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Running title

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Verification of indicated skin entrance air kerma for cardiac x-ray guided intervention using Gafchromic film

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The aim of this work was to verify the indicated maximum entrance surface air kerma, ESAK using a GE Innova IGS 520 during cardiac interventional procedures.

Gafchromic XR RV3 films were used for the patient measurements to monitor the maximum ESAK. The films were scanned and calibrated to measure maximum ESAK. Thermoluminescent dosemeters were used to measure the backscatter factor from an anthropomorphic thorax phantom.

The measured backscatter factor, 1.53, was in good agreement with Monte Carlo simulations but higher than the one used by the imaging system, 1.20. The median of the ratio between indicated maximum ESAK and measured maximum ESAK was 0.68.

In this work the indicated maximum ESAK by the imaging system's dose map model underestimates the measured maximum ESAK by 32%. The threshold ESAK for follow-up procedures for patient with skin dose in excess of 2 Gy will be reduced to 1.4 Gy.

INTRODUCTION

Interventional radiology procedures can involve high local skin doses which above approximately 2 Gy can cause early transient erythema that may occur shortly after irradiation[1]. Until recently, imaging systems were not able to show where on the patient's skin the maximum dose was located. They were only able to provide information on the accumulated air kerma without backscatter at the interventional reference point (IRP), defined as 150 mm below the isocenter point, towards the x-ray focus[2], or air kerma area product (P_{KA}), without spatial information. Today some modern interventional x-ray systems do indicate the point of maximum exposure. These systems will keep track of the different projections used during the x-ray guided procedure in order to estimate the spatial distribution of entrance surface air kerma, (ESAK). However, the indicated maximum ESAK at the patient's skin may underestimate the true ESAK if the contribution of backscattered radiation from the patient's body to the skin is neglected. This backscatter contribution may be as much as 48 %[3,4] of the maximum ESAK.

The Innova IGS 520 (General Electric Health Care) has a dose map function indicating the maximum ESAK corrected for backscatter and variation in distance from the IRP to the patient's skin. This system uses a mathematical model of the patient to further correct for variations in distance due to the patient contour. Bordier et al[5] claims that the accuracy in indicated maximum ESAK is within 25% verified with phantom measurements. A suitable method to estimate ESAK is to use Gafchromic film placed in direct contact with the patient's body during the interventional procedure, sampling all exposures [6,7,8]. However, this method is complicated and time consuming and cannot be used on a regular basis.

The aim of this work was to compare the maximum ESAK as indicated by the GE Innova IGS 520 with the measured maximum ESAK using Gafchromic film during cardiac interventional

procedures to find out if it is possible to use the indicated maximum ESAK directly or with a correction factor.

METHODS

Air kerma measurements

Gafchromic XR RV3 films (ISP Technologies Inc., Wayne, USA) were used to measure a limited number of 20 patients who underwent a cardiac fluoroscopic intervention (13 coronary angiographies, 7 percutaneous coronary interventions) to monitor the maximum ESAK during the procedures. A 35x43 cm^2 film sheet was placed on the mattress, just beneath the patient's back, with the orange emulsion side facing the x-ray tube below the table. The film remained in this position during the whole procedure. The films were then scanned in a flatbed scanner (EPSON Perfection V600 Photo) in professional mode with all corrections disabled. 48 bit color and 300 dpi was used. The scanned image was separated into its three color components. The red component's maximum signal was determined manually by placing a region of interest (ROI) in the image and using the software ImageJ (National Institutes of Health) to calculate statistical information within the ROI. Data on the total accumulated air kerma at the reference point and the maximum ESAK from the x-ray system was obtained from the dose map report stored in the Picture Archiving and Communication System (PACS) for each patient. The total accumulated air kerma was given numerically, but the maximum ESAK was indicated graphically by a schematic dose map of the patient's posterior side (see figure 3). A bar chart indicated the maximum value of the dose map. The air kerma area product (KAP) was also registered for each procedure. A correction factor of 1.1 was obtained by comparison with a Patient Dose Calibrator (PDC) KAP meter (Radcal,

Monrovia, CA, USA), positioned close to the isocenter and calibrated at a secondary standards laboratory at the Swedish Radiation Safety Authority.

Film calibration

The Gafchromic XR RV3 films were calibrated to air kerma at the level of the film by irradiating 7 pieces of film to air kerma in the range 0-2 Gy. The radiation source was an x-ray tube operated at 80 kV, with 3 mm Al total filtration. The air kerma was simultaneously measured with a T20 Piranha air kerma probe (RTI Electronics AB, Mölndal, Sweden). A correction factor of 0.94 was applied for differences in air kerma due to the heel effect as the T20 probe was not positioned on the central beam axis. A fourth-order polynomial fit between the red component pixel values from the seven scanned calibration films and air kerma at the films were computed using Microsoft Excel (figure 1). This calibration curve was subsequently used to estimate the maximum ESAK for 20 studied patients. The expanded uncertainty of the T20 probe was 2.3% (k=2) according to the calibration document.

Figure 1. Film calibration curve

The reproducibility of the flatbed scanner was tested by scanning the calibration films ten times and comparing the resulting red component signal. The homogeneity of the response of the scanner was also tested by scanning one film at nine different positions on the flatbed scanner area.

Estimation of backscatter

An anthropomorphic thorax phantom (Multipurpose Chest phantom N1 "Lungman", Kyoto Kagaku Co, Japan) was used to measure the contribution of backscatter from the body to the patient's skin. Thermoluminescent (TL) dosemeters (LiB, $H_p(0,07)$), was chosen to measure the backscatter factor since it is an independent dosemetric system. A Rados RE2000 TLD reader (Rados technology, Finland) and an Alnor Dosacus TLD irradiator were used to calibrate the individual TLD tablets. These were calibrated to measure personal dose equivalent $H_p(0.07)$ using the radiation quality N-100 and were traceable to secondary standard laboratory at National Radiation Safety Authority in Stockholm, Sweden. The estimated total uncertainty in the $H_p(0.07)$ was ±20% (95% confidence level).

In the first step, two sets of TLDs, each set containing four dosemeters, were placed on the patient table mattress, without the thorax phantom in position, to measure the dose without backscatter from the thorax phantom. The procedure was repeated with the thorax phantom in position. The table height was adjusted so that the top side of the table was at the IRP, 150 mm below the isocenter. The air kerma at the IRP was verified by measuring with the T20 probe on the table top, without the mattress, before exposing the TL dosemeters.

RESULTS

Film calibration

The indicated accumulated air kerma at the IRP agreed with the measured air kerma above the table at this point to within 1%, i.e. well within the accuracy of the dosemeter. Two relative standard deviations in the signal from ten repeated scans of the seven calibration films from the flatbed scanner ranged from 0.21-0.41% at 0-2 Gy, which corresponds to an uncertainty of

2.7% and 1.7% in air kerma at 0.2 Gy and 2.0 Gy, respectively, due to the shape of the calibration curve (figure 1). The fourth-order polynomial fit introduces an uncertainty in measured air kerma of 2.4% (on average) and a maximum of 7.4% at low air kerma. The variation in signal of the flatbed scanner at different positions was 1.7% (2 standard deviations), which corresponds to an uncertainty in air kerma of 7% at 2 Gy.

Measured maximum air kerma and backscatter

The median KAP was 34 $Gy.cm^2$ with a range of 6-179 $Gy.cm^2$. The median ratio of measured maximum ESAK (estimated with the Gafchromic films) and total KAP was 8.0±5.0 $mGy/Gy.cm^2$ with a range 2.8-18.7 $mGy/Gy.cm^2$. The median ratio of indicated maximum ESAK and measured maximum ESAK was 0.68±0.35 Gy/Gy with a range of 0.47-1.76 Gy/Gy. The uncertainty in reading the indicated maximum ESAK from the dose map graphical scale was 0.26% (2 standard deviations). Figure 2 shows the measured maximum ESAK as function of indicated maximum ESAK.

Figure 2

The action dose level in terms of indicated maximum ESAK for selecting patients for follow-up regarding potential skin injury was set to 1.4 Gy. This measurement suggests that the maximum ESAK is approximately 1.5 times higher than the indicated maximum ESAK in the dose report from the imaging system.

Figure 3

Figure 3 shows a graphical, qualitative comparison between the geometrical dose distributions calculated by the equipment and measured air kerma distribution based on a scanned Gafchromic film.

The backscatter factor in this work was 1.53 which is in agreement with backscatter factors calculated using Monte Carlo simulations[3,4]. However, calculating backscatter according to the geometry used in this work by using the formula given by Bordier *et al.*[5] results in a backscatter factor of 1.20.

DISCUSSION

The use of Gafchromic films to estimate the maximum ESAK is recommended[9] and reasonably practicable in a small sample population such as in this study, where the purpose was to compare indicated and measured maximum ESAK values. Some modern x-ray imaging systems (such as the one used in this work) computes the maximum ESAK from x-ray tube output settings, added filtration, collimation and angle of projection, and compile the data in a graphical map of air kerma at the entrance surface of the patient's body. This representation assumes the patient is placed in a predefined, standard position on the table or that the operator measures the actual position of the patient on the table and inserts this information into the system. Quality control measurements of ESAK with film are still needed since the models used to correct for backscatter from the patient's body and tube output variations due to variations in the height of the table, are still under development and can give quite large uncertainties[5].

In this work the film did not follow the patient contour exactly. For practical reasons the film was not attached to the patient's sides resulting in a distance between film and patient skin on the sides. On the other hand the maximum air kerma on the film was in most cases positioned in the central part of the film where the film was in direct contact with the patient's skin.

No corrections for energy dependence of the film have been applied in this work.

The backscatter factor of 1.53 in this work is in agreement with previous works[3,4] estimating backscatter factors using Monte Carlo methods.

The median KAP from this study is within 10% of the average value of the last annual median value and approximately 50% of the Swedish diagnostic reference level for coronary angiography. Based on the measured ratio between maximum ESAK and KAP in this work $(8.0\pm5.0$ mGy/Gy.cm^2), the KAP needs to be higher than 250 Gy.cm^2 to exceed ESAK of 2 Gy. This KAP is two times higher than the 95% percentile value from the patient dose data record accumulated in the treatment room of the year previous to this study. In this respect patients with transient skin erythema are unlikely to be encountered, but indeed one patient from this small sample exceeded a measured maximum ESAK of 2 Gy. In addition, the percutaneous coronary intervention part of the procedure is more likely to use a smaller number of beam directions compared with coronary angiography. This therefore decreases the difference between the maximum and total indicated ESAK, since more beam directions will spread out the air kerma over a larger area. Furthermore, collimating the x-ray beam will typically decrease the KAP, but with a small influence on ESAK. The large range of the ratio of ESAK to KAP found in this work indicates that the KAP may not be a reliable predictor of maximum skin dose and that the indicated maximum ESAK is better, since it shows a smaller variation in individual patient measurements. Hence the model implemented by Bordier et al[5] on the GE Innova 520 system is a welcome step towards a more accurate estimation of patient skin dose.

We have refrained from using skin dose as dosimetric quantity, but instead used the entrance surface air kerma, ESAK. The two are related by the ratio of the mass energy absorption coefficients for skin and air $(\mu_{en}/\rho)_{air}^{skin}$. With an average tube voltage of 87 kV (HVL=6.1 mm Al, average photon energy 54.4 keV) for patients in the clinic of the present study, this

results in an average $(\mu_{en}/\rho)_{air}^{skin}$=0.99 and hence the skin dose takes approximately the same numerical value as ESAK.

CONCLUSIONS

The measurements in the present study suggest that the indicated maximum ESAK underestimates the ESAK by on average 32%. Hence, an indicated maximum ESAK of 1.4 Gy will be used to identify patients with estimated skin dose in excess of 2 Gy for which temporary erythema may occur.

ACKNOWLEDGEMENTS

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FIGURE LEGENDS

Figure 1. Calibration curve of the red component of the Gafchromic film signal from the Epson flatbed scanner versus the air kerma measured using the T20 probe.

Figure 2. Measured maximum ESAK as a function of indicated maximum ESAK. The correlation coefficient $r^2 = 0.97$ and the slope of fitted curve through origin is 1.79.

Figure 3 Graphical, qualitative comparison of the spatial air kerma distribution generated by the imaging system (left) and that measured by a Gafchromic film (right). The film image is cut to show only the most irradiated regions of the patient's back which had the highest estimated ESAK from this study. Please note that the greyscale on the film image is inverted to match the imaging system's dose map grayscale representation. According to Bordier *et al.*[5] the accuracy in the indicated maximum ESAK is within 25%.
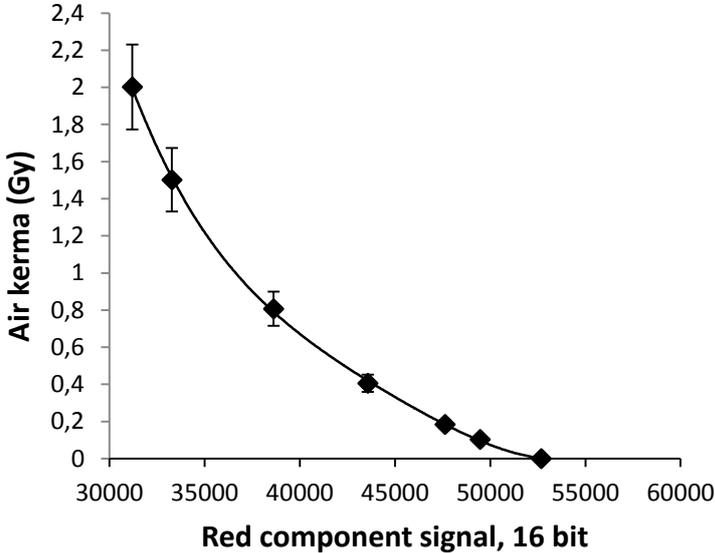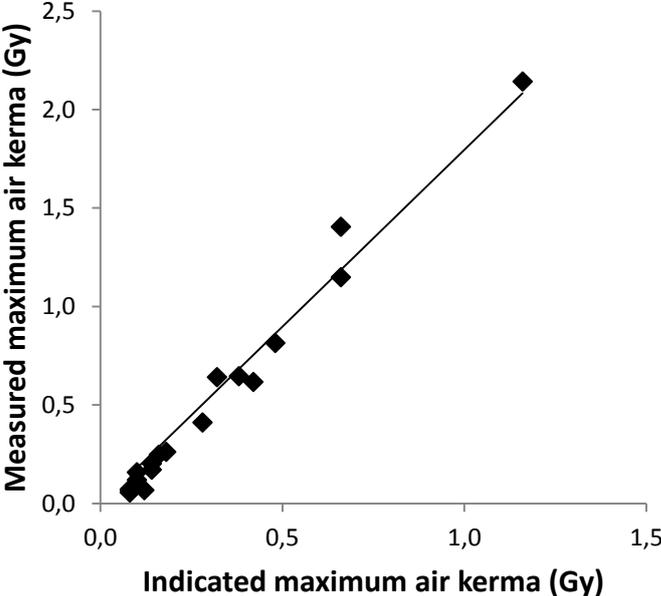
Figure 1

Figure 2

Figure 3