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 (P_{KA})
  - P_{KA} 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

$$E = \text{Dose Conversion Coefficient (DCCE)} \times P_{KA}$$

Effective Dose Estimation

Exam	DCCE (mSv/Gy-cm^2)	Typical E (mSv)
Hepatic chemoembolization	0.26	70
Renal/Visceral PTA with stent	0.26	60
Vertebroplasty	0.20	15
Pulmonary angiography with filter	0.12	15
Carotid stent	0.09	14

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

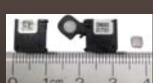
Reference: Wagner, BIIJ 2007;3:e22

Skin Dose Measurement Methods

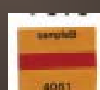
- Direct
  - Placement of a detector directly on the patient's skin for a localized dose measurement
- Indirect
  - Calculation of skin dose from fluoroscopy equipment acquisition parameters

Direct Point Dosimeters

- Single or arranged in an array to cover exposed skin area



Nanodot (Landauer)



Radiosensitive dye (Radimap)

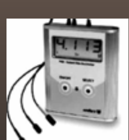
Reference: Suzuki et al, Radiology 2005;239:541

Direct Point Dosimeters

- Merits:
  - Accurate dose value and localization
  - Measurements obtained over a large area
  - Not visible in x-ray image
- Drawbacks:
  - No real-time feedback
  - Labor-intensive readout process – not practical for routine dose monitoring

Direct Readout Dosimeters

- Single or multiple wired detectors with electronic readout display



PSD (Unfors/Raysafe)

MOSFET (Best Medical)

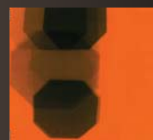
Direct Readout Dosimeters

- Merits:
  - Accurate dose and localization
  - Real-time feedback
- Drawbacks:
  - Measurement locations limited
    - Placement at peak dose location difficult
  - Dosimeter may be visible in image

Reference: Chida et al, Acta Rad 2009;50:474

Film Dosimetry

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



GAFCHROMIC (International Specialty Products)

Direct Exposure Film

Film Dosimetry

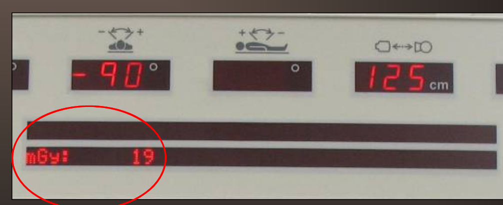
- Merits:
  - Accurate localization
  - Dose measurement over a large area
  - Not visible in fluoroscopic image
- Drawbacks:
  - No real-time feedback
  - Positioning for lateral projection difficult
  - Careful calibration required for dose accuracy

Skin Dose Measurement Methods

- 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

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

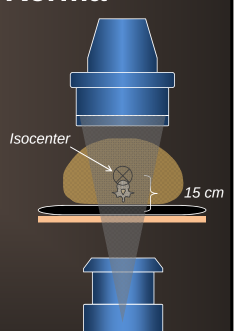
- Display at operator's position required for fluoroscopes manufactured after June 2006*



** 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

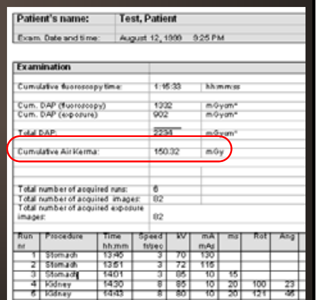


$K_{a,r}$ Measurement Methods

- Kerma area product meter
  - $K_{a,r} = P_{KA}$ / 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 able to be archived as an image



Patient's name:	Test, Patient
Exam. Date and time:	August 12, 1999 9:25 PM

Examination		
Cumulative fluoroscopy time:	1:16:33	hh:mm:ss
Cum. DAP (fluoroscopy)	1332	mGycm²
Cum. DAP (exposure)	902	mGycm²
Total DAP:	2234	mGycm²
Cumulative Air Kerma:	150.32	mGy
Total number of acquired runs:	6	
Total number of acquired images:	82	
Total number of acquired exposure images:	82	

Run nr	Procedure	Time hh:mm	Speed fr/sec	kV	mA mAs	ms	Rot	Ang
1	Stomach	13:45	3	70	130			
2	Stomach	13:51	3	72	116			
3	Stomach	14:01	3	85	10	15		
4	Kidney	14:30	8	85	10	20	100	23
6	Kidney	14:43	8	80	10	20	121	46

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Indirect Skin Dose Estimation

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

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Skin Dose Estimation Steps *

1. $K_{a,r}$ 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*

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1. $K_{a,r}$ Calibration

- $K_{a,r}$ ± 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*

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1. $K_{a,r}$ Calibration

- Correction factor should be determined
  - Service adjustment of $K_{a,r}$ 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

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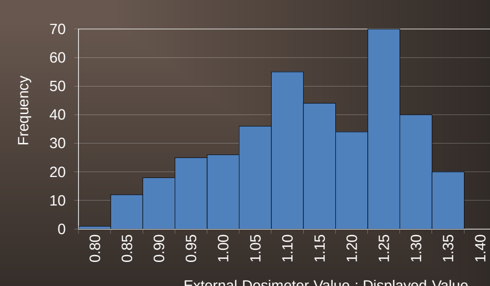
$K_{a,r}$ Correction Factor



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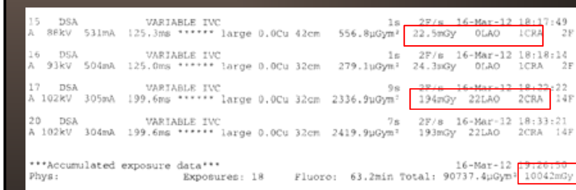
2. Entrance Skin Location

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

2. Entrance Skin Location

- Data per DA series may also be available in a dose report or DICOM header elements

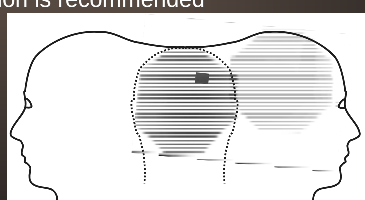


```
15   DSA          VARIABLE IVC                        1s   2F/s  16-Mar-12 18:17:49
A  88kV  531mA  125.3ms ****** large 0.0Cu 42cm   556.8µGym²  22.5mGy   0LAO   1CRA   2F
16   DSA          VARIABLE IVC                        1s   2F/s  16-Mar-12 18:18:14
A  93kV  504mA  125.0ms ****** large 0.0Cu 32cm   279.1µGym²  24.3mGy   0LAO   1CRA   2F
17   DSA          VARIABLE IVC                        9s   2F/s  16-Mar-12 18:22:22
A 102kV  305mA  199.6ms ****** large 0.0Cu 32cm  2336.9µGym²  194mGy  22LAO   2CRA  14F
20   DSA          VARIABLE IVC                        7s   2F/s  16-Mar-12 18:33:21
A 102kV  304mA  199.6ms ****** large 0.0Cu 32cm  2419.9µGym²  193mGy  22LAO   2CRA  14F

***Accumulated exposure data***                              16-Mar-12 19:26:50
Phys:                Exposures: 18     Fluoro:  63.2min Total: 90737.4µGym² 10042mGy
```

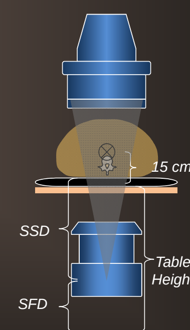

2. Entrance Skin Location

- Verify close entrance ports with a phantom and film or fiducial markers
- If field overlap is possible, a single skin port location is recommended



3. Distance Correction

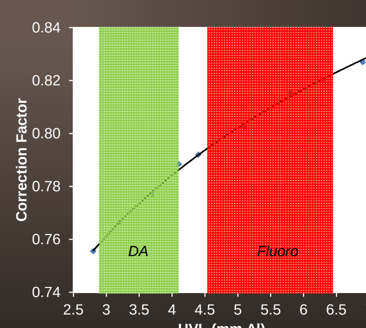
- Inverse square correct $K_{a,r}$ to actual source-skin distance (SSD)
- SSD will vary depending on table height used clinically
  - SSD = Table height – source-floor distance – pad height
- Table height depends on physician preference
- DICOM header for DA
  - Tag (0018, 1111)



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

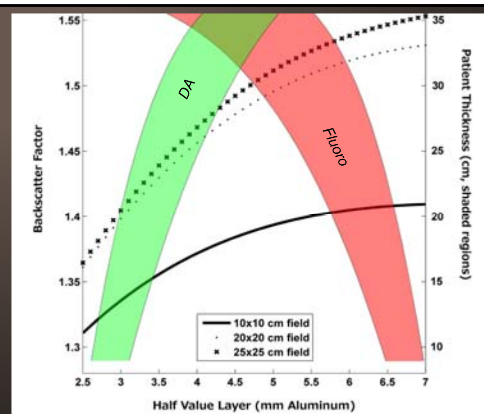
4. Table/Pad Attenuation Correction



Example 20x20 cm field

5. Backscatter Factor

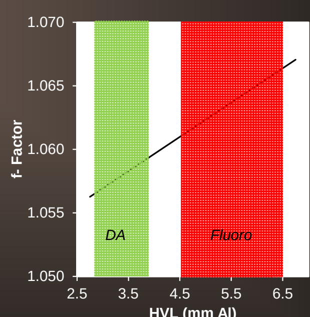
- Scatter from exposed tissue contributes to skin dose
- Typical backscatter factor is 1.3 to 1.55
- Backscatter factor depends on:
  - X-ray beam quality
  - X-ray field size (estimate as $P_{KA}/K_{a,r}$)



Reference: Jones and Pasciak, JACMP 2011;12:231

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

Exam	DA	Fluoro
$K_{a,r}$ (mGy)	3057	2120
- Distance correction $(60/68)^2$	0.78	0.78
- Table + pad attenuation	0.77	0.81
- Backscatter factor	1.43	1.52
- f-factor	1.058	1.062
Combined correction factors	0.91	1.02

Total peak skin dose = 4944 mGy

Indirect Skin Dose Estimation

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

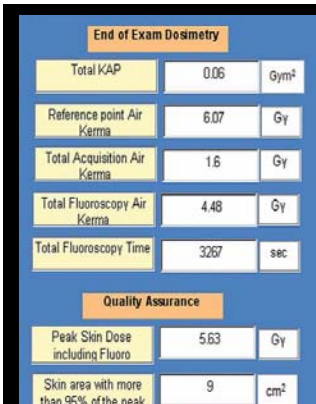
DICOM Radiation Dose Structured Report

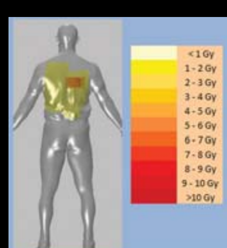
- Dose report includes acquisition parameters for each "irradiation event" in an exam*
  - Irradiation event: DA image, DA series or fluoroscopy foot-switch
  - Data for each event includes: $K_{a,r}$, P_{KA}, C-arm angles, filter, kVp, mAs, source-patient, source-detector distances, table position

**DICOM Sup 94 Dose SR 2005*

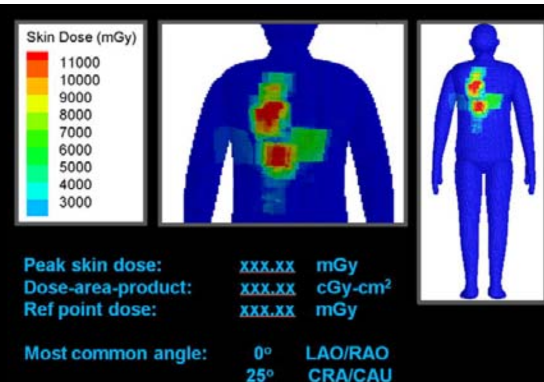
Automated Skin Dose Calculation

- Patient is represented by a computational model
  - Position and location on the table specified manually
- For each irradiation event, $K_{a,r}$ 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



Reference: Johnson et al, Med Phys 2011; 38: 5490

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