Estimation of effective dose in some digital angiographic and interventional procedures

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Abstract. In general, effective dose values for similar interventional vascular radiology (IVR) procedures are different. This is due to problems with the classification of radiological procedures, which make comparisons difficult. Patient size, examination technique and clinical condition as well as the skill of the medical radiologists also affect effective dose. Currently, there is a broad agreement on the classification of similar procedures so that effective dose estimates can be made from measurements of the dose area product (DAP). Thus, reference dose values may be established and comparative studies between different services and hospitals can be made. The objective of this study is to provide dose data for some digital angiographic and interventional procedures. Values of measured DAP for 143 patients for five types of procedures are presented. Procedures investigated were abdominal angiography, arteriography of lower limbs, biliary drainage, embolization of spermatic vein and nephrostomy. All the procedures were performed using digital equipment. Values of DAP and effective dose were 30 Gy cm\(^2\) and 6.2 mSv for arteriography of lower limbs and 150 Gy cm\(^2\) and 38.2 mSv for biliary drainage. In each one of these procedures, effective dose values per minute of fluoroscopy and per radiography film have been calculated. It is possible to use this information for the rapid estimation of effective dose.

Introduction

Recently the number of interventional vascular radiology (IVR) procedures performed in different countries has increased [1, 2]. This has been partly due to the introduction of new equipment with improved imaging capabilities. These procedures have enabled the diagnosis and treatment of vascular and non-vascular diseases, with very little discomfort to patients and minimal hospitalization time. These techniques use radiographs to guide the passage of catheters into the patient’s organs. In general, during procedures performed using current equipment, the patient is examined for long periods of time and a large number of radiographic images obtained. Consequently, patient dose is high.

Some of the equipment used in interventional vascular radiology incorporates the latest technical advances in imaging systems and processing acquisition of images. Technical parameters are selected in an automatic or semiautomatic way, while the radiation field size and the focus-to-skin distance depend on the radiologist’s preference.

Recently, deterministic effects have been observed [3] in patients following interventional procedures. These effects must be considered when the benefits are evaluated. Some manufacturers have already incorporated dose monitoring equipment into their systems to measure or calculate the dose area product (DAP), as an indication of the radiation dose to the patients. Patient doses must always be kept as low as reasonably achievable (the ALARA principle).

Training of medical and other healthcare personnel is required to reduce patient doses. At present, digital subtraction angiography (DSA) equipment can give different dose values, depending on the training of the staff performing the procedures.

Due to many technical and human factors, a set of reference dose values for IVR procedures have not been proposed. The World Health Organisation [2] has proposed some reference dose values. However, these values cannot be compared because the type of procedure nor the dosimetry method is clearly specified.

DAP values may be used in IVR as an indicator of the associated radiological risk [4]. However, its validity is limited since it would also be necessary to know the dimensions and location of the
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irradiated area. Effective dose is a better indicator of radiological risk [5], but its magnitude cannot be measured directly. It must be estimated from values of DAP or entrance surface dose (ESD). In either case, it is necessary to have conversion factors between the quantity measured and effective dose.

Conversion factors can be obtained using different methods. Marshall et al [6] have proposed the simulation of each IVR procedure using an anthropomorphic phantom loaded with TLD-100 dosemeters located at anatomical positions corresponding to radiosensitive organ. Effective dose may be calculated from the equivalent dose to each radiosensitive organ. Simultaneous measurement of DAP allowed the derivation of a conversion factor relating effective dose and DAP.

Another approach consists of obtaining the conversion factors using Monte Carlo methods to simulate the interaction of X-rays in an anthropomorphic mathematical phantom. Hart et al [7] have published tables of these conversion coefficients. To use these conversion coefficients it is necessary to establish a similarity between each IVR procedure and the radiological projections listed in NRPB-R262 [7].

The purpose of this investigation was to calculate the effective dose, through the measurement of the DAP during various IVR procedures. Effective dose has been estimated through the application of conversion coefficients proposed [7] using the software Eff–Dose version 1.02 [8].

Materials and methods

Technical characteristics of the IVR equipment

The equipment used was a Philips Integris V3000 with a Super 100 CP high frequency microprocessor controlled generator with a voltage range of 40–125 kV. A metallic, water-cooled Super Rotalix X-ray tube with a double focus of 0.6 and 1.2 mm was used. The anode angle was 15°. The X-ray tube housing incorporated a collimation system with two semi-transparent steps, which could be moved or rotated independently. The total beam filtration from X-ray tube was 2.5 mm Al. The ionization chamber used added a filtration of 0.5 mm Al making the total filtration 3 mm Al equivalent.

The Integris V3000 equipment included an automatically programmed radiography (APR) facility which allows a semi-automatic selection of radiological techniques. Tube potential as well as the total number and acquisition frequency of images for each projection depended on the region of the body examined. The equipment has an automatic exposure control system, which controlled the mAs.

A metallic image intensifier (Pentaview) with a titanium screen containing five circular field sizes: 38, 31, 25, 20 and 17 cm in diameter with optical fibre coupling was used. A swivel TV camera and two Hm 20S monitors were also used.

The X-ray beam could be rotated at right angles to the table (90° to both right and left) also 100° towards the left and 210° towards the right at the head of the table. The patient table has a maximum height of 104 cm and minimum of 76 cm and can be extended 100 cm lengthwise and 36 cm at the sides.

Calibration of IVR equipment

The calibration of the IVR equipment was performed monthly. In addition, it was checked periodically with a previously calibrated NERO 4000 M+ ionization chamber. Coefficients of variation less than 3% were recorded for reproducibility, linearity and efficacy. Correction factors were applied when necessary. Moreover, monitoring of the Integris V3000 system was carried out by qualified technical personnel every 6 months. This equipment had a DAP calculation system which gave the results on the screen in dGy cm². The total DAP for each procedure and the contribution corresponding to fluoroscopy and radiography may be obtained as well.

Measurement equipment of DAP

DAP values were measured using a Diamentor M2 ionization chamber (supplied and calibrated by PTW-Freiburg, Germany). The chamber was aligned with the beam diaphragm. The energy response of this chamber was independent of energy within ±5% for applied tube potentials between 50 and 100 kV. The DAP meter has been calibrated in situ.

Dosimetric method

143 procedures were analysed. The following data were acquired for each procedure: technical parameters for both fluoroscopy and radiography, field size, fluoroscopy time and number of radiographic films. Moreover, the DAP value (cGy cm²) measured by the Diamentor chamber was obtained, as well the total estimated value calculated by Integris V3000 (this included the fluoroscopy DAP value and the radiography DAP value).

The DAP value was corrected for the attenuation of the patient table when the undercouch tube was used. In order to establish this attenuation value, DAP measurements were made in comparable conditions to different IVR procedures, using a plastic phantom to simulate the patient.
Measurements were performed with the plastic phantom on the table, as well as withdrawing the table, but with the phantom at an equal distance from the tube with the same radiation area. The attenuation value was 0.73. All procedures analysed used an undercouch tube. Therefore all the DAP values were corrected with this factor.

For arteriography of the lower limbs the DAP value corresponding to the irradiation of the pelvic zone was used alone. The irradiation of the legs was taken into account for the effective dose calculation, since there is no published data on conversion coefficients [7]. Use of a conversion factor [9] which varies between 0.01 and 0.03 mSv Gy cm\(^{-2}\) has been proposed. Using this factor to account for irradiation of the legs would increase the total effective dose by only 2% approximately.

Effective dose was estimated by comparing the actual procedure with simple radiographic projections proposed in [7]. Effective dose was calculated independently for radiography and fluoroscopy in each procedure. Evaluation of total effective dose is easy using the Eff–Dose program and the measurement data. Eff–Dose V1.02 software estimates the effective dose using the weighing factors proposal by NRPB-R262 [7] as suggested in ICRP-60 [5]. Eff–Dose calculates the effective dose equivalent using the method of ICRP-26 [10]. The Eff–Dose program is based on four parameters: kV, total beam filtration, dose area product and projection used.

In addition, the contribution of radiography and fluoroscopy to this value for each IVR procedure can be determined. Effective dose per unit fluoroscopy time and effective dose per film can be deduced.

Radiological procedures

Abdominal angiography

This is a diagnostic procedure involving the abdominal arteries (aorta, renal, mesenteric and celiac trunk). A catheter is introduced through the femoral artery and is manipulated under fluoroscopic control. Iodide contrast is introduced and radiography film series are obtained.

There are differences between patients in respect of radiological technique, field sizes and duration of the fluoroscopy and the number of images obtained. However, the irradiated anatomical area is the same. The projection “Abdomen PA” has been considered most suitable for this procedure [7].

Arteriography of the lower limbs

This is an investigation to diagnose vascular alterations in the lower limbs. It is accomplished by puncturing the femoral artery and introducing a catheter under fluoroscopy control, until the catheter reaches the branching aorta. Afterwards, the contrast is introduced and series of radiographic films on both lower limbs are taken, from the pelvis to below the knees. The projection “Pelvis PA” has been considered most suitable for this procedure [7].

Biliary drainage

This is a therapeutic procedure which is carried out to direct bile past an obstruction in the bile duct to the duodenum or to drain it to outside the body. To do this, a catheter is introduced into the bile duct or the duodenum. The hepatic area is irradiated. The projection “Kidney PA” [7] has been considered most appropriate for this procedure.

Embolization of spermatic vein

This is a therapeutic procedure which consists of unblocking the spermatic vein with metallic wires, separating it from the renal vein. During the procedure, fluoroscopy and radiography are used. The radiation fields extend from the renal area down to the testicles passing through the paralumbar area. This procedure is especially interesting from the radioprotection perspective, as the patients are young and because of the area irradiated. The projection “Pelvis PA” [7] has been considered most appropriate for this procedure.

Nephrostomy

This therapeutic procedure permits taking urine out of the kidney via an external catheter. The affected kidney is punctured and a catheter is introduced into the renal pelvis. The renal area is irradiated. In this procedure, the patient is put in the decubitus prone position. The projection “Kidney AP” [7] has been considered most representative.

Results and discussion

The average age of the patients is relatively high, particularly so in arteriographies of lower limbs (60.9 years). In contrast, for patients with varicocele undergoing embolization of the spermatic vein the average age was 27 years.

Average values of the technical parameters used to perform the fluoroscopy part of the examinations are given in Table 1. Table 2 shows the corresponding values for the radiography part of each procedure. We can see that the standard deviations both in tube potential and in current are relatively small, whereas variations in the duration of the fluoroscopic part of the examinations are quite noticeable. Average values of the numbers
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Table 1. Fluoroscopy parameters (standard deviations in parentheses)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>kVp</th>
<th>mA</th>
<th>t</th>
<th>Fs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdominal angiography</td>
<td>86 (10.9)</td>
<td>5.4 (0.9)</td>
<td>402 (390)</td>
<td>30</td>
</tr>
<tr>
<td>Arteriography of lower limbs</td>
<td>73 (5.4)</td>
<td>3.9 (1.1)</td>
<td>222 (186)</td>
<td>38</td>
</tr>
<tr>
<td>Drainage biliary</td>
<td>92 (11.8)</td>
<td>5.7 (0.3)</td>
<td>2052 (690)</td>
<td>32</td>
</tr>
<tr>
<td>Embolization of spermatic vein</td>
<td>77 (5.4)</td>
<td>4.4 (0.5)</td>
<td>1416 (1038)</td>
<td>30</td>
</tr>
<tr>
<td>Nephrostomy</td>
<td>87 (7.6)</td>
<td>5.6 (0.4)</td>
<td>756 (438)</td>
<td>32</td>
</tr>
</tbody>
</table>

kVp, mean kilovoltage; mA, mean milliampere; t, time in seconds; Fs, average field size, circular in shape (cm of diameter).

Table 2. Radiography parameters (standard deviations in parentheses)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>kVp</th>
<th>mA</th>
<th>t</th>
<th>Fs</th>
<th>No. films</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdominal angiography</td>
<td>78 (5)</td>
<td>471 (56)</td>
<td>86 (24)</td>
<td>30</td>
<td>37 (30)</td>
</tr>
<tr>
<td>Arteriography of lower limbs</td>
<td>66 (5)</td>
<td>455 (92)</td>
<td>94 (45)</td>
<td>37</td>
<td>37 (15)</td>
</tr>
<tr>
<td>Drainage biliary</td>
<td>81 (14)</td>
<td>415 (61)</td>
<td>110 (0)</td>
<td>30</td>
<td>4 (2)</td>
</tr>
<tr>
<td>Embolization of spermatic vein</td>
<td>72 (3)</td>
<td>422 (41)</td>
<td>81 (28)</td>
<td>22</td>
<td>3 (3)</td>
</tr>
<tr>
<td>Nephrostomy</td>
<td>78 (11)</td>
<td>402 (66)</td>
<td>135 (111)</td>
<td>31</td>
<td>3 (3)</td>
</tr>
</tbody>
</table>

kVp, mean kilovoltage; mA, mean milliampere; t, time in milliseconds; Fs, average field size circular in shape (cm diameter); No. films, average numbers of films.

Table 3. Dose–area product and numbers of procedures (standard deviations in parentheses)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>No.</th>
<th>DAP (Gy cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Range</td>
</tr>
<tr>
<td>Abdominal angiography</td>
<td>16</td>
<td>8–192</td>
</tr>
<tr>
<td>Arteriography of lower limbs</td>
<td>35</td>
<td>9–77</td>
</tr>
<tr>
<td>Drainage biliary</td>
<td>18</td>
<td>51–291</td>
</tr>
<tr>
<td>Embolization spermatic vein</td>
<td>20</td>
<td>7–260</td>
</tr>
<tr>
<td>Nephrostomy</td>
<td>54</td>
<td>1–213</td>
</tr>
</tbody>
</table>

No., numbers of procedures; DAP, dose–area product in Gy cm²; Mean, mean value of DAP; Range, minimum and maximum values; Median, median value or 2nd quartile; 3rd Q, third quartile; R, radiography DAP value; Fl, fluoroscopy DAP value.

Table 4. Once the effective dose values were obtained, the corresponding data for E per radiographic film and E per minute of fluoroscopy in each procedure were calculated. These values are also presented in Table 4. Even though these values have an uncertainty due to the approximation made between the IVR procedure and the simple projection, as well as that due to Monte Carlo method, they can be taken as factors which permit making an effective dose estimating from the knowledge of only the fluoroscopy time and the number of films.

In the radiological procedures analysed, the values of the DAP measurements and the effective

![Figure 1. Mean values of DAP for vascular interventional radiological procedures.](image)

The results of the DAP measurement are shown in Table 3. Biliary drainage procedures result in the highest values of DAP. Relatively high standard deviations are to be found in every case thus indicating the great variability in the parameters influencing the value of the DAP in each procedure. The range of the average values of these procedures can be observed in Figure 1.
Table 4. Average effective doses

<table>
<thead>
<tr>
<th>Procedure</th>
<th>E (mSv)</th>
<th>E/film (mSv f&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>E/min (mSv min&lt;sup&gt;-1&lt;/sup&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>Fl Total</td>
<td></td>
</tr>
<tr>
<td>Abdominal angiography</td>
<td>3.1</td>
<td>5.1 8.2</td>
<td>0.1 0.8</td>
</tr>
<tr>
<td>Arteriography of lower limbs</td>
<td>3.8</td>
<td>2.4 6.2</td>
<td>0.1 0.6</td>
</tr>
<tr>
<td>Drainage biliary</td>
<td>1.8</td>
<td>36.4 38.2</td>
<td>0.5 1.1</td>
</tr>
<tr>
<td>Embolization of spermatic vein</td>
<td>0.4</td>
<td>16.9 17.3</td>
<td>0.1 0.7</td>
</tr>
<tr>
<td>Nephrostomy</td>
<td>0.9</td>
<td>12.7 13.6</td>
<td>0.3 1.0</td>
</tr>
</tbody>
</table>

E, effective dose; E/film, effective dose per film; E/min, effective dose per minute; R, radiography; Fl, fluoroscopy.

dose estimated are comparable in some instances with those obtained by other authors and, in other cases, there are clear discrepancies with published values. Castellano et al [13] have reported that 62% of the DAP is due to fluoroscopy. However, Hoskins et al [9] state that it is only 12%. Our data for arteriography of lower limbs indicate that the fluoroscopy contributes 36% of the total DAP value.

Vaño et al [14] published the mean value of DAP for biliary drainage and arteriography of lower limbs (68.9 and 66.6 Gy cm<sup>2</sup>, respectively). Our measurements gave values of 150 and 30 Gy cm<sup>2</sup>. It is possible that differences will arise because the radiological procedures are not classified in a similar manner, or they have been accomplished with different techniques. It is important to establish definitely the exact classification of the IVR procedures to be able to perform valid comparative studies.

The mean effective dose obtained from femoral arteriography in a recent work by Thwaites et al [15] gives 4 mSv; lower than the 6.2 mSv estimated in this study. Effective dose values per minute of fluoroscopy and per film are also given by Thwaites et al (0.15 mSv per minute of fluoroscopy and values ranging between 0.28 and 0.01 mSv per film), depending on the part of the body being radiographed. Table 4 gives the corresponding values from this study as 0.6 mSv per minute of fluoroscopy and 0.1 mSv per film as an average for all films. These differences could be partly due to the different imaging equipment used in the two studies, i.e. conventional as opposed to digital systems.

Conclusions

The comparative analysis of the dose values obtained for the IVR procedures performed in different Services and Hospitals requires an exact description of all the parameters which influence dose.

The fluoroscopy component of these procedures makes a large contribution to the total DAP values. For example, in abdominal angiography it corresponds to 59%, arteriography of lower limbs 37%, biliary drainage 95%, embolization of spermatic vein 97% and 93% for nephrostomy. A similar influence is observed on the average values of the effective dose.

The average effective dose to the patients from embolization of the spermatic vein was 17.3 mSv. This value as well as the youth of the patients must be taken into account when the stochastic risk is evaluated. The induction of hereditary genetic defects should also be considered, in principle, since these patients have this radiological procedure as part of treatment for infertility. However, the hereditary risk is reduced, since the treatment is only successful in a few cases.

Effective dose values per minute of fluoroscopy and per radiographic film in each one of the five types of procedure analysed can be taken as conversion factors to estimate approximately the effective dose in other centres in which similar IVR procedures are performed. The results obtained with the application of these factors will be considered as a first approximation of the effective dose to the patients.

References

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