Procedural radiation exposure of interventional cardiologists and radiologists
Kuipers, G.

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CHAPTER 2

Personal dosimetry in interventional cardiology in the period 1999-2004

Gerritjan Kuipers, Xandra L. Velders DDS, PhD, Jan J. Piek, MD, PhD.

Department of Cardiology; Academic Medical Center (AMC) Amsterdam.

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Introduction
At the AMC Heart Center, patients are examined and treated by means of fluoroscopy. Besides the AMC Heart Center, fluoroscopy-guided procedures are performed at the departments of Radiology, Gastro-Enterology and to a lesser extend at the departments of Urology, Anesthesiology and Surgery. During such procedures, patients as well as medical staff are exposed to ionizing radiation. Patients are mainly exposed to primary radiation beams, whereas the medical staff is exposed to scattered radiation beams.

To determine the radiation exposure of physicians (referred to as interventional specialists), appropriate personal dose monitoring devices (personal dosemeters) should be provided. Measured doses of interventional cardiologists are recorded in the ‘National Dose Recording and Information System’ (NDRIS) as effective dose. When it is plausible that the measured dose deviates strongly from the effective dose, for example when a lead apron is worn, additional measurements or calculations have to be done. Subsequently the Dutch legislation requires the modified dose value to be registered as effective dose in NDRIS\(^1\) instead of the originally measured dose.

Interventional specialists at the AMC wear a lead apron and a lead collar during the procedures. The personal dosemeter is positioned outside the lead apron/lead collar. As the lead apron protects the person who is wearing it, the measured dose outside the lead apron deviates from the effective dose. To enable an estimation of the effective dose these interventional specialists receive, additional dose measurements with dosemeters positioned inside the lead apron were performed. These additional dose measurements have been recommended by the International Commission on Radiological Protection (ICRP) in their ‘publication 85’\(^2\). It is stated that for the estimation of the effective dose of interventional specialists the use of two personal dosemeters is recommended: one positioned outside the lead apron and one positioned inside the lead apron. If two personal dosemeters are used, the effective dose could be more closely estimated. For the conversion of the measured dose of two personal dosemeters into an effective dose, several algorithms exist. An overview of algorithms has been published by Järvinen \textit{et al.}\(^3\).

In 1990, the ICRP reduced the occupational exposure limit to 20 mSv/year\(^4\). It was expected that the ICRP recommendation would be adopted by the Dutch legislation in
2001. For this reason, an additional personal dosemeter was introduced in the AMC in 1999, because the annual dose of the interventional cardiologists exceeded the exposure limit.

This study contains data of dose measurements of interventional specialists measured outside as well as the additional dose measurements inside the lead apron between 1999-2004. For this study, the dose measurements of both dosemeters in relation to the position of the personal dosemeters were evaluated. Not only the influence of different positions of the dosemeters was studied, but also the possible existence of a relation between measurements outside and inside the lead apron was assessed. This paper also contains data on the estimated effective dose of interventional cardiologists. For this estimation two methods were applied: a method to estimate the effective dose by means of single dosemeter and a method to estimate the effective dose by means of two dosemeters.

**Materials and methods**

In the period from 1999 until 2004, three interventional cardiologists carried two personal dosemeters. One personal dosemeter was placed outside the lead apron and one inside the lead apron.

From the start of this study until 2003, the interventional cardiologists were instructed to position the personal dosemeters on the left sleeve, outside the lead apron. The left sleeve is a position close to the primary beam during interventional procedures. No specific instructions were given concerning the positioning of the personal dosemeter inside the lead apron. This personal dosemeter was generally placed in, or on the pocket at breast height.

In 2003, the instruction for positioning the personal dosemeter outside the lead apron was modified. From then on, the interventional cardiologists were instructed to place their personal dosemeter at the collar, outside the lead apron. No specific instructions were given concerning the positioning of the personal dosemeter inside the lead apron. This policy remained unaltered during the remainder of the research period.

Two methods are used in order to estimate the effective dose of interventional cardiologists: a method based on the use of one personal dosemeter and a method based
on the use of two personal dosemeters. The correction factor, as published by the Dutch Association for Radiation Dosimetry (NCS), was applied for the estimation of the effective dose by one personal dosemeter\(^5\). The algorithm according to report 122 of the NCRP\(^6\) was used to estimate the effective dose based on the measurements of two personal dosemeters.

The cardiologists used lead aprons and thyroid collars of 0.50 mm lead equivalent thickness 100 kVp (Medical Development and Technology B.V, Hilvarenbeek, Netherlands). Furthermore, the cardiologists used ceiling-mounted lead glass screens (Pb equivalent 0.50 mm, MAVIG, Munich, Germany) and table shield systems (Pb equivalent 0.50 mm, Kenex (Electro-Medical), Harlow, England).

The personal dosemeters were provided by the Nuclear Research and Consultant Group (NRG, Arnhem, the Netherlands). The personal dosemeters were replaced every 4 weeks and were read out by NRG. In the dose reports the doses were presented by means of the personal dose equivalent at a depth of 10 mm, the Hp(10). The doses were reported in multiples of 0.01 mSv. Doses below 0.005 mSv were reported as <0.01 mSv. These values have been denoted report as 0 mSv.

**Results**

In the period from 1999 until 2004, a total of 420 dose measurements were performed. Hundred seventy-six dose measurements were performed outside the lead apron on the left sleeve, 34 outside the lead apron at the collar and 210 inside the lead apron.

The measured doses (median) on the left sleeve varied between 1.5 and 6.0 mSv/4-weeks and at the collar between 0.5 and 2.8 mSv/4-weeks (Table 1). These results differed significantly between the three interventional cardiologists (left sleeve: \(p < 0.05\); collar: \(p < 0.05\) (Kruskal Wallis)). The measured doses on the left sleeve were significantly higher than the measured dose at the collar (\(p < 0.05\) (Kruskal Wallis). The difference in measured doses on the left sleeve compared to at the collar for the group of interventional cardiologists was a factor 1.9.

The results of the measurements inside the lead apron varied between 0.02 and 0.12 mSv/4-weeks. The measurements inside the lead aprons differed significantly between
the three interventional cardiologists (p < 0.05 (Kruskal Wallis)).

Figures 1 and 2 present scatter-plots reflecting the 4-weekly dose measurements outside the lead aprons compared to the 4-weekly dose measurements inside the lead aprons. In Figure 1 the results of the dose measurements on the left sleeve and the dose measurements inside the lead apron are presented. In Figure 2 the results of the dose measurements at the collar of the lead apron and the dose measurements inside the lead apron are presented. Using regression analysis, no significant linear relation could be found between the measurements outside the lead apron and the measurement inside the lead apron. This applies to the measurements on the left sleeve and the measurements inside the lead apron as well as to the measurements at the collar and the measurement inside the lead apron (ANOVA P > 0.05).

**Table 1**: Measured doses (mSv/4-weeks) outside and inside the lead apron of interventional cardiologists. The dose measurements outside the lead apron are measured on the left sleeve (1999-2003) and at the collar (2003-2004). The dose measurements inside the lead apron are measured at the collar (1999-2004).

<table>
<thead>
<tr>
<th>Interventional cardiologists</th>
<th>Measured dose (Hp(10)) 1999-2004 (mSv/4-weeks)</th>
<th>Outside Lead apron</th>
<th>Collar</th>
<th>Inside lead apron</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left sleeve</td>
<td>25th</td>
<td>50th</td>
<td>75th</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>3.05</td>
<td>6.02</td>
<td>8.26</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>1.57</td>
<td>2.41</td>
<td>3.61</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>0.70</td>
<td>1.46</td>
<td>2.29</td>
</tr>
</tbody>
</table>

**Table 2**: Effective dose (mSv/4-weeks) of interventional cardiologists. The effective doses are estimated for measurements on the left sleeve (1999-2003) and on the collar (2003-2004) according to the method for single dosimetry (NCS) and for double dosimetry (NCRP).

<table>
<thead>
<tr>
<th>Interventional cardiologists</th>
<th>Left sleeve Single dosimetry (mSv/4-weeks)</th>
<th>Collar Single dosimetry (mSv/4-weeks)</th>
<th>Left sleeve Double dosimetry (mSv/4-weeks)</th>
<th>Collar Double dosimetry (mSv/4-weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25th</td>
<td>50th</td>
<td>75th</td>
<td>25th</td>
</tr>
<tr>
<td>1</td>
<td>0.20</td>
<td>0.40</td>
<td>0.55</td>
<td>0.14</td>
</tr>
<tr>
<td>2</td>
<td>0.10</td>
<td>0.16</td>
<td>0.24</td>
<td>0.01</td>
</tr>
<tr>
<td>3</td>
<td>0.05</td>
<td>0.10</td>
<td>0.15</td>
<td>0.00</td>
</tr>
</tbody>
</table>
In Table 2 the estimated effective doses of the interventional cardiologists are shown. The estimation of the effective doses based on one dosemeter positioned on the left sleeve varied from 0.10 and 0.40 mSv/4 weeks. The effective doses estimated based on one dosemeter positioned at the lead collar varied from 0.03 and 0.19 mSv/4-weeks. Measurements based on two dosemeters revealed that the effective doses on the left sleeve varied between 0.05 and 0.25 mSv/4-weeks and the effective doses at the collar varied between 0.01 and 0.15 mSv/4 weeks. The estimation of the effective doses based on one dosemeter located on the left sleeve was significantly higher than the estimated effective doses based on double dosimetry, for cardiologist 2 and 3 (p < 0.05 (Kruskall Wallis)). The estimated effective doses based on one dosemeter at the collar, did not differ significantly from the estimated effective doses based on double dosimetry (p > 0.05 (Kruskall Wallis)).

**Discussion**

The measured doses on the left sleeve were higher compared to the measured doses at the collar. The difference in measured doses on the left sleeve and at the collar was a factor 1.9. Similar results have been published by Vano et. al.\(^7\). Vano et al. described that the dose measured on the left sleeve is at average a factor 2 greater than the dose measured at the collar.

The results show no relation between doses measured outside the lead apron and doses measured inside the lead apron. Consequently, it was not possible to determine the protection factor of the lead apron (transmission) for the interventional cardiologists. There are studies however, in which the transmission of lead aprons with a thickness of 0.5 mm Pb equivalent could be determined\(^8,9\). For lead aprons with a thickness of 0.50 mm Pb equivalent and an X-ray high voltage of 70 kVp, the transmission varies between 0.6% and 1.6%.

The lack of a relation between the measured doses outside the lead apron and inside the lead apron could possibly be caused by the lack of a standardized measuring method. Communication with the interventional cardiologists paid little attention to the exact positioning of the personal dosemeters. The interventional cardiologists were only instructed to wear the personal dosemeter on the outside of the lead apron on the left sleeve or later at the collar. No instructions were given concerning the position of the
**Figure 1:** Plot with doses (mSv/4-weeks) measured on the left sleeve outside the lead apron (X-axis) and doses measured inside the lead apron (Y-axis).

**Figure 2:** Plot with doses (mSv/4-weeks) measured at the collar outside the lead apron (X-axis) and doses measured inside the lead apron (Y-axis).
personal dosemeter inside the lead apron. Moreover, the dosemeters outside the lead apron were possibly not always exchanged simultaneously with the dosemeters placed inside the lead apron. These factors could have influenced the accuracy of the dose measurements. In order to determine a relation between the measurements outside the lead apron and inside the lead apron, it is important that positions of the personal dosemeters are fixed and that both personal dosemeters are changed at the same time.

The effective doses estimated according to the method of the NCS (single dosimetry) were sometimes higher compared to the estimated effective doses according to the NCRP (double dosimetry). This difference could be explained by differences in the policy of both organizations, because estimations of effective doses according to NCS-method are never underestimated, whereas this does occur using the method of the NCRP. The underestimation of the effective dose according to NCRP-method can be up to a factor of $3.3^{6,10}$. In spite of this, the effective dose can also be overestimated with both methods. With the NCS-method, the overestimation of the effective dose can reach a factor 12, whereas the NCRP-method has a maximum overestimation of a factor $2^{5,11}$.

In the Netherlands, interventional specialists generally used single dosimetry. The personal dosemeter is usually positioned outside the lead apron. The positioning of the personal dosemeter in the hospitals in other European countries may also deviate from the recommendations of the ICRP. In 2008, Foti et al.$^{12}$ published results of a study concerning the positioning of the personal dosemeter in several European hospitals. It appears that double dosimetry is only applied in some of the examined European hospitals. This study also shows that in most of the hospitals single dosimetry is applied, with the personal dosemeter positioned either outside or inside the lead apron.

The results of this study do not provide a definite answer regarding the use of two personal dosemeters. Thus it remains unknown whether this effectively leads to a more precise estimation of the effective dose compared to the use of a single personal dosemeter. However, the results reveal, that the dose measurement inside the lead aprons cause a lot of uncertainty. The results of the dose measurements inside the lead apron are generally below the detection threshold of the personal dosemeters. For this reason, the contribution of the natural background radiation will exert a large influence on the measurements$^{13}$. Furthermore, the results of this study show that the contribution of the
dose measured inside the lead apron to the estimation of the effective dose is negligible. For the lead aprons with a thickness of 0.50 mm lead equivalent, as applied in this research, the measured dose outside the lead apron contributes on average for 93% to the estimated effective dose.

Additional studies are warranted to determine whether the effective dose can be estimated more closely by the use of two personal dosemeters compared to one personal dosemeter.

**Conclusion**

It is important to wear the personal dosemeter at a predetermined, fixed position, as the position of the personal dosemeter influences the dose measured.

The results of this study did not show a relation between the measured dose outside the lead apron and inside the lead apron. To determine whether a relation exists between both measurements, the position of the personal dosemeters is important. Moreover, the personal dosemeters placed outside and inside the lead apron must to be replaced simultaneously.

The effective doses estimated with the NCS method for single dosimetry were in this study sometimes higher than those estimated according to the NCRP method for double dosimetry. However, when the NCS method is applied for single dosimetry the effective dose may be over-estimated, compared to the NCRP method to estimate the effective dose for double dosimetry.
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11. Franken Y, Huyskens CJ. Guidance on the use of protective lead aprons in medical radiology: protection efficiency and correction factors for personal dosimetry. Paper 17, 6th European ALARA Network Workshop, Madrid, Spain,
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