced the submitted work.

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