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EDR2 Film for Skin Dose Measurement in Coronary Angiography

(Pengukuran Dos Kulit dalam Koronari Angiografi Menggunakan Filem EDR2)

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ABSTRACT

Patient skin dose measurements were performed at the cardiology department in a hospital in Penang, Malaysia using EDR films during coronary angiography (CA) procedures. The EDR2 film was first characterized in terms of dose and energy dependence as well reproducibility. For patient dose measurements, the films were placed on the table underneath the patient for an under couch tube position. A total of 27 CA procedures were studied. Results for peak skin doses (PSD) ranged from 35 to 684 mGy while the dose area product (DAP) values were from 5.5 to 93.1 Gy cm^2. DAP correlated reasonably with PSD for CA procedure (R^2= 0.8212). The highest PSD value in this study is below the threshold dose value of 2 Gy for early transient skin injury recommended by the Food and Drug Administration (FDA 1994).

Keywords: Dose area product; EDR2 Film; interventional cardiology; peak skin dose

ABSTRAK

Pengukuran sinaran dos pesakit telah dijalankan di bahagian kardiologi, sebuah hospital di Pulau Pinang, Malaysia dengan menggunakan filem EDR2 semasa menjalankan prosedur koronari angiografi (CA). Pencirian filem EDR2 pada mulanya dilakukan dalam sebutan kebergantungan dos dan tenaga dan juga keupayaan kebolehpenghasilan semula. Untuk mengukur dos pesakit, filem EDR2 diletakkan di atas meja dan di bawah badan pesakit dengan tiub X-ray yang terletak di bawah meja. Sebanyak 27 prosedur CA dikaji. Keputusan nilai puncak dos kulit (PSD) adalah dalam julat 35 – 684 mGy, sementara pendaraban dos dengan luas (DAP) pula adalah dalam julat 5.5 – 93.1 Gy cm^2. DAP berkorelasi secara wajar dengan PSD dalam prosedur CA (R^2 = 0.8212). Nilai PSD maxima di dalam penyelidikan ini adalah di bawah nilai ambang dos 2 Gy untuk kecederaan kulit yang dicadangkan oleh Pentadbiran Makanan dan Ubat-ubatan (FDA 1994).

Kata kunci: Filem EDR2; intervensi kardiologi; pendaraban dos dengan luas; puncak dos kulit

INTRODUCTION

Interventional coronary angiography (CA) procedure is the first step in the diagnosis of cardiovascular disease. Here a patient is injected with a contrast media through a catheter and the blood vessels in the anatomical region of the heart are then highlighted on a sequence of radio graphical images to detect the narrowing of coronary arteries (Morrish et al. 2008). CA procedures are known to give high radiation doses to patients as the procedures involve long fluoroscopy times and several cine runs. This is of concern as the number of angiographic studies has increased dramatically in Malaysia (Ng et al. 1999; Sapiin et al. 2004). The extensive use of X-rays in this technique results in an increase risk of deterministic effects.

To determine the radiation exposure to a patient, some dosimetric techniques have been investigated by previous authors (Balter et al. 2006; Betsou et al. 1998; Canne et al. 2006; Delichas et al. 2005; Dogan et al. 2008; Fletcer et al. 2002). Research on patient dose evaluations in interventional cardiology mainly focuses on the measurement or the estimation of two basic parameters. They are dose area product (DAP) and the peak skin dose (PSD) over the most irradiated patient area. DAP is the most convenient method for the indirect measurement of patient dose especially for dynamic procedures such as interventional procedures where the X-ray irradiation area to the patient and projection direction of the X-ray beam are continuously varying. DAP is also convenient for estimating stochastic risk for patient (Le-Heron et al. 1992; McParland et al. 1998). However, DAP cannot be used to evaluate deterministic risk because DAP cannot provide information about the most irradiated area in the patient skin. Therefore, direct measure of patient entrance skin doses such as PSD is necessary to evaluate the deterministic effect.

Many types of slow radiographic films have been introduced to directly mapping patient skin doses to determine the probability of a possible injury. Slow films such as Kodak X Omat V and EDR2 (extended dose range) have been successfully used to measure patient skin dose (Guibelalde et al. 2003; Morrell et al. 2006; Vano et al. 1997). Silver halide films are sensitive to room light and require wet chemical processing and also cannot give online information. However these films are cheaper than gafchromic film which requires no chemical processing and relatively insensitive to room light. EDR2 film unlike Kodak X Omat film with has a wider dose range and is good to estimate skin dose distributions in coronary angiography

(CA), where the peak skin dose is normally below 1Gy. Guibelalde et al. (2003) successfully used it to measure peak skin dose up to 1400 mGy for patients undergoing CA and percutaneous transluminal coronary angioplasty (PTCA) procedures.

Because there is a limited patient dose data during CA procedures in Malaysia, the main purpose of this study was to determine patient skin dose using Kodak EDR2 films. The performance of the film was first characterized in terms of dose, energy dependence and reproducibility. Patient dose measurements were then performed at a local private hospital in Penang. It is also quite common for the patients to decide on PTCA at a later date due to cost. It is then necessary to assess and record the dose during the CA.

Materials and Methods

Characterization of EDR2 Film

Kodak EDR2 film (Eastman Kodak, Rochester, New York) is a low sensitive film and is available in 25.4 cm × 30.5 cm sheets. It belongs to the line of Kodak Ready-Pack products. Kodak EDR2 films are pre-wrapped in light proof paper and are ready to use with an exposure range from 25 cGy to 1000 cGy. The film is sufficiently large to cover most of the radiation fields in CA procedures. The film is relatively insensitive to the X-ray energies normally used in radiotherapy.

Exact dose responses of EDR2 are a function of facility dependent factors such as processing conditions (processing time, processing temperature, processing equipment, processing chemistry), the density sampling (digitizer equipment and calibration) and exposure monitoring equipment. For characterization of film, the large film was cut into 6 pieces; each piece was sealed in the original light-tight envelopes in the darkroom.

As in all films it was first necessary to characterize the EDR2 film for dose, energy and dose rate dependence as well as reproducibility. The dose-response of EDR2 film could change from film to film as it is strongly influenced by processing conditions. Thus, the EDR2 for dose-response calibration curve needs to be determined and verified simultaneously with the EDR2 used for patient dosimetry to obtain reliable reading.

Since many lot of interventional procedures were performed daily in the cardiac laboratory, it was not easily available to calibrate EDR2 film using the Philips Integris HM3000 interventional unit. To avoid interruption of the cardiac laboratory operation, the EDR2 film calibration was performed using the Toshiba X-ray Radiography system model KXO-15R at the Medical Physics department in Universiti Sains Malaysia (USM) instead of at the local hospital. Therefore, to ensure that the interventional unit and X-ray radiography system gave the same dose-response calibration curve, the EDR2 film was calibrated with both the X-ray systems.

In the Toshiba X-Ray Radiography system, EDR2 films were positioned on top of a 30 cm × 30 cm with a 10 cm thick Perspex phantom to provide sufficient backscatter. The backscatter was found not to change after 8 cm thickness. The films were positioned close to the X-ray tube with source to detector distance (SDD) 33cm, along the central axis. At this closest distance, the radiation dose given to the film was sufficiently high as those given in CA procedures. The film could be irradiated at only one distance. Hence the dose rate could not be studied on the X-ray system.

A 1cc flat ionization chamber type 77337 (PTW, Freiburg) was positioned behind the EDR2 films, in the center area and used to measure air kerma delivered to EDR2 films. According to the manufacturer's guideline, the ion chamber which was connected to the PTW UNIDOS electrometer has a total uncertainty of ±5 %.

In this X-ray system, the energy dependence of EDR2 film from was evaluated from 60 kVp to 120 kVp (the half value layer, HVL, was between 2.0 mmAl and 3.8 mmAl) which are typical kVp values used in the clinical interventional procedures. A series of known doses in the range of about 150 mGy to 850 mGy were given at these X-ray energies. To study the reproducibility, the EDR2 films were irradiated on 3 different days at energy range from 60 to 120 kVp. The development of EDR2 films was also carried out on 3 different days.

In the Philips Integris HM3000 Interventional unit which has an undercouch system, the EDR2 films were positioned below a 30 cm × 30 cm and a 10 cm thick Perspex phantom. The ionization chamber was positioned on top of the film in the center area. The Perspex phantom has a holder to accommodate the ion chamber. To maximize the dose rate and to reduce the time of irradiation of films, the films were placed as close as possible to the source to detector distance (SDD) of 52 cm. The calibration between Toshiba X-ray Radiography System and Interventional Unit using EDR2 film were evaluated at radiation doses between 10 to 600 mGy with a 10 cm × 10 cm field size. The selected X-ray energy was 80 kVp. For the interventional unit, the HVL at 90 kVp is 3.8 mmAl.

The irradiated EDR2 films irradiated with the Toshiba X-ray system and Interventional unit were developed under the same processing condition using the Konica Minolta automatic medical film processor. All films were stored in a light tight box and developed 24 h after exposure to allow the response of the film to stabilise. The optical density was measured with a X-rite 301 densitometer which had a reproducibility of ± 1%.

The dose (D) was calculated from the optical density (OD) using the equation suggested by Morrell and Rogers (2004) which is shown below:

$$D = -\frac{1}{\alpha}\ln\left(\frac{OD_{max} - OD}{OD_{max} - OD_{min}}\right) \quad (1)$$

where OD is the optical density due to x-ray exposure, OD_{max} is the saturation density of the film, OD_{min} is the base-plus-

fog and D is the dose and α is a constant obtained from the gradient.

Patient radiation dose was obtained from the straight line graph using (1). The high dose in the saturation region can be more easily read from this plot. The sensitometric curve was obtained using calibrated films each time the CA films were developed.

PATIENT DOSE MEASUREMENTS

Patient dose measurements were carried out at the cardiology department at a local private hospital in Penang. The catheterization laboratory in the cardiology department has a Philips Integris HM 3000 Interventional Unit (Philips Medical System, Best, The Netherlands) equipped with a DAP meter and an image intensifier and the system operates at a pulsed fluoroscopy of 12.5 film per second. The unit had lead curtains below to protect the cardiologists' legs and a ceiling suspended screen to protect the head from scattered radiation. The patient selection was random. The peak skin doses of 27 patients who underwent coronary angiogram (CA) were measured.

Relevant data such as DAP value, fluoroscopy time, type of procedure, patient gender, weight and age were recorded for each procedure. The X-ray unit had passed quality control (QC) evaluation. Pulsed fluoroscopy at 12.5 frames per second (12.5f/s) was used.

EDR2 films were placed on the table underneath the patient for the under table tube position and centered as close as possible to the most irradiated area of the patient. The films were processed with the Konica Minolta SRX 101A automatic processor and the optical density was read. The peak skin dose was obtained from the film dose-response calibration curve.

RESULTS AND DISCUSSION

CHARACTERIZATION OF EDR2 FILM

In clinical practice, the dose rates and X-ray energies of the interventional unit vary during CA procedures. It is then important to determine the response of the EDR2 film irradiated under different X-ray energies and dose rates. The results obtained from EDR2 films irradiated at different X-ray energies are shown in Figure 1.

For the different energies from 60 to 120 kVp and dose range from 150 mGy to 850 mGy, shown in Figure 1, the dose response of the EDR2 film in terms of optical density fitted well to the polynomial line with a regression coefficient of $R^2 = 0.9906$. The response of the film is dose dependent but energy independent. Thus one calibration curve can be used to analyze peak skin doses for different patients where different beam qualities are used.

The data from the EDR2 film irradiated and developed on 3 different days was plotted and is shown in Figure 2. Dose range from 10 to 950 mGy was delivered to the EDR2 films. The quadratic lines for 3 different calibration days were different. The high variation in the film response was mainly due to changes in processing conditions and in inter-film emulsion differences (Khan 2003). Thus, it is important to calibrate and obtain the dose-response calibration curve of the EDR2 when CA films are developed.

The dose-response of EDR2 film was studied using the Toshiba X-ray radiography system and the Interventional Unit. The range of doses 10 to 650 mGy was delivered at 80 kVp for both systems. Although the kVp was the same but the HVL was different for the two systems. The source to film distance also differed hence the dose- rates were

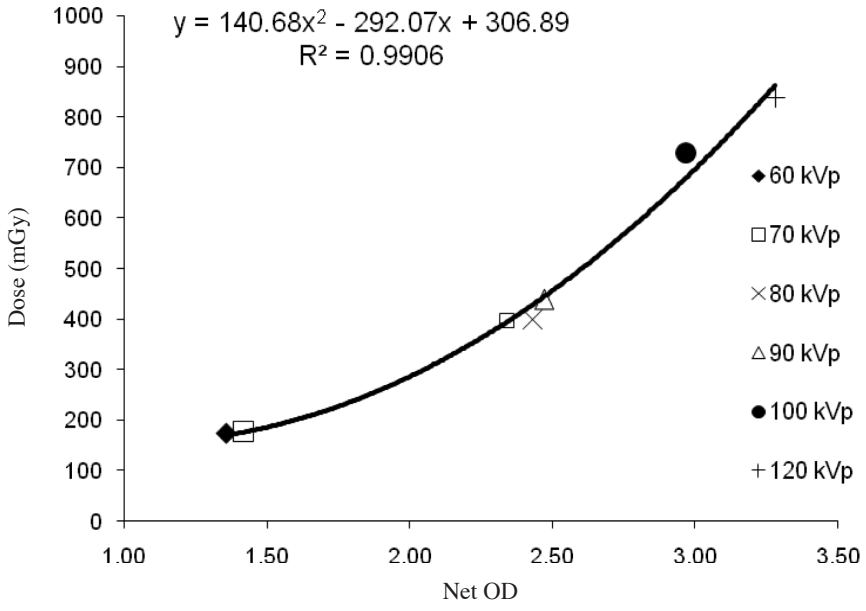

FIGURE 1. EDR2 film dose response to different X-ray energies

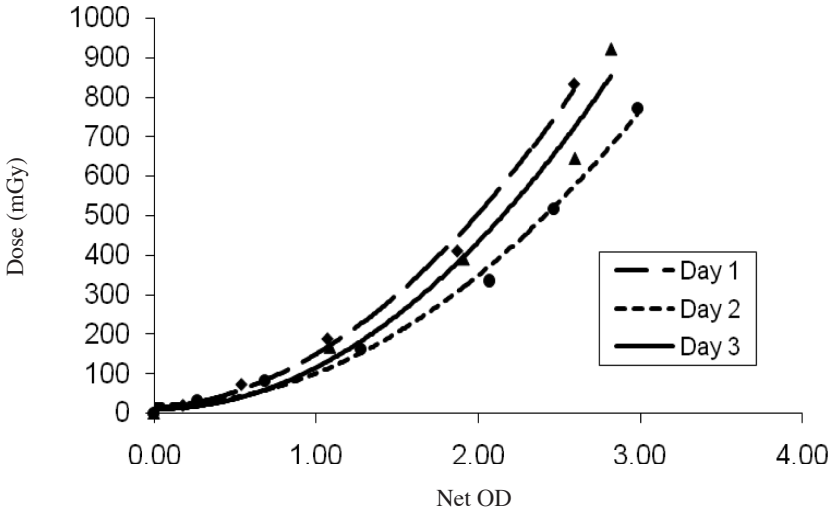

FIGURE 2. Dose-response calibration curve for 3 different days

not similar. The dose response of the two systems as net optical density (OD) against dose as well as the plot of $-\ln\left(\frac{OD_{max}-OD}{OD_{max}-OD_{min}}\right)$ against dose is shown in Figure 3(a) and Figure 3(b). Optical density against dose for the two different X-ray equipments fitted a quadratic line with a good regression coefficient of 0.9975. A straight line was fitted passing through the origin with $R^2 = 0.9894$ when using the equation 1. However estimating the dose above 500mGy using either the quadratic equation or the linear equation gave a variation of 15 to 25%.

Hence the dose-response calibration curve of the Toshiba X-ray radiography system can be used to obtain patient entrance skin dose from the Philips Interventional unit. In addition, the film was dose rate independent as the dose rates of the two X-ray machines were different.

PATIENT DOSE MEASUREMENTS

Patients' data obtained in CA procedures is shown in Table 1. In the CA procedures, the following values were obtained for the different parameters: cine frame, 305 – 1006; fluoroscopy time, 0.5 – 5.6 min; cinefluorography time, 0.38 – 1.34 min; DAP, 5.5 – 93.1 Gy cm^2; PSD, 35 – 684 mGy (including backscatter); mean radiation field size at the entrance of the patient, 64 – 139 cm^2. The mean DAP value per procedure for CA was 25.0 ± 18.6 Gy cm^2, the exposure time was 1.4 ± 1.1 min for fluoroscopy time and 0.66 ± 0.23 min for cine time whilst the mean PSD was 136 ± 142 mGy. Patient 24 from Table 1 was extremely complicated as this patient had very high calcium concentration in his artery and the cardiologist had a very difficult time to mount the catheter into the patient's artery. Long cinefluorography time and various projections were used to get better image quality. This invariably increased the number of images as well as the DAP value.

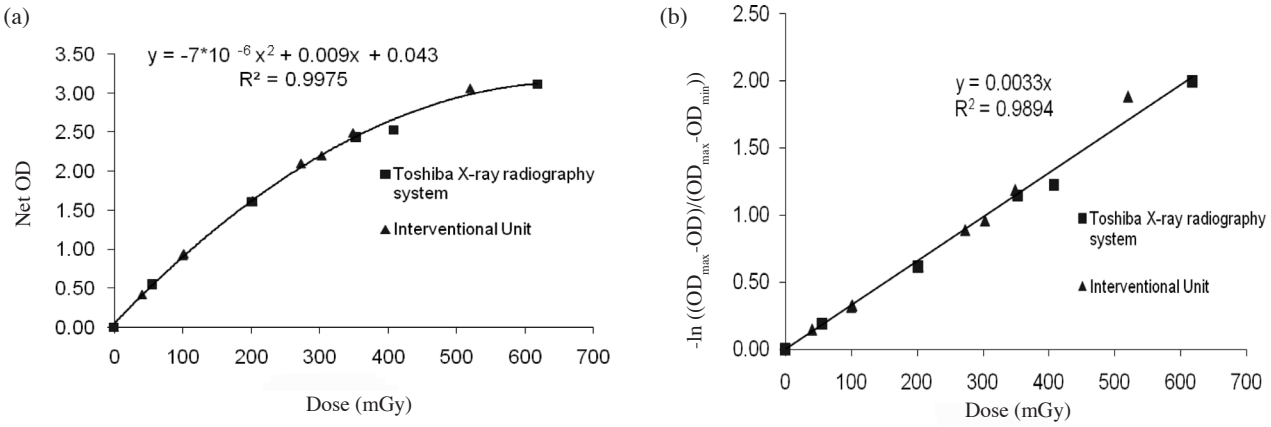

FIGURE 3. (a) Dose-response calibration curve from both the Toshiba X-ray radiography and the Interventional systems when plotted using net OD and (b) Dose-response calibration curve from both the Toshiba X-ray radiography and the Interventional systems when plotted using Morrell and Rogers equation

TABLE 1. Dosimetric parameters for CA procedures

No of patients	No of images	Fluoroscopy time (min)	Cine time (min)	Total time(min)	DAP (Gy cm^2)	PSD (mGy)	Mean field area (cm^2)
1	534	1.0	0.71	1.71	18.1	59	86
2	594	1.8	0.79	2.59	18.1	74	96
3	621	0.6	0.83	1.43	5.5	57	94
4	308	1.2	0.41	1.61	30.0	107	90
5	287	1.1	0.38	1.48	10.9	35	87
6	317	1.1	0.42	1.52	20.8	123	88
7	na	1.7	na	na	na	125	82
8	397	1.0	0.53	1.53	17.3	82	76
9	578	0.4	0.77	1.17	15.2	131	110
10	305	0.5	0.41	0.91	12.8	46	88
11	446	1.6	0.59	2.19	24.8	119	77
12	419	1.0	0.56	1.56	16.9	94	90
13	417	2.4	0.56	2.96	33.1	193	88
14	373	1.7	0.50	2.20	19.5	116	81
15	651	5.6	0.87	6.47	67.7	511	139
16	591	0.8	0.79	1.59	20.3	94	70
17	466	0.6	0.62	1.22	18.4	82	64
18	465	0.9	0.62	1.52	21.8	122	90
19	643	1.6	0.86	2.46	38.1	149	83
20	409	0.7	0.55	1.25	20.9	123	63
21	320	1.5	0.43	1.93	13.5	116	88
22	479	0.5	0.64	1.14	17.2	56	86
23	516	0.7	0.69	1.39	19.5	47	100
24	1006	0.6	1.34	1.94	93.1	684	90
25	330	0.6	0.44	1.04	12.6	42	93
26	843	3.7	1.12	4.82	42.6	210	93
27	467	2.3	0.62	2.92	21.70	82	74

The distribution of peak skin dose (PSD) for CA procedures is shown in Figure 4. The PSD of 24 patients were less than 200 mGy, 2 patients had PSD between 500-700 mGy. If the 2 patients do perform PTCA at a later time, they may likely exceed the 2 Gy for early transient skin injury.

The comparison of the mean DAP value as well as the mean effective dose of this study with other studies for CA procedures in recent years is shown in Table 2. In this study, the mean value of 25.0 Gy cm^2 for CA procedure is lower than some quoted studies, this may possible due to the patient size being relatively smaller than a European patient. To convert DAP in Gy cm^2 to effective dose in mSv, the conversion factor of 0.183 mSv Gy^{-1} cm^{-2} calculated by Betsou et al (1998) was applied. The mean DAP from our measurements gave a mean effective absorbed dose of 4.6±3.4 mSv. However patient 24 with the highest DAP value would have received an effective dose of 17.0 mSv. In UK, the National Radiological Protection Board has given effective patient doses of 3-10 mSv for CA (Hart & Wall 2002).

However the DAP measurement cannot provide information regarding the most irradiated area in the patient's skin, so that the radiological risk cannot be deduced directly from this value. Therefore the measurement of peak skin dose is required.

The correlation between the DAP and PSD values for CA procedures were studied and the results shown in Figure 5. Figure 5 show a reasonable correlation (R^2 = 0.8212) between the PSD and DAP values for the CA procedures. DAP may be a good indicator of peak skin dose in CA procedures when doses are below 800 mGy. The relationship between the fluoroscopy time and PSD value for CA procedures gave a relatively poor regression coefficient of 0.2936, Figure 6(a). The poor regression was partly due to patient 24 in Table 1 who had an extremely complicated procedure where the fluoroscopy time was relatively long. If this patient data was not taken into account then the regression coefficient became 0.6312, Figure 6(b).

CONCLUSION

EDR2 film was suitable to monitor patient skin doses below 1000 mGy which is normally encountered in CA procedures. Skin doses in the local hospital were relatively low for CA procedures where 93% of patients' skin doses were less than 300 mGy. This excludes the 2 extremely complicated procedures. Although EDR2 film is relatively cost effective, it has to be calibrated for dose response when the CA films are developed.

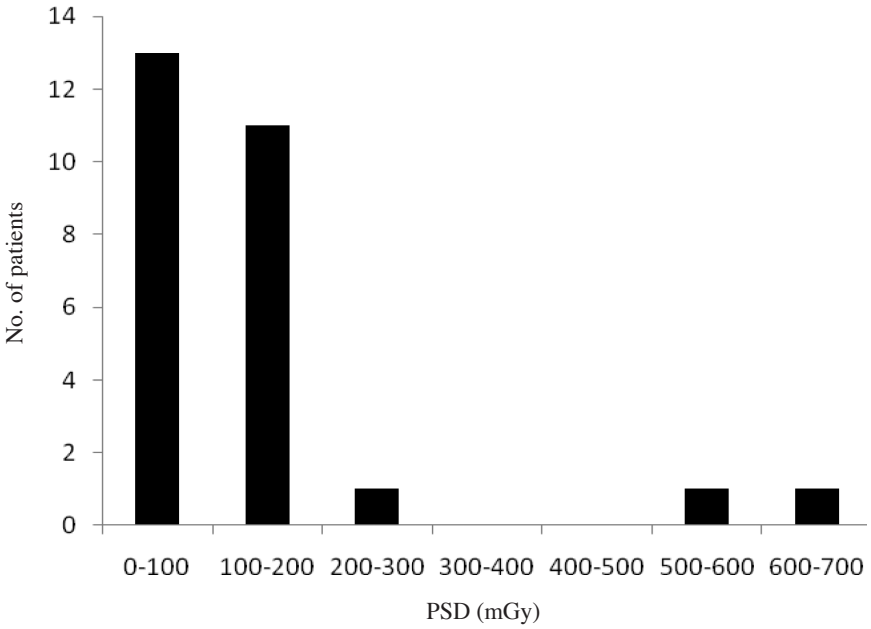

FIGURE 4. Distribution of peak skin dose

TABLE 2. Published CA values between 1995-2008

References	Year	Mean DAP (Gy cm^2)	Mean Effective Dose
Vano et al.	1995	66.5	12.2
Betsou et al.	1998	30.4	5.6
Padovani et al.	1998	39.3	7.2
Van de Putee et al.	2000	60.6	11.1
Tsapaki et al.	2003	47.3	8.7
Morrish et al.	2008	49.9	9.1
This study	2009	25.0±18.6	4.6±3.4

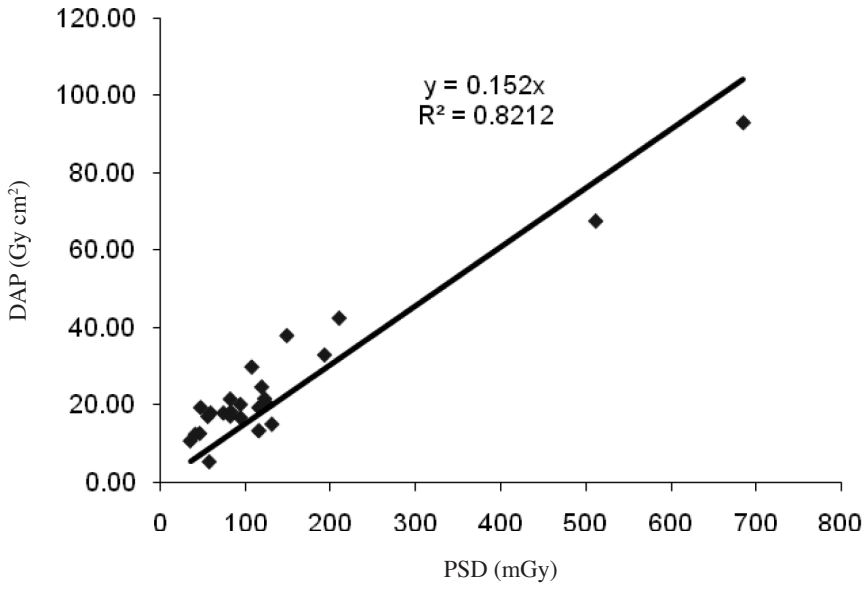

FIGURE 5. Correlation between DAP and PSD

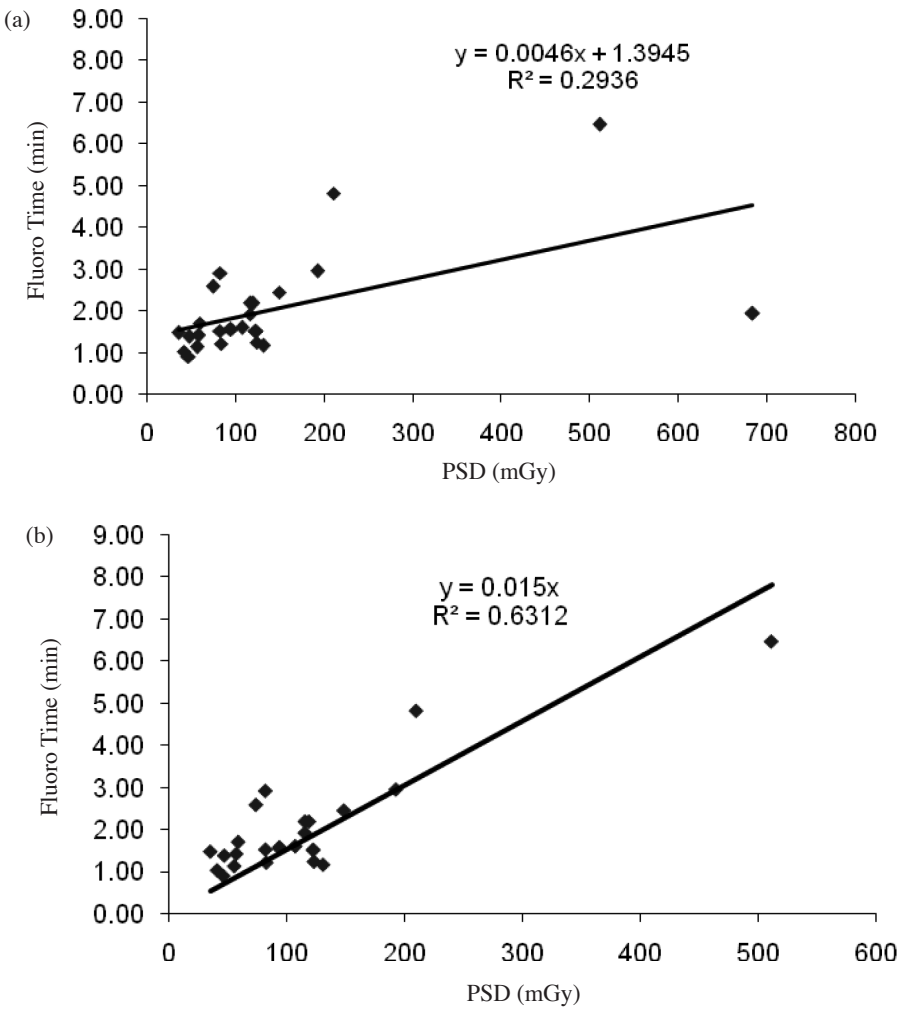

FIGURE 6. (a) Correlation between fluoroscopy time and PSD and (b) Correlation between fluoroscopy time and PSD excluded patient No. 24

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