A study on patient skin doses in cerebral embolisation using radiochromic films

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Aims and objectives

Fluoroscopically-guided interventional neuroradiology (INR) is being increasingly utilised in treatment of cerebral aneurysms, arteriovenous malformations (AVM) and dural arteriovenous (AV) fistulas. Such interventions are minimally invasive and allow complex vascular lesions to be treated. However, INR procedures are associated with long fluoroscopy times and high skin doses to the patients. As a result, several reports describing acute radiation-induced skin injuries have been published in the recent years [1-5].

Skin doses for INR procedures have been investigated by several studies. Single or arrays of thermoluminescent dosimeters (TLDs) or photoluminescence dosimeters (PLDs) were used to measure the skin doses and investigate the dose distributions. Giles and Murphy [15] have assessed the Gafchromic-XR radiochromic films in terms of dose linearity, energy dependence and suitability for monitoring doses in interventional radiology procedures. It was concluded that radiochromic films are a simple and reliable method to assess localised skin doses and dose distributions.

Christie Medical Physics and Engineering provide Medical Physics Expert advice for a number of hospitals in the North West region of England. This study was set-up following a report of hair loss for two patients in a neurointerventional suite in 2011. The aim of this study was to measure the maximum entrance skin doses for fifty patients undergoing cerebral embolisation (CE) using radiochromic films.
Methods and materials

Digital Subtraction Angiography X-ray unit

A Philips Integris Allura biplane digital subtraction angiography (DSA) X-ray system was used. The system offers a choice of three fluoroscopy modes (low, normal and high) and three frame rates (2 frames/second, 3 frames/second and 6 frames/second). Four field sizes are available for the posterior-anterior (PA) plane and three for the lateral (LAT) plane. The smallest field size (13 cm) and hence, the highest magnification was used for both planes and for all procedures. For the embolisation of aneurysms and AVMs, 3 frames/second and 6 frames/second were used respectively. For all procedures, the low fluoroscopy mode was used. The entrance patient dose rates for the fluoroscopy mode and for the small magnification were 13.6 mGy/min and 10.3 mGy/min for the PA and LAT plane.

Both X-ray tubes are equipped with dose-area product (DAP) meters. The total DAP and entrance surface dose (CESD) for the two planes are displayed and recorded for the fluoroscopy and DSA mode separately.

The DAP meters for both X-ray tubes are calibrated by Christie Medical Physics and Engineering as part of the routine quality control. As the x-ray system displays the total DAP for both X-ray tubes, an average DAP calibration factor for both planes was applied to the recorded DAP values. The half-value layers (HVL) measured at 80 kV were 5.6 mm Al equivalent and 4.7 mm Al equivalent for the PA and LAT X-ray tubes respectively.

Radiochromic films

Gafchromic RTQA-2 (ISP,Ashland,New Jersey) radiochromic films were used to measure the maximum entrance skin dose (MESD) and to visualise the radiation fields. RTQA-2 radiochromic films consist of an opaque white backing material and orange coloured transparent front polyester cover with an active layer of 17 µm thickness. The recommended dose range is 0.2 Gy to 8 Gy.

Three batches of RTQA-2 films were used in this study. Calibration curves were obtained for the three batches separately. The films were calibrated on a GE Advantx (GE Healthcare) cardiac angiographic X-ray system. The HVL of the cardiac X-ray system was 6 mm Al equivalent, which closely matches the HVL of the DSA X-ray system. A 2 mm thick copper sheet was placed at the back surface of the phantom to increase the tube voltage to 75 kV. The films were cut into small pieces (5x5 cm²) and placed on the front surface of a perspex block with dimensions of 30x30x10 cm³. The dose
to the films was measured using a 6 cm$^3$ ionisation chamber (Radcal, California), with calibration traceable to national standards, coupled to an Accu Pro 9096 multi-purpose meter (Radcal, California) placed in between the front surface of the perspex block and the films. Self-attenuation correction factors were applied to the measured doses. A transmission densitometer DT 1105 (R. Y. Parry Ltd) was used to measure the optical density of the films at 24 hours post-exposure.

Three pieces of films were used per calibration dose and the average optical density of the three films was calculated and plotted against the measured dose. The standard error of the mean per calibration dose was less than 1%. A third degree polynomial was fitted to the calibration curve.

The tube voltages for both modes ranged from 75 kV to 95 kV for all procedures in this study. The corresponding mean energies were calculated as 47 keV and 57 keV using the SRS-78 Spectrum Processor [16]. For this energy range, a 7% variation in the energy response was measured by Butson et al [17]. Therefore, in this study it was assumed that the energy response of the RTQA-2 films was flat for the energy ranges used.

Patient Doses

Maximum entrance skin doses (MESD) were measured for fifty patients. The PA MESD was measured with a film placed on the headrest underneath the patient's head. A second film was placed on the left side of the patient's head to measure MESD for the LAT plane.

The fluoroscopy time, DAP and CESD for both fluoroscopy and DSA modes and the total number of DSA images were recorded for each patient.
Results

Twenty-nine female and twenty-one male patients were treated for 38 intracranial aneurysms, 10 AVMs and 2 dural AV fistulas. Table 1 shows the mean, median, minimum and maximum values for all recorded and measured variables.

**Table 1. Mean, median, minimum and maximum values for all recorded and measured variables.**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total DAP (Gycm$^2$)</td>
<td>176</td>
<td>139</td>
<td>47</td>
<td>634</td>
</tr>
<tr>
<td>DAP fluoroscopy (Gycm$^2$)</td>
<td>74</td>
<td>57</td>
<td>19</td>
<td>323</td>
</tr>
<tr>
<td>DAP DSA (Gycm$^2$)</td>
<td>102</td>
<td>87</td>
<td>21</td>
<td>321</td>
</tr>
<tr>
<td>CESD (Gy)</td>
<td>1.0</td>
<td>0.8</td>
<td>0.1</td>
<td>3.4</td>
</tr>
<tr>
<td>CESD fluoroscopy (Gy)</td>
<td>0.4</td>
<td>0.3</td>
<td>0.0</td>
<td>1.7</td>
</tr>
<tr>
<td>CESD DSA (Gy)</td>
<td>0.6</td>
<td>0.5</td>
<td>0.1</td>
<td>1.8</td>
</tr>
<tr>
<td>Fluoroscopy time (min)</td>
<td>44.9</td>
<td>38.4</td>
<td>12.4</td>
<td>107.0</td>
</tr>
<tr>
<td>Total number of images</td>
<td>506</td>
<td>436</td>
<td>155</td>
<td>1443</td>
</tr>
<tr>
<td>MESD PA (Gy)</td>
<td>1.7</td>
<td>1.3</td>
<td>0.2</td>
<td>5.8</td>
</tr>
<tr>
<td>MESD LAT (Gy)</td>
<td>1.2</td>
<td>0.9</td>
<td>0.2</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Table 1 indicates that CE of intracranial aneurysms, dural AV fistula, and tumours involve long fluoroscopy times, large number of DSA images, high DAP values and skin doses that can potentially cause radiation-induced skin injuries.
The average total DAP was 176 Gycm$^2$ in this study. The contribution of the fluoroscopy and DSA mode to the total DAP was 42% and 58% respectively.

The average fluoroscopy time and the total number of images were 45 minutes and 506 DSA images respectively.

The average MESDs measured with the radiochromic films for the PA and LAT planes were 1.7 Gy and 1.2 Gy respectively.

The average total CESD calculated by the X-ray system was 1.0 Gy. The contribution of the fluoroscopy and DSA modes to the total CESD was 40% and 60% respectively. The average CESD was lower than the PA and LAT MESD.

In figure 1, the distributions of MESDs for the PA and LAT plane are shown.

![Figure 1: Frequency distribution of maximum entrance skin doses for PA and LAT planes](image)

**Fig. 1**: Frequency distribution of maximum entrance skin doses for PA and LAT planes

**References**: The Christie NHS Foundation Trust, Christie Medical Physics and Engineering - Manchester/UK
Figure 1 indicates that the most frequent PA MESD values were below 2 Gy, which is the transient erythema threshold dose [1] and the LAT MESDs were below 1 Gy. However, six patients received a PA MESD above 2 Gy and seven patients received a PA MESD above 3 Gy, which is the threshold dose for temporary epilation [1]. Two out of the seven patients received an MESD above 4 Gy and one above 5 Gy.

With regards to the LAT plane, six patients received an MESD above the transient erythema threshold dose but only one patient received an MESD above the dose threshold for temporary epilation.

In total, fourteen patients received an MESD above 2 Gy either from the PA/LAT plane or from both planes. Twelve out of the fourteen patients received a fluoroscopy time longer than 60 minutes, a total number of DSA images higher than 400 and a total DAP greater than 200 Gycm$^2$. The fluoroscopy time, number of images and total DAP for the patient who received the maximum MESD were 83 minutes, 1443 DSA images and 634 Gycm$^2$ respectively.

For all fourteen patients, the films indicate that the radiation fields were localised to the same skin area. For the majority of the fourteen patients, the MESD was due to a single radiation field (figure 2). However, for a number of patients the MESD occurred at skin areas where two or three radiation fields overlapped. These areas were as small as 3x2 cm$^2$ (figure 3) and this signifies the importance of using dosimetric methods that allow the visualisation of the radiation fields.
**Fig. 2:** PA film (MESD=4.3Gy)

**References:** The Christie NHS Foundation Trust, Christie Medical Physics and Engineering - Manchester/UK
Fig. 3: Figure 3. PA film (MESD=3.1Gy)

References: The Christie NHS Foundation Trust, Christie Medical Physics and Engineering - Manchester/UK

Figure 4 shows the total DAP distribution for all patients.
**Fig. 4:** Frequency distribution of the total dose-area product (Gycm²)

**References:** The Christie NHS Foundation Trust, Christie Medical Physics and Engineering - Manchester/UK

The most frequent values of the total DAP were in the range of 150 Gycm² and 200 Gycm². Fifteen patients had a total DAP greater than 200 Gycm² and an MESD close or above 2 Gy.

Figure 5 shows the relationship between the total MESD and total CESD.
Figure 5 shows that the total MESD correlates linearly with the total CESD with a correlation coefficient of 0.85. This means that the total MESD can be calculated from the CESD using the equation shown in figure 5.

This study has shown that the threshold for transient erythema was exceeded when:

1. the fluoroscopy time was longer than 60 minutes and
2. the total number of DSA images was higher than 400 and
3. the total DAP was greater than 200 Gycm$^2$

These levels could be used as warning levels for exceeding a skin dose of 2 Gy for CE procedures involving the use of one or two radiation fields. In addition, the linear equation shown in figure 5 could be used for estimating the total MESD from the displayed CESD.

Patients at the neurointerventional suite are followed-up in a clinic at 6 weeks post-procedure. If a radiation injury is suspected, the patients are referred to the dermatology department depending on the severity of the reaction, otherwise, they are counselled about restorative skin care.
Table 2 compared the results of this study with the MESDs and DAPs from other published studies.

**Table 2. Comparison with published studies.**

<table>
<thead>
<tr>
<th>Study</th>
<th>MESD (Gy)</th>
<th>DAP (Gycm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>This study</td>
<td>1.7 (PA), 1.2 (LAT)</td>
<td>173</td>
</tr>
<tr>
<td>12</td>
<td>1.16</td>
<td>413</td>
</tr>
<tr>
<td>10</td>
<td>1.9</td>
<td>257</td>
</tr>
<tr>
<td>14</td>
<td>0.72 (coiling)</td>
<td>121 (coiling)</td>
</tr>
<tr>
<td></td>
<td>0.79 (embolisation)</td>
<td>189 (embolisation)</td>
</tr>
<tr>
<td>7</td>
<td>0.77 (PA), 0.78 (LAT)</td>
<td>106</td>
</tr>
<tr>
<td>9</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1.4</td>
<td>91.55</td>
</tr>
</tbody>
</table>

The complexity, the experience of the neuroradiologists, the equipment specifications and exposure protocols result in the wide variation of MESDs and DAPs between the published studies.
Fig. 1: Frequency distribution of maximum entrance skin doses for PA and LAT planes

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Fig. 2: PA film (MESD=4.3Gy)

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Fig. 3: Figure 3. PA film (MESD=3.1Gy)

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**Fig. 4:** Frequency distribution of the total dose-area product (Gycm²)

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**Fig. 5:** Relationship between total maximum entrance skin dose (MESD) and total calculated entrance dose (CESD)

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Conclusion

This study used radiochromic films to measure the maximum entrance skin dose for cerebral embolisation procedures.

The results showed that six out of fifty patients exceeded the threshold for transient erythema and eight out of fifty patients exceeded the threshold for temporary epilation.

This study has shown that for a fluoroscopy time of 60 minutes and a total number of DSA images of 400 and a total DAP of 200 Gycm$^2$, the threshold dose for transient erythema is likely to be exceeded and hence, the above values could be used as a warning level.
References
