Joint ICTP/IAEA Advanced School on Dosimetry in Diagnostic Radiology and its Clinical Implementation

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Dosimetry in Interventional Radiology

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EFOMP
Dosimetry in interventional radiology

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Introduction

• Introduction to interventional radiology
• Dosimetry in IR
  • Code of Practice
  • Skin dosimetry methods
Interventional era started in 1977

- Gruntzig, Zurich
- Crude catheters
- Long fluoroscopy
- Many cine runs
- Big increase in radiation to staff and patients
Interventional radiology: guided fluoroscopy
Interventional cardiology

PTCA

Case: bifurcation lesion

AP, 38 CR

LAD-D1

LAO 50, 38 CR
Case 1 bifurcation lesion

stent and balloon inflation

balloon angioplasty (PTCA) technique

PTCA & stenting technique
The frequency of procedures in Europe

- Number of diagnostic and interventional cardiac procedures (PCI) per million inhabitants in European countries is continuously increasing.
- Practice is not uniform across Europe.

![Time trends in the annual use of PCI numbers per 1 million inhabitants](chart.png)
The practice: type of procedures

Distribution of IR procedures
(Germany, 1994)

Most of them are fluoroscopy guided procedures
Frequencies and contribution to the collective effective dose of IR

Friuli Venezia Giulia, Italy
Frequency of radiological examinations
820 examination/year, 1000 inh
year 2006

Radiography 84.5%
CT 58.4%
Interventional radiology 10.4%
Radiography 16%
GI examinations 2.8%
Nuclear medicine 12.4%

1.2 mSv/year.per-caput

Friuli Venezia Giulia, Italy
Year 2006

R. Padovani & others, North-east Italy, 2006
### Patient dose range in angiographic procedures (UNSCEAR 2000)

<table>
<thead>
<tr>
<th>Angiographic Procedure</th>
<th>Technique</th>
<th>Fluorotime (min)</th>
<th>KAP (Gy.cm²)</th>
<th>Effective dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary</td>
<td>Cine film</td>
<td>3.6 – 9.8</td>
<td>16.1 - 98</td>
<td>2 – 15.8</td>
</tr>
<tr>
<td></td>
<td>Digital cine</td>
<td>5.7</td>
<td>47.7</td>
<td>9.4</td>
</tr>
<tr>
<td>Cerebral</td>
<td>DSA/conventional</td>
<td>1.2 – 36</td>
<td>12 – 120</td>
<td>2.7 – 23.4</td>
</tr>
<tr>
<td>Abdominal</td>
<td>Hepatic (DSA)</td>
<td>2.3 – 28.6</td>
<td>28 – 279</td>
<td>4 – 48</td>
</tr>
<tr>
<td></td>
<td>Renal DSA</td>
<td>5.5 - 21</td>
<td>41 - 186</td>
<td>6 - 34</td>
</tr>
<tr>
<td></td>
<td>Renal angiogr.</td>
<td>0.5 – 9.3</td>
<td>17 – 327</td>
<td>2.8 – 11.5</td>
</tr>
</tbody>
</table>
### Patient dose range in interventional procedures (UNSCEAR 2000)

<table>
<thead>
<tr>
<th>Interventional procedures</th>
<th>Localized dose to skin (Gy)</th>
<th>Fluoro time (min)</th>
<th>KAP (Gy.cm²)</th>
<th>Effective dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTCA</td>
<td>0.05 - 5</td>
<td>3 - 92</td>
<td>20 - 402</td>
<td>7.5 - 57</td>
</tr>
<tr>
<td>PTA</td>
<td>0.4</td>
<td>5 - 68</td>
<td>5 - 338</td>
<td>10 - 12.5</td>
</tr>
<tr>
<td>TIPS</td>
<td>0.4 – 5</td>
<td>9 - 115</td>
<td>7 - 1131</td>
<td>2 - 181</td>
</tr>
<tr>
<td>RF ablation</td>
<td>0.1 – 8.4</td>
<td>3 - 195</td>
<td>7 - 532</td>
<td>17 – 25</td>
</tr>
<tr>
<td>Embolization</td>
<td>0.2 – 0.5</td>
<td>1 – 90</td>
<td>7 – 918</td>
<td>6 – 43</td>
</tr>
</tbody>
</table>

ICRP recognise as ‘high dose’ procedures, giving potentially high skin doses:
- Embolisation: aneurysm and arteriovenous malformation
- Angioplasty (cardiac = PTCA)
- Radiofrequency ablation
- Transjugular intrahepatic porto-systemic shunt (TIPS)
Photograph of the patient's back 21 months after a coronary angiography and two angioplasty procedures within three days; the assessed cumulative dose was 15 - 20 Gy (Photograph courtesy of F. Mettler).
Staff: high exposure work area

0.5 – 2.5 mSv/h
1- 5 mSv/h
2- 10 mSv/h
Patient dosimetry in IR

1. Dosimetry for quality assurance
   - Air kerma area product (KAP, $P_{KA}$)

2. Dosimetry for stochastic risk evaluation
   - Dose equivalent to selected organs
   - Effective dose

3. Dosimetry to prevent deterministic effects of radiation (maximum skin dose assessment)
   - Maximum skin dose (MSD or $D_{skin,max}$)
(8.5 Fluoroscopy)

- Since no standardized method exists, recommendations on how to measure the maximum entrance surface air kerma in interventional procedures will not be given in this Code of Practice.

(Appendix VI)

- Deterministic effects only occur in diagnostic radiology in special circumstances when the local dose is very high. The most important example is the high skin dose which can arise during interventional procedures using X rays.
The assessment of absorbed dose to the most exposed area of the skin is essential in complex interventional procedures.

Knowledge during the procedure of the skin dose is necessary to avoid deterministic effects or to reduce their severity.

Knowledge after the procedure of the skin dose is necessary in order to decide which patients require follow-up.

The determination of the skin dose to the most exposed area is not easy since exposure parameters and projection angle change during the procedure.

The most exposed area cannot be predicted in most cases.
• In fluoroscopy guided interventional procedures, the air kerma–area product, $P_{KA}$, offers a convenient quantity for monitoring patient exposure.

• In order to estimate the peak skin absorbed dose it is necessary to have a detector that registers the skin dose at many points.
• Real time measurements are possible with detectors located on or near the skin but these cannot generally provide complete dose mapping.

• Two alternative approaches to estimate the maximum possible incident air kerma:
  • Measurements at a Interventional Reference Point (IEC-60601-2-43) as a point on the central ray of the X ray beam which is 150 mm from the isocentre of the radiological equipment in the direction of the X ray tube. The cumulative air kerma at the IRP may overestimate the maximum incident air kerma.
  • Measurements of $P_{KA}$ can provide an indication of the maximum possible incident air kerma if the focus to skin distance and field area are recorded.
Interventional Radiology Point (IRP)

Cumulative ESAK to Interventional Radiology Point (IRP) measured with a flat ion chamber or calculated by the system and displayed in the angio room

(IEC-60601-2-43)
Patient dosimetry to prevent deterministic effects (skin injuries)

- **Dosimetric quantity:**
  - Maximum skin dose (MSD)

- **Real time measurement/evaluation of MSD**
  - Point or area detectors
  - Cumulative dose at IRP (interventional radiology point)
  - Calculation from technical data

- **Off line methods**
  - Area detectors: TLD array, slow films, radiochromic films
  - From KAP and CD measurement
Method for MSD evaluation: TLD grid

(Thomas W. Slowey, K&S)

- 80 LiF TLD’s
- Attached to polyethylene carrier
  - 8 x 10 chip matrix
  - 4 cm x 4 cm grid spacing
Method for MSD evaluation: TLD grid

- 22 CVL studies: 18 studies 0.1 – 0.45 Gy
- Fluoro Time Range: 1.3 - 53.7 min.
- Max Dose Range: 0.07 – 2.52 Gy
- Area of Dose > 0.2 Gy: 32 - 328 sq cm

- 13 PTCAs: 6 PTCA > 1 Gy
- Fluoro Time Range: 2 - 51 min.
- Max Dose Range: 0.22 – 4.16 Gy
- Area of Dose > 1 Gy: 32 - 160 sq cm
Method for MESAK evaluation: slow film method

Method for MESAK evaluation: radiochromic large area detector

Example: Radiochromic films type Gafchromic XR R 14”x17”
- useful dose range: 0.1-15 Gy
- minimal photon energy dependence (60 - 120 keV)
- acquisition with a flatbed scanner: b/w image, 12-16 bit/pixel
  or, measure of OD measurement with a reflection densitometer
Benefits of radiochromic films

- The radiochromic film:
  - displays the maximum dose and its location
  - shows how the total dose is distributed
  - provides a quantitative record for patient files
  - provides physician with guidance to enable safe planning of future fluoroscopically guided procedures
  - improves fluoroscopic technique and patient safety

Example of an exposed radiochromic film in a cardiac interventional procedure
Evaluation methods of radiochromic

1. Rapid semi-quantitative evaluation with comparison chart

2. Quantitative measurements with:
   a. Densitometer (point measurements)
   b. Digital flat bed scanner
1. Rapid semi-quantitative evaluation

- For each batch number (lot #) of gafchromic film a Comparison Tablet is provided
- A simple direct comparison of the Comparison Tablet with the exposed film allows to estimate the maximum dose
Rapid semi-quantitative evaluation: example

- In the reported example we easily can recognise that the darkness area of the film, corresponding to the skin area that has received the maximum local dose, has an Optical Density that correspond at about 4 Gy
2.a - Quantitative measurements with spot densitometer

2.a Spot measurements with reflective densitometer

• Spot reflective densitometer reading the Optical Density (OD) of the gafchromic film in the red region is an easy, accurate and fast method for skin dosimetry and for the estimation of the maximum local skin dose
Calibration procedure for radiochromic film

- Each piece of gafchromic is read with the reflection densitometer (typical results are reported in the table).
- Air kerma vs. OD are interpolated in an Excel sheet.
- The resulting calibration curve (a straight line in this case) is adopted for the patient dose calculation.
- In the example: \( \text{ESD (mGy)} = -8290 + 7771 \times \text{OD} \)
2. Quantitative measurements with flat bed scanner

2.b OD measurements with a colour flat bed scanner

- A colour flat bed scanner can be used to digitise an exposed gafchromic film.
- The dosimetric system, including the scanner, the acquisition parameters and the image processing methodology, has to be properly tested and calibrated.
2.B Calibration procedure for radiochromic film

- The red component of the image is selected (in RGB format the image has red, blue and green components) because the maximum light absorption is in the red region of the spectrum.
- Manually, or with a dedicated software, a ROI is created inside each piece and the mean OD calculated.
- Finally, a calibration curve is calculated; a cubic curve is usually adopted.

In the example: (i) in the table the grey levels (GL) vs air kerma values (AK) (ii) the coefficients of the cubic interpolating curve: $AK = 6.563 \times 10^3 - 0.2932 \times GL + 4.209 \times 10^{-6} \times GL^2 - 1.918 \times 10^{-11} \times GL^3$
Patient skin dose evaluation (I)

- The patient film is acquired with the scanner in manual mode, with the parameters registered/stored in the calibration procedure.
- The red component of the image is selected.
- The image can be smoothed with a 5x5 filter.
- The red levels (GL) of the extracted image is converted to entrance dose to air applying the calibration curve.
Patient dose evaluation and evaluation accuracy

Examples of patient skin dose distributions in PTCA procedures

Accuracy of dose evaluations:
- comparing MSD evaluated with the different quantitative methodologies described, differences of less than 10% are expected.
Monitoring of skin dose in high dose procedures (IAEA survey)

- Radiochromic films used to measure patient skin dose in a sample of 392 interventional procedures in a IAEA international study
- In 52 procedures (7.4%) the PSK > 2 Gy, 15 proc. > 4 Gy
- maximum PSK 6.6 Gy; 38 PTCA, 6 RF ablation, 1 neuro and 6 hepatic embolisations
- 39 occurred at two hospitals!
**MSD evaluation: computational method**

- **CAREGRAPH (Siemens)**
  - **Dose Distribution**

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<table>
<thead>
<tr>
<th>Patient name:</th>
<th>Mayer, Friedrich</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient ID:</td>
<td>1947_08_11</td>
</tr>
<tr>
<td>Patient size:</td>
<td>186 cm</td>
</tr>
<tr>
<td>Patient weight:</td>
<td>91 kg</td>
</tr>
<tr>
<td>Patient position:</td>
<td>Head first, Supine</td>
</tr>
<tr>
<td>Patient-Table pos.:</td>
<td>8 cm from top</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>acc. max. Hot Spot:</th>
<th>1321 mGy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluoro:</td>
<td>720 mGy</td>
</tr>
<tr>
<td>Acquisition:</td>
<td>480 mGy</td>
</tr>
</tbody>
</table>

- **plane A**
  - acc. dose area product: 148 Gy/cm²
    - Fluoro: 63 Gy/cm²
    - Acquisition: 85 Gy/cm²
  - Fluoro: 17 Gy/cm²
  - Acquisition: 28 Gy/cm²

- **plane B**
  - acc. dose area product: 45 Gy/cm²
    - Fluoro: 63 Gy/cm²
    - Acquisition: 85 Gy/cm²

<table>
<thead>
<tr>
<th>Plane A fluoro time:</th>
<th>1 h 18 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plane B fluoro time:</td>
<td>0 h 32 min</td>
</tr>
</tbody>
</table>

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- **x-ray projection:**
  - **plane A:** RAO=60° Caud=15°
  - **plane B:** -- --
Method for MSD evaluation: MSD/KAP factors

- Skin doses in IR and IC
  - Measurements of dose rates for different type of procedures, field size, orientation, continuous/pulsed fluoroscopy
    - Extended assessment of KAP/ESD factors for different procedures/field size/orientations
    - Possible use of ESD/KAP factor to estimate skin dose, in alternative to more direct methods of skin dose measurements
Method for MSD evaluation:
MSD/KAP factors for cardiac procedures

<table>
<thead>
<tr>
<th>Projection</th>
<th>MSD/KAP (mGy/Gycm²) vs field size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23 cm</td>
</tr>
<tr>
<td>PA</td>
<td>4.67</td>
</tr>
<tr>
<td>RAO 30° + 25° CAU</td>
<td>4.11</td>
</tr>
<tr>
<td>RAO 10° + 10° CAU</td>
<td>4.13</td>
</tr>
<tr>
<td>Lateral</td>
<td>7.64</td>
</tr>
<tr>
<td>LAO 45°</td>
<td>3.56</td>
</tr>
<tr>
<td>LAO 45° + 25° CAU</td>
<td>3.55</td>
</tr>
<tr>
<td>RAO 30°</td>
<td>3.02</td>
</tr>
</tbody>
</table>
MSD vs. Cumulative air kerma

- In some procedures, CD is well correlated with maximum (peak) skin dose.
- CD can be a good indicator of doses higher than the thresholds for skin injuries.
- A “trigger value” of 2000 mGy for CD can be adopted to alert interventionalists the threshold for skin erythema could be reached.
- A follow-up protocol can be adopted.

**Liver Embolisations**

\[ y = 1.1745x \]

\[ R^2 = 0.9256 \]

About 20% of patients have >2 Gy at the skin (Udine, 2008)

(IEC-60601-2-43)
Recommendations to reduce the probability of skin injuries in IR

- Periodic monitoring of skin doses on high dose procedures
- A “trigger value” in term of KAP or CD to IRP should be adopted to alert interventionalist
- A follow-up protocol should be introduced for patients could have received high skin doses
Udine

Friuli-Venezia Giulia region

Thank you!

Mandi!