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Short communication

Patient dosimetry in interventional radiology using slow films

[1,2]E VAÑÓ, PhD, [1]E GUIBELALDE, PhD, [2]J M FERNÁNDEZ, MSc, [1]L GONZÁLEZ, PhD and [1]J I TEN, MSc

[1]*Medical Physics Group, Department of Radiology, University Complutense of Madrid, 28040 Madrid, and*
[2]*Medical Physics Service, San Carlos University Hospital, 29040 Madrid, Spain*

Abstract. A method for the evaluation of patient doses in interventional radiology procedures is presented and discussed. The method requires the analysis of slow non-screen films such as those used in radiotherapy. Dose–area product and patient skin dose can be estimated with fair accuracy depending on the interventional procedure type. The agreement between the slow film method and diamentor measurement is better than 5% after the application of appropriate corrections. The cost is reasonable (£5 per film) making it a worthwhile option in patient dosimetry, especially when the X-ray equipment does not include any fixed dose–area measuring device. Additional valuable information which may be applied to optimization of procedures (*e.g.* irradiated areas, number and types of projections, check of appropriate use of beam limiting devices) is achieved by examining the different irradiation fields on the film.

Introduction

Interventional radiology (IR) and in particular interventional cardiology (IC) are the specialties in which the highest patient doses are imparted with the use of fluoroscopy X-ray techniques in diagnostic or therapeutic procedures [1]. Clinical patient benefit usually compensates radiological risk; however, there is agreement among experts about the need for measuring patient doses routinely and the urgency of setting up optimization procedures [2].

The number of interventional procedures, dedicated radiological installations and centres applying those interventions increases continuously. Technical improvements in the design of dedicated IR equipment and the imaging system incorporating digital procedures are progressing. Nowadays, medical specialists are able to choose the image quality level they wish for each procedure. Improving image quality is usually associated with higher patient and staff doses. Unfortunately, most IR equipment in use does not include dose measuring devices. Many new installations do not incorporate them in their basic options. An international standard related to safety conditions on IR systems, where presumably the inclusion of these dose measuring devices will be specifically recommended, is about to be published by the International Electrotechnical Commission (IEC/SC/62B/WG 24 Draft version, Safety of X-ray equipment used for IR, June 1995). Even in these cases, the measurement system will not provide enough information about body areas receiving higher doses.

Patient dosimetry in IR and IC is extremely complex due to the irradiation of different anatomical areas, with the X-ray beam changing to various projections, diverse field sizes, radiation qualities, focus-to-skin distances and focus-to-image intensifier distances. Some X-ray equipment includes the possibility of introducing high absorption filters (*e.g.* copper filters in the Philips Integris system) to achieve extra patient dose reductions by hardening the beam. For all these reasons, patient entrance doses, derived from the technical parameters (kVp and mA) applied during the examination, are very difficult to calculate. Monte Carlo techniques applied on mathematical phantoms have proven successful in conventional radiology [3, 4] but are complicated to apply in IR due to the number of variables and the associated large uncertainty on results. The US Food and Drug Administration (FDA) has recently issued a report for the evaluation of patient doses in IC, indicating the level of uncertainties involved in this type of calculation [5], being between 50 and 150%.

Until now, research on patient dose evaluations in IR has been mainly focused on the measurement or estimation of two basic parameters: (1) dose–area product (DAP), used more by European groups [6], in general related to the stochastic radiation risks, and (2) the skin or surface entrance dose over the most irradiated patient area, usually related to deterministic risks, generally carried out

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by North American groups [7]. In the USA increasing awareness is claimed concerning the possible problems derived from high patient skin doses and resulting injuries. In 1994, the FDA published a safety standard establishing limits for maximum skin patient dose rates imparted by fluoroscopy equipment [8]. The FDA has also published recommendations about the risk of patient injuries and about the parameters to be registered for certain procedures [1].

In October 1995, the World Health Organization (WHO) and the German Institute of Radiation Hygiene organized a joint workshop on efficacy and radiation safety in interventional radiology in which these questions have been discussed. As a result of this workshop a WHO guide including measuring procedures will be published during the next few months.

The authors have published a previous paper [9] presenting results of an IR patient dose survey obtained from a Spanish pilot programme. This survey included DAP values and the so called "surface dose indicator" (estimated by adding the readings of four thermoluminescent dosemeters (TLDs) placed over, under and on both sides of the perimeter of the most irradiated patient region during the interventional radiology). The latter parameter might be used for patient skin dose estimations. The authors themselves criticized this risk indicator since the influence of the correct placement of the TLD chips, before the intervention, over the most irradiated patient area is a source of possible uncertainties of the proposed method. It was also stated that the use of that method was limited to procedures in which the radiation fields were reasonably static.

The method proposed in this paper (until now applied to a sample of 50 cardiac and vascular interventions) forms an integral approach to the patient dose evaluation in IR and IC. It allows the simultaneous estimation of DAP, skin patient dose and the distribution of the irradiated fields together with their corresponding dose levels. The latter may be essential in some instances, as possible skin injuries [1] depend not only on the doses but also on the areas where the dose is received [10]. The method is based on film dosimetry using Kodak "Ready Pack" film used in radiotherapy departments [11]. This method has been used successfully by several authors for measuring entrance skin exposures for fluoroscopic examinations [12].

Methodology

Kodak 33 × 41 cm, X-Omat V film (Eastman Kodak Co., Rochester, NY, USA) has been used to visualize and estimate doses from the different patient irradiation fields. This film is designed for verifying the orientation and the approximate patient doses in radiation therapy procedures. The film records linear doses from 400 mGy (producing a net density of 1.00) to 2000 mGy (producing a net density of 3.00) for the ^{60}Co photon energies. The film packaging does not need darkroom loading. It may be safely handled under standard safelight filters; automatic processing is recommended.

X-ray sensitometry was carried out to calibrate the X-Omat V film for the X-ray spectrum and filtration usually employed in IR and IC. The characteristic curve was obtained by a time-scale sensitometry at 70 kVp (by increasing exposure times). Errors in exposure estimates due to changes in film speed and contrast with tube potential are less than 5% for the range used (60–100 kVp) [12]. Doses and reproduction of technical parameters were checked by using a calibrated chamber (Victoreen 4000M+). Doses were also measured with TLDs placed in contact with the film. The X-ray equipment and automatic processor (Kodak X-Omat-M6B with Kodak chemicals) are optimized under quality assurance programmes. Optical density (OD) readings were obtained with a digital densitometer, Victoreen 07–424.

The characteristic curve obtained is shown in Figure 1. It can be seen that doses between 10 mGy and 500 mGy could probably be evaluated, but that the best fit to a dose–response curve is obtained between 20 and 200 mGy. This curve is fitted with a r factor of 0.9974 and a curve fit standard error of 0.0692. The analytical form of the curve is:

$$\mathrm{OD} = \frac{A_0}{1 + (\mathrm{dose}/A_1)^{A_2}} \qquad (1)$$

For the selected X-Omat V film, the obtained fit parameters (using a commercial scientific fit

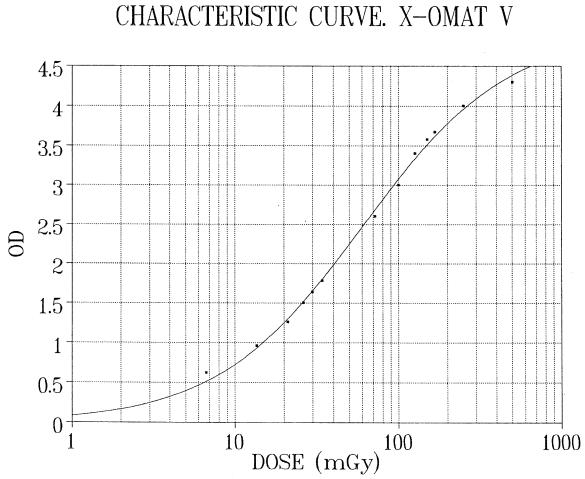

Figure 1. X-Omat V characteristic curve obtained at 70 kVp. Experimental data have been fitted to a dose–response curve.

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software) were for dose values in mGy:

$$A_0 = 4.92 \pm 0.14; \quad A_1 = 59.90 \pm 4.59; \quad A_2 = -0.98 \pm 0.04 \qquad (2)$$

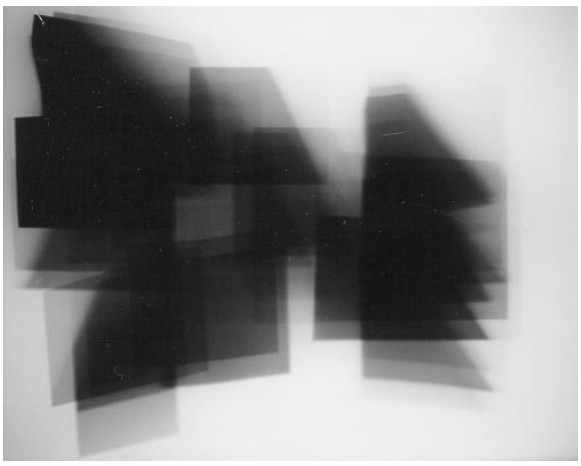
Obviously, those values could change from batch to batch and be strongly influenced by processing conditions [11]. It is advisable to revise periodically the calibration curve to minimize dose uncertainties. Alternatively, as we are actually doing in this initial experimental stage, some TLDs (four or five chips individually calibrated) could be attached in different positions over each film to be irradiated in the field conditions. This will ensure the appropriate dose–density calibration and will enable a realistic dose value to be derived when optical densities over 4.0 are obtained. Observed shifts in the analysed sample have been under 20% in all cases. However, the main source of error could be due to the propagation of the error when the OD function is reversed to calculate doses. This error is less than 10% over the linear range (20–200 mGy) and around 30% on the toe and on the shoulder of the curve. This will be discussed further in the results section.

The curve fitted analytically allows the estimation of doses at different points of the different irradiated areas by measuring optical densities. Thus, doses at the most irradiated areas could be estimated and dose maps could be drawn. From the different blackening areas, a parameter may be derived which is related to the total DAP imparted during the interventional procedure, assuming the tube angle does not produce images outside the size covered by the film or, alternatively, when the percentage of the dose outside film is known (*e.g.* as discussed in next section, for coronary angiography). DAP could be calculated by measuring areas and weighting them with their dose values both manually or automatically with the help of digitalization scanners and graphic computing tools. The confirmation of this possibility is being carried out by measuring with a calibrated transmission chamber (PTW Diamentor) the total DAP during the intervention and comparing it with the value calculated from the optical density profiles.

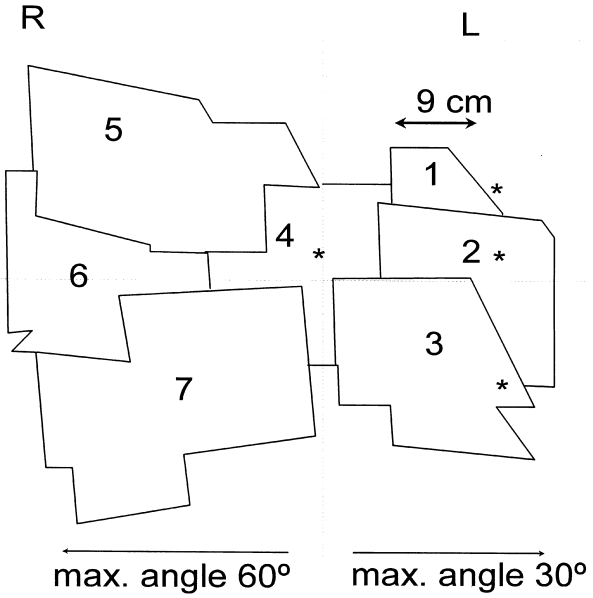
The film should be placed on the table underneath the patient for an undercoach tube position. The film must be centred as closely as possible to the area of the patients one expects to be the most irradiated. When the type of interventional procedure originates field distribution much larger than the area covered by the film size, two films could be placed on the table. If the intervention implies lateral projections, also extra films could be employed surrounding the sides of the patient.

Discussion and results

Our first experience using the proposed method is that just one 31 cm × 41 cm film is enough to evaluate appropriately the entrance patient doses and the total DAP, provided the film is correctly placed under the patient. Previous knowledge of the protocol to be employed during the intervention enables the doses to be corrected for the projections not included inside the film. For example, the sample of coronary angiographies analysed until now (28) has shown that the left lateral projection (not recorded in the "on-table" film) contributes 10–15% to the total imparted



(a)



(b)

Figure 2. (a) Image of a coronary angiography procedure showing densities and irradiated fields. (b) Schematic profiles of the distribution of the main projections obtained during the intervention. Position of the TLDs shown by *. 1, RAO–CAUD; 2, RAO; 3, RAO–CRAN; 4, AP; 5, LAO–CAUD; 6, LAO; 7, LAO–CRAN.

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DAP. This percentage could be added to the doses estimated from the recorded field images.

Figure 2 shows an example of the image obtained after a coronary angiography procedure. The film has been placed on the table underneath the supine patient and centred about 5 cm away from the patient centreline towards the left side, so that the heart was centred over the film. Observe the sketch of Figure 3 to see the film aligned along the length of the patient dorsal spine. One can identify all the standard projections for this type of intervention [5]. These projections have been schematically outlined in Figure 2b. Note that some fields overlap, resulting in optical densities near the overexposed curve zone. In order to reduce the error due to this curve shoulder, it is preferable to estimate doses from other points, unless any TLD was exactly in those areas and measurements could be corrected. Even when the film is clearly overexposed with a superimposed series of images (*e.g.* the intervention shown in Figure 4 representing a renal arteriography) it is always possible to estimate that the maximum skin dose imparted in a determined area is higher than a certain value. Measurements carried out in the film of Figure 4 supplied a dose value of 271 mGy over 400 cm^2 approximately. The specialists could then judge, for example, whether the risk of repeating the procedure is reasonable.

Until now, this presented methodology has been used on a sample of 50 patients including IR and IC procedures. We expect to have results for a wider sample and to submit a complementary and detailed paper including those results. Data obtained from a representative coronary angiography and its profile (Figure 2) are shown in Table 1 as an example. The agreement with TL doses and with DAP measurement is quite good, considering that doses obtained from film and TLD include backscattering. This is not reflected in the transmission chamber total DAP. However, cGy cm^2 values obtained from film densities and areas must be corrected by adding about 12% of extra dose due to the left lateral projection (not registered in this film). The total error in measuring DAP with transmission chamber and with film could be then estimated around 20%. If appropriate backscatter correction and table attenuations were roughly estimated the agreement is improved (see Table 1). However, the agreement is not always so good, mainly as a result of film misalignment in non-standard procedures, or overexposed areas. The renal arteriography procedure presented in Figure 3, for example, has a total measured DAP of 8213 cGy cm^2, and a calculated DAP of 11 363 cGy cm^2 (without backscatter corrections applied to the transmission chamber) from the recorded optical densities (in some points near 4.00 OD) and areas.

Conclusions

These results indicate that the technique represents a valid alternative for patient dosimetry in interventional radiology and cardiology. It allows for the estimation, with fair accuracy (uncertainty 5–20%), of the skin doses and the irradiated areas where the doses are imparted. In certain

Table 1. Measured and calculated dose and DAP values for the coronary angiography shown in Figure 2

Projection	TLD readings[a] (mGy)	Doses[a] calculated from ODs (mGy) at the TLD position	DAP[a] calculated from ODs and areas (cGy cm^2)	DAP measured values (cGy cm^2)
1. RAO–CAUD	22.8	22.7	136.2	—
2. RAO	61.8	58.8	287.3	—
3. RAO–CRAN	11.1	11.3	529.9	—
4. AP	36.9	44.4	398.1	—
5. LAO–CAUD	—	—	665.3	—
6. LAO	—	—	620.7	—
7. LAO–CRAN	—	—	377.4	—
Total	—	—	3015	2678
Estimated doses due to lateral projection (+12%)			3467	
Backscatter (+25%) and table attenuation corection (−3%)				3267

[a] Measurements including backscattering and attenuation through the table.
RAO, right anterior oblique; CAUD, caudal; AP, anteroposterior; LAO, left anterior oblique; CRAN, cranial.

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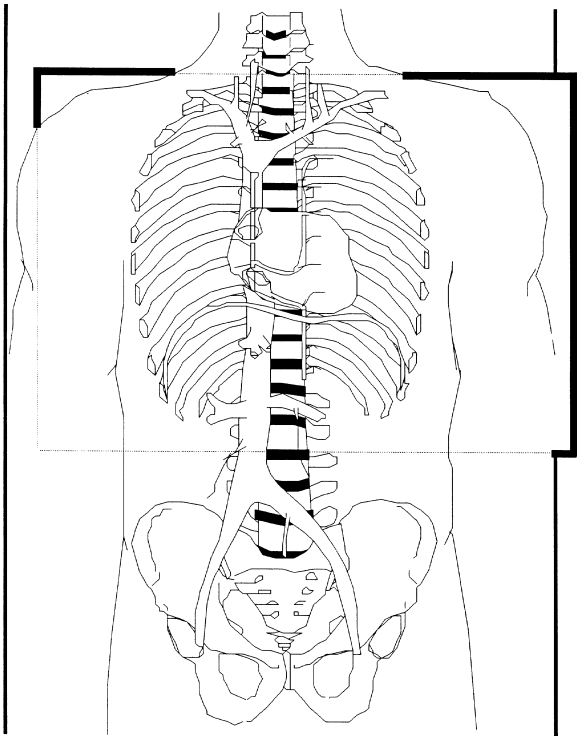

Figure 3. Film position for a coronary angiography.

interventions, DAP values could be also measured with uncertainties around 25%, obtaining extra information with respect to the transmission chamber measurement, that is, the distribution of the anatomical irradiated areas. This fact is of importance for patient radiation protection optimization, since it helps to assess the optional use of alternative protocols, in those situations where an interventional procedure is to be repeated.

This dosimetry procedure can be supplied far from a given installation, sending by mail films and TL chips and analysing the images afterwards in a specialized Medical Physics Service.

The total cost of the procedure (about £5 per film and £10–15 per TL dosimetry) is low enough with respect to the cost of the interventional procedure to consider the widespread implementation of the methodology in IR and IC.

Acknowledgments

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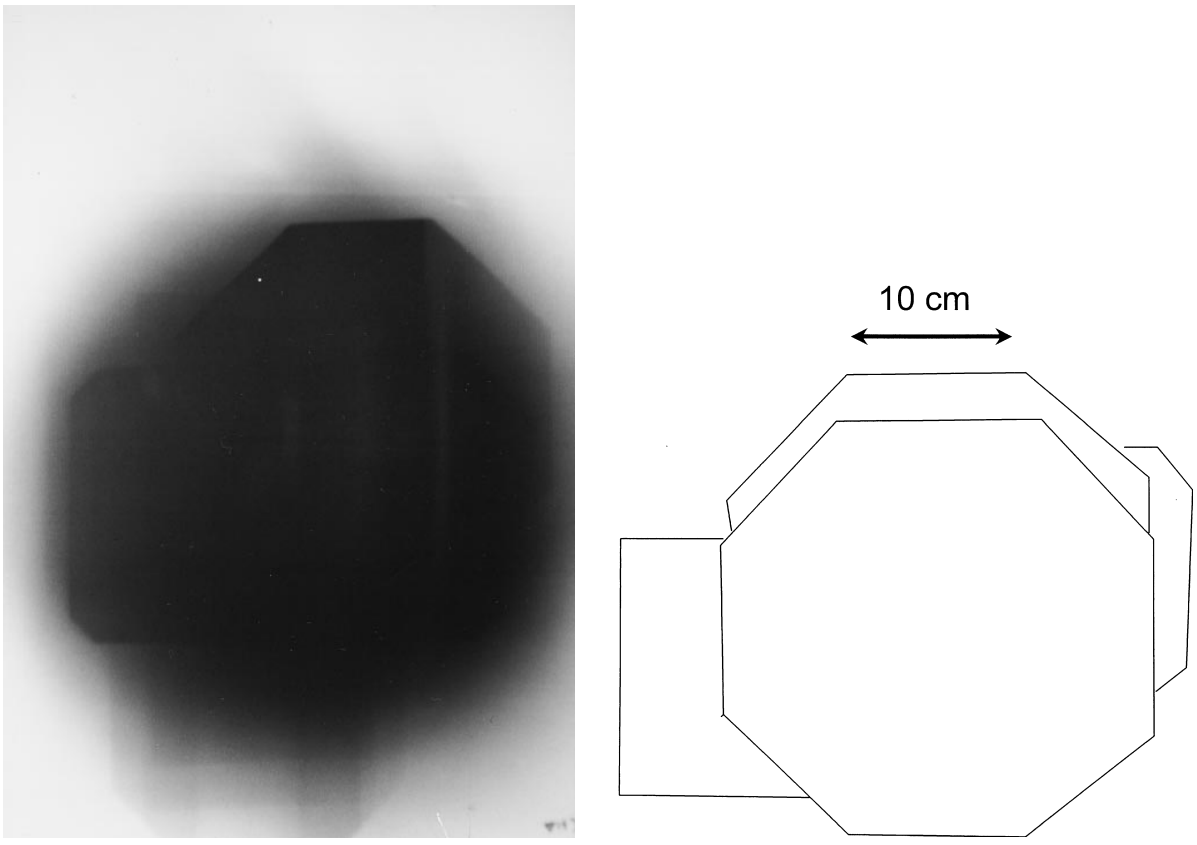

(a) (b)

Figure 4. (a) Image of a renal arteriography procedure showing densities and irradiated fields. (b) Schematic profiles of the distribution of the main projections obtained during the intervention.

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