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The interdependence of staff and patient doses in interventional radiology

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Abstract. Staff doses arising from the use of X-rays are principally due to scattered radiation. This is related to the dose received by the patient expressed as the dose–area product (DAP). Doses to patients in interventional radiology are generally higher than for other fluoroscopically guided procedures. Doses to interventional radiologists are, therefore, amongst the highest associated with the use of diagnostic X-rays. The results of staff dose monitoring normalized to DAP should provide an indicator of those procedures which are associated with particularly high radiation exposures to staff, and should help to identify those radiologists whose practice may result in unnecessarily high doses to themselves. A study has been made of patient doses in two X-ray rooms used for interventional procedures associated with vascular and liver diseases. Doses to radiologists in these rooms were normalized to DAP. It was found that the average doses to the body, neck and hands were 0.05, 0.89 and 2.45 μSv/(Gy cm^2), respectively for those radiologists with no significant involvement in hepatobiliary procedures. Higher doses were found for one radiologist whose workload included biliary drainage. The whole body dose was 0.17 μSv/(Gy cm^2) or 5.8 mSv per year. It was shown that the doses to the neck and hands for the biliary drainage work was 6.59 and 29.0 μSv/(Gy cm^2), respectively. This study has demonstrated the value of DAP as a measure of radiologist workload in respect of its significance in terms of staff dose.

Introduction

Some of the highest doses to patients from medical X-rays, other than CT scanning, arise from interventional radiology procedures. Doses are sufficiently large for there to be concerns about potential deterministic effects on the patient's skin [1]. A recent survey of interventional procedures in Spain showed that the average values of dose–area product (DAP) for certain coronary and non-coronary interventional procedures were in the range 66–96 Gy cm^2, and for transjugular intrahepatic portosystemic shunts (TIPSS) was 354 Gy cm^2 [2]. This may be compared with the reference values for barium enema and meal examinations which are 60 and 25 Gy cm^2, respectively [3]. The dose and consequent risk to patients for these procedures is justified on the basis that they are often very sick patients, with life threatening disease. Moreover, the radiation risk is generally low compared with other risks associated with the intervention and with the risks of alternative, more invasive treatments. Nevertheless the as low as reasonably achievable (ALARA) principle must be applied and auditing dose is an important tool in dose optimization.

Of greater potential concern to the radiation protection adviser is the dose being received by staff. Most radiologists do not receive significant radiation doses. A report has shown that 88% of radiologists recorded less than 0.5 mSv in a single year and only three out of 335 received more than 2 mSv [4]. Potentially the highest dose to radiologists, other than from interventional radiology, arises from barium contrast studies. These are carried out on equipment which normally has effective local shielding so that the dose rate to the radiologist outside the lead coat is relatively low, in the region of 60 μSv h^{-1} during fluoroscopy [5]. This can be contrasted with the situation in interventional radiology in which C-arm equipment is generally used with minimal local shielding and in which the radiologist is often working close to the area under examination with his or her fingers close to the primary beam.

This study was initiated when it was noted that the dose recorded on a series of film badges worn under the lead apron for one radiologist at the Royal Infirmary of Edinburgh had increased over a period of 5 years from 0.8 mSv to 2.8 mSv per year. This increase appeared to be caused by a significant increase in the numbers of interventional radiology procedures in patients with liver disease. These were directed almost exclusively by this radiologist. Following more intensive dose monitoring and further increases in workload, a decision was made to designate the radiologist as a classified person in accordance with the Ionising Radiations Regulations [6]. At this time a second interventional room was commissioned

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in the department and there was an associated increase in workload associated with vascular disease. The study of dose to patients and staff was extended to include the work in the second room.

The use of dose–area product for the estimation of scatter dose to the walls of X-ray rooms has been described in an earlier paper [7]. This study was designed to establish the relationship between the dose received by radiologists and DAP. The relationship would be expected to depend upon the nature of procedures being undertaken and on the working practices of the individual radiologists. The aim of establishing such a relationship was to be able to identify radiologists whose techniques were leading to higher personal doses and to provide further predictive indicators for more intensive personal dose monitoring which could lead to a need for classification.

Materials and methods

Interventional radiological procedures and diagnostic catheterizations other than cardiac procedures are performed in two rooms at the Royal Infirmary. Room X is equipped with a Philips Integris 3000 C-arm system with a 35 cm image intensifier. Room Y has a GE L-U system with a 22 cm intensifier. In both rooms the equipment is used with the X-ray tube under the examination couch. The image intensifier input kerma rates measured with a 1 mm copper filter were 0.38 $\mu Gy\ s^{-1}$ and 0.48 $\mu Gy\ s^{-1}$ in rooms X and Y, respectively, for the maximum fields of view.

In Room X, DAP is automatically computed from the X-ray factors and collimator setting. Room Y was fitted with a Diamentor M2 DAP meter (PTW, Freiburg, Germany). The meters were calibrated using a 15 cm^3 ionization chamber (Keithley, Cleveland) with a traceable calibration. The chamber was positioned 20 cm above the couch top and at least 20 cm below the image intensifier face. Air kerma was measured for a beam with an area of approximately 100 cm^2, the area being measured using radiographic film.

DAP data are routinely recorded for all patients in these rooms. The study was performed retrospectively and there were some missing data. In particular, the DAP meter was removed from Room Y for a period of 6 weeks. For that period DAP values equal to the average recorded value for each procedure were used for this analysis. Average values were also used for other missing data. No local shielding was available in Room Y. A ceiling mounted screen with 2 mm lead equivalent glass was available in Room X. However, its use was generally considered to be impractical for the studies being performed by the radiologists involved in this study.

Studies were made of the doses received by five radiologists and of their workload, and expressed in terms of dose–area product. Three of the radiologists were consultants (A, B, C) and two were Research Fellows (D, E). The studies were conducted over a period of 19 months for A, 15 months for B and C and 4 and 8 months for D and E, respectively. Radiologist A's workload was largely concerned with patients with hepatobiliary and pancreatic disease. In particular, the major proportion of interventional procedures were TIPSS, chemoembolizations of the liver and biliary drainage. All of this work was done in Room Y. In respect of these studies, radiologists B and C used Room X exclusively. Their work was predominantly concerned with diagnosis and interventions in peripheral vascular disease. The two Research Fellows, who had consecutive appointments in the Department, were principally concerned with the vascular studies in Room X but also supported Radiologist A in Room Y.

The data for the study were taken from the Radiology Department's database of interventional and diagnostic catheterization procedures. The records include a procedure code, DAP and coding for the operator. Three fields for operator were available with the first field recording the coding for the radiologist carrying out the catheterization and intervention and the second and third operator fields, when relevant, for the radiologist who was in the room assisting or teaching. For the purpose of analysing the relationship between personal dose and DAP, it was assumed that the second and third operators would be standing less close to the source of scatter than the first operator. An arbitrary weighting factor of 50% was applied to DAP for the radiologists studied when they were recorded as having been second or third operator. This factor was chosen following the observation that the second operator generally stood approximately 0.5 m further from the area under examination than the first operator who stood at a distance of about 1 m.

Staff wore film badge dose monitors issued by Landauer (Glenwood, Illinois). One monitor was worn on the trunk under the lead apron, a second film badge was worn outside the lead apron at the neck. Thermoluminescent dosemeter (TLD) ring monitors were worn on each hand. When not in use, the neck and finger monitors were kept in the protected areas in the X-ray rooms in which the individual most commonly worked. Radiography staff ensured that they were worn for all cases. The monitors under the lead apron were worn for other radiology duties. Compliance with the wearing of these monitors was less easily checked by radiography staff and was probably less consistent than for the other dosemeters. The lead coats used by the radiologists had 0.35 mm lead equivalence except for Radiologist C who used a lead coat with 0.5 mm lead equivalence.

For a period of 4 weeks, Radiologist A wore a direct reading monitor as well as the film badge at the neck (Pendix, GST, Heidelberg). This was used to assess the relative contributions to the dose in this position for different procedures.

Results

Table 1 shows an analysis of workload for the five participating radiologists presented as the percentage of dose–area product for the most common procedures. Table 2 gives DAP values for those procedures for which at least 25 cases were included in the analysis.

Table 3 summarises the average monthly number of cases and DAP for each radiologist. The monthly DAP is the total for the radiologist as operator 1 plus 50% of the total as operator 2 or 3. The percentage of the total as operator 1 is shown. The personal doses in Table 3 are the penetrating or deep personal dose equivalent, $H_p(10)$, for the whole body and neck monitors and the superficial personal dose equivalent, $H_p(0.07)$, for the ring monitors worn on the fingers. This is the maximum dose to the hands which was in all cases the dose to the left hand (all five radiologists are right handed). The ratios of personal dose to DAP are given. Uncertainties in these values are shown for the neck and hand doses and are equal to twice the standard error of the mean.

Table 1. Analysis of interventional workload for each radiologist expressed as a percentage of total dose–area product

Procedure	Radiologist				
	A	B	C	D	E
Angioplasty	0.0	16.3	19.9	14.6	16.6
Biliary drainage	24.4	0.0	0.0	0.0	2.1
TIPSS	27.3	0.0	0.0	22.9	32.2
Arteriography					
Lower limb	0.2	50.1	46.1	40.6	24.9
Mesenteric	29.4	1.4	0.8	0.0	2.1
Other	3.4	17.2	25.0	7.9	13.0
Venography	2.8	5.6	2.0	3.8	2.3
Central line insertion	0.0	2.5	0.0	0.0	0.4
Other diagnostic	0.4	0.3	1.3	0.0	0.3
Other IR	12.0	6.6	4.8	10.2	6.1

The results of monitoring at the neck for Radiologist A using a direct reading monitor are shown in Table 4. For the purpose of this analysis the procedures have been classified as biliary, TIPSS and remainder. It can be seen that the scatter dose to the neck normalized to DAP is 7.4 times greater for biliary drainage procedures than for TIPSS and other procedures carried out by Radiologist A. This difference is due to the need for the radiologist to manipulate catheters inserted directly into the liver which is the region from which the scatter arises. Observation of working practice showed that for these procedures the radiologist stood within 0.5 m of the area under examination whereas for TIPSS and other procedures the distance was approximately 1 m.

Figure 1 shows the neck doses for Radiologists B, C, D and E plotted against DAP. A linear regression fit to the data constrained to pass through zero is displayed. The correlation coefficient is 0.496 which is significant at the $p=0.001$ level. There was no significant correlation between whole body or hand dose and DAP when the data for the four radiologists were combined.

Table 2. Patient dose data given as dose–area product (Gy cm^2) for those procedures in which there were 25 or more cases during the period of study (first quartile, median, third quartile and maximum values are shown in addition to the average DAP)

Procedure	No.	Ave.	1st q.	Med.	3rd q.	Max.
Arteriography						
Lower limb	323	77.9	49.4	68.6	97.5	306.0
Abdominal aortagram	41	97.9	59.0	77.3	131.8	297.4
Carotid (extracranial)	25	61.4	34.9	60.7	84.0	124.7
Renal	36	77.0	58.5	75.3	92.9	169.8
Mesenteric	108	111.9	54.4	86.5	145.4	351.7
CTAP	30	8.2	3.4	5.2	11.8	39.7
Venography						
Arm	26	22.9	7.0	14.7	37.4	57.0
Angioplasty	100	67.3	23.9	44.6	82.5	289.7
Angioplasty + stent	43	89.0	35.3	63.7	135.9	407.9
Chemoembolization	27	105.0	69.2	89.0	136.0	351.7
TIPSS	56	182.3	103.2	158.4	237.4	470.1
TIPSS follow-up	73	72.4	35.8	57.6	93.2	265.8
Central line insertion	71	10.9	3.3	5.1	9.5	231.7
Biliary drainage	86	42.9	18.5	29.6	60.5	167.1
Biliary drainage + stent	74	50.8	15.4	37.3	63.1	283.6

Table 3. Average monthly workload and personal dose for each radiologist (uncertainties in the ratio of the dose monitor reading to DAP for the neck and hand are twice the standard error on the mean)

Radiologist	Period (months)	Monthly averages						Dose/DAP (μSv/(Gy cm^2))		
		No. of cases	DAP (Gy cm^2)	% DAP as OP-1	Badge doses (mSv)			Body	Neck	Hand
					Body	Neck	Hand			
A	19	46.2	2863	90.4	0.48	6.55	25.7	0.17	2.29 ± 0.41	8.97 ± 3.07
B	15	24.8	1358	90.5	0.03	1.50	4.10	0.02	1.10 ± 0.25	3.02 ± 0.58
C	15	27.6	1883	87.4	0.17	1.42	3.09	0.09	0.75 ± 0.14	1.64 ± 0.15
D	4	23.8	1319	94.5	0.00	1.08	3.33	0.00	0.82 ± 0.47	2.52 ± 1.40
E	8	30.0	1982	86.4	0.06	1.56	4.83	0.03	0.79 ± 0.19	2.84 ± 1.19
Average for B, C, D and E								0.05 ± 0.03	0.89 ± 0.24	2.45 ± 0.69

Table 4. Results of neck dose measurements normalized to dose–area product for Radiologist A using a direct reading dosemeter (the 95% confidence limits equal to twice the standard error on the mean are given)

Procedure type	No. of cases	DAP (Gy cm^2)	Neck dose/DAP (μSv/(Gy cm^2))
Biliary	29	423	4.22 ± 0.77
TIPSS	13	1559	0.59 ± 0.10
Remainder	12	611	0.51 ± 0.19

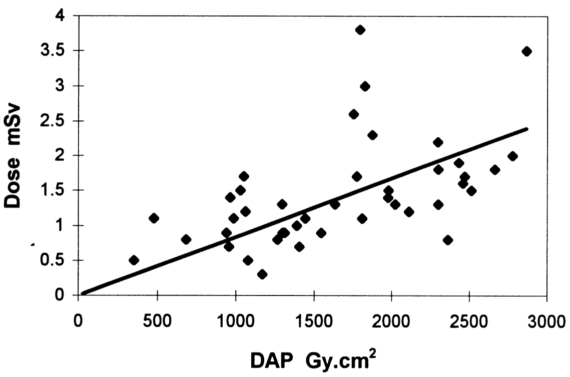

Figure 1. Neck dose plotted against dose–area product for four radiologists (B, C, D and E). The line is a linear regression fit to the data which is constrained to go through the origin.

Discussion

Patient doses summarised in Table 2 may be compared with those reported by Vañó et al [2] for 10 centres in Spain. They reported median doses equal to 51.8 and 82.7 Gy cm^2 for lower limb and renal arteriography, respectively. The doses reported here are 32% greater and 9% lower than these values. For biliary drainage and TIPSS the doses in this study are approximately half of those reported by Vañó et al [2]. DAP for lower limb arteriography were much greater than the average values reported by Castellano et al [8] (13.1 Gy cm^2) and by Steele and Temperton [9] (42.9 Gy cm^2). Steele and Temperton [9] also published average DAP data for carotid and renal angiography, 27.4 and 95.0 Gy cm^2, respectively, which are 45% and 123% of the doses reported here. High DAP values for femoral angiography were noted in an earlier paper [10]. It was concluded in that study that this was due to the number of spot film exposures. The present study, which is principally concerned with staff dose, was made retrospectively over a similar time period to the earlier work. Changes in doses due to the implementation of revised protocols are therefore not reflected in this report.

A wide variation was noted in the whole body doses recorded for the five radiologists on badges worn under the lead apron. The highest dose was for Radiologist A and corresponded to 5.8 mSv in a full year. The ratio of body badge dose to DAP was 0.17 μSv/(Gy cm^2). This may be compared with an average ratio of 0.05 μSv/(Gy cm^2) for the other four radiologists. This difference is probably due to the differences in the nature of the work which will be discussed below. There was a significant variation in the normalized whole body dose for the four radiologists (B to E). In part this may have been due to the low average monthly dose (0.08 mSv) which is approximately equal to the precision in dose recording (0.1 mSv). It should also be noted that there was a variable compliance with monitoring requirements for the whole body badge.

The average ratio of equivalent dose at the neck to DAP was 0.89 μSv/(Gy cm^2) for radiologists B, C, D and E with no significant variation between them. This may be compared with dose ratios of 0.23 and 0.20 μSv/(Gy cm^2) measured at chest height for radiologists carrying out cerebral angiography and arterial embolizations, respectively, calculated from data reported by Marshall et al [11]. The site of catheter insertion for both cerebral interventional procedures and for most of those reported here is the groin. The distance from the insertion point and the area under investigation is greater for neuroradiological procedures than for those in this study. For this reason alone the normalized doses would be expected to be greater in this instance.

The closest proximity of the radiologist to the area under examination in this study was for biliary drainage procedures. These represented 24.4% of the workload of Radiologist A with a negligible proportion for the other radiologists. The annual dose at the neck for this Radiologist was 80 mSv which is sufficient for designation as a classified person due to the potential dose to the eyes if unprotected. The dose to the neck from biliary drainage can be estimated by assuming that the dose to DAP ratio for Radiologist A was the average value for the other four radiologists for the non-biliary drainage proportion of the workload. For these procedures the average monthly dose to the neck can be estimated as 1.9 mSv. The remaining neck dose (4.7 mSv) may be ascribed to biliary drainage work for which a dose to DAP ratio of 6.59 μSv/(Gy cm^2) can then be derived. This is 7.4 times greater than the ratio for the remaining workload. Direct measurement of dose at the neck showed that the neck dose normalized to DAP was 4.22 μSv/(Gy cm^2) (Table 4). The difference is probably due to the incorrect calibration of the direct reading monitor for the low energy spectrum of scattered X-rays and to differences in the positions in which the monitors were worn. The ratio between the normalized neck dose for biliary drainage and other procedures derived from the direct reading monitor was 7.4. This is in exact agreement with the result extrapolated from the film badge data.

The average ratio of body dose to neck dose was 0.057 for Radiologists B, C, D and E and 0.073 for Radiologist A. This is greater than the expected transmission of scatter radiation through a 0.35 lead equivalent coat which is between 2% and 3% for X-ray energies in the range 80 and 90 kV which were used for this work [12]. There are a number of reasons for this discrepancy. The body badges were generally worn at waist level. The waist is closer to the source of scatter than the neck and this difference is most significant when the radiologist is standing close to the patient. The angle of scatter at the neck is less than for the waist using an undercouch tube. This results in greater absorption in the patient [7] which would result in a lower dose to the neck. In addition, the scatter radiation will be at an oblique angle to the film monitor which may reduce its response for angles of incidence greater than about 45°. It should also be noted that the body badge was worn for other work in the department.

Hand doses were measured using ring monitors. The results may represent an underestimate of the dose to the finger tips because of the distance from finger tip to the dose monitor. However, the extent of the underestimate is not likely to be significant because the hand is kept in a semi-clenched position whilst the fingers are used to manipulate catheters. This reduces the distance from finger tip to the ring.

The hand doses for Radiologists B, C, D and E were less consistent than for the neck. Normalized doses varied between 1.64 and 3.02 μSv/(Gy cm^2). Radiologist B had the highest hand dose. It was thought that this may have been due to 2.5% of the workload being concerned with central line insertions which required the hands to be particularly close to the edge of the beam. However, the dose data for the hands showed no correlation with the monthly DAP for this work.

Greater inconsistency between operators might be expected for the hand dose than for the dose to the neck. The hands are generally closer to the source of scatter and the actual distance will depend critically on the operator's technique. In addition, there are occasions on which the operator's hands stray into the transmitted primary beam and the frequency with which this happens would be expected to depend on the individual. The dose to the hands of Radiologist A, 8.97 μSv/(Gy cm^2), was very much greater than the other four and could not just be ascribed to technique. For the workload reported here, the dose averaged 308 mSv per year which was the primary reason for designation as a classified person. The high dose was ascribed to the biliary drainage procedures during which the left hand remained very close to the site of catheter insertion throughout the procedure and the primary X-ray beam extended almost to that position.

The data presented in this report were reviewed after the first 6 months of monitoring. For this initial period, the hand dose normalized to DAP for Radiologist A was found to be 14.9 μSv/(Gy cm^2). At that time additional checks were made of the X-ray collimation. It was found that the maximum X-ray beam size produced by a rectangular collimator system extended by 1 cm outside the field of view. Subsequently it was restricted to 1 cm within the field of view. In the following 13 months, the hand dose fell to 6.2 μSv/(Gy cm^2). This is equivalent to a change in annual dose from 510 mSv to 210 mSv.

An estimate has been made of the relationship of hand dose to DAP for biliary procedures alone by assuming that the dose from non-biliary drainage procedures was equal to the average value for the other four radiologists (2.45 μSv/(Gy cm^2)). For the first 6 months of the study the contribution of the biliary procedures to the hand dose was estimated to be 53 μSv/(Gy cm^2) and for the following 13 months it was 18 μSv/(Gy cm^2) with an average ratio of 29 μSv/(Gy cm^2) for the full period of the study.

Conclusions

It has been confirmed that the radiation dose to interventional radiologists can be high. Doses were sufficiently high to require the classification of one radiologist specializing in hepatobiliary disease and to require the classification status of other interventional radiologists to be under regular review. For this type of work, additional monitoring of the neck and hand doses is important in the assessment of radiologist dose. In the analysis of these doses the use of DAP as a normalizing factor has been found to be of great value. The dose outside the lead apron at the neck was found to be 0.89 $\mu Sv/(Gy\ cm^2)$ for a case load which principally involved arteriography within the abdomen, pelvis and lower limbs. Hand doses in the range 1.67–3.02 $\mu Sv/(Gy\ cm^2)$ were found. For biliary drainage procedures the doses were much greater. The dose at the neck was 6.6 $\mu Sv/(Gy\ cm^2)$ and, with a well collimated beam, 19 $\mu Sv/(Gy\ cm^2)$ to the hands. With 2 cm wider collimation the hand dose was found to have increased to 53 $\mu Sv/(Gy\ cm^2)$. Quality control programmes must ensure that the X-ray beam is constrained to be within the field of view. Radiologists should be aware of the significance of rectangular collimation when their hands are close to the access site. The recorded doses have reinforced the requirement of all staff working in these rooms to wear thyroid shields and for radiologists to wear eye protection if they cannot use other shielding devices. The use of DAP as a measure of the radiologically significant workload is recommended. Its value in the analysis of staff radiation exposure in order to identify procedures and individual practices which may result in unnecessary exposure to scatter radiation has been demonstrated. It is recommended that, for the type of work reported here, particular attention should be paid to the dose to radiologists whose monthly workload expressed in terms of DAP exceeds 1000 $Gy\ cm^2$. For radiologists or other clinicians who use X-rays to guide biliary drainage procedures, it is recommended that monthly patient doses in excess of 200 $Gy\ cm^2$ should be sufficient to trigger a thorough investigation of operator dose.

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