INFLUENCE OF STANDING POSITIONS AND BEAM PROJECTIONS ON EFFECTIVE DOSE AND EYE LENS DOSE OF ANAESTHETISTS IN INTERVENTIONAL PROCEDURES

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More and more anaesthetists are getting involved in interventional radiology procedures and so it is important to know the radiation dose and to optimise protection for anaesthetists. In this study, based on Monte Carlo simulations and field measurements, both the whole-body doses and eye lens dose of anaesthetists were studied. The results showed that the radiation exposure to anaesthetists not only depends on their workload, but also largely varies with their standing positions and beam projections during interventional procedures. The simulation results showed that the effective dose to anaesthetists may vary with their standing positions and beam projections to more than a factor of 10, and the eye lens dose may vary with the standing positions and beam projections to more than a factor of 200. In general, a close position to the bed and the left lateral (LLAT) beam projection will bring a high exposure to anaesthetists. Good correlations between the eye lens dose and the doses at the neck, chest and waist over the apron were observed from the field measurements. The results indicate that adequate arrangements of anaesthesia device or other monitoring equipment in the fluoroscopy rooms are useful measures to reduce the radiation exposure to anaesthetists, and anaesthetists should be aware that they will receive the highest doses under left lateral beam projection.

INTRODUCTION

During X-ray guided interventional radiology procedures, medical staff are exposed to high radiation dose since they work in a fluoroscopy room with large amount of scattered radiation. The primary operators who usually stay longer and stand closer to the patient’s right side are most likely to receive the highest exposure among all staff involved in interventional procedures. The radiation exposure to the primary operator has been widely investigated and measures of radiation protection were also recommended¹–⁴.

With the rapid popularisation and development of new techniques in interventional radiology, more and more anaesthetists who operate the anaesthesia device and check other monitoring equipment are involved in the clinical procedures for the patient care. During interventional procedures, the anaesthetists usually stay shorter time in the fluoroscopy room than the primary operators. It was thought that their radiation exposure would be lower than the primary operators. However, recent surveys indicated that their exposure could also be relatively high. Anastasian et al.⁵ found that the averaged radiation exposure to anaesthetists’ face was >3-fold of the exposure to radiologists in the neurointerventional suite. Ismail et al.⁶ reported that the averaged dose to anaesthetists was 0.28 mSv for an endoscopic retrograde cholangiopancreatography procedure and 2.32 mSv in cardiac catheterisation suite over 6 months. Routine monitoring of radiation for anaesthetists working in the cardiac catheterisation laboratory was also suggested by Henderson et al.⁷.

Compared with the primary operators, the anaesthetists usually stand on the left side or the head side of the patients, and their standing positions are more flexible. It is thought that their exposure can be reduced by changing their standing positions and trying to avoid the main scattered radiation according to the X-ray beam projections. In this work, based on Monte Carlo simulations, both the effective dose and eye lens dose of anaesthetists were calculated under different irradiation conditions. The effect of four standing positions of anaesthetists and some common beam projections on the effective dose and eye lens dose were studied and partially compared with field measurements. Furthermore, the correlations between the eye lens dose and personal dose equivalent \( H_p(10) \) over apron were also estimated.

MATERIALS AND METHODS

Simulations

For Monte Carlo simulations, the software MCNPX version 2.5.0 was used⁸. Similar scenarios, which were observed during the field measurements of this study for anaesthetists were simulated in the Monte Carlo set-up. A modified ORNL-MIRD phantom⁹,
was used as a patient and the reference male voxel phantom\(^{(10)}\) was used to represent an anaesthetist. In all simulations, the anaesthetist wears a 0.5-mm Pb lead apron, which fits well to the body with a thyroid shield.

An X-ray spectrum corresponding to a tube voltage of 80 kV\(_p\) with a filtration of 3 mm Al was used. The X-ray photons were supposed to emit from a point source and collimated into a cone with a field diameter at the entrance of the image intensifier of 40 cm and the distance from source to detector was fixed to 90 cm. The image intensifier was simplified to be a radiation absorber and the thickness of the window was set to be 1.5 mm Al.

The four mostly observed standing positions of anaesthetists in the field measurements of this study are illustrated in Figure 1 and the X-ray beam projections are illustrated in Figure 2. For the head irradiation, seven X-ray beam projections were considered, namely as posterioro-anterior (PA), right anterior oblique (45°RAO), left lateral (LLAT), right lateral (RLAT), left anterior oblique (45°LAO), caudal (30°CAUD) and cranial (30°CRAN). For the thorax irradiation, five projections were considered, i.e. PA, 45°RAO, 45°LAO, LLAT and RLAT.

The energy deposition in different organs or tissues was calculated by using F6 tally in the MCNP code in the voxel model representing anaesthetists. Based on the calculated organ doses and the tissue weighting factors recommended in ICRP 103, the effective dose was summed up over the equivalent doses for all organs and tissues. Eye lens dose was calculated in a small volume of 3-mm depth at the eye positions to represent \(H_{p}(3)\). As the simulation results of MCNPX were normalised by the number of simulated particles in order to compare the results with the measured quantity, the calculated doses were further normalised to the kerma area product (KAP) in this work. Therefore, along the beam axis, a thin air layer between the X-ray focal spot and patient was constructed to simulate the KAP value, which is the product of the air kerma to the layer and the area of the X-ray beam on the layer.

The number of simulated source photons was set to be \(\sim 10^8\) for all simulations. Assuming the organ factors including size and density to be constant, the uncertainty of the effective dose or \(H_{p}(3)\) was propagated from the uncertainty of calculated organs/tissue doses. The uncertainty of effective dose was <5 %, and the uncertainty \(H_{p}(3)\) was generally <10 %.

**Measurements**

Field measurements were carried out for 12 neurology (INR), 10 radiofrequency ablation (RFA) and 9 vertebroplasty interventional procedures in two Belgian hospitals. Information including the standing positions of anaesthetists, total KAP, exposure time and shielding facilities was also recorded during the measurements.

For each procedure, the eye lens dose of anaesthetists was measured by the Eye-D\(^{(14)}\) dosemeter which was calibrated against \(H_{p}(3)\). This dosemeter is composed of an MCP-N (LiF: Mg,Cu,P) type of thermoluminescent detector (TLD) and an optimised polyamide capsule. The lower limit of detection (LLD) for the dosimeter was estimated as twice its background variation (2\(\sigma_{BG}\)). Four chips of the TLDs were kept in the laboratory as background control. If the readout value of the TLD was lower than the LLD, the value was recorded as half of the LLD value\(^{(12)}\).

For each procedure, four DIS-1 dosemeters\(^{(13)}\) were used to monitor the personal dose equivalent \(H_{p}(10)\) at the level of the neck over the thyroid collar, the waist over the apron and the chest level over and under the apron. DIS dosemeters were positioned on the side facing the X-ray tube. Therefore, in cases where the anaesthetist turned away from the X-ray tube, the DIS was positioned on his back. The effective dose was estimated with different single and double-dosimetry algorithms for interventional radiology personnel, with the \(H_{p}(10)\) measured at the neck over the thyroid collar and chest level under the apron. These results are also compared with the calculated effective doses. Additionally, correlations between eye lens dose and \(H_{p}(10)\) values over apron at those three sites were also explored, respectively.

The DIS detector was tested within the ORAMED project in a scattered radiation field, and its overall uncertainty was \(\sim 20\% (2\sigma)\). For TLDs, a 20 % (2\(\sigma\)) measurement uncertainty was also considered\(^{(15)}\).

**RESULTS AND DISCUSSION**

**Calculated effective dose**

The normalised effective dose \((E/KAP)\) of an anaesthetist in different conditions of standing positions and beam projections were calculated and are shown in Figure 3. As shown in Figure 3, the normalised effective doses depend not only on the standing
positions, but also on the beam directions. For the head irradiation, the highest dose of 0.096 μSv (Gy$^{-1}$ cm$^{-2}$) at the P-2 position under LLAT projection is \( \sim 12 \) times higher than the lowest of 0.007 μSv (Gy$^{-1}$ cm$^{-2}$) at the P-4 position under 45° LAO. While for the thorax irradiation, the highest of 0.156 μSv (Gy$^{-1}$ cm$^{-2}$) at the P-3 position under LLAT projection is 13 times higher than the lowest of 0.011 μSv (Gy$^{-1}$ cm$^{-2}$) at the P-4 position under 45° LAO.

For the head irradiation, the effective doses at P-1, P-2, P-3 and P-4 were averaged to be 0.059, 0.046, 0.035 and 0.016 μSv (Gy$^{-1}$ cm$^{-2}$) for the seven different beam projections, respectively. For the thorax irradiation, the doses at P-1, P-2, P-3 and P-4 were averaged to be 0.037, 0.042, 0.059 and 0.033 μSv (Gy$^{-1}$ cm$^{-2}$) for the five different beam projections, respectively. The results are reasonable because P-1 for the head irradiation and P-3 for the thorax irradiation are closer to the centre of radiation fields than the position of P-4. Therefore, in order to reduce the radiation exposure to anaesthetists, it is suggested to set the anaesthesia device and other monitoring equipment as far away from the bed as possible provided the changes of positions do not affect the patient care during the interventional procedures.

Furthermore, it is found that the doses to anaesthetists at the same position are always the highest under LLAT projections among the different beam projections. It suggests that the anaesthetists should avoid staying at their positions when the beam is on with the LLAT projection. However, from the viewpoint of radiation exposure, the LLAT projection is generally preferable for primary operators\(^5\), \(^6\). Therefore, under the instructions of primary operators, a selection of a reasonable time to enter the fluoroscopy room can also reduce the radiation exposure to anaesthetists.

**Calculated eye lens dose**

The normalised eye lens dose (\( H_p(3)/KAP \)) of an anaesthetist in different conditions of standing positions and beam projections were calculated and are shown in Figure 4. As shown in Figure 4, the normalised eye lens doses depend on not only the standing positions, but also on the beam directions. For the head
irradiation, the highest dose of 2.228 μSv (Gy⁻¹ cm²⁻²) at P-1 under RLAT projection is 500 times higher than the lowest of 0.004 μSv (Gy⁻¹ cm²⁻²) at P-2 under 45° LAO. While for thorax irradiation, the highest dose of 2.399 μSv (Gy⁻¹ cm²⁻²) at P-1 under RLAT projection is nearly 200 times of the lowest of 0.012 μSv (Gy⁻¹ cm²⁻²) at P-2 under 45° LAO.

Under different beam projections, the averaged eye lens doses are 1.305, 0.278, 0.555 and 0.281 μSv (Gy⁻¹ cm²⁻²) at P-1, P-2, P-3 and P-4 for the head irradiation, and 1.209, 0.321, 0.955 and 0.522 μSv (Gy⁻¹ cm²⁻²) for the thorax irradiation, respectively. The dose at P-1 presents the highest dose among the four positions. It suggests that the anaesthetists should avoid staying at P-1 during the interventional procedures and facing to the patients.

Furthermore, it is also found that the eye lens doses of anaesthetists are generally much higher under LLAT or RLAT projections than under other beam projections. It also suggests that the anaesthetists should avoid staying at their positions when the beam is on with the LLAT or RLAT projections.

**Comparisons**

By applying the algorithms for the estimation of the effective dose suggested by other researches, the effective doses for anaesthetists during INR procedures were calculated and is shown in Table 1. As listed in Table 1, compared with single dosimetry (SD), more narrow ranges of effective dose values are found with the double dosimetry (DD). It implies that the DD will give a more stable result, while the SD is more likely to lead to a larger deviation. For the averaged dose, different algorithms lead to a maximal difference by a factor of over 5. As these algorithms were suggested for main operators during interventional procedures, further studies are still needed to provide a more accurate algorithm to estimate the effective dose of anaesthetists.

![Diagram](Figure 4. Eye lens dose of anaesthetists calculated under different conditions: (a) head irradiation and (b) thorax irradiation.)

**Table 1. Comparisons among effective doses derived from different algorithms for 12 INR procedures.**

<table>
<thead>
<tr>
<th>Positions of dosemeters</th>
<th>Algorithm a</th>
<th>Effective dose b (μSv (Gy⁻¹ cm²⁻²))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single dosimetry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huyskens et al. (1994)</td>
<td>$H_u$: trunk under apron $H_o$: trunk over apron</td>
<td>$E = 3 H_u$ $E = 0.2 H_o$</td>
</tr>
<tr>
<td>McEwan (2000)</td>
<td>$H_u$: trunk under apron $H_o$: collar over shield</td>
<td>$E = 0.71 H_u + 0.05 H_o$</td>
</tr>
<tr>
<td>Double dosimetry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wambersie et al. (1993)</td>
<td>$H_u$: chest under apron $H_o$: neck/shoulder over shield</td>
<td>$E = H_u + 0.1 H_o$</td>
</tr>
<tr>
<td>McEwan (2000)</td>
<td>$H_u$: trunk under apron $H_o$: collar under shield</td>
<td>$E = 0.71 H_u + 0.05 H_o$</td>
</tr>
<tr>
<td>Clerinx et al. (2008)</td>
<td>$H_u$: chest under apron $H_o$: neck over shield</td>
<td>$E = 1.64 H_u + 0.075 H_o$</td>
</tr>
<tr>
<td>von Boetticher (2010)</td>
<td>$H_u$: chest under apron $H_o$: neck over shield</td>
<td>$E = 0.84 H_u + 0.051 H_o$</td>
</tr>
</tbody>
</table>

a$H_u$ and $H_o$ represent $H_{P(10)}$ under or over apron/thyroid shield.
bDose value is exhibited as mean (min–max).
During this study, both the effective dose and eye lens dose for >30 anaesthetists were monitored. For easy comparisons, both the simulated and measured doses were normalised to the KAP first, and then the comparison result is listed in Table 2. As seen from Table 2, simulated doses are in a reasonable range compared with measured ones. The variances may arise from the different dimensions between the standard voxel phantom and the anaesthetists. Moreover, the exact position and movement of the anaesthetist are also hard to be accurately simulated.

As shown in Table 2, the normalised dose in average differs from the procedure types, with the highest for the RFA procedure. Furthermore, even for the same type of procedure, the dose also obviously varies among different measurements. Anaesthetists were not always in the fluoroscopy room, they entered the room only when needed during the procedure. Besides the total exposure time for anaesthetists were different, the beam projections were not necessary the same when they entered the rooms. However, the authors still have a strong impression that if the anaesthetist stayed significantly longer, their doses are higher. The eye lens dose of the anaesthetists was averaged to be 68 mSv per INR procedure in this study. It was 10 times higher than the value (6.5 ± 5.4 mSv) in similar quantity (exposure to the face) reported by Anastasian et al. (5). In Anastasian’s study, there was a shield between the anaesthetist and fluoroscopy equipment, while there was not any protection shield for the anaesthetists in this work. It indicates that an additional shield set between the anaesthetist and fluoroscopy equipment may significantly reduce the eye lens dose of anaesthetists.

Table 2. Comparisons between the simulated and measured dosea.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>No.</th>
<th>Positions</th>
<th>Effective dose, mean (range)</th>
<th>Eye lens dose, mean (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>INR (head)</td>
<td>12</td>
<td>P-2, P-3, P-4</td>
<td>0.019 (0.001–0.039)</td>
<td>0.384 (0.093–1.353)</td>
</tr>
<tr>
<td>Vertebroplasty (thorax)</td>
<td>9</td>
<td>P-2, P-3</td>
<td>0.071 (0–0.159)</td>
<td>0.592 (0.144–1.337)</td>
</tr>
<tr>
<td>RFA (thorax)</td>
<td>10</td>
<td>P-1</td>
<td>0.092 (0–0.268)</td>
<td>2.208 (0.504–5.422)</td>
</tr>
<tr>
<td>Simulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INR (head)</td>
<td></td>
<td>P-2, P-3, P-4</td>
<td>0.032 (0.007–0.096)</td>
<td>0.371 (0.004–1.287)</td>
</tr>
<tr>
<td>Vertebroplasty (thorax)</td>
<td></td>
<td>P-2, P-3</td>
<td>0.050 (0.013–0.156)</td>
<td>0.638 (0.012–2.246)</td>
</tr>
<tr>
<td>RFA (thorax)</td>
<td></td>
<td>P-1</td>
<td>0.037 (0.024–0.056)</td>
<td>1.209 (0.536–2.399)</td>
</tr>
</tbody>
</table>

*aThe unit of dose is in μSv (Gy⁻¹ cm⁻²). Measured effective doses were estimated based on von Boetticher’s algorithm (2010). The simulated doses were summarised over seven and five beam projections for head and thorax irradiation, respectively.

CONCLUSION

In this study, based on Monte Carlo simulations and field measurements, both the effective dose and eye lens dose of anaesthetists in some interventional procedures were studied. The results showed that the radiation exposure to anaesthetists depends not only on their standing positions, but also on the beam projections used during interventional procedures.

In general, a close position to the bed and the left lateral (LLAT) beam projection will deliver a higher exposure to anaesthetists. The eye lens dose of an anaesthetist may reach several tens of microSieverts in a single procedure. Reducing stay time in the fluoroscopy room, enlarging distance and radiation shield can reduce their radiation dose. Adequate arrangements of anaesthesia device or other monitoring equipment in the fluoroscopy rooms are useful measures to reduce the radiation exposure to anaesthetists. Anaesthetists should be aware to avoid to enter the fluoroscopy room during procedures.
Further research works are still needed to study the effects of different thicknesses of the lead apron and the X-ray filtration, different postures of the anaesthetist at work, and so on.

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