Determination of Patient Dose from Exposure Index (EI) in Digital Imaging

Chung Cha Fu[1], Engku Nelly Lydia Binte Ishaq[1], Muzdalifah Binte Zainal[1], Ervin Tan[2], Cheryl Lian Pei Ling[1]

[1] Health and Social Sciences Cluster, Singapore Institute of Technology, Singapore
[2] Philips APAC Centre, Singapore

Introduction

The Exposure Index (EI) is an accepted metric in modern radiography practice that indicates digital detector response to incident radiation. The EI provides feedback to the radiographer on the exposure techniques applied. For example, an overexposed image will display an incorrect EI. In the spirit of ALARA dose management, it is of interest in our experimental study to determine the level of agreement between phantom doses acquired by applying both direct dose measurement methods and indirect dose measurement methods. Our direct dose measurement methods included the use of self-developing radiochromic film (RCF) XR-RV3 which was calibrated against a gold-standard reference dosimeter, the Unfors solid state detector. Indirect dose measurement involved recording the equipment dose-area-product (DAP) meter readout as well as using third party virtual radiography simulation software, TechnicVR v2.0 (Shaderware Ltd, UK).

Objectives

Our research question was : “Is EI a good estimate for patient dose?”
Specific objectives were:
1. To determine the level of agreement between measured entrance surface doses (ESD)
2. To investigate the effect of varying phantom thickness, collimation size and exposure factors on the ESD and EI

Methods and materials

RCF (XR-RV3) were first calibrated free-in-air to obtain control calibration curves for various photon energies. For data collection, a 20cm-thick adult pelvis anthropomorphic phantom was used. Incremental 5cm-thick animal fat slabs of similar composition to human adipose tissues were placed on the phantom to simulate patient thickness of 25cm, 30cm, and 35cm. The phantom was placed supine on the table couch with the detector in the Bucky tray with a non-removable grid. The phantom was centered and collimated following Merrill's Radiographic positioning guidelines. Images were acquired at 2 collimation sizes (32x40cm and 34x43cm) using exposure factors in Table 1. For each irradiation, one XR-RV3 film (5x5cm) was placed on the phantom at the center of the collimated field. Films were then scanned 48 hours after irradiation and the degree of darkening was measured. The degree of darkening was then input into the calibration curves to obtain the ESD absorbed by the films. The amount of ESD measured by film was then compared to ESD estimated from DAP readings as well as Technic VR simulation.

Figure 1: Experimental setup depicting the use of both direct and indirect dose measurement methods.

Tube Voltage	Time exposure product	Tube Voltage	Time exposure product	Tube Voltage	Time exposure product
60 kVp	20 mAs	80 kVp	20 mAs	100 kVp	20 mAs
60 kVp	40 mAs	80 kVp	40 mAs	100 kVp	40 mAs
60 kVp	60 mAs	80 kVp	60 mAs	100 kVp	60 mAs

Table 1: Exposure factors selected for the experiments (3 kVp x 3 mAs = 9 combinations of exposure factors).

Results

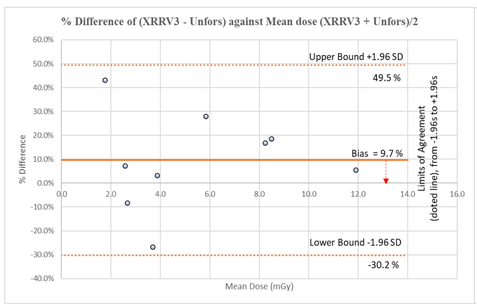


Figure 2: Bland-Altman plot between measured ESD using XR-RV3 versus solid state reference dosimeter.

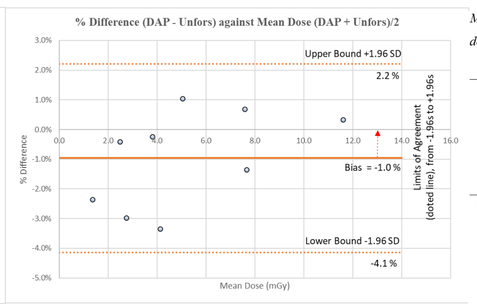


Figure 3: Bland-Altman plot between measured ESD using DAP versus solid state reference dosimeter.

Mean bias ± Standard Deviation and 95% Limits of Agreement (LOA) between each dosimtery against Reference (Unfors) measurement

	Mean Bias[a] (%)	Standard Deviation[b] (SD) (%)	Lower Bound of LOA[c] (Mean Bias - 1.96 SD) (%)	Upper Bound of LOA (Mean Bias +1.96 SD) (%)
Reference (Unfors)	N.A.	N.A.	N.A.	N.A.
XR-RV3	9.7%	20.3%	-30.2%	49.5%
DAP	-1.0%	1.6%	-4.1%	2.2%
TechnicVR	11.1%	2.7%	5.8%	16.4%

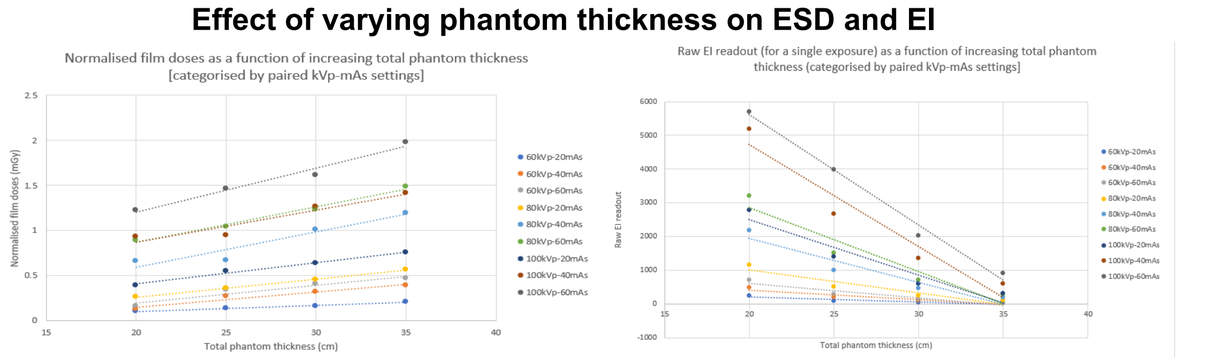
Note. The Unfors dosimeter is calibrated for use in medical facility in accordance with IAEA Code of Practice and Singapore NEA Standards of Practice.

Level of agreement between measured doses

There was good agreement between the Philips radiography unit DAP readout and the reference Unfors detector (within ± 5%). There was a poor agreement of –30% to 49% between the RCF (XR-RV3) versus the reference Unfors detector. The TechnicVR simulated doses agreed with the reference Unfors detector to within 20% limits. The different levels of agreement between detectors are due to:

- differences in the effective depth of measurement (i.e., detector construction differences)
- known energy response of film
- backscatter doses which the film measured but which were filtered out by the lead backing of the Unfors detector used

Effect of varying phantom thickness on ESD and EI



Normalised film doses = Total measured doses / # of exposures due to lower limit of detection for film

Figures 4 and 5 Effect of varying phantom thickness on ESD and EI.

From Figure 4, keeping kVp and mAs constant, dose increases with increasing phantom thickness. These observations were consistent across the nine exposure factors. Higher doses could be attributed by the increasing proximity to the x-ray tube source.

From Figure 5, keeping exposure factors constant, EI decreases with increasing phantom thickness. The decreasing trend was expected since less radiation reaches the detector as patient thickness increases, but the observation of a decreasing trend is only applicable for Philips X-ray EI.

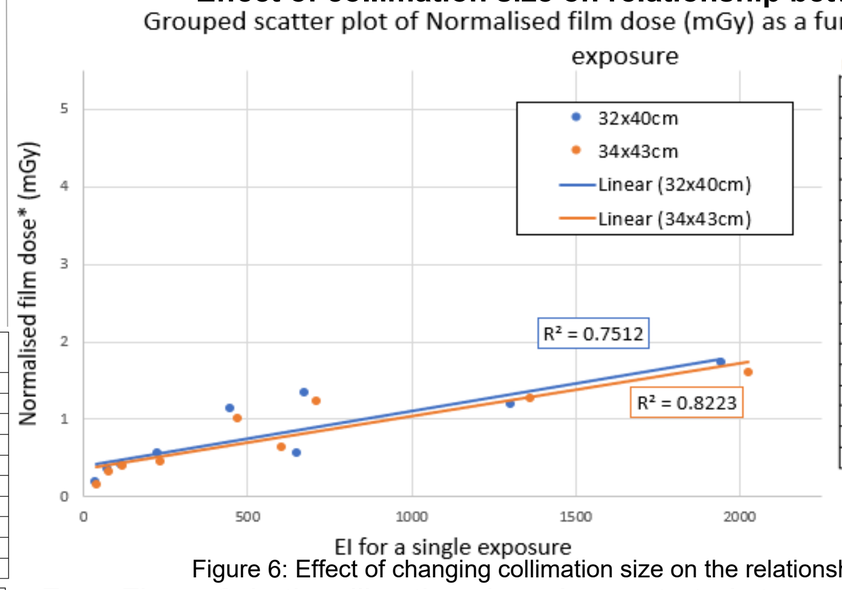
Exposure factors		Thickness 20cm	
kVp	mAs	Dose	EI
60	20	0.10	239
60	40	0.12	477
60	60	0.16	711
80	20	0.27	1157
80	40	0.67	2185
80	60	0.89	3198
100	20	0.39	2773
100	40	0.93	5200
100	60	1.22	5710

Exposure factors		Thickness 25cm	
kVp	mAs	Dose	EI
60	20	0.14	92
60	40	0.27	184
60	60	0.34	274
80	20	0.35	507
80	40	0.67	1008
80	60	1.04	1502
100	20	0.55	1398
100	40	0.95	2678
100	60	1.46	3983

Exposure factors		Thickness 30cm	
kVp	mAs	Dose	EI
60	20	0.16	39
60	40	0.32	79
60	60	0.40	119
80	20	0.46	237
80	40	1.01	472
80	60	1.24	709
100	20	0.64	603
100	40	1.27	1361
100	60	1.61	2026

Exposure factors		Thickness 35cm	
kVp	mAs	Dose	EI
60	20	0.21	15
60	40	0.39	30
60	60	0.47	45
80	20	0.56	98
80	40	1.20	196
80	60	1.48	295
100	20	0.76	298
100	40	1.41	599
100	60	1.98	898

Effect of collimation size on relationship between ESD and EI



For a patient thickness of 30cm,

kV	mAs	Collimation	EI	Dose
60	20	32x40	37	0.19
60	40	32x40	75	0.35
60	60	32x40	113	0.42
80	20	32x40	224	0.56
80	40	32x40	449	1.13
80	60	32x40	674	1.34
100	20	32x40	649	0.57
100	40	32x40	1300	1.19
100	60	32x40	1943	1.73
60	20	34x43	39	0.16
60	40	34x43	79	0.32
60	60	34x43	119	0.4
80	20	34x43	237	0.46
80	40	34x43	472	1.01
80	60	34x43	709	1.24
100	20	34x43	603	0.64
100	40	34x43	1361	1.27
100	60	34x43	2026	1.61

*Normalised film dose = total measured dose/ # of exposures due to lower limit of detection for film

Figure 6: Effect of changing collimation size on the relationship between ESD and EI

From Figure 6, both collimation sizes demonstrated strong relationships between EI and patient dose. As collimation size decreases from 34x43 (R^2=0.82) to 32x40 (R^2=0.75) EI is less able to explain the variations in average patient dose. A decrease in collimation size lowers the amount of radiation received by the detector, hence the EI varies. Further investigation should be done to determine whether even smaller collimation sizes can weaken the relationship between EI and patient dose to a point EI is no longer able to reliably explain patient dose.

Conclusions

We have found that EI correlates well to patient dose. Factors such as varying phantom thickness, exposure techniques and collimation size resulted in observable changes to measured EI and patient doses (ESD). However, where measured doses were concerned, known uncertainties such as the need to establish kilovoltage backscatter factors and to characterize film response to radiation quality needs to be performed before radiochromic film dosimetry can be implemented in clinical radiography practice.

Acknowledgment

We would like to express sincere thanks to Mr. Sheik Ismaildeen from Philips Singapore for his help and support in our use of the Digital Radiography and Computed Tomography facilities at Philips APAC Centre.

References

Davidson, R. (2020). Dose Creep in Digital Radiography. In *General Radiography*. https://doi.org/10.1201/9781003047278-4
Erenstein, H. G., Browne, D., Curtin, S., Dwyer, R. S., Higgins, R. N., Hommel, S. F., Menzinga, J., Pires Jorge, J. A., Sauty, M., de Vries, G., & England, A. (2020). The validity and reliability of the exposure index as a metric for estimating the radiation dose to the patient. *Radiography (London, England : 1995)*, *26 Suppl 2*, S94–S99. https://doi.org/10.1016/j.radi.2020.03.012
IAEA 2007 Dosimetry in diagnostic radiology: an international code of practise Technical Reports Series No.457 International Atomic Energy Agency
Long, B. W., Curtis, T., & Smith, B. J. (2016). *Merrill's atlas of radiographic positioning and procedures.* 13th ed. St. Louis, Mo.: Mosby
Shanahan M. C. (2017). A pilot study investigating two dose reduction techniques for AP lumbar spine radiography using direct dosimetry and Projection VR. *Radiography (London, England : 1995)*, *23*(3), 222–228. https://doi.org/10.1016/j.radi.2017.03.015