Radiation Exposure and Risks to Patients and Staff During Selected Non-Cardiac Interventional Procedures: Pernambuco, Brazil Experiences

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Fluoroscopically-guided Interventions

Interventional Radiology

- Cardiology
- Neurology
- Vascular Surgery
- Urology
- Orthopedic Surgery
- Obstetrics and Gynecology
- Gastroenterology and Hepato-biliary System
- Anesthesiology and Pain Management
Cerebral Angiography: 158 Adults
15 Children

Cerebral Embolization: 70 Adults

Hepatic Chemoembolization: 55 adults (3 hospitals)

Prostatic Artery Embolization: 5 adults
$P_{KA}$ represents the integral of air kerma across the entire x-ray beam emitted from the x-ray tube. Its units are Gy cm$^2$.

The accuracy of the display can be checked directly or indirectly.
Calibration PKA chamber

PKA (DAP) Display on control

\[ P_{KA} = k_a \times K_Q \times F_{P,T} \times A \]

Pka Calibration Factor

Conventionally true indicated DAP

![Graph showing PKA calibration factor with mean 0.83](chart.png)

PKA chamber
Ionization chamber
Film
PKA
(\(K_{a,r}\))

“Interventional reference point”, “Cumulative reference point air kerma”, “Cumulative dose”, “Patient entrance reference point”

The accuracy of the \(K_{a,r}\) display is checked with an ion chamber.

Tolerance ± 35 % for > 100 mGy

\(K_{a,r}\) approximates \(K_{a,e}\) for patients undergoing body interventions such as cardiac and hepatic procedures, but overestimates it for patients in cerebrovascular interventions.

IEC 60601-2-43, 2000 & NCRP 168, 2010
$P_{KA}$ Tolerance $\pm$ 35% for $> 2.5$ Gy cm$^2$
Protection Dosimetry – Interventional Radiology

- **Stochastic Effects**
- **P_{KA}**

**Diagnostic Reference Levels in terms of P_{KA}**

- **Deterministic Effects**
- **Maximum (Peak) Organ Dose**
  - Skin
  - Eye Lens

**Patient Follow-up**

**Peak Skin Dose:** 3 Gy (ICRP, NCRP), 15 Gy (U.S. TJC)

**Cumulative Air Kerma:** 5 Gy; \( P_{KA} : 500 \text{ Gy cm}^2 \); **Fluoroscopy Time:** 60 min (NCRP)
Threshold doses for approximately 1% morbidity incidence

<table>
<thead>
<tr>
<th>Effect</th>
<th>Organ/tissue</th>
<th>Time to develop effect</th>
<th>Acute exposure (Gy)</th>
<th>Highly fractionated (2 Gy per fraction) or equivalent protracted exposures (Gy)</th>
<th>Annual (chronic) dose rate for many years (Gy y⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main phase of skin reddening</td>
<td>Skin (large areas)</td>
<td>1-4 weeks</td>
<td>&lt;3-6</td>
<td>30</td>
<td>NA</td>
</tr>
<tr>
<td>Skin burns</td>
<td>Skin (large areas)</td>
<td>2-3 weeks</td>
<td>5-10</td>
<td>35</td>
<td>NA</td>
</tr>
<tr>
<td>Temporary hair loss</td>
<td>Skin</td>
<td>2-3 weeks</td>
<td>~4</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Late atrophy</td>
<td>Skin (large areas)</td>
<td>&gt; 1 year</td>
<td>10</td>
<td>40</td>
<td>NA</td>
</tr>
<tr>
<td>Telangiectasia @ 5 years</td>
<td>Skin (large areas)</td>
<td>&gt; 1 year</td>
<td>10</td>
<td>40</td>
<td>NA</td>
</tr>
<tr>
<td>Cataract (visual impairment)</td>
<td>Eye</td>
<td>&gt;20 years</td>
<td>~0.5</td>
<td>~0.5</td>
<td>~0.5 divided by years duration</td>
</tr>
</tbody>
</table>

ICRP 118, 2012
- $P_{KA}$ and $K_{a,r}$: showed at equipment display
- Radiochromic film: dose distribution estimated on patient’s skin
- TLD dosimetry in some body regions
Adult patient doses received during cerebral procedures performed in Recife

Dosimeters: TLD-100
Paediatric patient doses received during cerebral procedures performed in Recife

- **Patients:** Data for 15 patients (7 female and 8 male), 3 to 15 years old.
- **Procedures:** 13 patients cerebral angiographies and 2 patients embolization neuroradiology procedure

**Distribution of the skin air kerma in the region of left and right eyes, forehead and thyroid**

**Reference cumulative dose for fluoroscopy, DSA and total neuroangiographic procedure**
### Pediatric Patient

<table>
<thead>
<tr>
<th>Mode of exposure</th>
<th>$P_{KA}$ (Gy.cm^2)</th>
<th>$K_{a,r}$ (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min.</td>
<td>Mean</td>
</tr>
<tr>
<td><strong>Fluoroscopy</strong></td>
<td>1,3</td>
<td>3,7</td>
</tr>
<tr>
<td><strong>DSA (n = 11)</strong></td>
<td>16,7</td>
<td>46,5</td>
</tr>
<tr>
<td><strong>DSA + 3D (n = 2)</strong></td>
<td>69,9</td>
<td>73,9</td>
</tr>
<tr>
<td><strong>Complete procedure</strong></td>
<td>18,8</td>
<td>53,6</td>
</tr>
</tbody>
</table>

### Adult Patient

<table>
<thead>
<tr>
<th>Mode of exposure</th>
<th>$P_{KA}$ (Gy.cm^2)</th>
<th>$K_{a,r}$ (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min.</td>
<td>Mean</td>
</tr>
<tr>
<td><strong>Fluoroscopy</strong></td>
<td>1,9</td>
<td>12,2</td>
</tr>
<tr>
<td><strong>DSA (n = 97)</strong></td>
<td>14,3</td>
<td>57,9</td>
</tr>
<tr>
<td><strong>DSA + 3D (n = 61)</strong></td>
<td>29,8</td>
<td>70,6</td>
</tr>
<tr>
<td><strong>Complete procedure</strong></td>
<td>16,3</td>
<td>75,1</td>
</tr>
</tbody>
</table>
In Interventional Exams, Maximum Skin Dose and $P_{KA}$ can be Determined with Film: Silver Halide and Radiochromic.
Radiochromic films

\[ y = -2.5785x^4 + 7.1213x^3 - 1.0846x^2 + 2.1863x \]

\[ R^2 = 0.9994 \]

N. Lunelli, 2012
Cerebral angiographies

Maximum Skin Dose

- 186 mGy
- 251 mGy
- 207 mGy

- 405 mGy
- 534 mGy
- 599 mGy
- 464 mGy

Cerebral Embolizations

2497 mGy

N. Lunelli, 2012
Maximum Skin Dose - Results
Neuroradiology Interventions

- Reaction in the patient - MSD=8030 mGy
- Vascular malformation
- Vascular malformation
- Aneurysm - left side

N. Lunelli, 2012
Maximum Skin Dose - Results

Hepatic Artery Chemoembolization

right  left

MSD=3.5 Gy

Right  Left

MSD=3.9 Gy

MSD=5.6 Gy

MSD= 5.6 Gy

MSD=2.4 Gy

MSD=2.2 Gy
Hepatic Artery Chemoembolization Results

Distribution of $P_{KA}$ across procedures and hospitals.

H.J. Khoury et al, 2015
### Prostatic Artery Embolization Results

Fluoroscopy time, acquisition images, total and partial $P_{\text{KA}}$ values per procedure.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Fluoroscopy time (min)</th>
<th>Fluoroscopy (%)</th>
<th>Acquisition images</th>
<th>$P_{\text{KA}}$ (Gy · cm²)</th>
<th>$P_{\text{KA}}$ (Gy · cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>DSA</td>
<td>3D CBCT</td>
<td>DSA (%)</td>
</tr>
<tr>
<td>1</td>
<td>38.4</td>
<td>118.2 (16)</td>
<td>598 (21)</td>
<td>396 (2)</td>
<td>577.4 (77)</td>
</tr>
<tr>
<td>2</td>
<td>25.5</td>
<td>81.4 (13)</td>
<td>458 (25)</td>
<td>397 (2)</td>
<td>489.7 (79)</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>142.9 (27.1)</td>
<td>447 (18)</td>
<td>—</td>
<td>384.7 (72.9)</td>
</tr>
<tr>
<td>4</td>
<td>25.3</td>
<td>68.1 (17)</td>
<td>486 (13)</td>
<td>—</td>
<td>333.7 (83)</td>
</tr>
<tr>
<td>5</td>
<td>20.4</td>
<td>43.3 (13)</td>
<td>575 (23)</td>
<td>—</td>
<td>279.2 (87)</td>
</tr>
<tr>
<td>Mean</td>
<td>29.1</td>
<td>90.8 (17.2)</td>
<td>512.8 (20)</td>
<td>396.5 (2)</td>
<td>409 (79.8)</td>
</tr>
</tbody>
</table>

—CBCT mode not used.

W.J. Garzon et al., 2016
Prostatic Artery Embolization Results

Patient skin dose distribution and radiation field beam variation observed on a radiochromic film used during a PAE procedure.

W.J. Garzon et al., 2016
# Prostatic Artery Embolization Results

PSD, cumulative air kerma, and DI for each PAE procedure in this study.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>PSD (mGy)</th>
<th>Fluoroscopy (%)</th>
<th>DSA (%)</th>
<th>CBCT (%)</th>
<th>Total</th>
<th>DI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3008</td>
<td>1008 (17.7)</td>
<td>4496.9 (79.2)</td>
<td>169 (3)</td>
<td>5674</td>
<td>0.53</td>
</tr>
<tr>
<td>2</td>
<td>3190</td>
<td>774.5 (15.7)</td>
<td>3995.5 (81.1)</td>
<td>154 (3.1)</td>
<td>4924</td>
<td>0.65</td>
</tr>
<tr>
<td>3</td>
<td>2500</td>
<td>1299 (25.1)</td>
<td>3884 (74.9)</td>
<td>—</td>
<td>5183</td>
<td>0.48</td>
</tr>
<tr>
<td>4</td>
<td>2380</td>
<td>810.7 (22)</td>
<td>2948.2 (78)</td>
<td>—</td>
<td>3758</td>
<td>0.63</td>
</tr>
<tr>
<td>5</td>
<td>2293</td>
<td>522.4 (14)</td>
<td>3214.7 (86)</td>
<td>—</td>
<td>3737</td>
<td>0.61</td>
</tr>
<tr>
<td>Mean</td>
<td>2674</td>
<td>882.9 (18.9)</td>
<td>3707.9 (79.8)</td>
<td>64.6 (1.2)</td>
<td>4655.2</td>
<td>0.58</td>
</tr>
</tbody>
</table>

—CBCT mode not used.
Medical Staff Dosimetry

TLD-100 chips attached next to the eyes, close to the thyroid (over apron-collar), on the thorax under the apron, at the hands in the region of the pulse, and at the feet.

The effective dose to the staff was estimated using the algorithm of von Boetticher.

\[ E = 0.84H_{p,u}(10) + 0.051H_{p,o}(10) \]

Where: \( H_{p,u} \) is the dosemeter reading under the apron

\( H_{p,o} \) is the dosemeter reading over the apron

<table>
<thead>
<tr>
<th>Monitored Regions</th>
<th>Operational Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes</td>
<td>( Hp(0.07); \ Hp(3) )</td>
</tr>
<tr>
<td>Neck (Over the thyroid shield)</td>
<td>( Hp(10) )</td>
</tr>
<tr>
<td>Thorax (Under the apron)</td>
<td></td>
</tr>
<tr>
<td>Hands (pulse area)</td>
<td>( Hp(0.07) )</td>
</tr>
<tr>
<td>Knees</td>
<td></td>
</tr>
<tr>
<td>Feet</td>
<td></td>
</tr>
</tbody>
</table>

Position of the TLDs on the physician’s body surface
Occupational Dosimetry
Cerebrovascular Aneurysms & Embolizations

N. Lunelli et al 2012
Prostatic Artery Embolization

Mean, minimum and maximum Hp(3), Hp(0.07) and Hp(10) values measured on the physician per location and procedure.

<table>
<thead>
<tr>
<th>Monitored location</th>
<th>Hp(3) (μSv)</th>
<th>Hp(0.07) (μSv)</th>
<th>Hp(10) (μSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Glabella</td>
<td>Left eyebrow</td>
<td>Right eyebrow</td>
</tr>
<tr>
<td>Mean</td>
<td>441</td>
<td>478</td>
<td>196</td>
</tr>
<tr>
<td>Minimum</td>
<td>321</td>
<td>341</td>
<td>80</td>
</tr>
<tr>
<td>Maximum</td>
<td>673</td>
<td>798</td>
<td>367</td>
</tr>
</tbody>
</table>

W.J. Garzon et al., 2016
Mean values of Hp (d) in several regions of the main physician and the medical staff

Hepatic Artery Chemoembolization
Physician Effective Dose / Procedure
Hepatic Artery Chemoembolization

W.J. Garzon 2015
Estimation of annual values of main physician’s effective dose and equivalent dose

- Considering that the doctor performs about 150 embolization per year

| Limit value       | Annual Dose |  |  |
|-------------------|-------------|----------------------------|
|                   | Annual      | Garzon et al, 2015 | Kong et al., 2013 |
| Effective dose    | 20          | 2.55          | 3.16          |
| Lens of eyes      | 20          | 41.40         | 9.27          |
| Hands             | 500         | 54.15         | ***           |
| Feet              | 500         | 133.5         | ***           |
Teaching the Hospitals Radiation Protection

Good practice - using shield devices

- 23.9 μSv
- 187.2 μSv

Without shield devices

- 84.6 μSv
- 449.5 μSv

80% decrease in radiation exposure

- 246.4 μSv
- 319.5 μSv

- 1007 μSv
- 1608.6 μSv
Measurements with radiochromic film and TLDs are very time consuming. But the methodology can be used to validate the DICOM Standards

- DICOM Header
- DICOM Services
  - e.g. modality performance procedure step (MPPS)
- Radiation Dose Structured Report (RDSR)
- Patient-RDSR (P-RDSR)
Skin Dose Maps
(JM Fernandez-Soto et al., 2016)

Sample of a radiochromic film image placed at the patient back in an interventional cardiology procedure (right) and two types of dose maps obtained from the DICOM RDSR for the same procedure. This also allows the estimation of the maximum dose at the skin entrance.
Patient Dose Determination: Data Flow Requirements

- X-Ray exposure techniques
  - Table, Gantry Angle, Beam Geometry, collimation, ...
  - Dose measure: CTDI, DAP, ...

- Equipment Information
  - Table dimension
  - Attenuating material, ...

- Patient Dose Surface
  3D map/view

- Patient Dose 2D view/map
  (e.g. iso-dose map)

- Calculated data for documentation and reference to images and RDSR's

D. Pelc, 2016