

An Approach for Online Determining the Entrance Surface Air Kerma (ESAK) in Digital Radiology

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Research Article

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An approach for online determining the entrance surface air kerma (ESAK) in digital radiology

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An online method is proposed to determine the entrance surface air kerma (ESAK) in digital radiology from console-displayed kerma area product (P_{KA}) data. ESAK values were calculated from X-ray tube outputs and patient exposure factors across five X-ray examinations. The corresponding P_{KA} values were taken from the Digital Imaging and Communications in Medicine (DICOM) header. Using linear regression between ESAK and values, the slope and intercept coefficients for each type of X-ray equipment and procedure were determined. The coefficient to determine ESAK from P_{KA} ranged from 59% for a posteroanterior chest to 88% for anteroposterior lumbar spine view X-ray procedures. The results demonstrated the possibility of online estimates of ESAK from a console that displayed using readily available digital information in radiology. The results may have important implications in interventional radiology, where ESAK values are crucial for preventing skin injuries due to prolonged fluoroscopy times.

Keywords: Digital radiology; kerma area product; Digital Imaging and Communications in Medicine (DICOM); patient dose.

1. Introduction

Radiation dosimetry is critical in radiology, as it can be used in the following scenarios: (1) for quality assurance purposes; (2) to establish and implement diagnostic reference levels; and (3) for departmental dose audits. The kerma area product (P_{KA}) and entrance surface air kerma (ESAK) are two crucial dosimetric quantities in diagnostic and interventional radiology [1,2]. ESAK is the air kerma measured on the X-ray beam axis at the point where the X-ray beam enters the patient or a phantom and includes the contribution of backscatter radiation. P_{KA} is the integral of the air kerma over the area of the X-ray beam in a plane perpendicular to the beam axis, which is a measure of the total radiation energy entering the patient [1,2]. Meters are available integrated into the radiographic unit or installed as add-on devices for P_{KA} measurements and is best suited for multiple projections, such as X-ray fluoroscopy and panoramic dental radiography.

Conversely, two approaches can be used to evaluate ESAK: using thermoluminescent dosimeters (TLD) applied to the patient's skin at the centre of the radiation field or exposure factor-based assessments using an ionizing chamber to measure X-ray tube outputs [3,4]. P_{KA} is a reasonable estimate of stochastic radiation risk. In contrast, ESAK in radiography and maximum skin dose in fluoroscopy (ESAK multiplied by the mass-energy absorption coefficient tissue-to-air) are more appropriate for estimating the likelihood of deterministic effects and tissue reactions as both are estimated at the localized position in the patient's skin [5].

Currently, digital radiography and fluoroscopy equipment are required to provide real-time dose information during radiological procedures. Several dose-optimization studies were

carried out using Digital Imaging and Communications in Medicine (DICOM) header information [6,7].

Previous studies were carried out and had correlated skin dose to *PKA* in showing a good correlation [8-10]. These studies concerned post-procedure dose assessments after obtaining information about X-ray exposure factors and other related information. A method that could be used to determine ESAK from currently available, real-time digital information obtained during radiological procedures will be precious to clinicians and medical physicists in hospital settings.

Herein, we aimed to provide an approach to estimate the patient skin dose in real-time using console-displayed *PKA* values available in digital radiology. The proposed approach could be significant in interventional radiology, where there is much need to provide trigger doses for deterministic effects and tissue reactions.

2. Materials and Methods

A method was proposed and experimentally illustrated using dose information and measurement across five direct digital radiography (DR) unit types (Philips/Dig.Diagnost). A summary of the X-ray tube information is presented in Table 1.

(Table 1)

DICOM information

The current experiment relies on the DICOM information available in digital radiography and fluoroscopy; experimental measurements were performed to illustrate the conceptual approach. Two sets of information were extracted from the DICOM headers for each of the five DR units:

- Patient exposure factors (tube voltage, tube current–exposure time product (mAs), and focus-to-skin (FSD) are used to estimate ESAK values.
- As DICOM information contains P_{KA} values per procedure, these values were

The data for adult patients aged ≥ 16 years with weights between 50–90 kg were included in the study.

2.2 Estimates of ESAK

First, the incident air kerma (K_i) (defined as the air kerma at the skin entrance at the centre of the field excluding the contribution from the backscattered radiation) was calculated from the measurements of the tube output and patient specific exposure factors collected during routine X-ray examinations [1,2]:

$$K_i = Y(kV, d). Q. \left(\frac{FDD}{FSD}\right)^2 \quad (1)$$

where $Y(kV, d)$ is the normalized tube output (mGy/mAs) measured at focus-to-detector distance (FDD) of 1 m using calibrated Xi Unfors digital dosimeter (Unfors Raysafe Inc., Billdal, Sweden). Q is the tube current–time product (mAs) and FSD is the focus to patient skin distance. Secondly, ESAK was estimated from the calculated K_i using the backscatter factors (BSF) that depends on the beam quality and field size [1,2].

$$ESAK = K_i. BSF \quad (2)$$

2.3 ESAK from the console-displayed P_{KA}

The correlation between P_{KA} and ESAK or patient skin dose is well established [8-10]. P_{KA} Can be obtained from the knowledge of K_i and the radiation field size (A) at the patients' skin as follows:

$$P_{KA} = K_i. A_{FID} \left(\frac{FSD}{FID}\right)^2 \quad (3)$$

Where A_{FID} is the radiation field size at the focus to detector or image receptor (FID).

From equations 2 & 3, ESAK can be determined from P_{KA} as follows [1,2]:

$$ESAK = \left(\frac{P_{KA}}{A_{FID}}\right) \cdot \left(\frac{FID}{FSD}\right)^2 \cdot BSF \quad (4)$$

Equation 4 shows a linear correlation between ESAK and the console-displayed P_{KA} in the form of the following standard equation:

$$ESAK = a + b \cdot P_{KA} \quad (5)$$

where a and b are the intercept and the slope coefficients, respectively that can be used to provide online estimates of ESAK values in radiography (or skin dose in fluoroscopy) from console displayed P_{KA} .

3. Results

Table 2 presents the radiographic exposure factors and P_{KA} extracted from the DICOM header, as well as the calculated ESAK values. The presented information is meant to provide an overview of the typical exposure factors at these hospitals.

(Table 2)

Figures 1–5 show the correlation between ESAK and P_{KA} for posteranterior (PA) chest, anteroposterior (AP) abdomen AP, pelvis AP, lumbar spine AP, and lateral (LAT) lumbar spine examinations, respectively. The linear regression equation and determination coefficients are also shown. The coefficients used to determine ESAK from P_{KA} from a linear fit are presented in Table 3. These coefficients suggest that ESAK determines 88% (in chest PA), 59% (in abdominal AP), 78% (in pelvic AP), 85% (in lumbar spine AP), and 83% (in lumbar spine LAT) of P_{KA} .

(Table 3)

Using equation 5 and the slope and the intercept coefficients given in Table 3, online

estimates. These coefficients differ because of differences in the ESAK and the field used for certain examinations; they also depend on equipment model and beam quality, the latter of which is defined by the added filtrations.

4. Discussions

Radiation dose quantities provide an essential link between the desires to obtain the best image quality at a minimum patient dose. The dose quantity P_{KA} is reasonable estimates for stochastic effect, whereas ESAK and skin doses are best suited for estimating deterministic effects [1-4]. The current study establishes a method for online determining the entrance surface air kerma (ESAK) from the console-displayed kerma area product (P_{KA}) in digital radiology. In the present study, a linear regression between ESAK console display P_{KA} values was deployed to determine slope and intercept determination coefficients (Table 3). Preferably these coefficients are to be determined separately for each equipment type during commissioning and annually as quality assurance, as the coefficients may change due to tube aging and other factors affecting equipment performance [11]. Previously, various authors have established a correlation between ESAK or patient skin dose via dose measurements on a patient or a phantom [8-10]. Kisielewicz et. al.[8], showed that ESD could be estimated from the measured DAP values at different field sizes with the uncertainty of 10%. Further study by Dickinson et al. in ref. [9] have established correlations between skin dose and (P_{KA}) values in interventional radiology providing conversion coefficients in a look-up table. The variations in the determination coefficients for estimating ESAK from could be ascribed to the inaccuracies in the kVp, radiation field size, and backscattered radiation [10].

The advantage of the current approach over the previous ones is that it estimates ESAK in radiography or skin dose in fluoroscopy in real-time during the X-ray procedure. This approach relies on the utilization of medical informatics, which is readily available thanks to digital radiology. The approach used in this work could hold greater importance in fluoroscopy-guided procedures, where there is a need to monitor skin doses to prevent deterministic effects.

This study has limitations: the experimental included only radiographic equipment, while fluoroscopy measurements could elucidate the estimate of skin dose from console displayed P_{KA} values are not studies.

Conclusions

A method was proposed and experimentally verified to provide real-time estimates of ESAK from console-displayed P_{KA} values in digital radiology. From the current results, the determination coefficient for ESAK from P_{KA} ranged from 59% (in abdominal AP) to 88% (in chest PA). These coefficients depend on equipment model and performance characteristics. The proposed approach may hold special importance in interventional radiology, where there is ample need to provide trigger doses for deterministic effects and tissue reactions. P_{KA} is the only console displayed dose quantity in digital radiography whereas in fluoroscopy, both P_{KA} and the CAK (the cumulative air kerma 15 cm back from the isocenter toward the focal spot) are displayed. For online estimates of maximum skin dose in fluoroscopy, it is recommended to establish the correlation between the skin dose and the CAK rather than P_{KA} to eliminate inaccuracies in field size involved in estimating P_{KA} .

Conflict of interest

The author has no conflict of interest to declare.

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References

1. IAEA, 2007. Dosimetry in diagnostic radiology: an international code of practice. International Atomic Energy Agency, *TRS No. 457*, Vienna, Austria.
2. ICRU, 2005. International Commission on Radiation Units and Measurements (ICRU). Patient dosimetry for X-rays used in medical imaging. *J. ICRU*, 5(2).
3. Radiation dose management for fluoroscopically guided interventional medical procedures. Report No. 168. National Council on Radiation Protection and Measurements, Bethesda, MD (2010).
4. International Electrotechnical Commission (IEC). Report 60601 Medical electrical equipment. Part 2 –43. Particular requirements for the safety of x-ray equipment for interventional procedures, second edn. (IEC, Geneva, Switzerland, 2010).
5. Ma CM, Coffey CW, DeWerd LA, Liu C, Nath R, Seltzer SM, Seuntjens JP. AAPM protocol for 40–300 kV x-ray beam dosimetry in radiotherapy and radiobiology. *Medical physics*. 2001 Jun;28(6):868-93.
6. Al-Jabri AJ, Alzimami K, Alsafi K, Alaamer AS, Al-Rajhi MA, Suliman II. Retrospective analysis of patient radiation doses in digital coronary angiography and interventions. *Radiat. Prot. Dosim.* 2019 Jun 1;183(4):497-502.

7. Suliman II. Estimates of patient radiation doses in digital radiography using DICOM information at a large teaching hospital in Oman. *Journal of digital imaging*. 2020 Feb;33(1):64-70.
8. McParland BJ. Entrance skin dose estimates derived from dose-area product measurements in interventional radiological procedures. *Brit. J. Radiol.* 1998 Dec;71(852):1288-95.
9. Kisielewicz K, Truskiewicz A, Wach S, Wasilewska–Radwańska M. Evaluation of dose area product vs. patient dose in diagnostic X-ray units. *Physica Medica*. 2011 Apr 1;27(2):117-20.
10. Dickinson RL, Zamora DA, Kanal KM, Stewart BK. Estimated skin dose look-up tables and their effect on dose awareness in the fluoroscopy-guided imaging suite. *American Journal of Roentgenology*. 2014 Sep;203(3):630-6.
11. Andria G, Attivissimo F, Guglielmi G, Lanzolla AM, Maiorana A, Mangiantini M. Towards patient dose optimization in digital radiography. *Measurement*. 2016 Feb 1;79:331-8.

Table 1. Equipment information, output, and HVL

Code	Make/Model	Modality	Output ($\mu\text{Gy}\cdot\text{mAs}^{-1}$) (70 kV; 1 m)	HVL (mm Al_{eq}) 70 kV
U01	Philips/Dig.Diagnost	Fixed/DR	36.1	2.7
U02	Philips/Dig.Diagnost	Fixed/DR	37.3	2.8
U03	Philips/Dig.Diagnost	Fixed/DR	16.7	2.8
U04	Philips/Dig.Diagnost	Fixed/DR	40.2	2.9
U05	Philips/Dig.Diagnost	Fixed/DR	14.6	2.9

Table 2. Radiographic exposure factors and P_{kA} extracted from the DICOM header, as well as the calculated ESAK values

Exam	Size	kV	mAs	FSD	ESAK	P_{kA}
Chest PA	76	150	1.56	150	0.18±0.07	0.09±0.08
Abdomen	64	84	13.1	80	0.96±0.90	0.96±0.64
Pelvic AP	34	77	16.6	80	1.4±1.4	1.18±1.1
Lumbar spine AP	87	77	30.5	80	2.76±2.70	1.16±1.06
Lumbar spine LAT	88	90	23.8	80	4.10±2.74	1.18±0.71

Table 3. The intercept and slope coefficients to determine ESAK (mGy) from P_{KA} ($Gy.cm^2$) from a linear fit

Exam	Projection	$a \pm \sigma$	$b \pm \sigma$	R^2
Chest	AP	0.023 ± 0.0073	0.18 ± 0.0077	0.88
Abdomen	AP	-0.075 ± 0.13	1.10 ± 0.11	0.59
Pelvis	AP	0.061 ± 0.17	1.10 ± 0.11	0.78
Lumbar spine	AP	0.050 ± 0.17	2.3 ± 0.11	0.83
Lumbar spine	LAT	-0.12 ± 0.24	3.5 ± 0.17	0.83

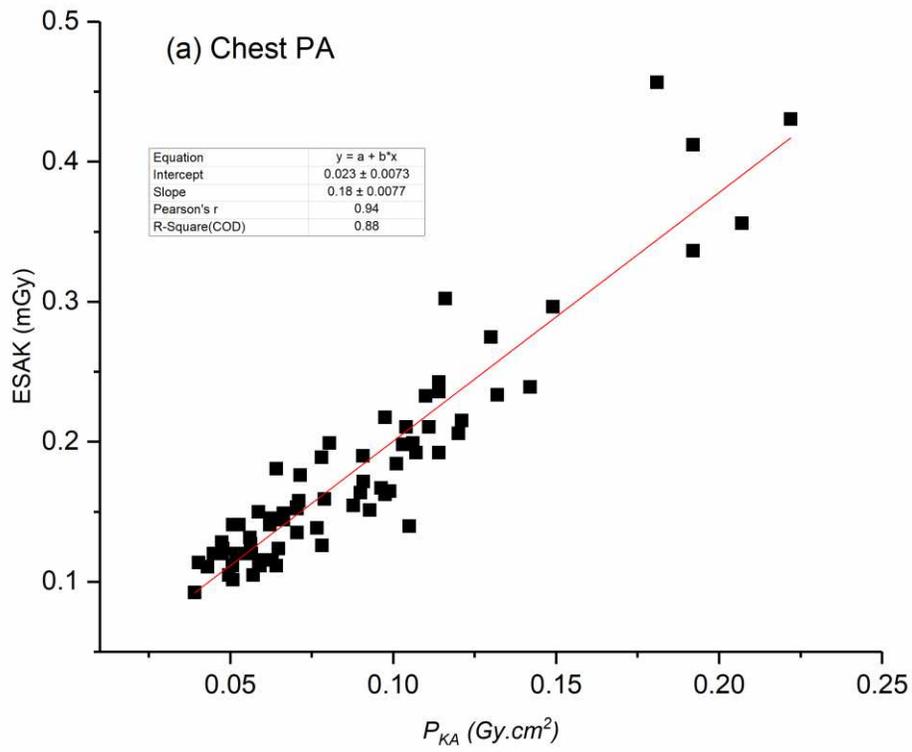


Figure 1. Linear regression of ESAK versus P_{KA} in chest PA.

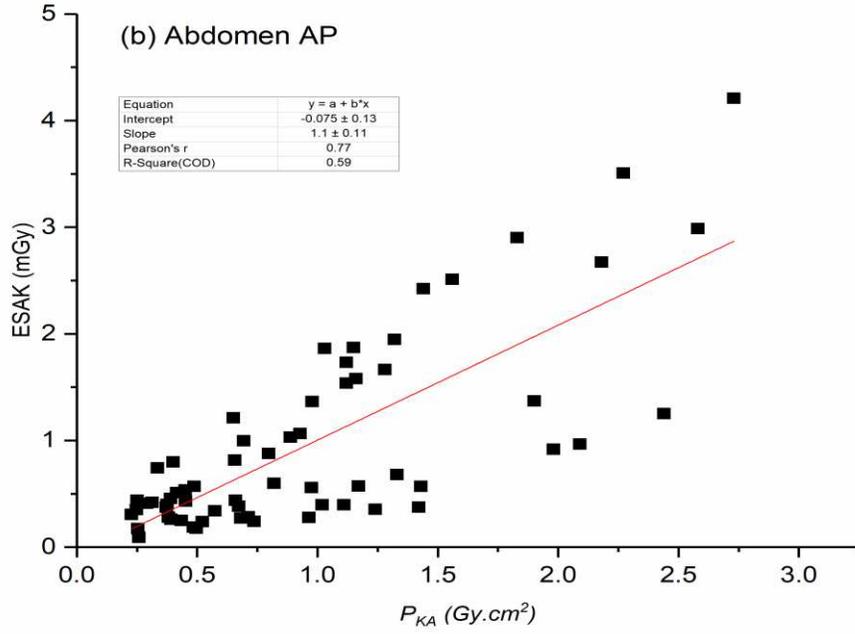


Figure 2. Linear regression of ESAK versus P_{KA} in abdominal AP.

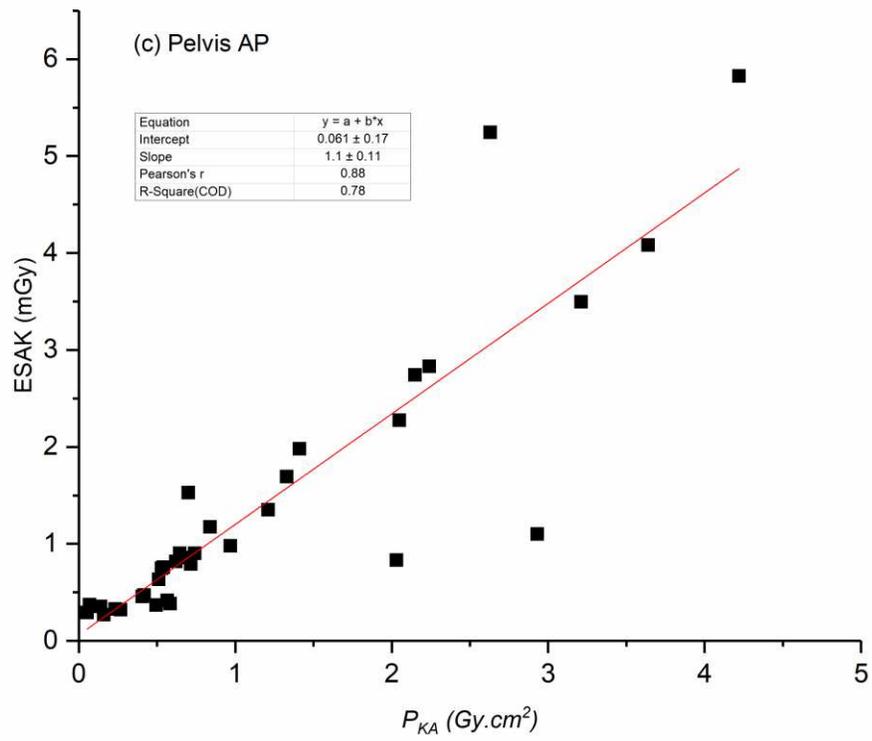


Figure 3. Linear regression of ESAK versus P_{KA} in pelvic AP.

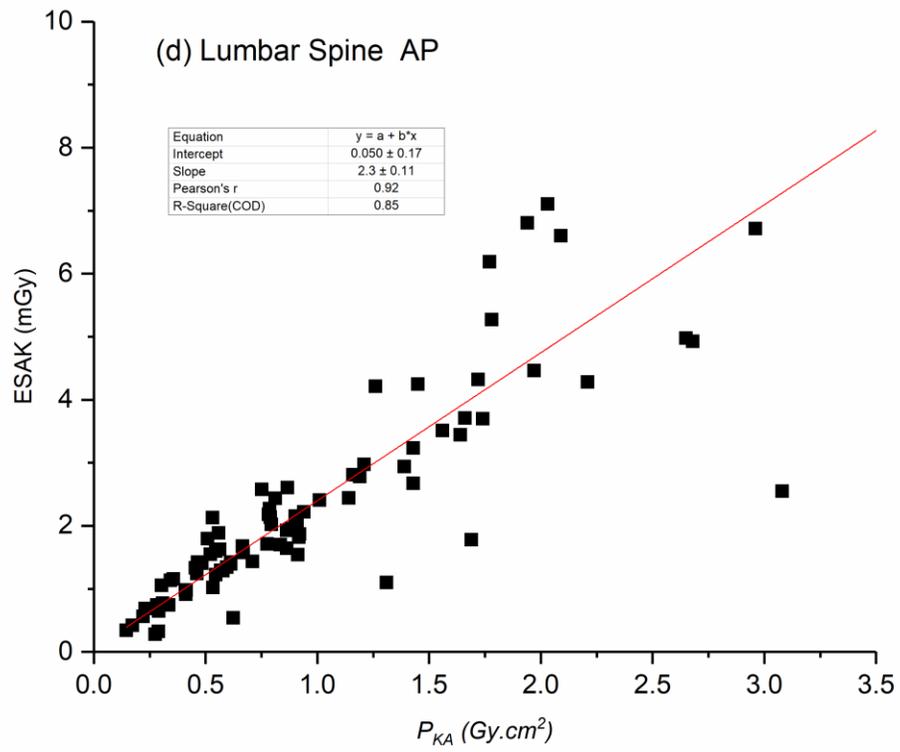


Figure 4. Linear regression of ESAK versus P_{KA} in lumbar spine AP.

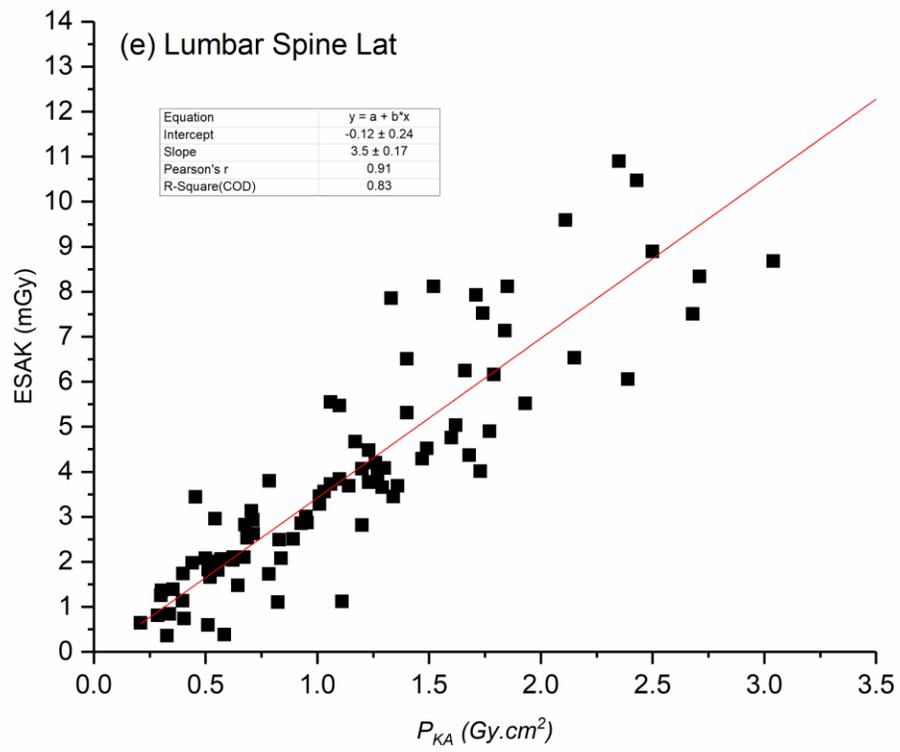


Figure 5. Linear regression of ESKA versus P_{KA} in lumbar spine LAT.