The Management and Reporting of Imaging Procedure Dose 1: Interventional Radiology/Cardiology WE-A-144-01

II. Measurements and Dose Calculations

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Why Measure Dose in Fluoroscopically-guided Interventional (FGI) Procedures?

- Estimation of radiation risk after a procedure
- Cancer and skin injury
- Evaluate radiation risk during a procedure
- Ensure appropriate follow-up for possible skin injury
- Practice quality improvement efforts
- Compliance with state regulations

Cancer Risk

- May be needed for IRB evaluation of research
- Particularly important for pediatric patients
- Estimate from individual organ doses
  - Generally, multiple organs would need to be included
- Estimate from effective dose, E
- E can be estimated from Kerma Area Product (PKA)
  - PKA represents total energy incident on patient

Kerma Area Product Measurement

- Displayed on most systems during the procedure
- Included in study data stored after procedure completed

Effective Dose Estimation

- E per unit Gy-cm² has been estimated for common FGI procedures
  - Simplified body phantom
  - X-ray field size, projection and location
  - Typical x-ray energy spectrum

  Dose Conversion
  \[ E = \text{Coefficient} \times P_{KA} \] 

  (DCCE)

Effective Dose Estimation

<table>
<thead>
<tr>
<th>Exam</th>
<th>DCCE (mSv/Gy-cm²)</th>
<th>Typical E (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hepatic chemoembolization</td>
<td>0.26</td>
<td>70</td>
</tr>
<tr>
<td>Renal/Visceral PTA with stent</td>
<td>0.26</td>
<td>60</td>
</tr>
<tr>
<td>Vertebroplasty</td>
<td>0.20</td>
<td>15</td>
</tr>
<tr>
<td>Pulmonary angiography with</td>
<td>0.12</td>
<td>15</td>
</tr>
<tr>
<td>stent with filter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carotid stent</td>
<td>0.09</td>
<td>14</td>
</tr>
</tbody>
</table>

Reference: NCRP Report 160
Fluoroscopic Skin Injury
• Estimate risk from peak skin dose
• Location and size of the exposed region
  • Follow-up skin evaluation
  • Planning subsequent procedures

Reference: Wagner, BIIJ 2007;3:e22

Skin Dose Measurement Methods
• Direct
  • Placement of a detector directly on the patient’s skin for a localized dose measurement
• Indirect
  • Calculation of skin dose from fluoroscopy equipment acquisition parameters

Direct Point Dosimeters
• Single or arranged in an array to cover exposed skin area

Nanodot (Landauer)
Radiosensitive dye (Radimap)


Direct Readout Dosimeters
• Single or multiple wired detectors with electronic readout display

PSD (Unfors/Raysafe)
MOSFET (Best Medical)

Film Dosimetry

- Placed on patient surface or on table
- Appropriate exposure sensitivity required

GAFCHROMIC (International Specialty Products)

Direct Exposure Film

Film Dosimetry

- Merits:
  - Accurate localization
  - Dose measurement over a large area
  - Not visible in fluoroscopic image
- Drawbacks:
  - No real-time feedback
  - Positioning for lateral projection difficult
  - Careful calibration required for dose accuracy

Skin Dose Measurement Methods

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  - Placement of a detector directly on the patient’s skin for a localized dose measurement
- Indirect
  - Calculation of skin dose from fluoroscopy equipment acquisition parameters

Reference Point Air Kerma, $K_{a,r}$

- Display at operator’s position required for fluoroscopes manufactured after June 2006*

* FDA (2009), 21 CFR Part 1020.32

Reference Point Air Kerma

- Air kerma at approximate entrance skin location
- Reference point for C-arms is 15 cm from isocenter of rotation back toward x-ray tube

$K_{a,r}$ Measurement Methods

- Kerma area product meter
  - $K_{a,r} = P_{k,r} / \text{exposure area}$
  - Exposure area determined from collimation positions
- Calculation from output measurements for actual kVp and mAs
Indirect Skin Dose Estimation

**Merits:**
- Real-time feedback
- Relatively easy to access
  - Some systems provide a dose report
  - Dose report may be archived as an image

**Drawbacks:**
- Corrections are needed for accurate skin dose estimation from $K_{ar}$ value
- $K_{ar}$ value is cumulative over all skin entrance ports
- Peak skin dose value, location and area not readily available without further computation

Skin Dose Estimation Steps *

1. $K_{ar}$ calibration
2. Entrance skin port location(s)
3. Source-skin distance correction
4. Table and pad attenuation correction
5. Backscatter factor
6. f-factor

* See Jones and Pasciak, JACMP 2011;12:231 for a detailed review

1. $K_{ar}$ Calibration

- $K_{ar}$ ± 35% accuracy per FDA *
  - AAPM Task Group 190 Accuracy and Calibration of Integrated Radiation Output Indicators will produce a report with verification procedure to an external dosimeter

* FDA (2009), 21 CFR Part 1020.32

**$K_{ar}$ Correction Factor**

- Correction factor should be determined
  - Service adjustment of $K_{ar}$ readout value is possible for some systems
  - Summary of collected field data for 12 systems monitored annually for 10 years, multiple vendors and models
    - Correction factor is fairly stable over time
    - Correction factors vary widely from system to system
2. Entrance Skin Location

- Determine if there were multiple, distinct entrance skin ports
- Biplane systems
- Widely separated C-arm angles
- Multiple treatment regions
- Review stored images

3. Distance Correction

- Inverse square correct $K_{a,r}$ to actual source-skin distance (SSD)
- SSD will vary depending on table height used clinically
  - $SSD = \text{Table height} - \text{source-floor distance} - \text{pad height}$
- Table height depends on physician preference
- DICOM header for DA
  - Tag (0018, 1111)

4. Table/Pad Attenuation Correction

- Thick foam pads are especially attenuating
- Typical correction factor is 0.75 to 0.85
- Measurement method:
  - Broad-beam geometry (scatter from table/pad included)
  - Same kVp, beam filtration, field size as used clinically
5. Backscatter Factor

- Scatter from exposed tissue contributes to skin dose
- Typical backscatter factor is 1.3 to 1.55
- Backscatter factor depends on:
  - X-ray beam quality
  - X-ray field size (estimate as $P_{\text{KA}}/K_{\text{r}}$

6. f-Factor

- Converts air kerma to absorbed dose in skin
- f-factor depends on x-ray beam quality

Fluoroscopy Contribution

- Above correction factors are easier to assess for DA
  - More difficult for fluoroscopy since generally not recorded
  - Do not assume fluoroscopy contribution is minimal
- Interview staff to estimate parameters
- Alternatively, assume same as DA
- Estimate x-ray beam quality from measurements with a phantom simulating patient thickness

Example Skin Dose Calculation

- 70 yo male, AAA stent graft placement
  - Average patient size
  - Minimal C-arm angulation
  - PA projection with exposure through table and pad
  - Single entrance port
  - Source-reference point distance = 60 cm

Example Skin Dose Calculation

- Source-skin distance = 68 cm
  - 32 cm FOV (20x20 cm field size) used for most of the procedure
  - DA:
    - 80-85 kVp, no Cu filtration – 3.5 mm Al HVL
  - Fluoro:
    - 70-80 kVp, 0.2 mm Cu filtration – 5.5 mm Al HVL
  - Measured table+pad attenuation for these beam conditions
Example Skin Dose Calculation

<table>
<thead>
<tr>
<th>Exam</th>
<th>DA</th>
<th>Fluoro</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{ax}$ (mGy)</td>
<td>3057</td>
<td>2120</td>
</tr>
<tr>
<td>Distance correction $(60/68)^2$</td>
<td>0.78</td>
<td>0.78</td>
</tr>
<tr>
<td>Table + pad attenuation</td>
<td>0.77</td>
<td>0.81</td>
</tr>
<tr>
<td>Backscatter factor</td>
<td>1.43</td>
<td>1.52</td>
</tr>
<tr>
<td>i-factor</td>
<td>1.058</td>
<td>1.062</td>
</tr>
<tr>
<td>Combined correction factors</td>
<td>0.91</td>
<td>1.02</td>
</tr>
</tbody>
</table>

Total peak skin dose = 4944 mGy

Indirect Skin Dose Estimation

- Drawbacks:
  - Corrections are needed for accurate skin dose estimation from $K_{ax}$ value
  - $K_{ax}$ value is cumulative over all skin entrance ports
  - Numerous assumptions required
- However, complete exposure data is available to produce a skin dose map

DICOM Radiation Dose Structured Report

- Dose report includes acquisition parameters for each "irradiation event" in an exam
  - Irradiation event: DA image, DA series or fluoroscopy foot-switch
  - Data for each event includes: $K_{ax}$, $P_{kV}$, C-arm angles, filter, kVp, mAs, source-patient, source-detector distances, table position

Automated Skin Dose Calculation

- Patient is represented by a computational model
  - Position and location on the table specified manually
  - For each irradiation event, $K_{ax}$ values corrected and mapped to the model surface
  - Summed events produce a skin dose map and peak skin dose value and location

Reference: Khodadadegan et al, Radiology 2012; 266: 246
Automated Skin Dose Calculation

- Both methods are transferable
- Use independent workstation and standard DICOM output
- Drawbacks:
  - Streaming of the DICOM Dose Report would be needed for real-time feedback to physician
  - Dose Report availability is currently limited

Conclusions

- Measurement of dose during fluoroscopic procedures is an important tool for assessment of individual patient radiation risk
- Use of reference point air kerma most practical method
- Skin dose mapping applications are under development