Estimating peak skin dose using available clinical data

A. Kyle Jones, Ph.D., FAAPM

The University of Texas MD Anderson Cancer Center

Disclosures

- President of FluoroSafety

Basic workflow

1. Start with $K_{a,r}$
2. Correct $K_{a,r}$ to the entrance surface of the patient
3. Correct incident air kerma to skin dose
4. Correct skin dose to peak skin dose


JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 12, NUMBER 4, FALL 2011

Calculating the peak skin dose resulting from fluoroscopically guided interventions. Part I: Methods

A. Kyle Jones,[1a] and Alexander S. Pasciak[2]


JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 13, NUMBER 1, 2012

Calculating the peak skin dose resulting from fluoroscopically-guided interventions. Part II: Case studies*

A. Kyle Jones[1a] and Alexander S. Pasciak[2]


JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 15, NUMBER 4, 2014

Erratum: Calculating the peak skin dose resulting from fluoroscopically guided interventions. Part I: Methods

A. Kyle Jones,[1a] Alexander S. Pasciak[2]

1. Start with $K_{a,r}$

Fluoroscopy time

- Don’t even bother
- PSD estimates produced from fluoroscopy time always underestimate the PSD and lead to mismanagement of the patient

Radiation Doses in Interventional Radiology Procedures: The RAD-IR Study
Part I: Overall Measures of Dose

Donald L. Miller, MD, Stephen Balter, PhD, Patricia E. Cole, PhD, MD, Hollington T. Lu, MS, MA, Beth A. Schueler, PhD, Michael Geisinger, MD, Alejandro Berenstein, MD, Robin Albert, MD, Jeffrey D. Georgia, MD, Patrick T. Noonan, MD, John F. Cardella, MD, James St. George, MD,[1] Eric J. Russell, MD, Tim W. Malisch, MD,[2] Robert L. Vogelzang, MD, George L. Miller III, MD,[3] and Jon Anderson, PhD

J Vasc Interv Radiol 2003; 14:711–727

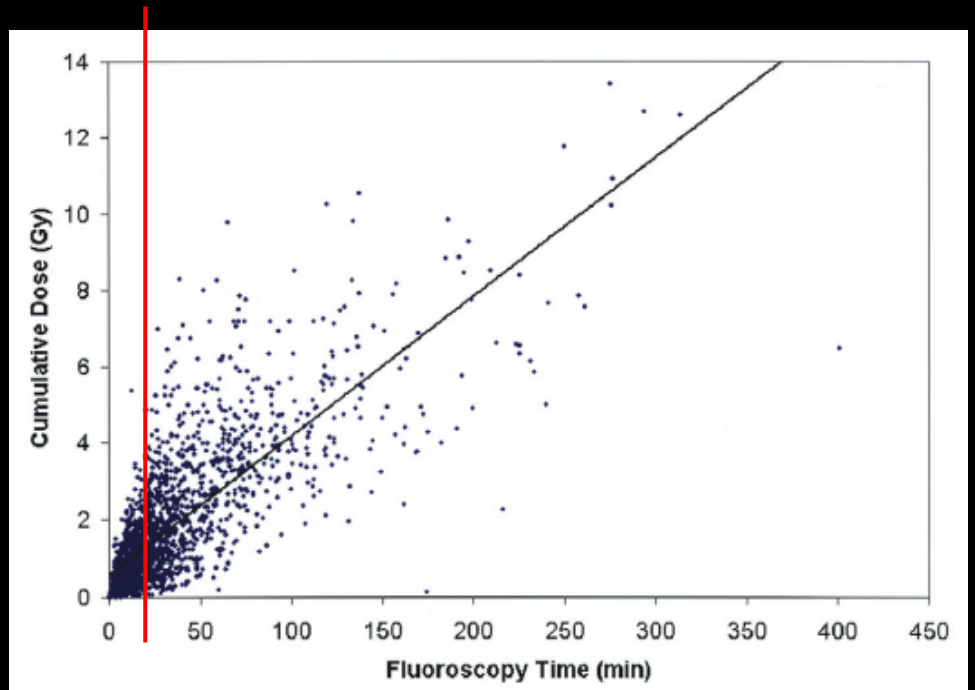
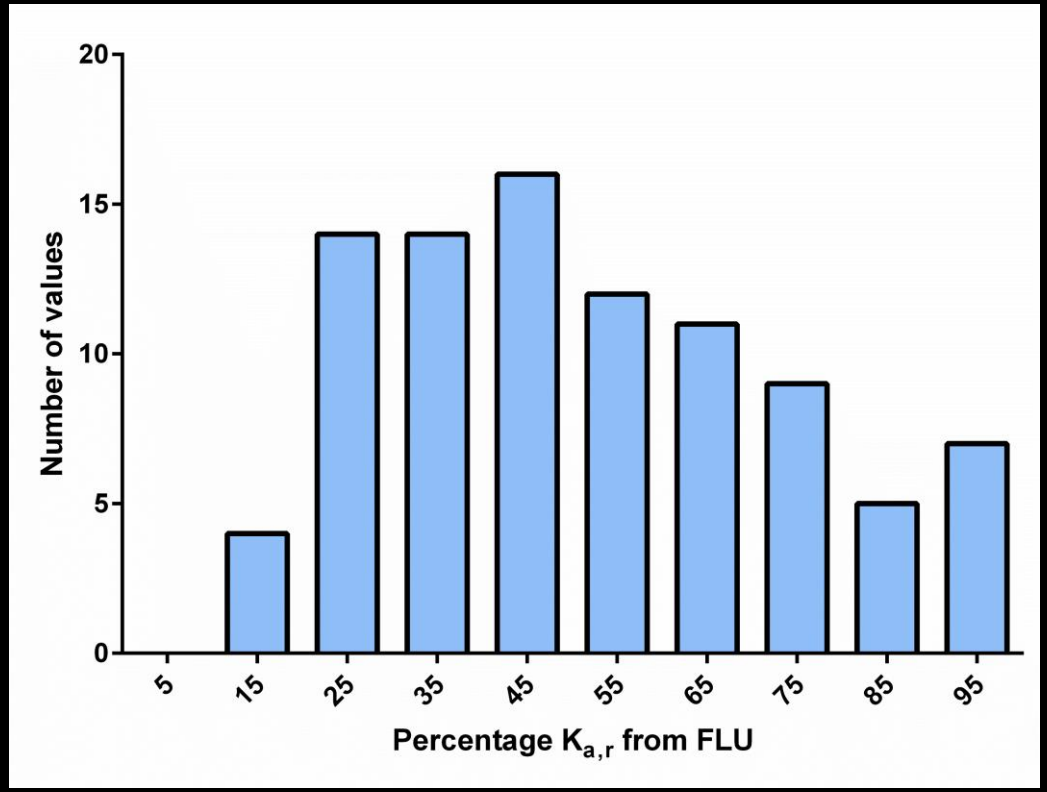


Figure 3. Scatter plot of fluoroscopy time and cumulative dose for 2,142 instances interventional radiology and interventional neuroradiology procedures. The regression line is shown.

Fluoroscopy time

- Don’t even bother
- PSD estimates produced from fluoroscopy time always underestimate the PSD and lead to mismanagement of the patient

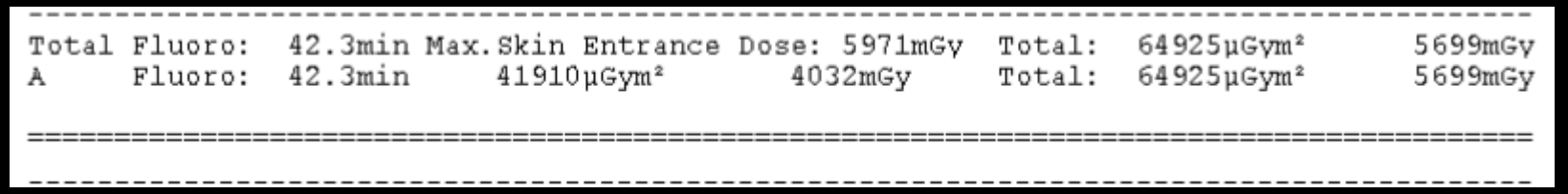


P_{KA}

- In the absence of $K_{a,r}$ (why would you not have this), P_{KA} can be used
- Convert P_{KA} to $K_{a,r}$
- However, you MUST USE the field size AT THE LOCATION OF THE PATIENT, and not at the image receptor (nominal FOV)

Where do I find these dose indices

- On the fluoroscope
- Secondary capture dose page in the procedure record
- RDSR



Total	Fluoro:	42.3min	Max.Skin Entrance Dose:	5971mGy	Total:	64925µGym²	5699mGy
A	Fluoro:	42.3min	41910µGym²	4032mGy	Total:	64925µGym²	5699mGy

2. Correct $K_{a,r}$ to the patient surface

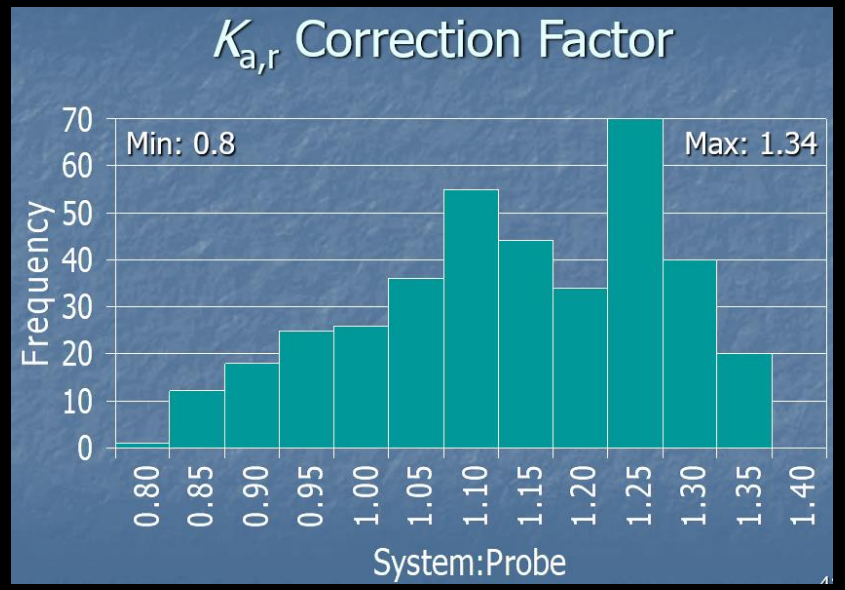
Important factors for this calculation

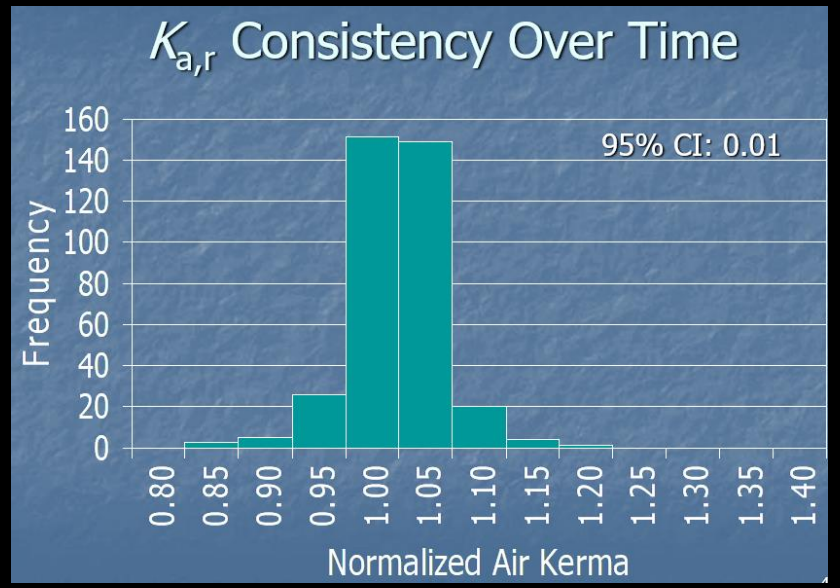
- Dose measuring device calibration factor
- Inverse square law correction
  - Magnitude depends on procedure type
- Backscatter factor
- Table and pad attenuation
- f-factor

Dose measuring device CF

- Report of AAPM TG 190 provides the method for measuring

- Space available to store single point calibration factor in RDSR
  - NEMA XR-27 provides the framework for actually storing this on the angio system





Beth Schueler, AAPM 2010

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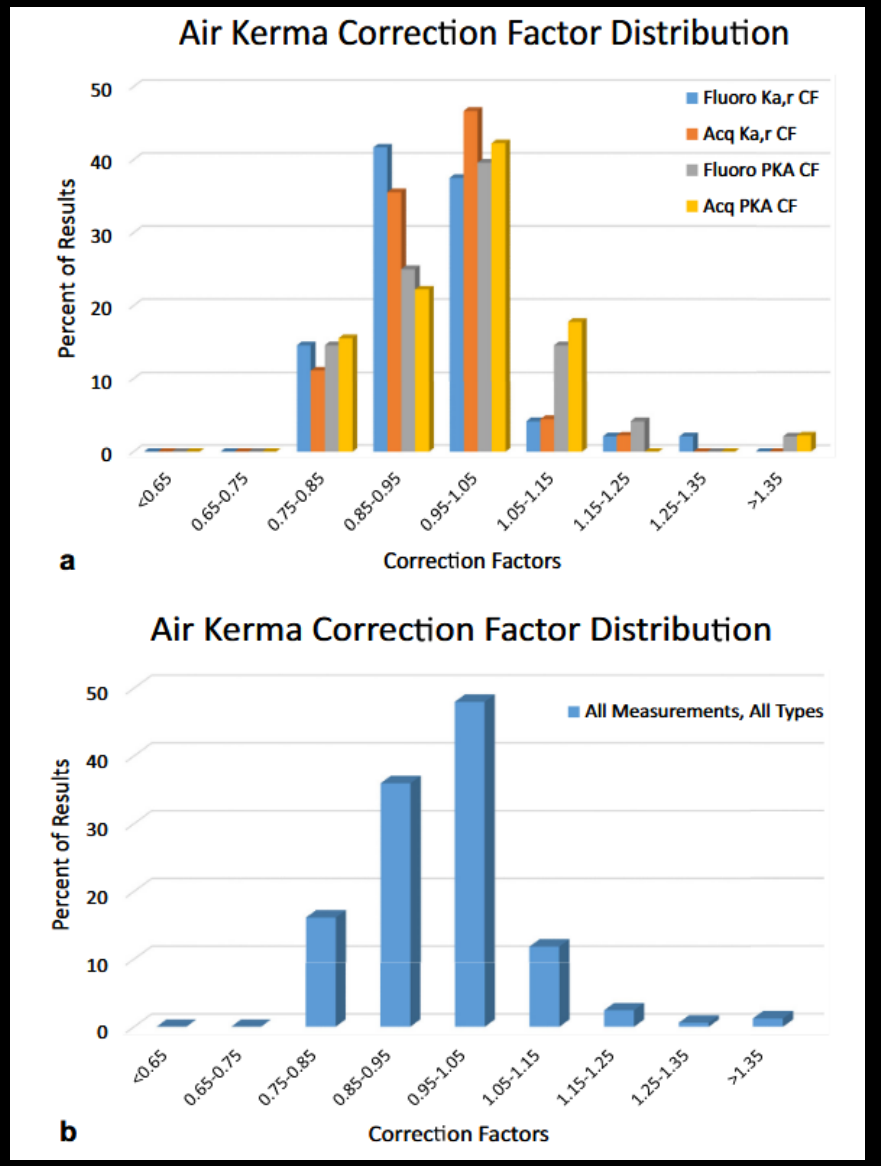
J Vasc Interv Radiol 2020; 31:1545–1550
https://doi.org/10.1016/j.jvir.2020.04.023

CLINICAL STUDY

The American College of Radiology Fluoroscopy Dose Index Registry Pilot: Technical Considerations and Dosimetric Performance of the Interventional Fluoroscopes

Kevin A. Wunderle, PhD, A. Kyle Jones, PhD, Shalmali Dharmadhikari, PhD, Xinhui Duan, PhD, Don-Soo Kim, PhD, Usman Mahmood, MS, Steve D. Mann, PhD, Jeffery M. Moirano, MS, Rebecca A. Neill, MS, and Alan H. Schoenfeld, MS



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Dose measuring device CF

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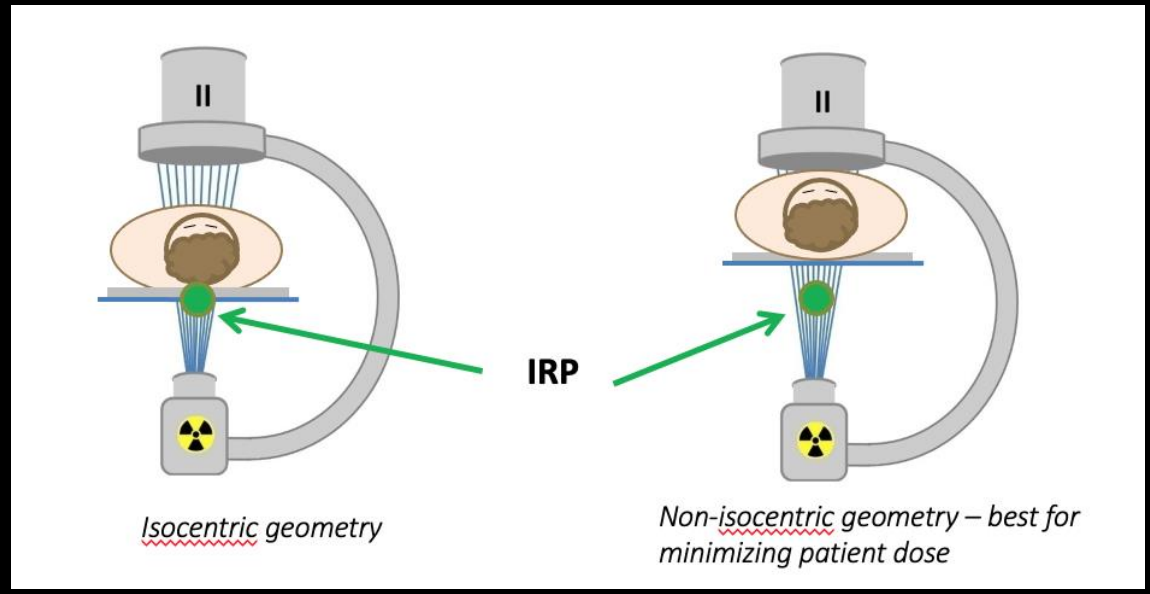
Table 3. Results of $K_{a,r}$ and P_{KA} Accuracy Tests in Fluoroscopic and Acquisition Modes

Dose Index	Mean (95% CI)	Range	SD	n
Fluoroscopic $K_{a,r}$	0.94 (0.92–0.96)	0.80–1.26	0.10	120
Acquisition $K_{a,r}$	0.95 (0.93–0.96)	0.77–1.19	0.08	114
Fluoroscopic P_{KA}	0.96 (0.93–0.98)	0.77–1.49	0.14	120
Acquisition P_{KA}	0.98 (0.95–1.00)	0.76–1.44	0.14	114
Absolute difference (fluoroscopic$_i$ – acquisition$_i$)	0.03 (0.03–0.03)	0–0.14	0.03	228

CI = confidence interval; $K_{a;r}$ = reference-point air kerma; P_{KA} = air kerma–area product; SD = standard deviation.

Inverse square law correction

- Magnitude depends on procedure type
- Know the meaning of the data you are using
  - Distance Source to Patient



Correction often close to 1.0

Correct often offsets BSF

Inverse square law correction

- Magnitude depends on procedure type

- Know the meaning of the data you are using
  - Distance Source to Patient

0x00181110 (4) - Distance Source to Detector: 1137
0x00181111 (11) - Distance Source to Patient: 729.8656098
0x00181114 (8) - Estimated Radiographic Magnification Fac: 1.557821

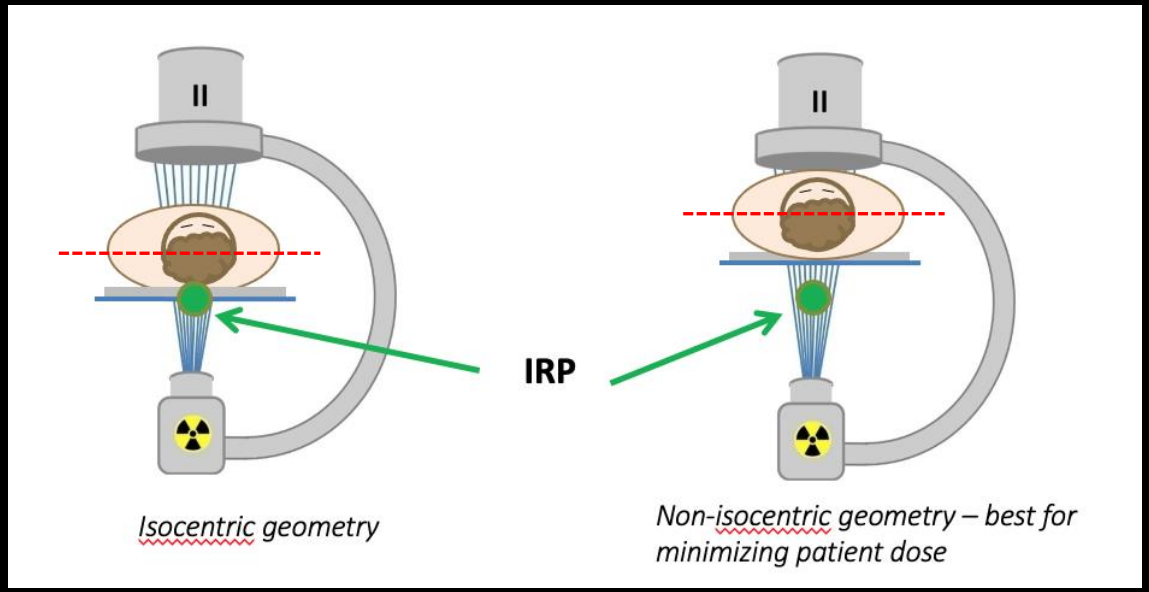


Table and pad attenuation

- Can be measured during commissioning of any new fluoroscope (or pad)
- Varies with incidence angle and beam quality
- If you don't have it, sources of data are available

Evaluation of skin dose calculation factors in interventional fluoroscopy

Matthew C. DeLorenzo | Allen R. Goode

J Appl Clin Med Phys 2019; 1–10

Table 3 Table transmission factor for the Siemens table and Burlington pad.

Field Size (cm^2)	kVp/mm Cu	TTF		
		0	0.3	0.9
5 × 5	60	0.52	0.65	0.70
	90	0.59	0.70	0.73
	120	0.63	0.72	0.74
10 × 10	60	0.54	0.68	0.72
	90	0.61	0.73	0.76
	120	0.65	0.75	0.77
15 × 15	60	0.56	0.71	0.74
	90	0.63	0.75	0.78
	120	0.68	0.77	0.80
21.6 × 21.7	60	0.59	0.73	0.78
	90	0.66	0.78	0.81
	120	0.70	0.80	0.83

TTF, Table transmission factor.

Table 4 Table transmission factor for the GE table and Burlington pad, using a 13.5 × 13.5 cm^2 field size at the ion chamber location.

kVp/mm Cu	TTF					
	0.0	0.1	0.2	0.3	0.6	0.9
60	0.62	0.68	0.71	0.73	0.75	0.77
70	0.64	0.70	0.73	0.75	0.77	0.78
80	0.67	0.72	0.75	0.76	0.79	0.80
90	0.68	0.74	0.76	0.77	0.80	0.80
100	0.70	0.75	0.77	0.78	0.80	0.81
110	0.71	0.76	0.78	0.79	0.81	0.81
120	0.72	0.76	0.78	0.79	0.81	0.82

TTF, Table transmission factor.

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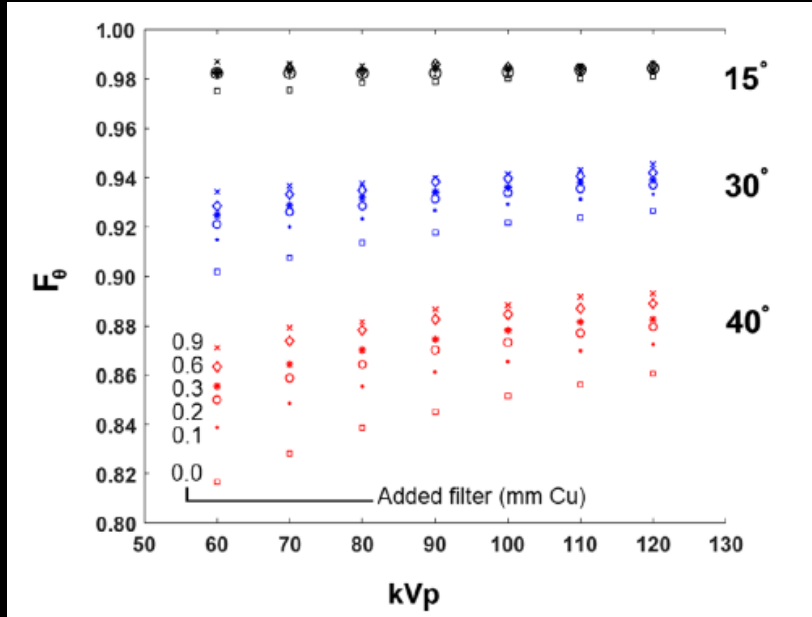
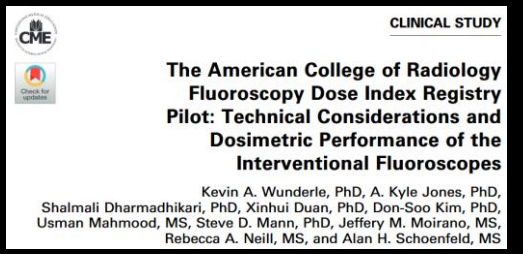


FIG. 5. Oblique correction for KCF. $F\theta$ plotted for three incident angles (15°, 30°, and 40°) with respect to 0°, found using the GE system with Omega V table and Burlington pad, and a medium field size (13.5 × 13.5 cm2). KCF decreases by about 2%, 7%, and 14% for incident angles of 15°, 30°, and 40°, respectively. GE, General Electric; KCF, kerma correction factor.

Table and pad attenuation

- Can be measured during commissioning of any new fluoroscope (or pad)
- Varies with incidence angle and beam quality
- If you don’t have it, sources of data are available



CLINICAL STUDY

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J Vasc Interv Radiol 2020; 31:1545–1550

https://doi.org/10.1016/j.jvir.2020.04.023

Table 4. Table and Pad Transmission Factors

Measurement Method	Mean Transmission Factor (95% CI)	Transmission Factor Range	SD	n
Narrow-beam	0.70 (0.69–0.71)	0.65–0.74	0.03	23
Broad-beam	0.76 (0.74–0.77)	0.70–0.85	0.04	22

CI — confidence interval; SD — standard deviation.

3. Correct IAK to skin dose

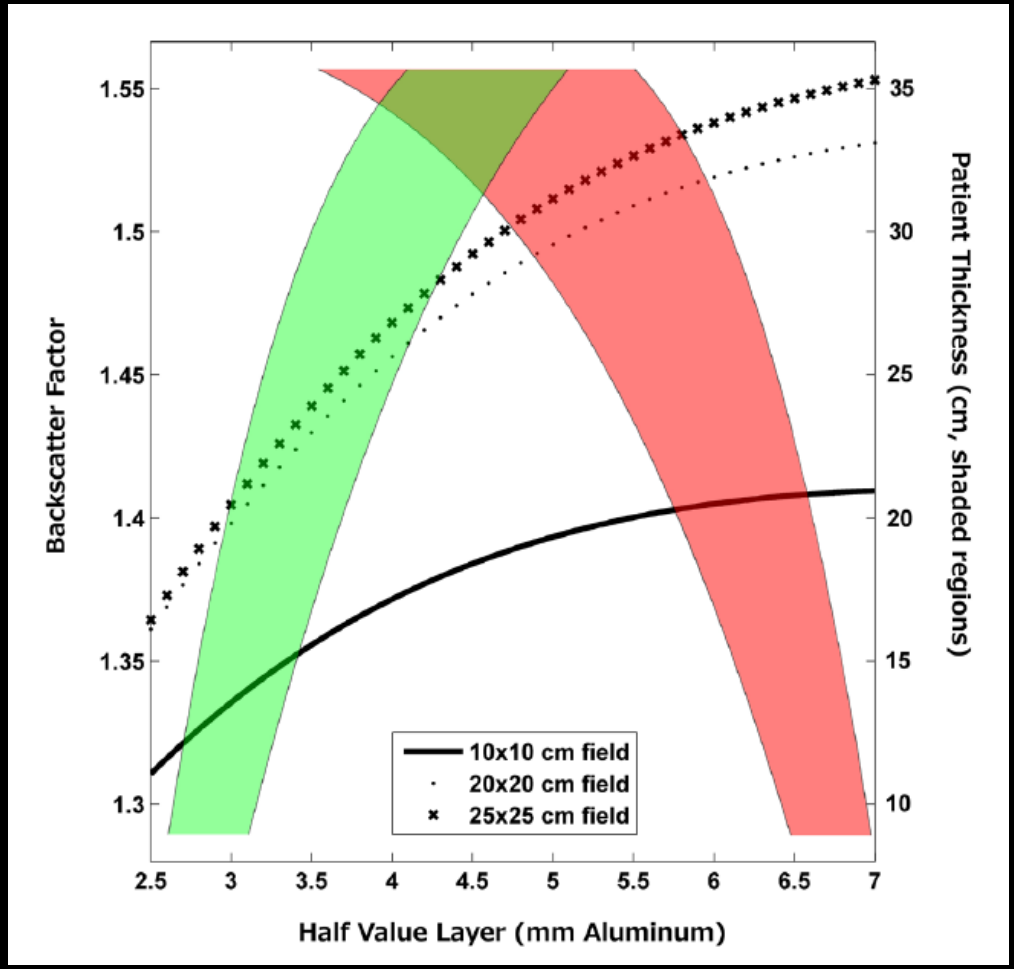
JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 12, NUMBER 4, FALL 2011

Calculating the peak skin dose resulting from fluoroscopically guided interventions. Part I: Methods

A. Kyle Jones,[1a] and Alexander S. Pasciak[2]

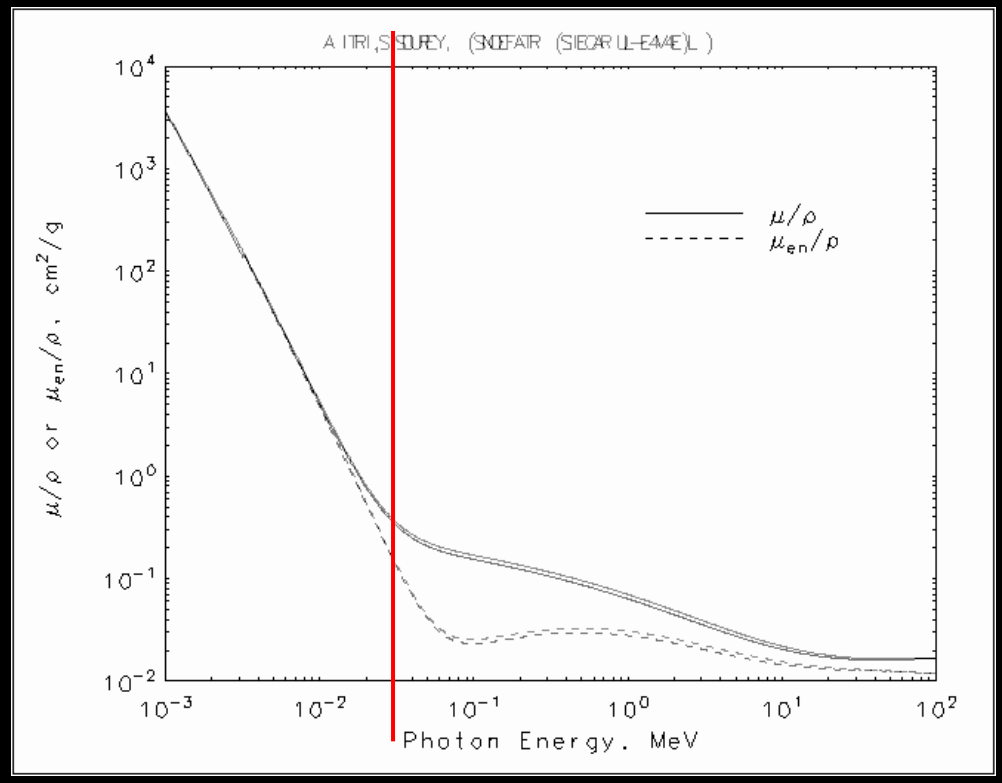
Backscatter factor

- Large magnitude, but varies within a small range
- Use of a single BSF (two at most) is usually sufficient



f-factor

- Ratio of mass energy absorption coefficient of skin to that of air
- Small (1.04 – 1.06)
- Very important caveat – for bone tissue is about 4



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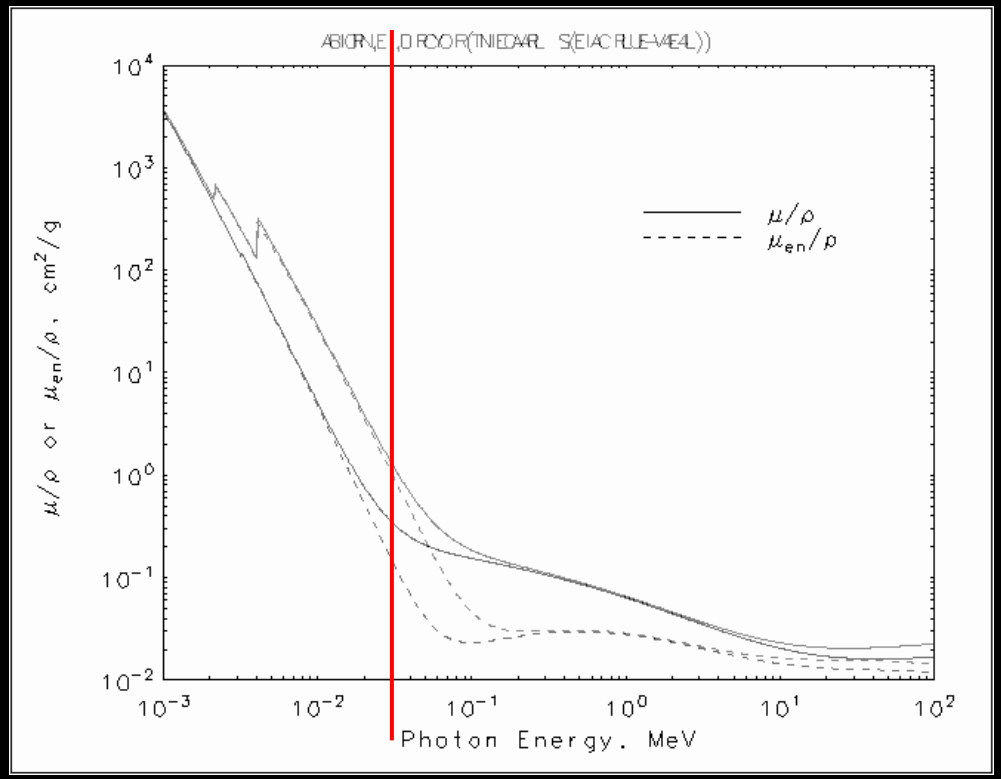


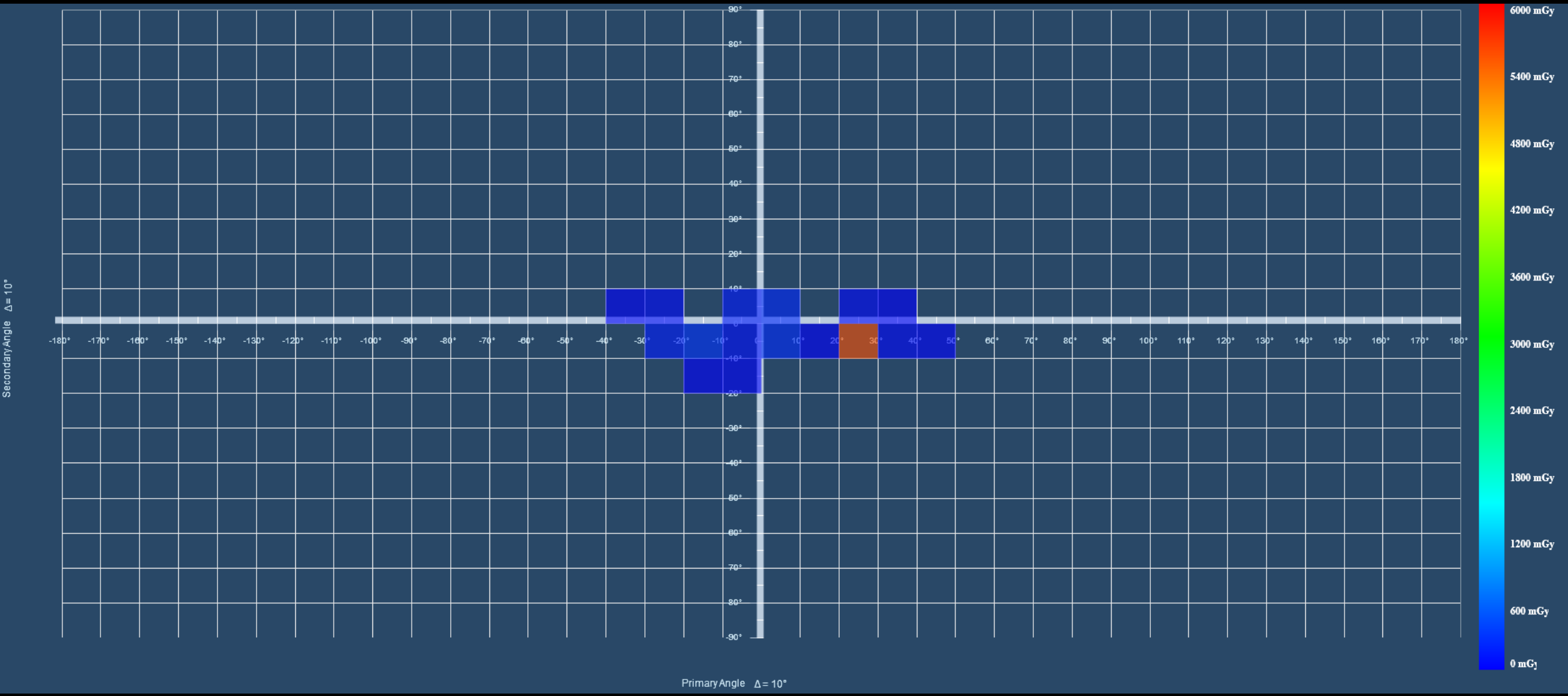
$$D_{skin} = K_{a,r} \times CF \times \left(\frac{d_{IRP}}{d_{SPD}}\right)^2 \times TAF \times f \times BSF$$

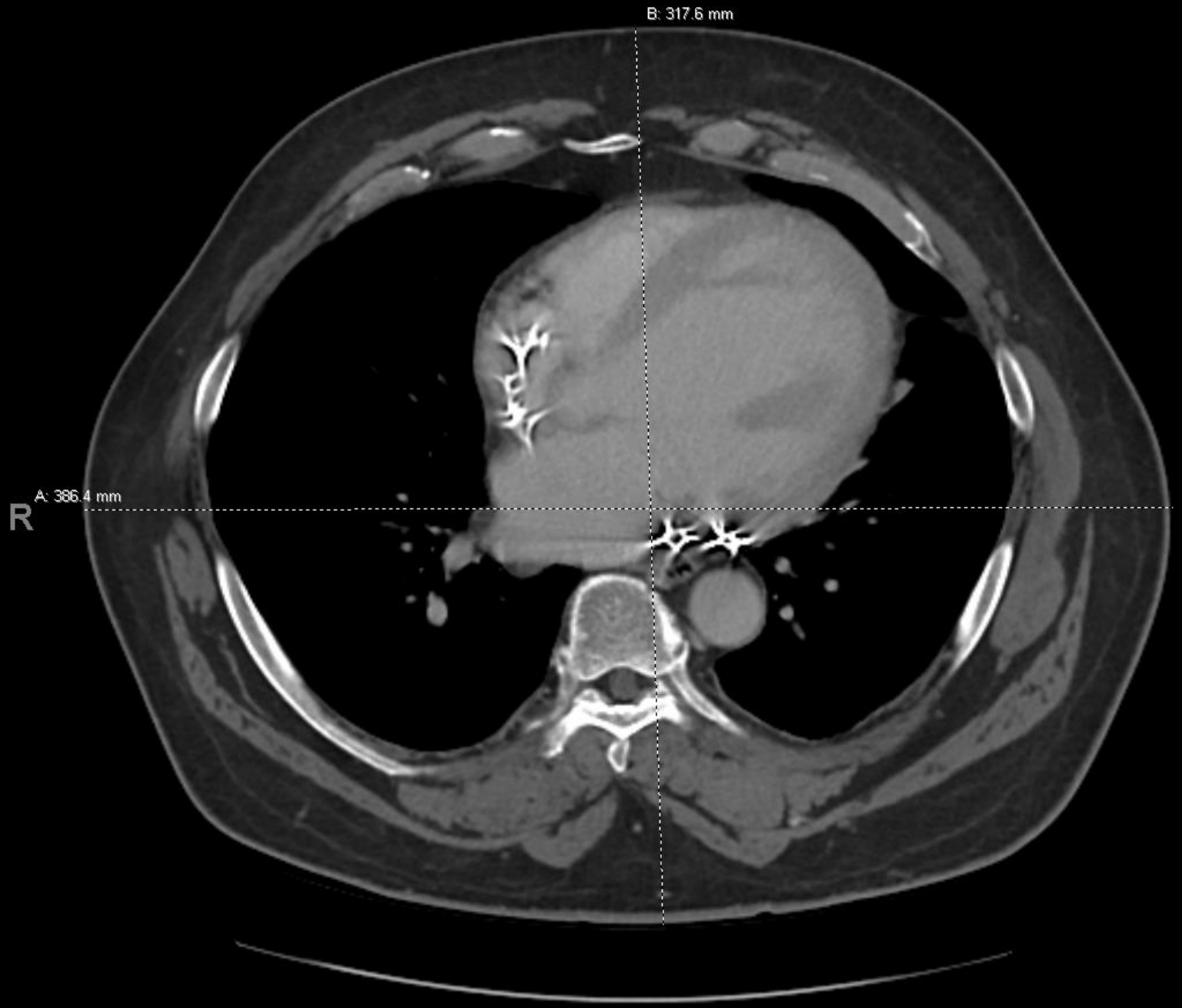
$$D_{skin}$$
$$= K_{a,r} \times CF(kVp, filt) \times \left(\frac{d_{IRP}}{d_{SPD}}\right)^2 \times TAF(kVp, filt, FOV) \times f$$
$$\times BSF(kVp, filt, FOV)$$

4. Convert skin dose to PSD

Accounting for changing gantry angle

- Procedural images (along with metadata) or RDSR is needed to study gantry angle
- If you do not have either of these, don’t attempt to make a correction
  - Assume all dose delivered to a single skin site – your calculated skin dose = PSD
- Gantry angle can be used as a radiation management strategy where appropriate


Secondary Angle Δ = 10°
Primary Angle Δ = 10°
6000 mGy
5400 mGy
4800 mGy
4200 mGy
3600 mGy
3000 mGy
2400 mGy
1800 mGy
1200 mGy
600 mGy
0 mGy



DAP [Gy-cm2]		Reference Point Dose [mGy]	
Total	1308.286	Total	6962.1
Fluoro	1266.6	Fluoro	6744.63
Acquisition	41.686	Acquisition	217.47

1308.286 / 6.962 = 188 cm^2

Nominal FOV ~ 32 cm

openheart C-arm rotation as a method for reducing peak skin dose in interventional cardiology

Alexander S Pasciak,[1] Austin C Bourgeois,[1] A Kyle Jones[2]

Open Heart 2014;**1**:e000141. doi:10.1136/openhrt-2014-000141

Table 1 Formats available for the two fluoroscopic systems simulated in this study and grouping of the formats as presented in figures in this work

Format	Siemens Artis zee* (cm)	Format group	Philips Integris H5000F† (cm)	Format group
1 (Zoom/Mag 0)	25	A	22.5 (9″)	A
2 (Zoom/Mag 1)	20	A	17.5 (7 ″)	B
3 (Zoom/Mag 2)	16	B	12.5 (5 ″)	C
4 (Zoom/Mag 3)	10	C	–	

Sizes are quoted as the diagonal of the field.
*Square fields.
†Octagonal fields.

Table 2 Patient sizes simulated in this study

Size group	Population percentile	Male AP dimension (cm)	Male trans dimension (cm)	Female AP dimension (cm)	Female trans dimension (cm)
	5	23.8	28.4	22.8	22.8
Small	10	24.9	29.4	23.8	23.5
	25	26.8	31.0	25.8	24.6
Average	50	29	32.9	28.5	25.8
	75	31.4	34.7	31.7	27.1
Large	90	33.8	36.5	35.2	28.3
	95	35.4	37.5	37.2	29.0

AP, anteroposeterior; trans, transverse.

openheart

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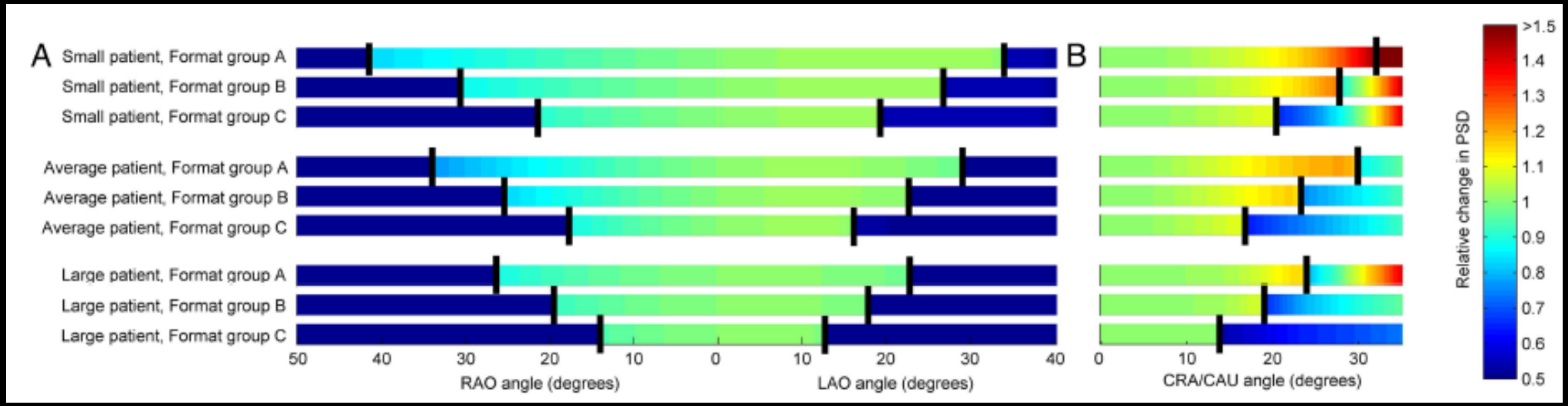

Does "Spreading" Skin Dose by Rotating the C-arm during an Intervention Work?

Alexander S. Pasciak, PhD, and A. Kyle Jones, PhD

J Vasc Interv Radiol 2011; 22:443–452

openheart

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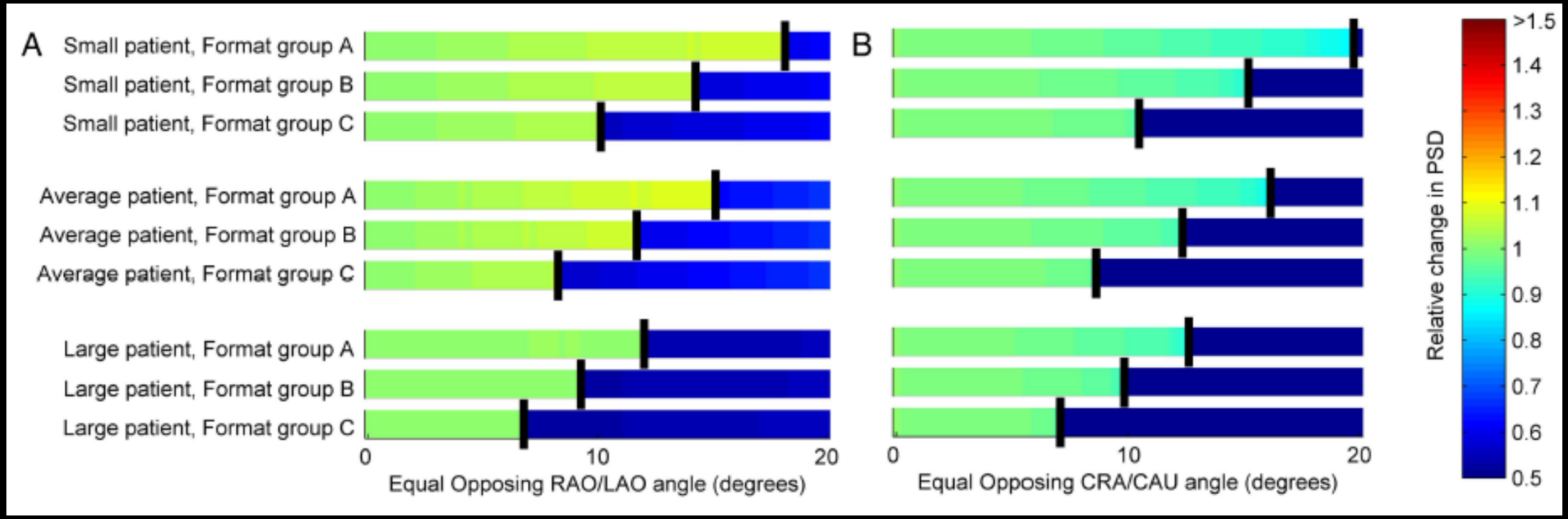
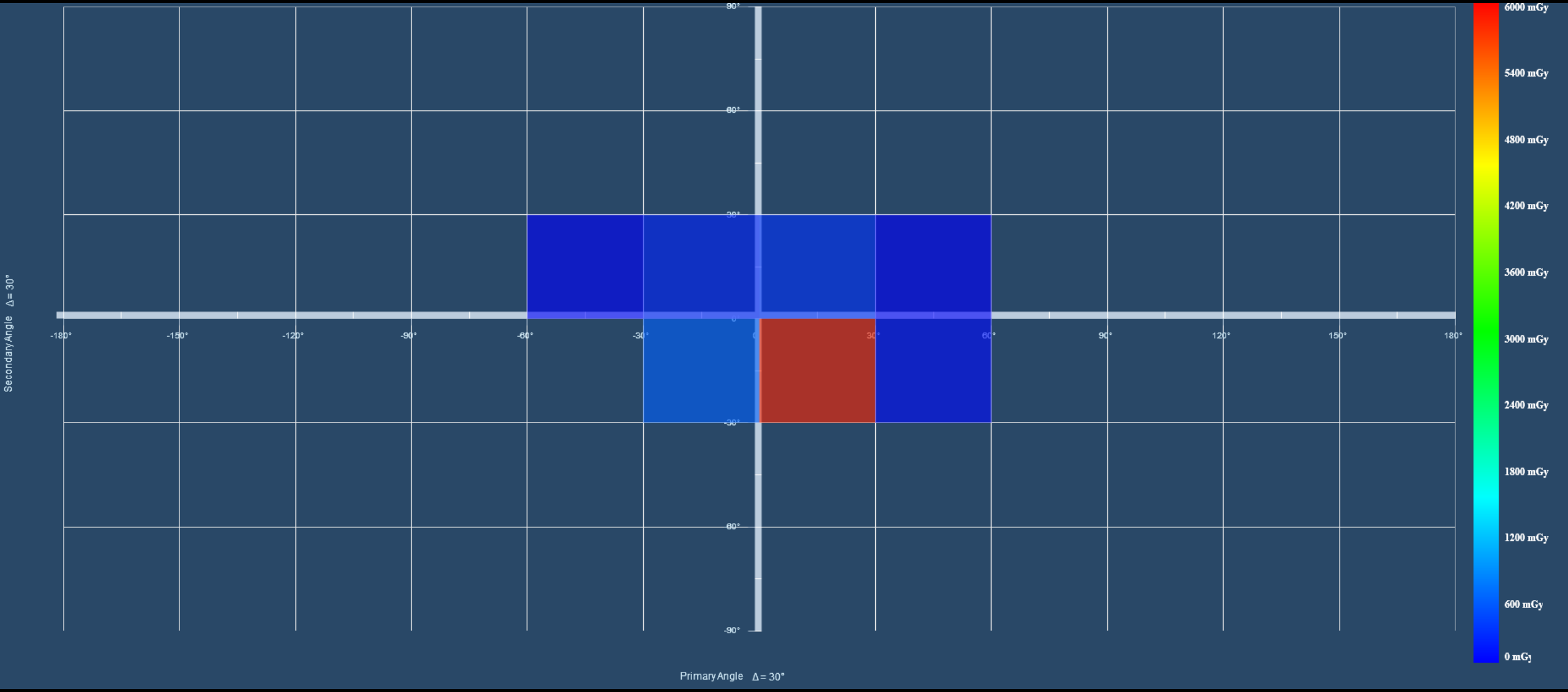


These simulations indicate that rotation between LAO and RAO angles of about 20 degrees can reduce PSD for most patients during cardiac interventions.


90°
60°
30°
0
-30°
-60°
-90°
-180°
-150°
-120°
-90°
-60°
-30°
0
30°
60°
90°
120°
150°
180°
Secondary Angle Δ = 30°
Primary Angle Δ = 30°
6000 mGy
5400 mGy
4800 mGy
4200 mGy
3600 mGy
3000 mGy
2400 mGy
1800 mGy
1200 mGy
600 mGy
0 mGy

Goal of the dose estimate

- Broadly categorize the PSD and possible effects
  - Patient communication
  - Follow up

Stephen Balter, PhD
John W. Hopewell, DSc
Donald L. Miller, MD
Louis K. Wagner, PhD
Michael J. Zelefsky, MD

Fluoroscopically Guided Interventional Procedures: A Review of Radiation Effects on Patients' Skin and Hair[1]

Radiology: Volume 254: Number 2—February 2010

Table 1

Tissue Reactions from Single-Delivery Radiation Dose to Skin of the Neck, Torso, Pelvis, Buttocks, or Arms

Band	Single-Site Acute Skin-Dose Range (Gy)*	NCI Skin Reaction Grade†	Approximate Time of Onset of Effects			
			Prompt	Early	Midterm	Long Term
A1	0–2	NA	No observable effects expected	No observable effects expected	No observable effects expected	No observable effects expected
A2	2–5	1	Transient erythema	Epilation	Recovery from hair loss	No observable results expected
B	5–10	1–2	Transient erythema	Erythema, epilation	Recovery; at higher doses, prolonged erythema, permanent partial epilation	Recovery; at higher doses, dermal atrophy or induration
C	10–15	2–3	Transient erythema	Erythema, epilation; possible dry or moist desquamation; recovery from desquamation	Prolonged erythema; permanent epilation	Telangiectasia‡; dermal atrophy or induration; skin likely to be weak
D	>15	3–4	Transient erythema; after very high doses, edema and acute ulceration; long-term surgical intervention likely to be required	Erythema, epilation; moist desquamation	Dermal atrophy; secondary ulceration due to failure of moist desquamation to heal; surgical intervention likely to be required; at higher doses, dermal necrosis, surgical intervention likely to be required	Telangiectasia‡; dermal atrophy or induration; possible late skin breakdown;wound might be persistent and progress into a deeper lesion; surgical intervention likely to be required

Note.— Applicable to normal range of patient radiosensitivities in absence of mitigating or aggravating physical or clinical factors. Data do not apply to the skin of the scalp. Dose and time bands are not rigid boundaries. Signs and symptoms are expected to appear earlier as skin dose increases. Prompt is <2 weeks; early, 2–8 weeks; midterm, 6–52 weeks; long term, >40 weeks.

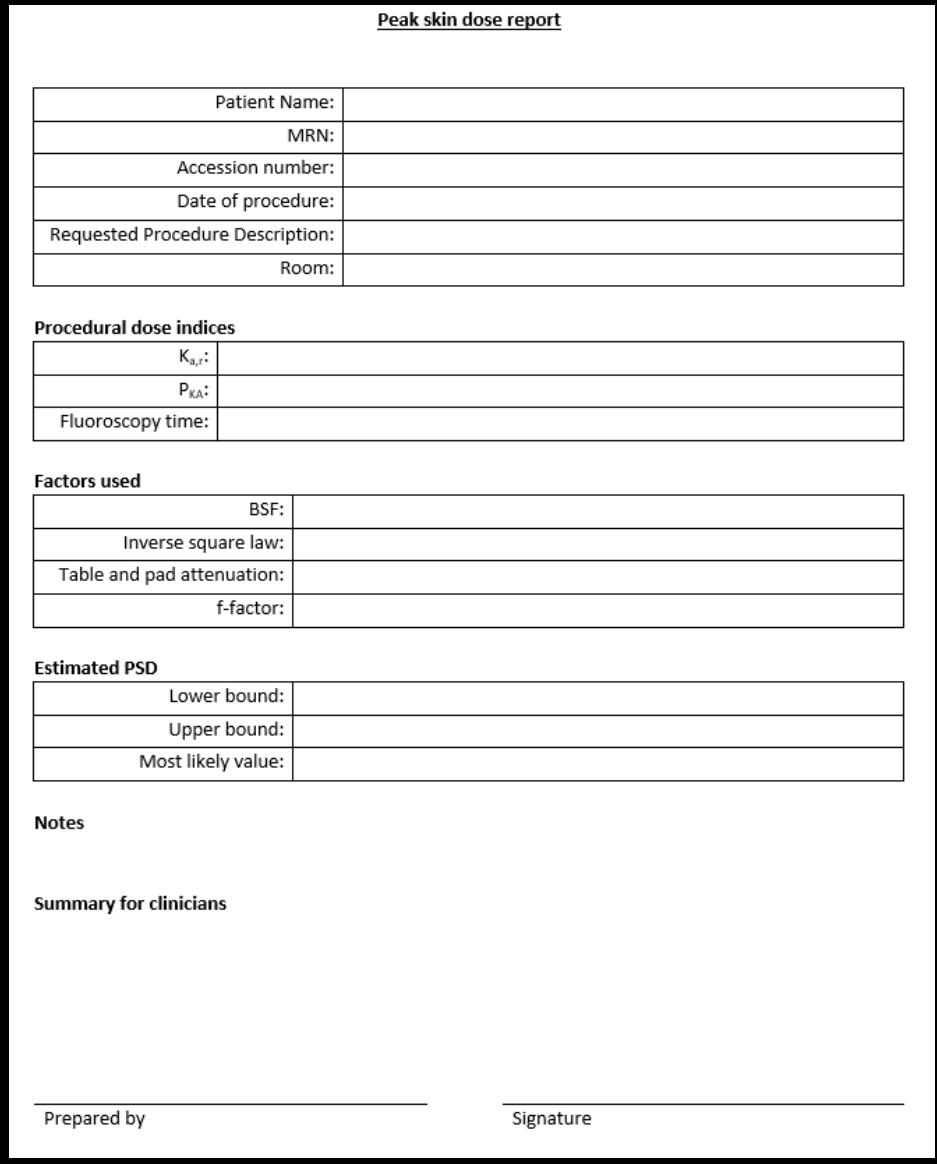
* Skin dose refers to actual skin dose (including backscatter). This quantity is not the reference point air kerma described by Food and Drug Administration (21 CFR § 1020.32 [2008]) or International Electrotechnical Commission (57). Skin dosimetry is unlikely to be more accurate than ± 50%. NA = not applicable.

† NCI = National Cancer Institute

‡ Refers to radiation-induced telangiectasia. Telangiectasia associated with area of initial moist desquamation or healing of ulceration may be present earlier.

Reporting

- Standardized format
- Key information easily identifiable
- Report should include both the most likely value and a range that reflects uncertainty



Peak skin dose report

Patient Name:	
MRN:	
Accession number:	
Date of procedure:	
Requested Procedure Description:	
Room:	

Procedural dose indices

$K_{a,r}$:	
P_{KA}:	
Fluoroscopy time:	

Factors used

BSF:	
Inverse square law:	
Table and pad attenuation:	
f-factor:	

Estimated PSD

Lower bound:	
Upper bound:	
Most likely value:	

Notes

Summary for clinicians

Prepared by

Signature

Methods

- Hand calcs
  - Jones and Pasciak methods
- RDIM
- Real time monitoring software

Multiple procedures

- Biologically effective dose (BED) approach
- Likelihood and severity of late effects is reduced when dose is fractionated
- Radiobiology of late effects
  - For skin α/β ~ 3.5 Gy
  - Complete repair in 24 hours
  - Repopulation in 2 months

Fluoroscopically Guided Interventional Procedures: A Review of Radiation Effects on Patients' Skin and Hair

Appendix E1

This approach uses models developed and tested for radiation therapy, which are used to calculate equivalent biologically effective doses when dose fractionation schedules are changed or to modify the subsequent dose if errors are found in the original dose prescription. The equations are based on the so-called linear quadratic model of cell survival, which takes account of the amount of repair of DNA damage between separate radiation exposures. For use with complex procedures consisting of multiple sessions, the full procedure should not extend over more than 1–2 months because the model has only been applied to standard radiation therapy schedules within this time scale. Initially a reference point is established for single dose procedure using the following equation:

$$\mathrm{BED} = D\left(1+\frac{D}{\alpha/\beta}\right), \qquad \text{(E1)}$$

where BED is the biologically effective dose to which the likely effects of a more complex procedure have to be compared, D is the size of the dose from the single procedure, and α/β is a tissue-specific constant related to the survival characteristics of the cells in the tissue at risk. For late radiation damage to the skin, a value of 3–4 Gy is frequently applied (82,83).

For a complex procedure involving multiple sessions with 24 hours or more between each session, the total dose D in the simple equation (ie, Eq [E1]) is replaced by the dose received at each stage, d_1, d_2, d_3, such that

$$\mathrm{BED_m} = d_1\left(1+\frac{d_1}{\alpha/\beta}\right)+d_2\left(1+\frac{d_2}{\alpha/\beta}\right)+d_3\left(1+\frac{d_3}{\alpha/\beta}\right)\ldots. \qquad \text{(E2)}$$

Multiple procedures

- "Equivalent" single procedure dose is less than the sum of the individual doses

- One strategy (justified by radiobiology):
  - Procedures separated by < 24 hrs: sum doses
  - Procedures separated by 24 hrs to 8 weeks: BED approach
  - Procedures separated by > 8 weeks: completely independent (?)

$$BED_m = 3.5\left(1+\frac{3.5}{3.5}\right)+5.9\left(1+\frac{5.9}{3.5}\right),$$

which yields a BEDm of 22.85. By using this BED value, the equivalent single dose can be calculated by using Equation (E1):

$$22.85 = D\left[1+\frac{D}{3.5}\right]$$

CLINICAL STUDY

Incidence of Chronic Radiodermatitis after Fluoroscopically Guided Interventions: A Retrospective Study

Mélanie Guesnier-Dopagne, MD, Louis Boyer, MD, PhD, Bruno Pereira, Joël Guersen, Pascal Motreff, MD, PhD, and Michel D'Incan, MD, PhD

ABSTRACT

Purpose: To assess the incidence and risk factors for chronic radiodermatitis after fluoroscopically guided interventions (FGIs) in high-risk patients.

Materials and Methods: Between 2010 and 2016, of 55,782 patients who underwent FGIs, 359 had a risk procedure for skin injury (maximal skin dose > 3 Gy, air kerma > 5 Gy, dose area product [DAP] > 500 Gy.cm^2, or fluoroscopy time > 60 minutes). Ninety-one of these patients were examined by a dermatologist for radiodermatitis (median time after procedure, 31.2 months [95% confidence interval, 14.2–50.7]). In each case, the clinical features and topography of the skin lesions were recorded and their incidence calculated. The characteristics of the patients and of the FGIs were tested as risk factors.

Results: Eight patients (8.8%) had chronic radiodermatitis; 19 (20.9%) had acute radiodermatitis. Body mass index, DAP value, and air kerma were the only risk factors identified.

Conclusions: This study shows that chronic radiodermatitis may be considered a frequent side effect in an at-risk population. The lesions are commonly benign, but extensive sclerosis can occur. Patients should be better informed about the side effects and offered a skin exam periodically.

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The 7-Year Itch: Is Chronic Radiodermatitis Common after Fluoroscopically Guided Interventions?

A. Kyle Jones

It is quite intriguing that 7 of the 8 patients experiencing chronic radiodermatitis experienced P_{KA} exceeding 500 Gy-cm^2, whereas only 2 experienced $K_{a,r}$ exceeding 5 Gy. This may indicate that the area of skin exposed to high doses may be more important than the peak skin dose for the development of chronic radiodermatitis. If true, tight collimation of the X-ray beam to the area of interest would be an important strategy for reducing the likelihood of chronic radiodermatitis.

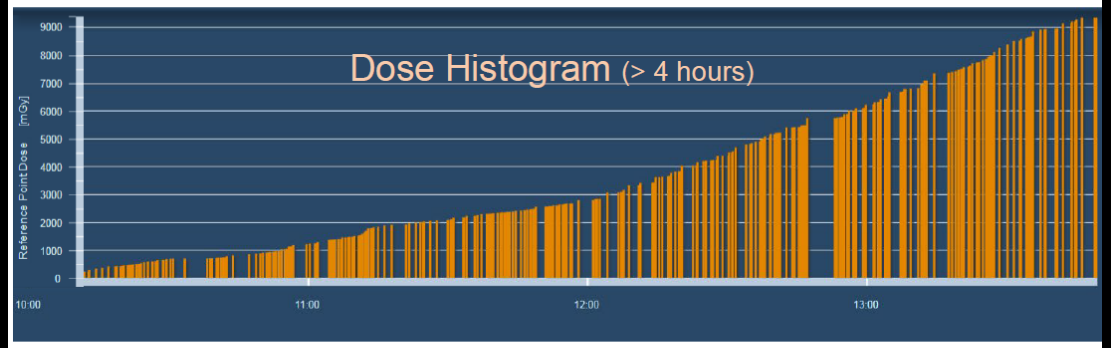
J Vasc Interv Radiol 2019; 30:699–700

Other factors

- Oblique incidence
  - Table and pad attenuation
  - Shape of X-ray field on skin
- Heel effect
- Protraction of exposure during long procedures

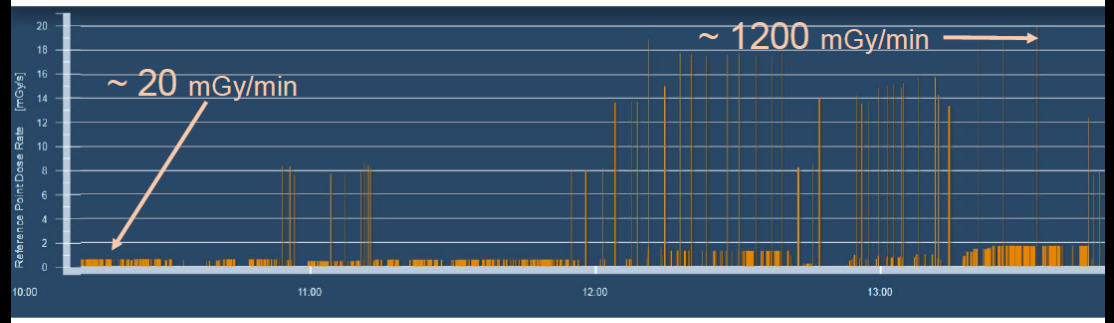
Kevin Wunderle, AAPM 2019

Total Procedure Time / Dose



Does it matter that this dose delivery was protracted?
Typical halftime for double strand DNA break repair is ~ 1-2 hours

Instantaneous Dose Rates



Instantaneous rates vary from ~ 20 mGy/min (Gy/hr) to 1200 mGy/min (Gy/hr) Does this affect outcomes?