INTERVENTIONAL CARDIOVASCULAR PROCEDURES IN BELGIUM: EFFECTIVE DOSE AND CONVERSION FACTORS

E. Bogaert*, K. Bacher and H. Thierens
Department of Medical Physics and Radiation Protection, University of Ghent, Proeftuinstraat 86, B-9000 Gent, Belgium

Effective dose \( (E) \), representing the risk of late radiation-induced effects, can be estimated by the use of conversion factors \( (CF) \), converting direct measurable quantities such as dose-area-product into \( E \). Eight Belgian hospitals participated in the study with a total number of 318 procedures. \( E \)-values, calculated with PCXMC, were compared for the different hospitals for diagnostic and therapeutic procedures separately. \( E \)-values varied significantly depending on the hospital where the procedure was performed \( (P < 0.001) \), on filtration insertion \( (P < 0.001) \), on whether a centre is a training centre or not, the dose conscious action of the cardiologists and the complexity of the procedure \( (P < 0.001) \). Hospital-specific CF were calculated. An average CF of 0.185 mSv Gycm

\( ^{2} \) was obtained with a satisfactory correlation \( (r = 0.966, P < 0.001) \). The differences in CF between hospitals were due to, a large extent, the availability of additional filtration in cinegraphy mode \( (P < 0.001) \) and not to the differences in irradiation geometries in the clinical protocol of the interventional procedures.

INTRODUCTION

As stated in the draft recommendations of the ICRP (2007)\(^{(1)} \), ‘Effective Dose \( (E) \) can be of value for comparing the use of similar technologies and procedures in different hospitals and countries as well as the use of different technologies for the same medical examination, provided the patient population is similar with regard to age and sex’. The determination of \( E \) value is very important for high-dose examinations as cardiovascular procedures carried out under fluoroscopic control. Moreover, in recent years, the number of fluoroscopy-guided procedures in interventional cardiology has increased substantially. Typical annual figures for percutaneous transluminal coronary angioplasty (PTCA) in developed countries are 500–1000 per million inhabitants\(^{(2)} \). Comparing the literature data, \( E \)-values range from 5 to 9 mSv for coronary angiography (CA) and from 6 to 15 mSv for PTCA\(^{(3–6)} \).

Yet, the determination of \( E \)-value being defined in ICRP 60\(^{(7)} \) as the sum of the weighted equivalent doses in 12 critical organs is quite complex since direct organ dose measurements are not possible in patients undergoing a cardiovascular procedure. Therefore, several indirect methods have been proposed to allow for a practical estimation of \( E \). Based on the use of Monte Carlo modelling of radiological exposures, these methods require only the measurement of the incident radiation, e.g. dose-area-product (DAP), to estimate the \( E \)-value\(^{(8)} \).

The goal of this study was to calculate \( E \) based on detailed DAP registration during the procedures and by the use of specific conversion factors (CF), for eight catheterisation rooms in Belgian hospitals representing the situation of the Belgian territory. Differences in mean \( E \)-values were analysed in terms of protocol- or equipment-related parameters. Hospital-specific CF converting DAP into \( E \), generated by the Monte Carlo simulation code PCXMC\(^{(9)} \), were compared with each other. The influence of different factors on the CF such as clinical protocol (orientation of the fluoroscopy and cine views), equipment (filtration) and procedure (diagnostic or therapeutic) was investigated.

MATERIALS AND METHODS

Eight Belgian hospitals participated in this study, providing a population of 221 male and 97 female patients, between 29 and 89 years of age. An average of 40 patients per catheterisation room was followed for both diagnostic CA and therapeutic procedures. Therapeutic procedures comprised both single or multiple balloon or stent dilatation as combined procedures. In the latter, the therapeutic part follows immediately the diagnostic part (CA) of the procedure. A total number of 200 diagnostic and 118 therapeutic procedures were included in this study.

The X-ray equipment in the participating hospitals, all manufactured by either Philips or Siemens, consisted of three biplane and five monoplane systems. Three of the systems had flat detectors for image capture. The others used conventional image intensifiers. All X-ray systems can be considered as contemporary state-of-the-art equipment with pulsed mode for X-ray generation. All systems inserted aluminium and copper filtration into the beam in fluoroscopy mode, but additional copper filtration was available only for four of them in cinegraphy.

*Corresponding author: evelien.bogaert@ugent.be

© The Author 2008. Published by Oxford University Press. All rights reserved. For Permissions, please email: journals.permissions@oxfordjournals.org
mode. All systems were provided with a build-in DAP-meter, which was calibrated in situ, using a 60-cc ionisation chamber (Radcal Corporation, Monrovia, USA) and a radiographic film (Eastman Kodak) for field size determination. Online computer registration of cumulative DAP and DAP rate made interpretation in terms of fluoroscopy and cinegraphy mode possible.

During a cardiovascular procedure, the following parameters were recorded: field size, tube potential, filtration, mode (fluoroscopy or cinegraphy), irradiation geometry, number of frames per second, complexity score of the procedure according to the cardiologist and patient characteristics (gender, age, height and weight). A three-point scale for the complexity score was based on the duration of the procedures with respect to an equivalent procedure under normal circumstances, the number of lesions, the accessibility of the coronary arteries and the number of frames in one fixed orientation.

For calculation of $E$ and CF, the Monte Carlo-based computer program PCXMC$^{(9)}$ was used. For each hospital, the irradiation geometry of the clinical protocol was described in ‘standard projections’. For calculation of $E$, the irradiation geometry of each procedure was described in terms of the standard projections. Field size, filtration and tube voltage recorded during the procedure and a fixed source to image receptor distance (SID) were used as input in the program. SID was 98 cm for monoplane systems and 105 for biplane systems. The distance from patient’s skin to the image receptor (PID) was 10 cm. For geometries with an angle in cranial direction larger than 40°, SID was increased with 5 cm and PID with 10 cm, according to the realistic clinical situation.

Statistical analysis was based on a multifactor ANOVA. In cases where only two groups had to be compared, a non-parametric two-tailed Mann–Whitney test was performed. A $P$-value of $<0.05$ was considered significant.

RESULTS AND DISCUSSION

$E$-values

$E$-value was calculated for each procedure taking into account the CF for the hospital where the procedure was performed. Overall histograms of $E$-values for diagnostic and therapeutic procedures are represented separately in Figure 1. The vertical lines represent the median values of these distributions and amount to 7.3 mSv for diagnostic procedures and 11.6 mSv for therapeutic procedures. Both distributions are strongly skewed, with $E$-values values reaching up to 79.8 mSv for therapeutic interventions. Overall mean values for $E$ are 9.6 mSv for diagnostic procedures and 15.3 mSv for therapeutic procedures.

Distributions of $E$-values were also calculated for different hospitals, for diagnostic and therapeutic procedures, respectively, and are represented in

![Figure 1. Histogram of effective dose $E$ (mSv) for diagnostic (full line) and therapeutic (dashed line) procedures. The median values are indicated by a vertical line.](image)
Figures 2 and 3. The median values of the overall distribution for diagnostic and therapeutic procedures, respectively, are taken as a guidance for comparison of local median \( E \)-values. In Figures 2 and 3, the local distributions and their median values are indicated by a full line and the overall median values are represented by a dashed line. Based on these histograms and on the ANOVA statistical analysis performed, we can conclude that \( E \) varies significantly depending on the hospital.
where the procedure was performed ($P < 0.001$), on filtration insertion ($P < 0.001$), on whether a centre is a training centre or not, the dose conscious action of the cardiologists and the complexity of the procedure ($P < 0.001$).

A comparison of the $E$ histograms for different hospitals revealed significant differences between the hospitals with respect to $E$ for the patient ($P < 0.001$). This means that in some hospitals doses are significantly higher or lower than the

Figure 3. Comparison of histograms of effective dose for therapeutic procedures for different hospitals involved in the study. The overall median value is indicated by a dashed line. The median value of the local distribution is indicated by a full line.
EFFECTIVE DOSE AND CONVERSION FACTORS IN INTERVENTIONAL CARDIOLOGY

average for both diagnostic and therapeutic procedures. In Hospital 6, higher E-values are obtained, whereas in Hospitals 2 and 7, lower E-values are obtained.

In Hospital 1 (training facility for cardiologists), we should take into account that, at the moment our measurements were carried out, different assistant cardiologists in training performed PTCA and stenting procedures. This explains the high E-values for therapeutic procedures related to this hospital. For both diagnostic and therapeutic procedures, the mean E-values of Hospital 6 were considerably higher than the overall figures. Although Hospital 6 is a also training centre, the high values could mainly be attributed to the poor attention of some cardiologists with respect to radiation burden of the patient and the continuous use of the fluoroscopy ‘high’ mode for fluoroscopy filtration setting.

In Hospital 7, diagnostic and therapeutic procedures are performed with the lowest E, which can be explained by the very-low tube-current setting in comparison to the tube currents of the other hospitals. Highest doses were recorded in Hospital 1, 3 and 6. These were the only departments where a manual filtration methodology was used. Hence, using automatic filtration insertion will generally result in lower E-values. It is, however, worthwhile to mention that only very little filter variability was implemented in the systems of hospitals 2 and 7. Therefore, in the latter centres, low E-values can be more attributed to the good practice in terms of the amount of radiation used by the cardiologist.

In conclusion, with respect to technical parameters, automated variable filtration settings result in significantly reduced effective patient doses (P < 0.001). This relates to Hospitals 2, 4, 7 and 8.

In centres where flat-panel technology was introduced (hospitals 4, 5 and 8), lower E-values were obtained. However, this effect did not reach significance (P = 0.068). A similar conclusion could be drawn for the comparison of E-values obtained in rooms equipped with a biplane and with a monoplane system. The use of biplane systems resulted in higher dose values.

The complexity of the procedure had a significant influence on E (P < 0.001). In the three-point difficulty scale used in this study, level 2 and 3 resulted in significantly higher median E-values compared with level 1 (4.1 versus 10.6 mSv).

Conversion factors

An excellent overall correlation between E and DAP was found (r = 0.966, P < 0.001). When analysing diagnostic and therapeutic procedures separately, similar correlations were found (r = 0.965, P < 0.001 and r = 0.964, P < 0.001, respectively). Table 1 describes the different hospital-specific CF from DAP to E. The average value for the CF is 0.185 mSv Gycm⁻². Statistical significance was not observed for the difference in CF between diagnostic (0.179 mSv Gycm⁻²) and therapeutic (0.190 mSv Gycm⁻²) procedures (P = 0.723). However, distinction based on filtration used in cinegraphy mode in terms of the availability of additional copper material in the beam does make sense. A CF of 0.207 mSv Gycm⁻² for systems that use extra copper filtration in cinegraphy was found, whereas the CF amounts to 0.177 mSv Gycm⁻² for the other systems. The beam hardening as a consequence of the additional copper filtration leads to a higher mean E-value for the same DAP value.

Although CF were calculated for each hospital individually, taking into account the X-ray set up and the clinical protocol, as stated by Schultz and Zoetelief(10), geometry-related factors did not result in significant differences in CF.

For practical use of CF for calculation of E, the availability of additional copper filtration can be taken into account. The CF factors derived in the present work can be used for both diagnostic and therapeutic procedures.

CONCLUSION

Local E-distributions show statistically significant differences between different hospitals. This means that further dose reduction is possible for interventional cardiovascular procedures in Belgium. The importance of additional copper filtration in clinical practice should be stressed. It is a very helpful tool that not only lowers E but also the entrance skin dose, as shown in a complementary study in the same eight hospitals(11). Entrance skin dose easily exceeds the threshold of 2 Gy(7) for deterministic effects in these high-dose procedures.

The use of CF provides a very practical methodology to calculate E from DAP. In the present work, separate CF are proposed for x-ray systems that use

<table>
<thead>
<tr>
<th>Hospital</th>
<th>CF (mSv Gycm⁻²)</th>
<th>Additional Cu?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.184</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>0.225</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>0.157</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>0.170</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>0.203</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>0.183</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>0.235</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>0.211</td>
<td>Yes</td>
</tr>
</tbody>
</table>
additional copper filtration in cinegraphy mode and systems that do not: 0.207 versus 0.177 mSv Gycm⁻².

ACKNOWLEDGEMENT
The authors wish to thank all cardiologists, nursing staff and technical personnel of the catheterisation departments of all hospitals involved in this study.

FUNDING
The Federal Agency for Nuclear Control is acknowledged for the financial support and the follow up of the project.

REFERENCES