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ORIGINAL ARTICLE
Radiation exposure to anaesthetists during interventional radiology*

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Summary
This prospective study determined the level of radiation exposure of anaesthetists during interventional radiological procedures performed in the endoscopic retrograde cholangiopancreatography suite and cardiac catheterisation laboratory and compared it with the current safety guidelines. Anaesthetists wore area-specific lithium fluoride thermo-luminescent dosimeter badges at standardised positions. A total of 1344 procedures were performed over a 6-month period. Anaesthetists were involved in 39/645 (6.0%) procedures associated with ionisation radiation in the endoscopic retrograde cholangiopancreatography suite and 86/699 (12.3%) in the cardiac catheterisation laboratory. The mean (SD) duration of endoscopic retrograde cholangiopancreatography was 54.8 (29.1) min compared with 67.9 (42.8) min for cardiac catheterisation suite procedures (p = 0.058). The mean (SD) fluoroscopy time per procedure for endoscopic retrograde cholangiopancreatography was 5.5 (4.1) min compared with 12 (10.9) min in the cardiac catheterisation suite (p < 0.001). The combined net radiation exposure over 6 months was 0.28 mSv for endoscopic retrograde cholangiopancreatography procedures and 2.32 mSv in the cardiac catheterisation suite. The combined exposure was less than the maximum recommended exposure of 20 mSv per year.

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Fluoroscopic procedures are the largest source of occupational exposure in medicine including anaesthesia [1]. Anaesthetists are routinely involved in managing patients undergoing fluoroscopic procedures both inside and outside of the operating room.

Studies of radiation exposure in anaesthesia have shown varying results. In a previous study conducted at our institution [2], we found the radiation exposure among trainee anaesthetists anaesthetising patients for endoscopic retrograde cholangiopancreatography (ERCP) to be higher when compared to exposure during urological and orthopaedic procedures. Buls et al. [3] studied staff exposure during ERCP and found them to be exposed to increased levels of radiation due to inappropriate use of X-ray equipment. Henderson et al. [4] found higher radiation exposure in anaesthetists working in the cardiac catheterisation laboratory compared to those working inside the operating rooms. They recommended routine monitoring of radiation levels for anaesthetists working at these sites. Durack et al. [5] demonstrated acceptable radiation exposure for anaesthetists working in interventional radiology areas, but this study was conducted over one calendar month only. The expanded role of anaesthetists merits more realtime studies over longer time periods. Our literature search revealed few publications regarding the exposure of anaesthetists to radiation during interventional radiology procedures. This prospective study was designed to determine the level of radiation exposure of anaesthetists working with high radiation procedures like ERCP and cardiac catheterisation, and to compare it with the current safety guidelines. The secondary
objective was to compare the exposure in these two different areas.

**Methods**

The study settings were the ERCP suite and cardiac catheterisation laboratory of our university hospital. The study subjects were anaesthetists providing general anaesthesia or monitored anaesthetic care in the above settings. After study review and approval by our local ethics committee, written informed consent was taken from the anaesthetists for their participation in the study. All cases managed by the anaesthetists from 1st March 2007 to 29th August 2007 were included. Three research assistant working 8-h shifts were responsible for data collection.

Anaesthetists wore lithium fluoride thermo-luminescent dosimeter (TLD) badges (Synodys Passive Dosimeter GmbH, Wermelskirchen, Nordrhein-Westfalen Germany). The dosimeters used were area specific: TLD (A) badges were allocated to the cardiac catheterisation laboratory; TLD (E) badges were allocated for use in the ERCP suite. The positions of the badges were standardised: TLD 1 was worn externally at the collar site, outside the protective clothing; TLD 2 was worn inside the protective lead apron, at the waist level. In total, four area- and position-specific TLD badges were used, being labelled as: TLD 1A; TLD 1E; TLD 2A; and TLD 2E. Research assistants ensured the correct placement of TLD badges with the detector chips facing outwards. The TLD badges were exchanged between anaesthetists working in the two areas. The TLD detector chips present inside the badge were 0.312 cm thickness and had a minimum detectable dose of 0.1 mSv.

Anaesthetists also wore protective lead aprons and thyroid shields of 0.5-mm equivalent lead thickness (Kenex Electro-Medical Limited, Harlow, UK) throughout the procedures. When not in use, the TLD badges were kept at a common location to control for non-occupational exposure.

Fixed multidirectional fluoroscopes with automatic brightness control modes were used during the procedures at both sites. The fluoroscope model used in the ERCP suite (Axiom Iconos R 100 Siemens medical, Erlangen, Germany) was positioned with the X-ray tube above the couch and the image intensifier under the couch. The maximum energy output was 150 keV with a maximum current of 800 mA. The machine was operated in an automatic mode in which the energy and current were selected according to X-ray attenuation in the patient.

The distance between fluoroscope and anaesthetist could not be standardised as the anaesthetists were constantly moving between the patient, anaesthetic equipment and monitors.

The number of cases requiring an anaesthetist’s involvement and the duration of radiation exposure were documented. Duration of exposure to radiation (in minutes and seconds) was read directly from the fluoroscopy machine. The total number of cases performed in each area was recorded. The data sheet was completed by the research assistants and was checked every day by one of the investigators for completeness and accuracy. The exposed crystals were sent to Karachi Institute of Radiotherapy and Nuclear Medicine (KIRAN) at three-monthly intervals by the medical physicist.

The anaesthetists who managed these cases were either senior residents in their final year of training or junior faculty on three-monthly rotations in the respective clinical areas. Their routine work schedule involved 8-h daily shifts with an ‘on-call’ commitment every fourth night. The ERCP procedures were all scheduled between 08:00 and 17:00 h whereas procedures in the cardiac catheterisation laboratory were undertaken at all hours.

Data were collected using EpiData version 3.0 software (EpiData Association, Odense, Denmark) and verified manually. Data were converted and analysed using SPSS software, version 16 (Chicago, IL, USA). Mean (SD) time was calculated for the total duration of procedures and the fluoroscopic period (combined monthly and quarterly). The independent sample t-test was used to compare the two groups (ERCP and cardiac catheterisation) and error bars charts with 95% CI were calculated for the duration of procedure and fluoroscopy times. A p value of < 0.05 was taken to be significant.

**Results**

A total of 1344 procedures were performed in the two locations during the 6-month study period. In all, 645 procedures were performed in the ERCP suite and 699 were performed in the cardiac catheterisation laboratory. The total number of procedures performed each month the number of cases requiring an anaesthetist’s involvement, the monthly mean duration of procedures, and the mean fluoroscopy time in the two areas are shown in Table 1. Anaesthetists were involved in 39/645 (6%) of the procedures associated with ionisation radiation in the ERCP suite and 86/699 (12.3%) in the cardiac catheterisation laboratory (Table 1).
The number of cases where radiation exposure occurred varied from month to month, with a minimum of four in the second and third months in the ERCP suite, and 11 in the second month in the cardiac catheterisation laboratory. The combined mean (SD) duration of procedures over 6 months in the ERCP suite was 54.8 (29.1) min compared with 67.9 (42.8) min for the cardiac catheterisation laboratory. This difference was not significant (p = 0.058; 95% CI 26.4 to 0.43). The mean fluoroscopy time for ERCP was 5.5 (4.1) min compared with 12 (10.9) min in the cardiac catheterisation laboratory (p < 0.001; 95% CI 9.17 to 3.85).

Table 2 lists the procedures performed under anaesthesia care in the cardiac catheterisation laboratory during the study period. These included patients with co-morbidities that precluded the provision of sedation by a non-anaesthetist, existing cardiac compromise, those requiring positive pressure ventilation, paediatric patients and those who required deep sedation.

The dosimeter readings for each of the four badges worn in the two areas were reported quarterly as total exposure in mSv. Total background exposure was also reported in mSv. Each specialty had a collar badge (facing outwards) and a waist badge (facing inwards). Four sets of readings per quarter were obtained for each badge. The equation for the calculation of the total net exposure and annual net exposure is given in Appendix 1. The data were analysed and compared separately for each quarter. The combined net exposure in the two specialties is given in Table 3. The combined net exposure over the 6-month study period was 2.6 mSv, with 0.28 mSv in the ERCP suite and 2.32 mSv in the cardiac catheterisation laboratory.

Table 1 Monthly radiation exposure of anaesthetists working in the ERCP suite and cardiac catheterisation laboratory. Values are number or mean (SD).

<table>
<thead>
<tr>
<th>Months</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>6th</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>Radiology (ERCP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Procedures</td>
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<td>116</td>
<td>100</td>
<td>182</td>
<td>105</td>
<td>74</td>
<td>645</td>
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<td>8</td>
<td>4</td>
<td>8</td>
<td>9</td>
<td>4</td>
<td>39</td>
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<tr>
<td>Duration of procedure; min</td>
<td>59.4 (25.4)</td>
<td>90.8 (67.2)</td>
<td>59.8 (20.4)</td>
<td>52.6 (14.6)</td>
<td>55.4 (21.4)</td>
<td>43.9 (18.3)</td>
<td>54.8 (29.1)</td>
</tr>
<tr>
<td>Fluoroscopy time; min</td>
<td>4.1 (1.6)</td>
<td>4.9 (2.9)</td>
<td>8 (4.6)</td>
<td>4.3 (3.3)</td>
<td>7.6 (5.6)</td>
<td>5.2 (4.8)</td>
<td>5.5 (4.1)</td>
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<td>Cardiac catheterisation laboratory</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procedures</td>
<td>92</td>
<td>105</td>
<td>120</td>
<td>107</td>
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<td>153</td>
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<tr>
<td>Procedures with anaesthetist involvement</td>
<td>10</td>
<td>11</td>
<td>22</td>
<td>13</td>
<td>12</td>
<td>18</td>
<td>86</td>
</tr>
<tr>
<td>Duration of procedure; min</td>
<td>108 (53.1)</td>
<td>62.5 (39.7)</td>
<td>63.3 (30.3)</td>
<td>73.4 (53.2)</td>
<td>41.5 (19.4)</td>
<td>69.9 (44.2)</td>
<td>67.9 (42.8)</td>
</tr>
<tr>
<td>Fluoroscopy time; min</td>
<td>19.1 (17.8)</td>
<td>9.8 (6.7)</td>
<td>10.9 (6.6)</td>
<td>18.5 (17.1)</td>
<td>6.7 (4.7)</td>
<td>10.5 (7.2)</td>
<td>12 (10.9)</td>
</tr>
</tbody>
</table>

Table 2 List of procedures performed in the cardiac catheterisation laboratory under anaesthesia care. Values are number of procedures.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Month 1</th>
<th>Month 2</th>
<th>Month 3</th>
<th>Month 4</th>
<th>Month 5</th>
<th>Month 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHC + PTCA</td>
<td>2</td>
<td>2</td>
<td>9</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>LHC + PTCA + TPM</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>LHC + PTCA + IABP</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>LHC</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>RHC</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<tr>
<td>PPM</td>
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<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
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<tr>
<td>ASD closure</td>
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<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
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<tr>
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<td>0</td>
<td>0</td>
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<td>0</td>
<td>1</td>
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<td>0</td>
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<tr>
<td>Aortic valvuloplasty</td>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Pulmonary valvuloplasty</td>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aortogram</td>
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<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<tr>
<td>PDA closure</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>VSD closure</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>IABP</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>11</td>
<td>22</td>
<td>13</td>
<td>12</td>
<td>18</td>
</tr>
</tbody>
</table>

LHC, left heart catheterisation; PTCA, percutaneous transcoronary angioplasty; TPM, temporary pacemaker; RHC, right heart catheterisation; IABP, intra-aortic balloon pump; ASD, atrial septal defect; PPM, permanent pacemaker; VSD, ventricular septal defect.
Radiation exposure is a significant concern for medical personnel performing interventional radiological procedures. The workload and complexity of such procedures have increased over the years without a corresponding increase in the number of medical specialists [6]. There have been several reviews on the risk of radiation exposure to the operator and the patient [7, 8]. Injury to DNA from ionising radiation (the stochastic or probabilistic effect) leads to an increased risk of developing cancer or genetic defects. Risk is cumulative with time and the effects are usually delayed. There is no known ‘safe’ dose below which an induced neoplasm does not occur [9]. The biological effect of radiation is measured in terms of ‘roentgen equivalents in man’ or ‘rem’, which relates the absorbed dose of radiation to its biological effect. The rem is equal to rad × quality factor (QF) where rad is the amount of energy deposited per unit weight of human tissue and QF is a number assigned to different types of ionising radiation depending on their ability to transfer energy to the cells of the body [10]. If one assumes a cancer risk of 20% for any population, then the total occupational exposure in rems multiplied by 0.04% has been used to estimate the increased occupational risk of cancer [11]. In an average interventional study, the operator receives approximately 0.004–0.016 rem. Should one receive 50 rem in a working life time e.g. in the cardiac catheterisation lab, the risk of cancer to the operator increases to: 50 × 0.04% + 20% = 22% [9].

The SI unit for radiation, the sievert (Sv), is equivalent to 100 rem [10].

The International Commission on Radiological Protection’s Publication 85 [12] lists staff exposure doses for various X-ray interventions. All radiation doses should be ‘as low as reasonably achievable’ [13]. The recommended maximum dose limits for exposure set by the International Commission on Radiological Protection is 20 mSv per year over a period of 5 years. [14].

Radiation exposure to staff is a function of three variables: time; distance; and barrier [15]. Anaesthetists have less control over the total radiation time as it is more dependent upon the operator performing the procedure and on the complexity of the procedure. The cumulative time is dependent upon the workload or number of cases performed over a certain time period. Our results have shown, more or less, an equal number of cases performed in both the ERCP suite and the cardiac catheterisation laboratory. The duration of procedures and fluoroscopy time was found to be significantly higher in the cardiac catheterisation laboratory than in the ERCP suite. The duration of procedures and requirements for anaesthesia are also dependent on the complexity of the procedures.

Distance (\(d\)) from the radiation source is an essential factor to reduce the dose effect of radiation. The power of the radiation beam is attenuated according to the inverse square law (\(1/d^2\)) [13]. It is advisable to move away from the radiation source whenever possible. According to Mehlmann et al. [16], exposure is minimal at a distance of more than 36 inches. However, patient care frequently mandates that the anaesthetist remain at the bedside, particularly during invasive procedures with monitored sedation, such as cardiac catheterisation and ERCP procedures, where it may be dangerous if the patient were to make any sudden movements. One limitation of our study was our inability to standardise the distance of the anaesthetists from the source of ionising radiation. This was considered impractical given the constant need for anaesthetists to change their position depending upon the type of procedure and type of anaesthesia. In addition, locations where anaesthesia is administered outside of the operating theatre are frequently cramped, limiting the ability of the anaesthetist to distance themselves adequately from the source of radiation.

The third important component, over which anaesthetists have more control, is the use of a barrier. A typical barrier includes a lead apron and thyroid collar. The protective shield material is ‘lead’ (actually a tin amalgam) and should be a minimum thickness of 0.5 mm lead equivalent. The sternum should not be exposed and a barrier includes a lead apron and thyroid collar. The wrap-around design is preferable to single aprons [4]. There should be no cracks or tears on visual inspection. A lead apron covers 82% of the active bone marrow, which still leaves a significant portion at risk to the effects of radiation [17]. During our study all anaesthetists wore protective lead aprons and thyroid shields (of 0.5 mm equivalent lead thickness) during the entire procedure.
Other important factors in providing adequate protection to staff include protective equipment quality control and staff education regarding the use of shielding devices and the impact of distance from radiation sources. Quality control requires periodic evaluation of radiologic equipment, including checking control devices and assessing the level of scatter. These parameters change as equipment ages. The use of appropriate techniques such as short bursts of fluoroscopic time should be mandatory [4].

Shook and Gross [15] have recommended that every anaesthetist involved in patient care in cardiac catheterisation laboratories should wear a dosimeter to track cumulative radiation exposure. A study by Katz in 2005 [17] looked at the radiation exposure of anaesthetists before and after the introduction of an electrophysiology laboratory. The aggregate radiation exposure for all members of the department doubled. The range of exposure levels was large, which made dosimeter tracking important. Vano et al. [18] stated that poor compliance with radiation badge policies was one of the main problems in many interventional cardiology services. Indeed it is possible that a lack of personal dosimeter use, rather than high levels of radiation protection, was responsible for the surprisingly low values of reported occupational radiation dose. McCormick et al. [19] reported that after a mandatory radiation protection training programme, physician and nurse clinician compliance with the radiation badge policy increased from 36% in 1999 to 67% in 2000 and 77% in 2001. We noticed that most of our anaesthetists were unaware of the use of TLD badges as they were not routinely worn in our hospital.

Various types of dosimeter have been employed for measuring radiation exposure. Thermo-luminescent dosimeters have been commonly used because of their small size. A previous systematic review [20] of studies on occupational radiation exposure identified that investigators used a variety of dosimeter position sites. These included the collar, trunk, eye, hand, pelvis or multiple sites to assess the effect of non-homogeneous radiation fields. They can be located over or under personal protection devices [20]. According to Niklason et al. [21], the effective radiation dose can be estimated based on two dosimeter readings, one reading being a dose measurement value under the lead apron and the other being a measurement from over the lead apron or thyroid shield. We opted for the dosimeters to be located at waist level under the lead apron, and on the collar site outside the thyroid shield. The effective dose is twofold higher when a thyroid shield is not used, because the thyroid shield protects much more than just the thyroid gland, including the underlying regions of skin, oesophagus, vertebrae, and bone marrow [21].

Our results confirm the finding of Durack et al. [5], that the radiation exposure of anaesthetists involved in procedures performed outside the operating room (such as those taking place in radiology suites) is within the acceptable limits of 20 mSv per year [14]. When extrapolating our 6-month study data to 1 year, the radiation dose did not cross these limits. However, our study differs from the study by Durack et al. [5] in several ways. They studied individual anaesthetists for a period of one calendar month and therefore did not account for any monthly variation in workload. Their study was limited to one area only i.e. the radiology suite. They did not describe the type of procedures except for ERCPs. In contrast we targeted two different areas outside the operating room where interventional radiological procedures were being performed under fluoroscopy. We conducted the study over a period of 6 months to get more real-time assessment of the workload and found that there was variation in the number of procedures performed each month. Endoscopic retrograde cholangiopancreatography procedures were generally elective and performed during routine working hours, whereas there were a variety of both elective and emergency procedures in the cardiac catheterisation laboratory that took place both within and outside of routine working hours. Another important difference between our study and that of Durack et al. [5] is that the latter conducted their study in a developed country where safety regulations are strictly followed; such standards may be lacking in developing countries. We were unable to identify any study reporting radiation exposure during interventional radiological procedures under fluoroscopy that was undertaken in our geographical region.

There are also substantial differences in occupational doses between different hospital settings [19, 22, 23]. This is caused by differences in: X-ray systems (old films-based systems vs digital units) and their particular settings; levels of training in radiation protection; and the frequency with which radiation protection equipment and personal dosimeters are used. In their 15-year follow-up of occupational exposure during interventional cardiology, Vano et al. [18] showed a significant reduction in the radiation exposure doses following the introduction of: more advanced and safer equipment; a systematic use of radiation facilities; and training in radiation protection.

Radiation exposure to staff is strongly dependent on the use of radiation protection measures and upon the operative condition of the X-ray tube being used. Buls et al. [3] found a higher level of radiation exposure to staff during ERCP procedures due to the use of inappropriate X-ray equipment. Over-couch tube X-ray units are not appropriate for performing interventional
radiology procedures [24], and studies of ERCP procedures [25–28] have either involved the use of this equipment or did not specify the equipment used. The fluoroscopy machine used in the ERCP suite of our hospital also had the X-ray tube above the couch and the image intensifier under the couch. This may indicate that ERCP procedures are often performed without adequate attention to the appropriate use of equipment.

Although our results suggest that radiation exposure is within the recommended safe limits, this should not lead to complacency. The overall workload and the number of cases undertaken in our institution may be different to other hospitals, another limitation of our study. Any increase in the number of cases will increase the occupational radiation exposure.

In conclusion, data from our study support earlier work suggesting that the radiation exposure of anaesthetists working in interventional radiology does not exceed the recommended dose limits set by the International Commission on Radiological Protection (20 mSv per year over 5 years) [14]. However, increased precautions can further reduce the exposure doses, especially those caused by scattered radiation. Care must be taken by medical personnel to achieve ‘as low as reasonably achievable’ exposure doses by adhering to good practice. Lead aprons and thyroid shields should be routinely used. A distance of at least 4 feet from the X-ray source should be maintained. Unnecessary exposure during the procedure should be avoided and necessary exposure limited by keeping the duration of radiation use to a minimum. There is also a need for tight quality control of radiological equipment, and education of the basics of clinical X-ray usage, techniques of shielding, dose monitoring and correct use of fluoroscopy.

**Acknowledgements**

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Appendix

Equation for calculation of total net exposure during study period and annual net exposure

Net exposure in each quarter = net collar reading (total – reference/background reading) + net waist reading (total – reference/background reading)

Combined net exposure during study period = net exposure in first quarter + net exposure in second quarter

Annual net exposure = combined net exposure × 2.