An investigation on the appropriateness of Exposure Index (EI) calibration and Exposure Index target (EI_T) values as a method of ensuring diagnostic image quality and optimum patient exposures in Digital Radiography.

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Learning objectives

Aim

To have standardised terminology across all DR equipment in one Hospital Trust which will act as a visual indicator to the radiographer that the image is correctly exposed and within national Dose Reference Levels (DRL's)

Objectives

[i] To test if EI and DI was appropriately calibrated in 8 DR rooms across multiple sites in a busy Hospital Trust in the UK.

[ii] To investigate if IEC 62494-1 would give the radiographer a reliable visual indicator of a correctly exposed image.

[iii] To identify if examination doses for the five body parts were below national DRLs.

Background

Digital Radiography has a high Detective Quantum Efficiency (DQE) which means that less radiation exposure is needed to achieve the same image quality, relative to conventional film screen radiography (FS).

Digital detectors offer the advantages of a wide dynamic range, adjustable image processing, better image quality, rapid image acquisition and image access at remote locations. [1] In addition, digital image processing can also compensate 100% for underexposure and more than 500% for overexposure[2] (see figure 1). DR processing amplifies the signal when underexposed and decreases it when overexposed, resulting in an acceptable image. In clinical departments it is well recognised that most staff training is delivered by applications teams and cascaded down through staff in the department [3]. It is imperative that this information is cascaded correctly and radiographers need to be cognisant of the Exposure Index (EI) in DR which is used to give an indication of radiation dose incident on the detector. Problems arise when more than fifteen DR manufacturers have their own proprietary EI metric and range, e.g. 'the Kodak EI' will increase if the exposure is excessive whilst Fuji EI 'S value' will decrease as exposure increases [4]. This variation causes confusion among radiographic staff and a lack of clarity in the imaging community regarding optimised clinical use and appropriate Quality Control programmes. This is of great significance when staff are working across multiple DR manufacturers in one department with different ranges of acceptability [5]. The International Electrotechnical Commission (IEC) attempted to standardise these variations in EI by publishing an exposure terminology standard in 2008; the IEC62494-1[6] the aim was to simplify EI, so three terms could be used across all manufacturers.

These three terms important to radiographers were:

(i) **Exposure index (EI)**- an index of the exposure at the detector in the relevant image region (RIR).

(ii)**Target exposure index (EI_T)**- the target reference exposure obtained when the image receptor is exposed properly. The EI_T should provide the exposure that produces a balance between image quality and dose.

(iii)**Deviation Index (DI)** - measures how far the actual EI value deviates from the EI_T.

The optimum DI is 0 indicating a perfect exposure. A negative DI indicates an underexposure whilst a positive DI indicates an overexposure. The higher the value the greater the over or under exposure (see figures 2 [7] and 3).

Images for this section:

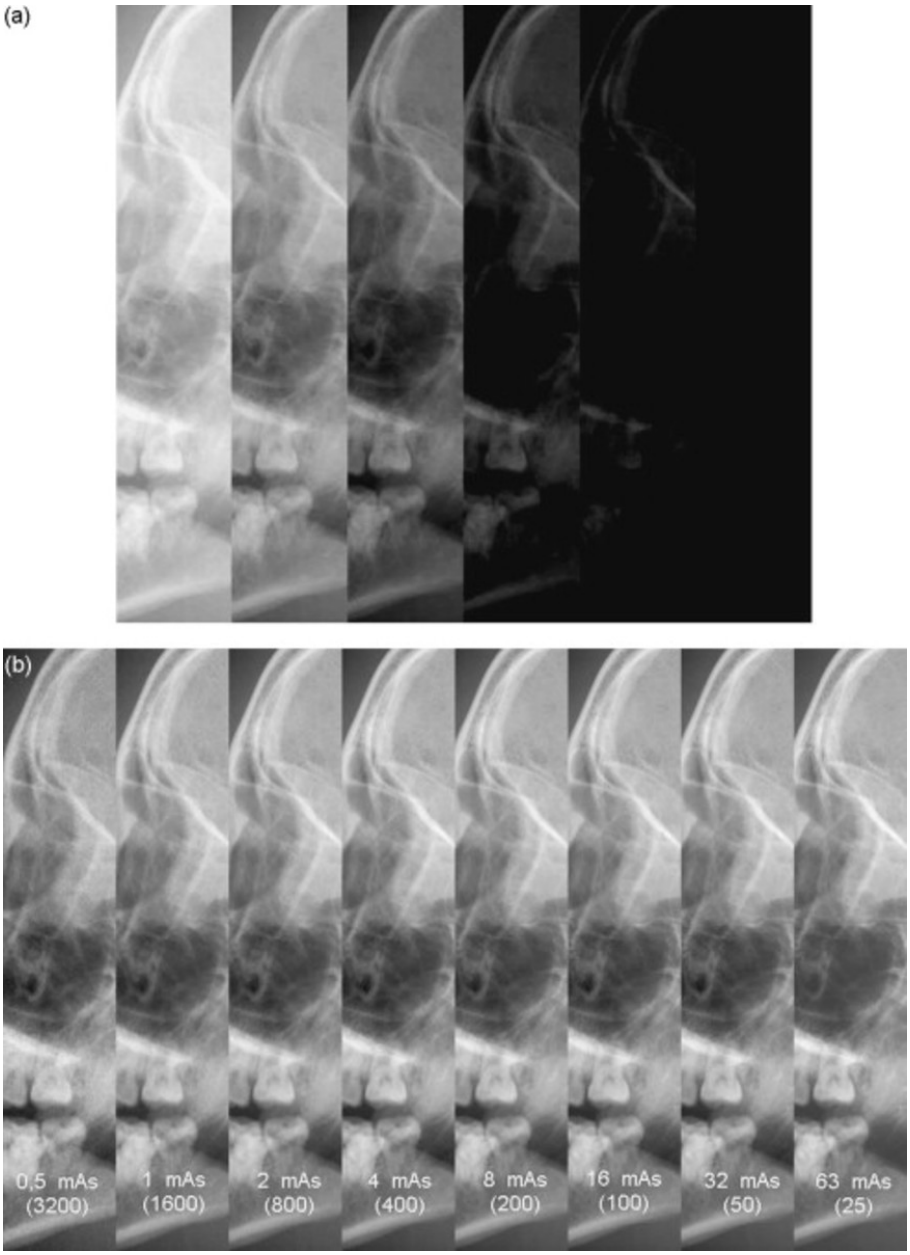

Fig. 1: Fig. 1. a, b: In a phantom series with stepwise progression of dose, the difference in dynamic range between a screen-film system (a) and a flat-panel detector (b) (Philips Medical Systems, Hamburg)

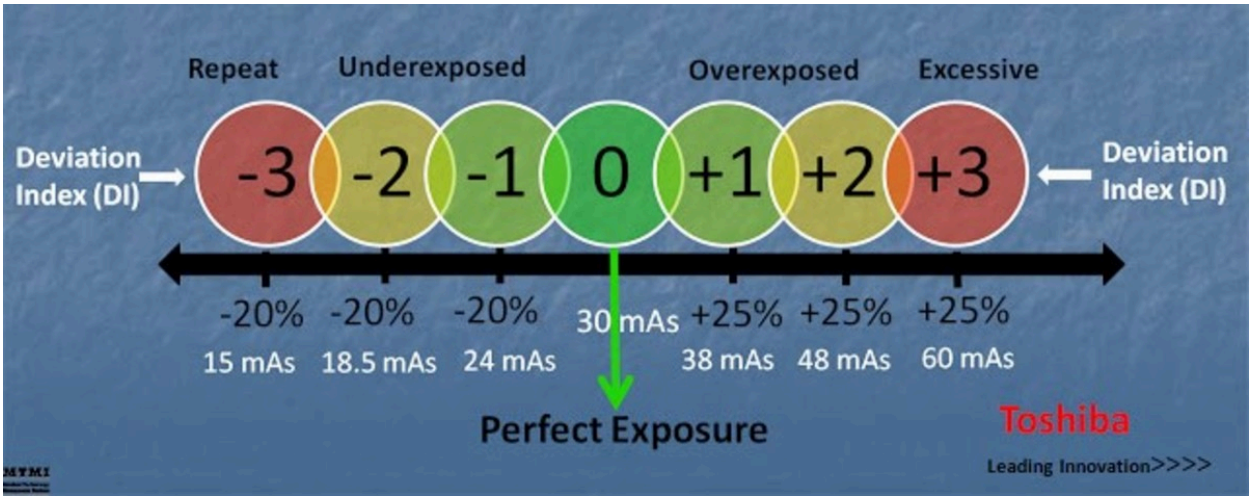

Fig. 2: Explanation of DI value and what this means to radiographers. [7]

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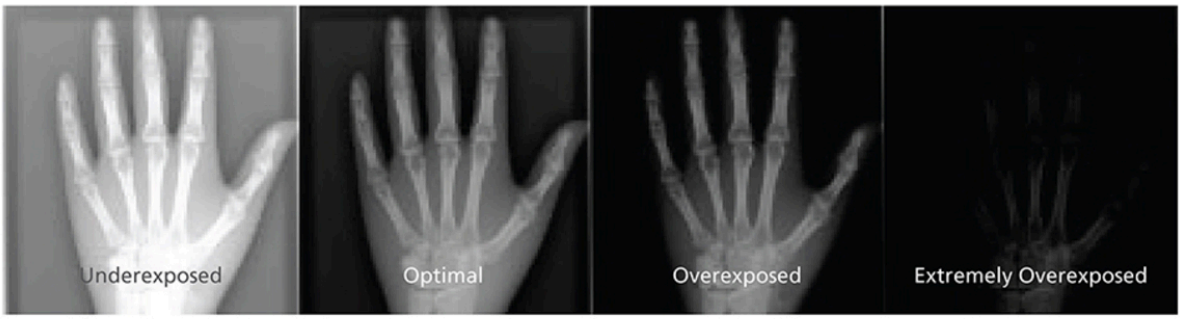

Figure 1: Range of exposures on analog film

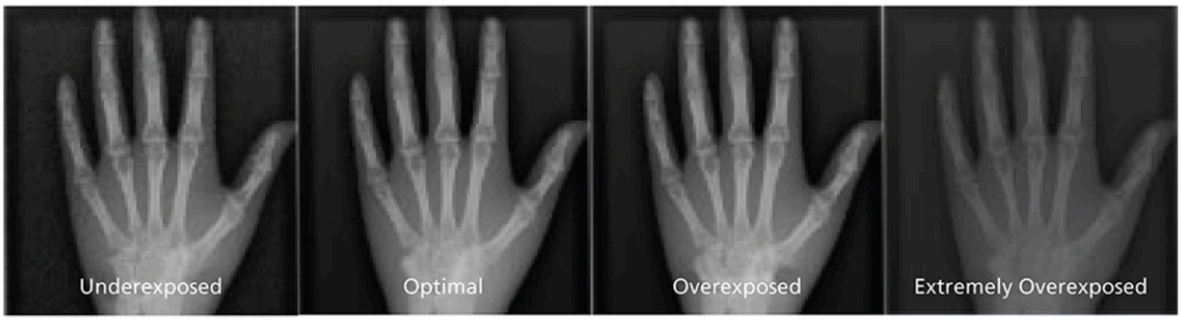

Figure 2: Range of exposures on digital receptor

Fig. 3: Range of exposures and associated image quality

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Findings and procedure details

Ethical and Research Governance Approval was sought and obtained. Eight DR rooms using equipment from three different manufacturers were investigated in one UK Trust. This included three Siemens Ysio units, two Carestream Evolution and three hybrid systems consisting of Shimadzu consoles and Canon detectors.

The methodology was divided into six phases.

1. Initially the EI used by a variety of DR manufacturers was investigated to check if it was calibrated according the IEC standard. Each manufacturer was contacted by email to ascertain how their EI was calibrated and identify their EI_T per body part.

2. A patient dose audit was undertaken for common patient examinations to document current EI and EI_T values and benchmark exposure levels against local DRLs to assess the scope for patient dose optimisation. This included 30 examinations per room for five body parts (n=1200).The exposure factors of kVp, mAs, EI and Dose Area Product (DAP) values were retrieved from the Dicom elements for each examination.

Inclusion criteria:

-X-ray examinations of Chest Postero-anterior (PA), Antero-posterior (AP) Abdomen, AP Pelvis, AP knee and Lateral lumbar spine.

-Only PA chest projections were included to ensure the source to image detector distance (SID) was standardised at 180cm.

-Both in-hours and out-of-hours examinations

Exclusion criteria:

-Paediatrics under 16 years of age to reduce significant variation in size.

3. Retake analysis was performed over three months prior to EI calibration checks to benchmark current repetition rates and categorise reasons for repeat exposures.

4. Experimental studies were performed with the aid of Medical Physics to determine if the EI calibration was according to IEC standard. ;

5. Where required, the findings from the EI investigation in phase 4 were used to

i. Calibrate the EI in the relevant equipment to IEC standard

ii. Adjust EI_T values as recommended by each manufacturer

iii.Adjust patient exposure factors to optimise clinical examinations to within local DRLs.

6. After the corrective action was undertaken, a repeat patient dose audit for each of the five body parts and a further retake analysis was undertaken to allow for comparison with baseline levels.

Results

The EI_T from each manufacturer is illustrated in Table 1, which is applied across all body parts.

Table 1. Target Exposure (EI_T) indices for each manufacturer.

Manufacturer 1	Manufacturer 2	Manufacturer 3
226.22	312	200

The exposure data from the dose audit are illustrated in Table 2. These values are the average obtained over 30 examinations for each of the five body parts per manufacturer.

Table 2. Mean kVp, mAs, DAP EI, EI_T, and DI values per five selected body parts for each manufacturer.

Manufacturer 1							
	kVp	**mAs**	**DAP dGycm²**	**DRL (dGycm²)**	**EI**	**EI_T**	**DI Value**
Abdomen AP	73.78	19.83	11.44	25	205.51	226.22	0
Chest PA	106.17	1.17	0.64	1	225.3	226.22	0

Lateral Lumbar spine	91.35	25.98	11.92	25	216.42	226.22	0
Pelvis AP	75.03	9.85	6.35	22	302.04	226.22	+1
Knee AP	64.23	2.1	0.42	none	277.72	226.22	+1
Manufacturer 2							
	kVp	**mAs**	**DAP dGycm²**	**DRL (dGycm²)**	**EI**	**EI_T**	**DI Value**
Abdomen AP	75.01	17.95	10.64	25	226.18	312	-1
Chest PA	125.34	1.11	0.51	1	128.42	312	-4
Lateral Lumbar spine	85.05	32.04	13.57	25	191.36	312	-2
Pelvis AP	71.85	14.38	8.87	22	313.49	312	0
Knee AP	59.8	2.03	0.5	none	165.33	312	-3
Manufacturer 3							
	kVp	**mAs**	**DAP dGycm²**	**DRL (dGycm²)**	**EI**	**EI_T**	**DI Value**
Abdomen AP	78.6	19.54	21.54	25	219.2	200	0
Chest PA	125	1.19	0.96	1	49.97	200	-6
Lateral Lumbar spine	84.98	71.58	41.17	25	245.56	200	+1

Pelvis AP	74.31	29.01	26.21	22	320.64	200	+2
Knee AP	68.02	2.19	0.52	none	350.71	200	+2

The average DI value was obtained by the following equation;

$DI=10 \log_{10}(EI/EI_T)$

Dose levels from manufacturer 1 were below the DRLs, the EI values achieved were close to the EI_T thus DI values were acceptable (0 and +1).

Dose levels from manufacturer 2 were below DRLs but as EI values were significantly below EI_T, DI values were negative and indicating underexposure. Only pelvis examinations had a DI of 0.

Dose levels from manufacturer 3 showed that the average DAP of 41.17 dGycm² for lateral lumbar spines (range 6-129 dGycm ^{2}) and 26.21 dGycm² for Pelvis examinations (range 3-98dGycm ^{2}) exceeded the DRL with 63% and 55% respectively of the sample receiving a dose above the DRL. There was a great variation noted in DI with no direct correlation between DI and DAP.

Retake analysis identified retake rates of 5.9%, 6.2% and 12.1% for Manufacturers 1- 3 respectively. On further analysis, less than 1% of images from each manufacturer were exposure related. The majority of reject reasons given by the radiographer were classed as "radiographer issues" i.e. positioning and anatomy cut off.

Experimental studies were performed and EI values were recalibrated with the aid of medical physics. As Manufacturer 1 was calibrated optimally, no further data was collected on that system, the DAPs were below the DRLs and retake rate was the lowest of the 3 manufacturers. DI appeared to correlate with DAP.

A repeat data collection (n= 900) and a further retake analysis was undertaken for Manufacturers 2 and 3 to establish if the corrective measures/recalibration had led to improvements in dose and image quality. Further results are illustrated in table 3.

Table 3. Mean kVp, mAs, DAP and EI values per five selected body parts for Manufacturer 2 and Manufacturer 3 post implementation of optimised calibration technique.

Manufacturer 2							
	kVp	**mAs**	**DAP dGycm²**	**DRL (dGycm²)**	**EI**	**EI_T**	**DI Value**
Abdomen AP	75.27	18.71	11.72	25	236.53	312	-1
Chest PA	124.9	1.188	0.622	1	95.24	312	-5
Lateral Lumbar spine	85.186	33.94	15.16	25	199.98	312	-2
PelvisAP	75.33	20.87	27.5	22	358.27	312	+1
Knee AP	60.03	2.11	0.5242	none	198.71	312	-2
Manufacturer 3							
	kVp	**mAs**	**DAP dGycm²**	**DRL (dGycm²)**	**EI**	**EI_T**	**DI Value**
Abdomen AP	78.66	22.3	24.406	25	266.13	200	+1
Chest PA	125	1.077	1.056	1	52.28	200	-6
Lateral Lumbar spine	95	47.67	36.04	25	300.32	200	+2
PelvisAP	83.37	15.72	19.72	22	322.4	200	+2
Knee AP	67.93	2.04	0.629	none	371.22	200	+3

The second retake analysis identified retake rates of 7.98% and 10.12% on Manufacturer 2 and 3 respectively. Previously Manufacturer 2 was 6.2% whereas Manufacturer 3 was 12.1%. Again the number of images repeated due to inappropriate radiation exposure, were very low with 0.22% and 0.35% for Manufacturers 2 and 3 respectively.

Conclusion

The initial dose audit revealed exposures for pelvis and lateral lumbar spines were above the DRL in the hybrid systems. Image optimisation was implemented whereby the "10kVp rule" was employed. Pre-programmed automatic exposure control (AEC) exposures for pelvis and lateral lumbar spines on the hybrid units were altered by raising the kVp by 10 kVp and halving the mAs to achieve the required density, hence reducing the exposure to the patient.

The second dose audit performed after recalibration of EI values revealed exposures for pelvis examinations were above the DRL in Manufacturer 2. After manually reviewing the images, it was ascertained that the examinations were performed using the AEC. To account for these higher doses than expected it is possible that the patients were not fully positioned over the AEC, in addition the x-ray field sizes lacked sufficient collimation which may have impacted on the dose received. Further audit of exposures is ongoing in these x-ray rooms to investigate use of collimation and DAP's received.

Lateral lumbar spine exposure in the hybrid systems still exceeded the DRL, triggering an additional paper audit of lumbar spine exposures which is ongoing.

As a result of this investigation, all 8 DR rooms have EI now correctly calibrated and all EI_Ts are inputted into the organ programs, so in theory, radiographers should be able to use DI as an indicator of correct exposure.

Herrmann et al[7], believe errors during exposure field recognition can cause inaccurate DI readings, which vary among manufacturers.

Radiographers must be aware that EI is not a measure of radiation dose to the patient but a method of tracking a pre-determined satisfactory exposure to the detector [8].This would suggest that DI alone cannot be used by the radiographer to assess image quality but in conjunction with DAP in a correctly calibrated DR unit.

The current authors argue that it is important for radiographers to have a visual indicator that patients are correctly exposed, by checking the DAP against the DRL, in conjunction with the DI, this will avoid dose creep [9].

There are limitations to the IEC 62494-1 standard as the EI is calibrated in the factory at only one kVp value which is not reflective of clinical work.

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