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Radiation dose to multidisciplinary staff members during complex interventional procedures

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ABSTRACT

Introduction: Complex interventional radiology procedures involve extensive fluoroscopy and image acquisition while staff are in-room. Monitoring occupational radiation dose is crucial in optimization. The purpose was to determine radiation doses received by staff involved in complex interventional procedures performed in a dedicated vascular or neuro intervention room.

Methods: Individual real-time radiation dose for all staff involved in vascular and neuro-interventional procedures in adult patients was recorded over a one-year period using wireless electronic dosimeters attached to the apron thyroid shield. A reference dosimeter was attached to the C-arm near the tube housing to measure scattered, unshielded radiation. Radiology staff carried shoulder thermoluminescent dosimeters with monthly read-out to monitor dose over time.

Results: Occupational radiation dose was measured in 99 interventional procedures. In many cases prostate artery embolization procedures exposed radiologists to high radiation doses with a median of 15.0 μSv and a very large spread, i.e. 0.2–152.5 μSv. In all procedures except uterine fibroid embolization radiographers were exposed to lower doses than those of radiologists, with endovascular aortic repair being the procedure with highest median exposure to assisting radiographers, i.e. 2.2 μSv ranging from 0.1 to 36.1 μSv. Median radiation dose for the reference dosimeter was 670 μGy while median staff dose for all procedures combined was 3.2 μGy.

Conclusion: Radiation doses for multiple staff were determined and the ratio between staff dose and reference dosimeter indicated proper use of shielding in general. Some high-dose procedures may need further optimization for certain staff members, especially those not primarily employed in radiology.

Implications for practice: The study provides benchmark doses that may be used widely in audits and in the ongoing effort to optimize radiation protection for staff in interventional radiology.

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Introduction

The number of interventional radiology (IR) procedures is rising10 and the length of fluoroscopy guided procedures involves high risk of occupational radiation exposure.3 Complex procedures involving multidisciplinary team efforts, such as endovascular aortic repair (EVAR), embolization treatment and transjugular intrahepatic portosystemic shunt (TIPS) procedures require extensive fluoroscopy and intra-operative image acquisition, sometimes using oblique views where protective lead shielding may be suboptimal.4 Even though the radiation doses received by staff is much lower than those of the patients, the cumulative dose to staff may be substantial over time.5 Therefore, interventional radiologists, radiographers and other staff involved face a higher cancer burden and increased risk of cataract and/or opacities in the eye lenses.6–8

Considerable variation in occupational exposure has been observed suggesting that radiation protection practice can be improved, this with the inclusion of additional lead-shielding both on the patient and freestanding in the room.15,10 Furthermore studies suggest, that complex procedures completed without protection of extra lead shields might lead to operators exceeding the recommended maximum annual eye lens radiation dose.11,12
Previous studies assessed radiation dose to the main operators during EVAR in a hybrid room setting, but only few also assesses dose for floor radiographers and anechistic staff who often sit in a potentially more exposed place close to the patient.2-11,17 A study assessing radiation dose to anesthetists during prostatic embolization revealed that eye doses may exceed 500 mSv with one weekly procedure.14 Relatively high occupational doses during TIPS was previously reported,13,15 but no studies focused on other than radiologist dose and most studies are of older date supposedly using less advanced, less dose efficient equipment. Regarding trans-arterial chemoembolization (TACE), only one study of older date (2006) and thus supposedly not comparable to current equipment was identified.18

The purpose of this prospective evaluation was to determine radiation doses received by staff involved in complex interventional procedures performed in a dedicated vascular or neuro-interventional room.

Methods

Ethical approval for this prospective, observational single-center study was waived by The Regional Committees on Health Research Ethics South for Southern Denmark (Journal No. S-20232000–132).

Before each procedure verbal consent was obtained from all staff involved.

We prospectively measured personal real-time radiation dose for all staff involved in vascular and neuro-interventional procedures in adult patients, i.e. radiologists, radiographers, vascular surgeons, surgical and anesthetic nurses, and occasionally a gastro-enterologist. Radiation dose was recorded using Raysafe I2 wireless electronic personal dosimeters (EPD) (Fluke Medical, Cleveland, US). Dosimeters were attached to the apron thyroid shield, i.e. above the apron to obtain an estimate of the eye lens dose.3 The reliability of the dosimeter in terms of angular dependence, linearity, dose-rate dependence and reproducibility was proven by Inaba et al. (2014).13 Before each procedure the dosimeter equipment was reset. Radiation dose was measured for all involved staff who were blinded to the dose measurements during procedures. Mobile phones were kept away from the dosimeters to avoid interference. Furthermore, Radiologists and radiographers carried shoulder thermo-luminescence (TLD) dosimeters which were routinely read-out monthly. Data collection was done during April 2022 to February 2023 and included the following procedures:

- EVAR incl. Thoracic EVAR (TEVAR)
- TIPS
- TACE
- Prostate artery embolization (PAE)
- Uterine Fibroid embolization (UFE)
- Neuro-interventional procedures, such as embolization and thrombectomy

Neuro-interventions were performed using a bi-plane angio suite (Allura Xper FD20, Philips, Amsterdam, NL). All other procedures were performed using dedicated interventional equipment (Artis Zee, Siemens Healthineers, Erlangen, DE). All procedures utilized tube-under-couch technique and frame rate was 7.5 and 2 frames/s in fluoroscopy and acquisition, respectively.

Scattered radiation was measured using a reference dosimeter attached to the C-arm near the X-ray tube housing as recommended by af Vano et al. (2020).13 Staff were allowed to add and adjust radiation protection devices such as lead glass walls and screens, lead curtains, soft radiation protection pads etc. as they saw fit.

Statistics

All results are presented descriptively using median, interquartile range (IQR) and min/max value. Relative exposure was determined as personal dose percentage of unshielded procedural DAP and correlation between personal dose and dose area product was assessed using linear regression analysis. Observations with dosimeter read-out = 0 µSv were interpreted as dosimeter failure and were treated as missing. Statistical analysis was performed using STATATA BE/17 (Statacorp, Texas, US).

Results

Occupational radiation dose was measured in 99 interventional procedures. In many cases prostate artery embolization procedures exposed radiologists to high radiation doses with a median of 15.0 µSv with a very large spread, i.e. 0.2–152.5 µSv. In all procedures except uterine fibroid embolization radiographers were exposed to lower doses than those of radiologists, with EVAR being the procedure with highest median exposure to assisting radiographers, i.e. 2.2 µSv ranging from 0.1 to 36.1 µSv. An overview of procedures and involved staff is presented in Table 1.

Median procedure time, fluoroscopy time and Dose Area Product for each procedure is presented in Table 2.

Median radiation dose for the reference dosimeter was 670 µGy while median staff dose for all procedures combined was 3.2 µGy; i.e. <1% indicating proper use of shielding in general. Overall staff dose and procedural DAP as measured by unshielded reference dosimeter were highly correlated; Pearson’s r = 0.81, p < 0.0001.

TLD shoulder dosimeters carried by radiologists (n = 4) and radiographers (n = 19) recorded mean radiation doses of 0.17 mSv (SD = 0.14) for radiologists and 0.03 mSv (SD = 0.02) for radiographers.

Both groups had a slight negative trend over time with a mean monthly decrease of 0.03 mSv, p = 0.051 for radiologists and 0.04 mSv, p = 0.016 for radiographers (Fig. 1).

Discussion

In this prospective study we investigated occupational radiation doses to multiple staff during a variety of interventional radiology procedures.

In 2017 Sailer et al.3 made a comprehensive clinical investigation on staff radiation in vascular interventional practice, which showed median radiation dose (33.4 µSv, range 1.2–614.0) for the operating radiologist measured at chest-high with real-time monitoring during 60 EVAR-procedures. Setup and procedure was comparable to our study, except that the procedures were performed in a hybrid operating theatre where additional shielding was not feasible. Thus, lead-shielding apart from personal aprons was not used in their setup and resultantly we found lower doses both for radiologists and radiographers underscoring the general effect of extensive use of lead-shielding, as demonstrated in numerous studies.3,9,10,12,13,22

During TIPS procedures the gastro-enterologist stands very close to the radiation field while performing ultrasound and fluoroscopy guided needle positioning resulting in very high dose (70.0 µSv). Improved shielding or alternative position should be considered.

Prostate artery embolization procedures exposed radiologists to very high radiation doses with a median of 15.0 µSv and a very large spread, i.e. 0.2–152.5 µSv. The procedure often encompasses difficult micro-catheter positioning resulting in elongated procedure and fluoroscopy time as indicated in a median fluoroscopy time of...
42.2 min similar to that of neuro-intervention procedures that also encompass micro-catheter positioning.

Similarly, a large spread in neuro-radiology procedures partly caused by diversity of included procedures, i.e. arterio-venous malformation embolization (n = 2), aneurism coil procedures (n = 11), aneurism embolization (n = 4), spinal angi (n = 1), carotid stenting (n = 1) and thrombectomy (n = 1). The equipment used for other than neuro-interventions was equipped with vendor-specific protocols shown to reduce radiation dose. The lack of such protocols in the neuro-intervention suite may explain the relatively high DAP-values in neuro-procedures.

In all procedures except uterine fibroid embolization assisting radiographers were exposed to lower doses than radiologists, with EVAR being the procedure with highest median exposure to the assisting radiographer, i.e. 2.2 μSv ranging from 0.1 to 36.1 μSv. In EVAR procedures the collimated field is quite large compared with the remainder and probably the radiographer cannot to the same degree seek shielding behind the radiologist during fluoroscopy and image acquisition, which can occur even though it may not be viewed as best practice. During EVAR anesthetic nurses reached median dose higher than that of radiographers and occasionally reached a single-procedure dose almost twice as high as the maximum dose to the radiologist, i.e. 89.6 versus 57.8 μSv. The anesthetic nurse sits near the patient’s head and may in some cases not have used additional shielding. This should be explored further in order to improve radiation protection for this group who does not have main responsibility for local staff safety.

A strong correlation between the overall staff dose and procedural DAP was demonstrated indicating that the protective measures were used consistently, as inconsistent use would have affected the ratio between staff dose and the reference dosimeter. The overall dose as measured by TLD shoulder dosimeters showed a slight negative trend over the study period. Though only statistically significant for radiographers, the trend may be caused by increased awareness of radiation protection as a result of participation in the study.

The study has a few limitations. The actual position of each staff member was not recorded and thus dose differences caused by different distance to the patient could not be further explored. However, as demonstrated by Dorman et al. (2023) increasing distance from the primary beam is a simple and effective protective measure.

In our study staff were blinded to the dose measurements during procedures. Presenting real-time results using an in-room monitor might be beneficial, but this was not possible in our current setup.

### Table 1
Median procedural radiation dose in units of μSv, IQR and range for different procedures and staff.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Total no. of procedures</th>
<th>Involved staff, no. of measurements</th>
<th>Median radiation dose, μSv (IQR; range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVAR 37</td>
<td>Radiologist, 36</td>
<td>3.5 (10.8; 0.1–57.8)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiographer, (assisting) 37</td>
<td>2.2 (5.4; 0.1–36.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiographer, (floor) 26</td>
<td>0.6 (0.7; 0.1–72.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vascular surgeon, 29</td>
<td>1.3 (5.7; 0.1–19.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anesthetic nurse, 35</td>
<td>2.5 (11.4; 0.1–89.6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgical nurse, 31</td>
<td>1.8 (5.8; 0.1–44.6)</td>
<td></td>
</tr>
<tr>
<td>TIPS 8</td>
<td>Radiologist, 8</td>
<td>5.5 (11.5; 1.2–46.3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiographer, (assisting) 8</td>
<td>0.6 (1.4; 0.1–5.9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiographer, (floor) 6</td>
<td>0.7 (1.1; 0.2–2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gastro-enterologist, 8</td>
<td>7.0 (5.5; 3.2–17.0)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anesthetic nurse, 7</td>
<td>1.3 (2.2; 0.1–9.6)</td>
<td></td>
</tr>
<tr>
<td>TACE 11</td>
<td>Radiologist, 7</td>
<td>2.5 (4.6; 0.2–8.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiographer, (assisting) 8</td>
<td>0.4 (2.4; 0.1–4.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiographer, (floor) 10</td>
<td>0.5 (0.9; 0.1–3.4)</td>
<td></td>
</tr>
<tr>
<td>PAE 15</td>
<td>Radiologist, 15</td>
<td>15.0 (51.7; 0.2–152.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiologist, (assisting) 10</td>
<td>13.3 (3.3; 0.1–28.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiographer, (assisting) 15</td>
<td>8.9 (8.1; 0.1–46.7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiographer, (floor) 15</td>
<td>4.6 (8.7; 0.4–16.0)</td>
<td></td>
</tr>
<tr>
<td>UFE 8</td>
<td>Radiologist, 6</td>
<td>0.5 (8.8; 0.1–41.7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiographer, (assisting) 6</td>
<td>1.2 (1.9; 0.2–10.0)</td>
<td></td>
</tr>
<tr>
<td>Neuro 20</td>
<td>Radiologist, 20</td>
<td>5.3 (3.8; 0.5–218.6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiologist, (assisting) 7</td>
<td>4.5 (4.3; 0.5–18.9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiographer, (assisting) 18</td>
<td>1.6 (0.1; 0.1–51.0)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiographer, (floor) 18</td>
<td>0.5 (0.8; 0.1–1.9)</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2
Median procedure time, fluoroscopy time and Dose Area Product (DAP) for each procedure. IQR: Inter-Quartile Range. *Dosimeter data missing in one EVAR and one Neuro, thus total n = 97.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>n</th>
<th>Procedure time, minutes (IQR)</th>
<th>Flouro time, minutes (IQR)</th>
<th>DAP Flouroscopy, μGy·m² (IQR)</th>
<th>DAP Exposure, μGy·m² (IQR)</th>
<th>DAP Total, μGy·m² (IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVAR 36*</td>
<td>112.5 (82.5)</td>
<td>12.0 (13.5)</td>
<td>3842.3 (5941.8)</td>
<td>9858.4 (9490.4)</td>
<td>14,125.5 (13,724.2)</td>
<td></td>
</tr>
<tr>
<td>TIPS 8</td>
<td>180.0 (100.0)</td>
<td>31.0 (19.4)</td>
<td>3006.2 (2856.9)</td>
<td>4558.5 (2977.4)</td>
<td>7564.0 (6595.3)</td>
<td></td>
</tr>
<tr>
<td>TACE 11</td>
<td>70.0 (45.0)</td>
<td>19.0 (18.2)</td>
<td>14680.0 (3184.2)</td>
<td>39336.0 (7311.3)</td>
<td>48775.0 (10,651.6)</td>
<td></td>
</tr>
<tr>
<td>PAE 15</td>
<td>120.0 (65.0)</td>
<td>42.2 (26.5)</td>
<td>9812.3 (109,884.0)</td>
<td>26,722.0 (26,218.7)</td>
<td>38,611.0 (22,825.0)</td>
<td></td>
</tr>
<tr>
<td>UFE 8</td>
<td>75.0 (57.5)</td>
<td>25.2 (14.0)</td>
<td>1479.6 (2467.0)</td>
<td>1482.0 (3232.8)</td>
<td>3580.5 (4651.0)</td>
<td></td>
</tr>
<tr>
<td>Neuro 19*</td>
<td>185.0 (80.0)</td>
<td>40.4 (36.4)</td>
<td>6590.6 (16,179.6)</td>
<td>52719.0 (5374.6)</td>
<td>17,125.7 (77,180.0)</td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

This study determined radiation doses for multiple staff members and the ratio between staff dose and reference dosimeter indicated proper use of shielding in general. Some high-dose procedures may need further optimization for certain staff members, especially those not primarily employed in radiology.

Conflict of interest statement

The authors declare that they have no conflict of interest.

Ethical approval

All procedures performed in the study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Acknowledgments

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