Estimation of Patient Skin Dose in Fluoroscopy:
Summary of a Joint Report by AAPM TG357 and EFOMP

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Report of AAPM TG357

- Second report of this general topic of DICOM data
  - *TG245 addressed the topic of needed DICOM data for organ dosimetry in CT (2019)*
- Collaboration with EFOMP
  - *European Federation of Organizations for Medical Physics*
- TG357 report included 16 authors, 18 consultants
- 26 pages, 21 figures, 6 tables, 8 equations, 75 references

Andersson J, Bednarek RD, Bolch W, Boltz T, Bosmans H, Gislason-Lee A, Granberg C, Hellström M, Kanal K, McDonagh E, Paden R, Pavlicek W, Khodadadegan Y, Torresin A, Trianni A, Zamora D. Estimation of patient skin dose in Fluoroscopy: Summary of a joint report by AAPM TG357 and EFOMP. Med Phys 2021;48(7):e671-96.

Report Motivation

- FGI are perhaps the most challenging area of patient dosimetry in the field of radiology
- Dosimetry of the skin is needed to identify possible skin injury and to inform patients and physicians regarding follow up and treatment
- Estimates of patient skin dose are needed to establish a knowledge base for best practices in the clinic

Dose-dependent guidance to patients and physicians

Balter S, Hopewell JW, Miller DL, Wagner LK, Zelefsky M. Fluoroscopically Guided Interventional Procedures: A Review of Radiation Effects on Patients' Skin and Hair. Radiology. **254** (2): 326-341 (2010).

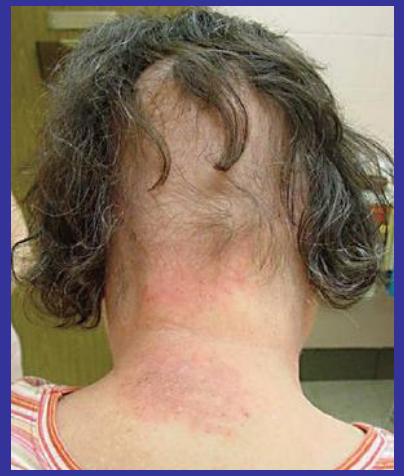


Table 2

General Advice to Be Provided to Patients and Treating Physicians

Band	Skin Dose Range (Gy)	Advice to Patient
A1	0–2	No need to inform patient, because there should be no visible effects; if patient reports skin changes, then treat in response to the signs and symptoms
A2	2–5	Advise patient that erythema may be observed but should fade with time; Advise patient to call you if skin changes cause physical discomfort
B	5–10	Advise patient to perform self-examination or ask a partner to examine for skin effects from about 2 to 10 weeks after the procedure; tell patient where skin effects would most likely occur; if skin erythema and itching occur, patient should call radiologist's office; skin reactions are often treated conservatively; might advise patient to be examined by dermatologist or other treating physician and to inform treating physician that injury may be due to radiation; radiologist should also provide that physician with medical details of where the radiation-related skin effects are likely to occur
C	10–15	Medical follow-up is appropriate; advice is same as that for band B but also advise dermatologist or other treating physician that skin effects may be prolonged due to radiation dose and that prophylactic treatment for infection and monitoring of wound progression mat be required; pain could become a concern if doses were in the higher range of this band
D	>15	Medical follow-up is essential, nature and frequency of which depending on estimated radiation dose; advice is same as that for band C, but advise treating physician that the wound could progress to ulceration or necrosis

Note.—Applicable to normal range of patient radiosensitivities in the absence of mitigating or aggravating physical or clinical factors.

Purpose and Overview

- **P1:** Summarize current state of the art in estimating skin dose from fluoroscopically guided interventional (FGI) procedures
- **P2:** Outline a road map regarding peak skin dose (PSD) estimates from FGI procedures

- **O1:** Metrics, concepts, and methods for estimating skin dose
- **O2:** DICOM information including the RDSR standard for FGI devices

Open-Source Framework

- Estimation of PSD from FGI procedures is a challenge
- Complex geometries, assessment of patient position, DICOM
- The report uses PySkinDose* for practical examples
- Translation of air kerma at the reference point to computational phantoms for skin dose mapping/PSD

*Hellström M. PySkinDose. https://github.com/rvbCMTS/PySkinDose (2019)

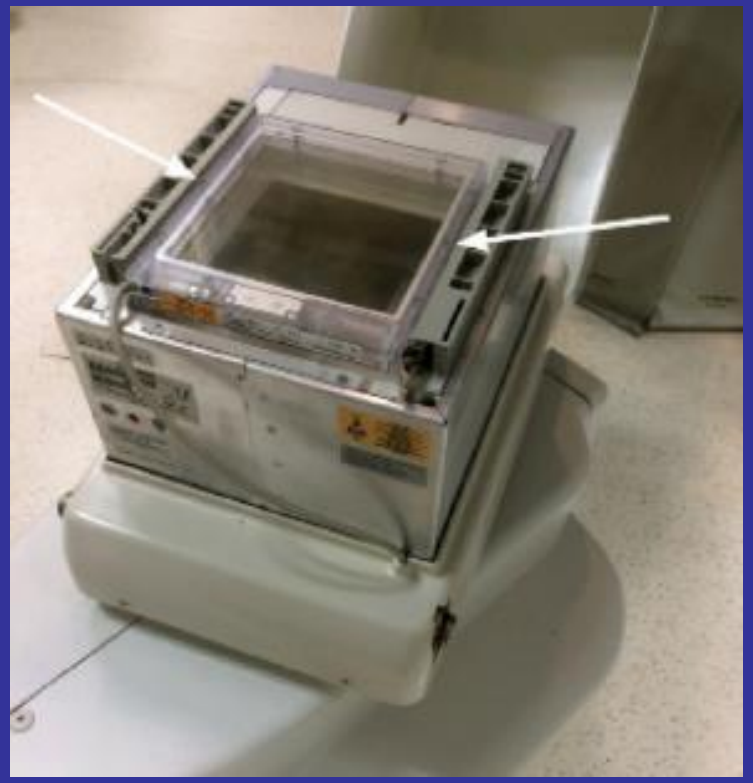
Out of Scope

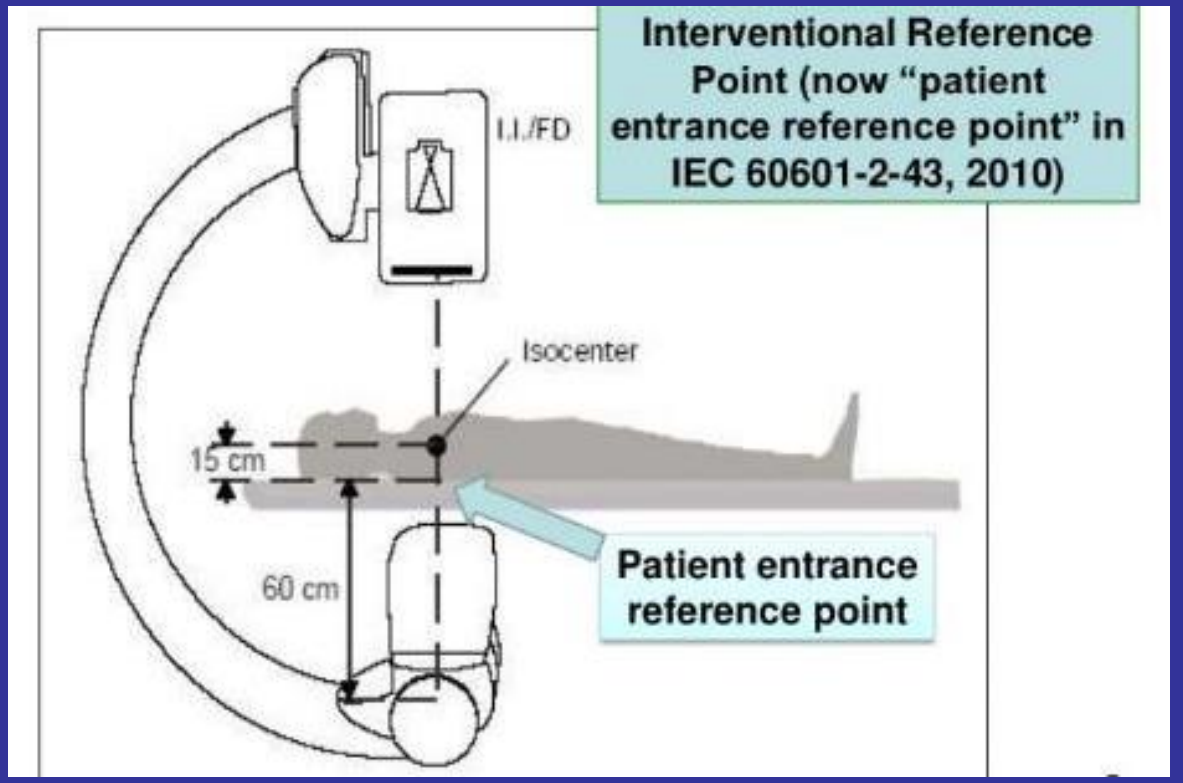
- This report focuses on FGI devices with flat panel detectors in a basic C-arm configuration
- No application for effective dose (other organs*)
- Note recent position statement from AAPM and ACR on longitudinal follow up patient dosimetry (stochastic - no, deterministic - yes)

*Omar A, Bujila R, Fransson A, Andreo P, Poludniowski G. A framework for organ dose estimation in x-ray angiography and interventional radiology based on dose-related data in DICOM structured reports. Phys Med Biol. 2016;61:3063–3083.

Dose Metrics

- The air kerma at reference point (Gy), K in the report (no consensus)
- The air kerma-area product (P_{KA}) in units of Gy . cm^2





PERP

PERP Location

- Patient Entrance Reference Point

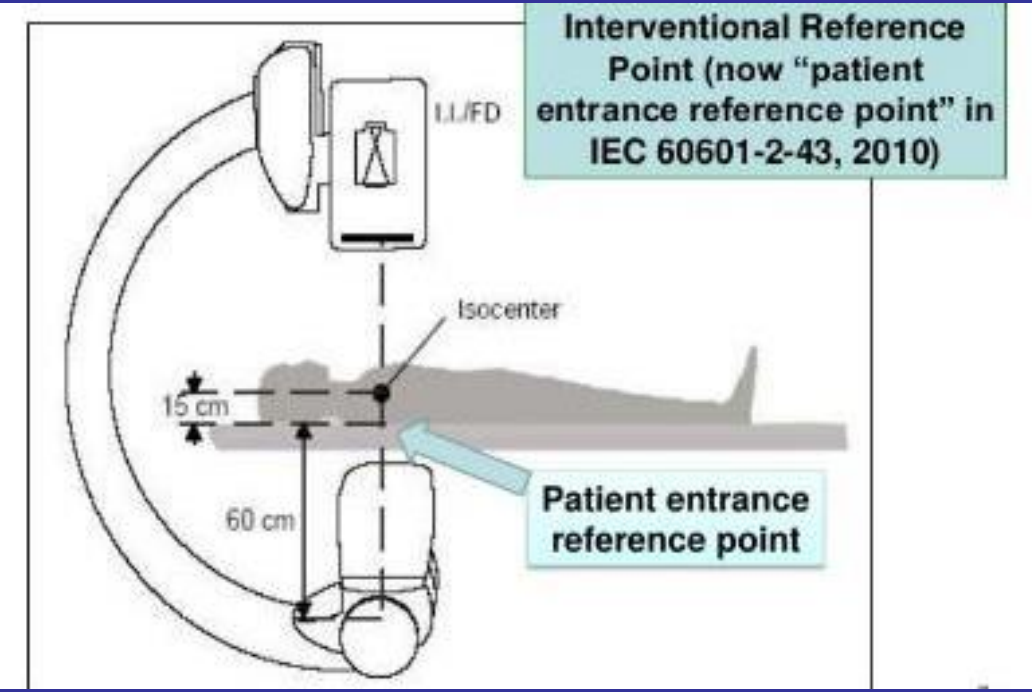


TABLE I. *K* reference point locations and specifications for different fluoroscopy systems.[1,15]

Fluoroscopic device type	Reference Point Location (IEC 2010)
C-arm	15 cm from isocenter toward the X-ray source along the beam axis or • for C-arm equipment without an isocenter, the manufacturer defines a point along the beam axis as being representative of the point of intersection of the beam axis with the patient surface; the rationale for the choice of the location should be given. • at the point representing the minimum focal spot to skin distance for C-arm equipment when the focal spot to image receptor distance is less than 45 cm.
X-ray tube under tabletop	1 cm above tabletop
X-ray tube over tabletop	30 cm above the tabletop with the end of the beam-limiting device or spacer positioned as closely as possible to the point of measurement
Fixed laterally projected fluoroscopy	Same as for C-arms 15 cm from the centerline of the X-ray tabletop and in the direction of the X-ray source with the end of the beam-limiting device or spacer positioned as closely as possible to the point of measurement. If the tabletop is movable, the tabletop shall be positioned as closely as possible to the lateral X-ray source, with the end of the beam-limiting device or spacer no closer than 15 cm to the centerline of the X-ray tabletop.

Automatic Exposure Control (AEC) in FGI Devices

- Sufficient image contrast
- Temporal and spatial resolution (small devices, movement)
- Minimize image noise and patient dose
- Report of AAPM TG125 and Gislason-Lee *et al*. (2013)*
- Continuous alteration of exposure parameters $\rightarrow$ a lot of DICOM information to consider (kV, pulses, spectral filtration, C-arm angulation, K, …)

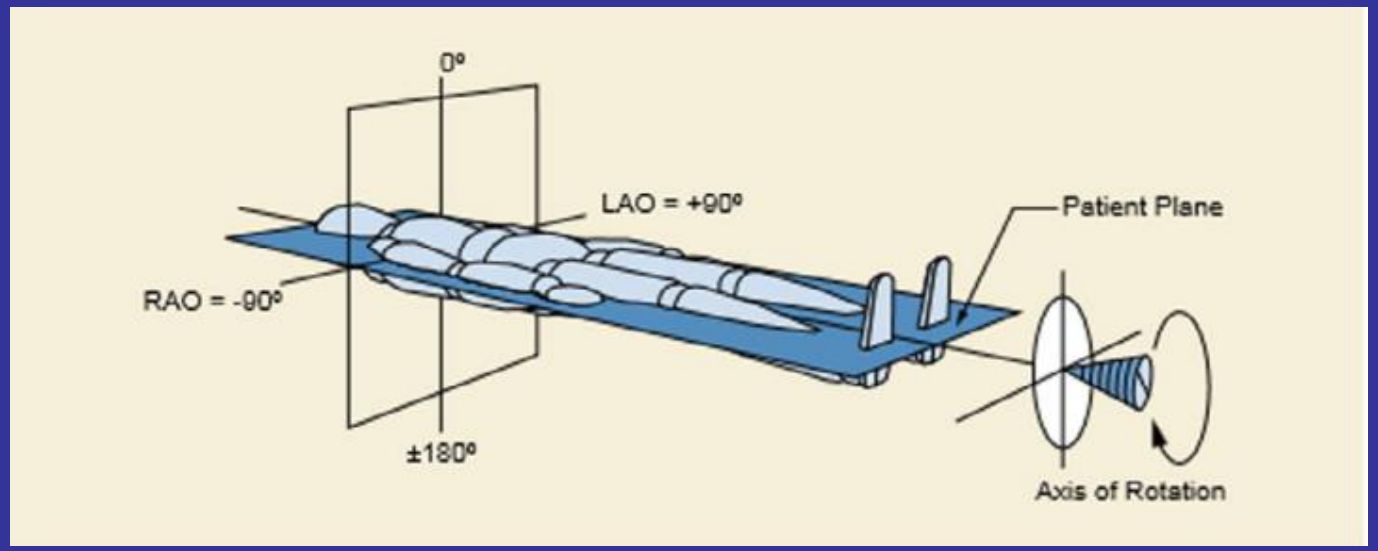
*Gislason-Lee AJ, McMillan C, Cowen AR, Davies AG. Dose optimization in cardiac x-ray imaging. Med Phys. 2013;40:091911.

Pertinent DICOM RDSR Content

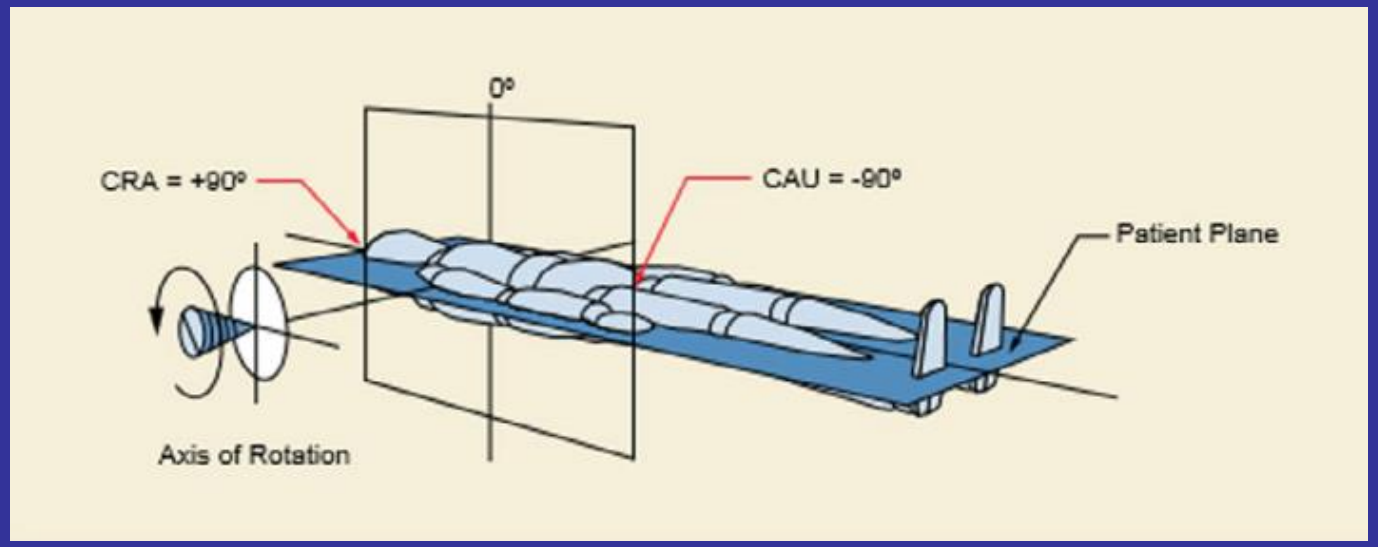
TABLE II. DICOM RDSR items pertinent to skin dose estimation

DICOM RDSR Item	Unit	Comments
Plane Identification		Identification of acquisition plane: "Single plane" for single plane systems (one X-ray tube), "Plane A" or "Plane B" for biplane systems, taken by the posterior or the lateral X-ray tube.
Distance Source to Patient/ Distance Source to Isocenter	mm	Distance from source to center of field of view. Traditionally referred to as Source Object Distance (SOD). Typically, the distance from X-ray source to the device rotational isocenter.
Distance Source to Detector	mm	Distance from X-ray source to image detector plane. Traditionally referred to as Source Image Receptor Distance (SID).
Collimated Field Area	m^2	X-ray field area at image detector plane
Dose RP	Gy	Measured or calculation model stated PERP air kerma free-in-air
Irradiation Event Type		Identification of irradiation event type: "Fluoroscopy" for fluoroscopic event, "Stationary Acquisition" for stationary image acquisition, "Rotary Acquisition" for rotational image acquisition.
kVp	kV	Voltage applied on X-ray tube
Positioner Primary Angle	°	Position of X-ray beams incidence angle in the RAO[a]/LAO[b] direction
Positioner Secondary Angle	°	Position of X-ray beams incidence angle in the CRA[c]/CAU[d] direction
Table Height Position	mm	Height of patient support table in relation to arbitrary reference point. Positive direction may vary for different vendors.
Table Lateral Position[e]	mm	Lateral position (in CRA/CAU direction) of patient support table in relation to arbitrary reference point
Table Longitudinal Position[e]	mm	Longitudinal position (in RAO/LAO direction) of patient support table in relation to arbitrary reference point
Filter Material		X-ray filter material, either copper, or aluminum
Filter Thickness Max	mm	Maximum thickness of added filtration
Filter Thickness Min	mm	Minimum thickness of added filtration

Positioner Angles



Positioner Primary Angle



Positioner Secondary Angle

Missing and Wanted DIOM Content

- End position of a fluoroscopic event
- Collimator shape
- Patient position relative to tabletop
- Field of view, collimation
- Attenuation, table and pad
- Water equivalent values of patient thickness

Basic Equation for Estimating Skin Dose

$$D_{skin} = K\prod_i k_i = K k_{isq} k_{BS} k_f k_{(T+P)}$$

Four parameter scaling of the air kerma per irradiation event

- K = air kerma at the patient entrance reference point (PERP)
- k_{isq} = the 1/r2 correction of K to place it at the true source-to-skin distance for the patient or model
- k_{BS} = the ratio of air kerma with patient body backscatter to K (no backscatter)
- k_f = conversion of air kerma to skin (tissue) absorbed dose (under CPE)
- $K_{(T+P)}$ = correction for table and pad attenuation (as appropriate for the beam geometry)

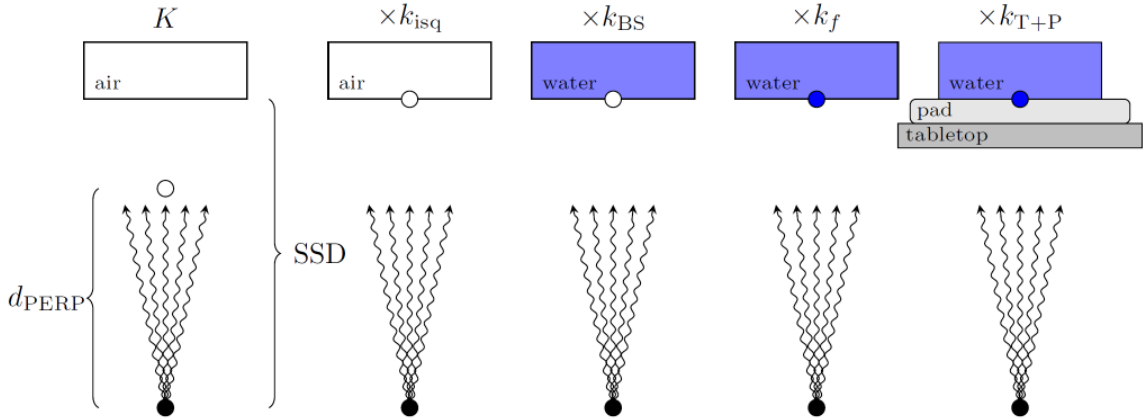
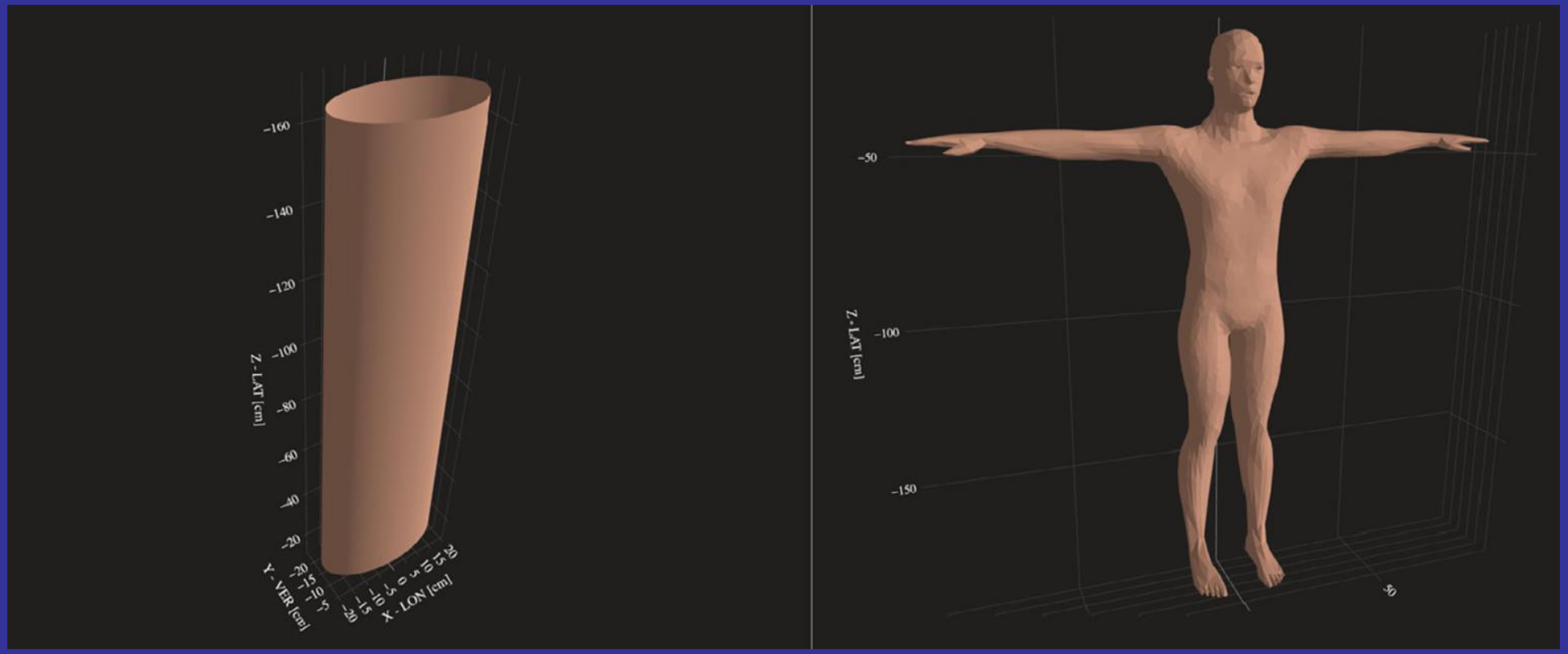


FIG. 4. Step-by-step correction of the FGI device indicated K to a skin dose estimate according to Eq. (5). The location of the measurement point is indicated with a white dot or a blue dot, respectively, depending on whether the measurement point is considered air or water equivalent.[7,8] [Color figure can be viewed at wileyonlinelibrary.com]

Refined Skin Dose Metrics

- C-arm angulation
- Patient position
- Mapping of skin dose contributions
- Identification of peak skin dose (PSD)
- PySkinDose (Python™ scripts and a wiki)

PySkinDose



Definition:

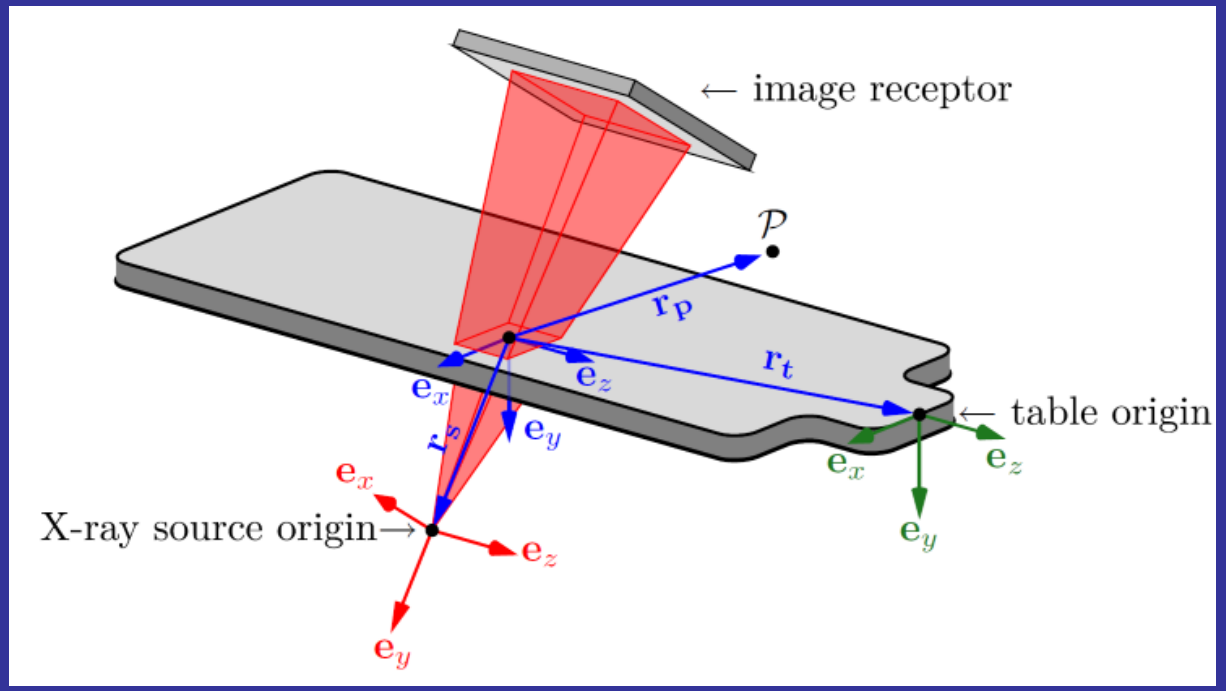
Skin patch – each polygon which comprises the skin surface model for which a tissue absorbed dose is estimated

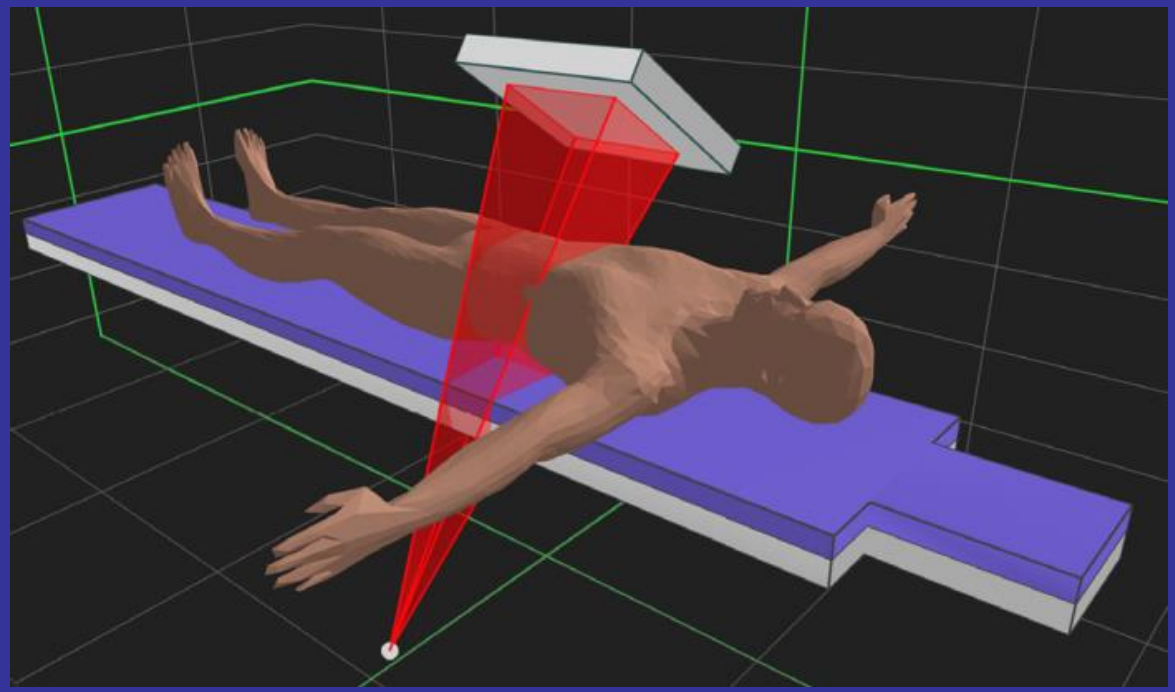
Example of patient phantoms for skin dose mapping

Left: ***A cylindrical phantom with elliptic cross-section.***
Right: ***A human-shaped phantom, constructed with the MakeHuman® software.***

Both phantoms are available in PySkinDose. Human skin phantoms are typically polygon-mesh models.

Aligning the X-ray Beam to the Isocenter of Rotation

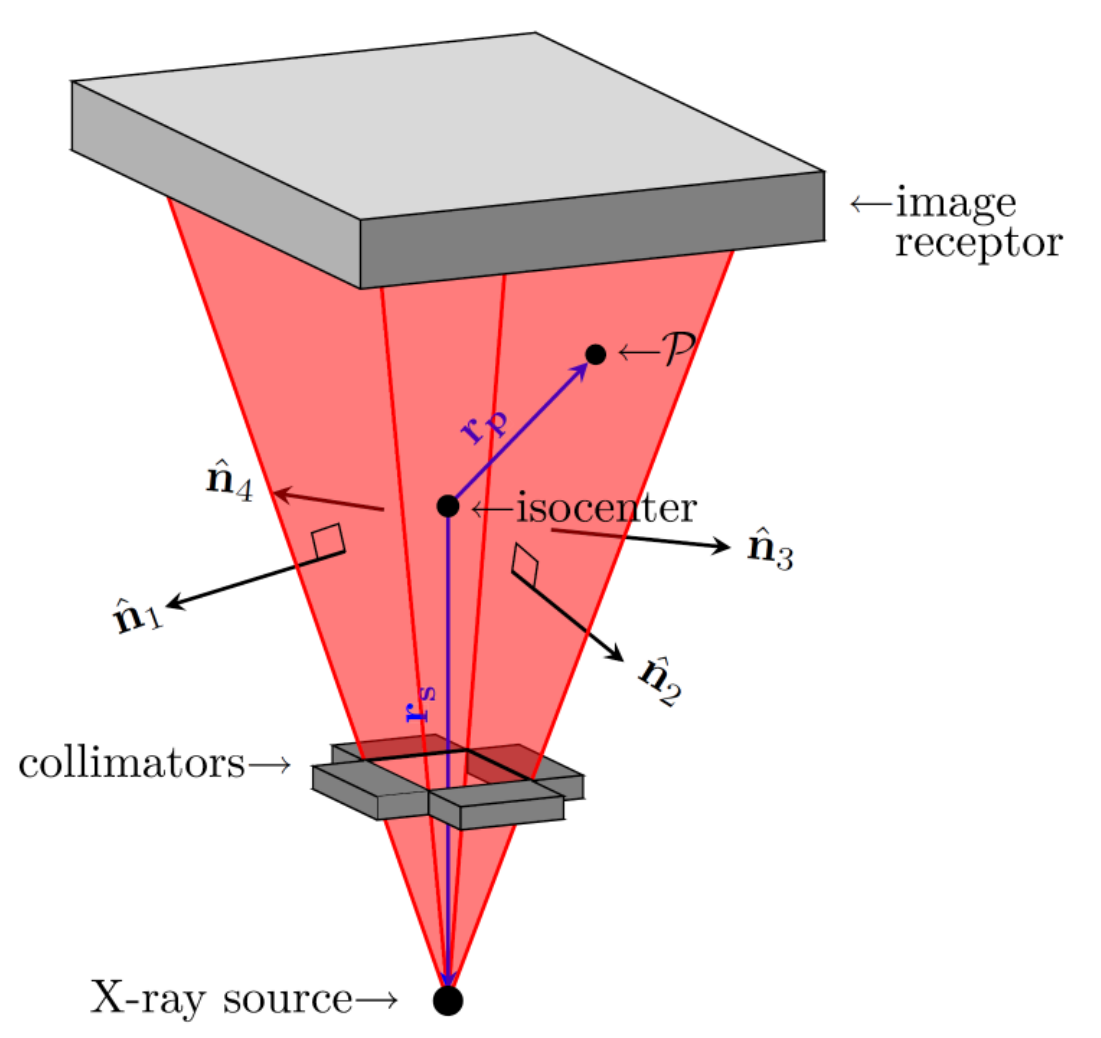




Note that the location of the X-ray beam and the tabletop location is stated in the RDSR with ***different*** reference points and directions. The relative position between these objects is not specified explicitly. This needs to be addressed before skin dose mapping can be performed.

The solution: Red coordinate system of the x-ray source is aligned to the green coordinate system of the table through the establishment of the blue coordinate system of the isocenter.

Calculating X-ray Beam to Patient Intercept



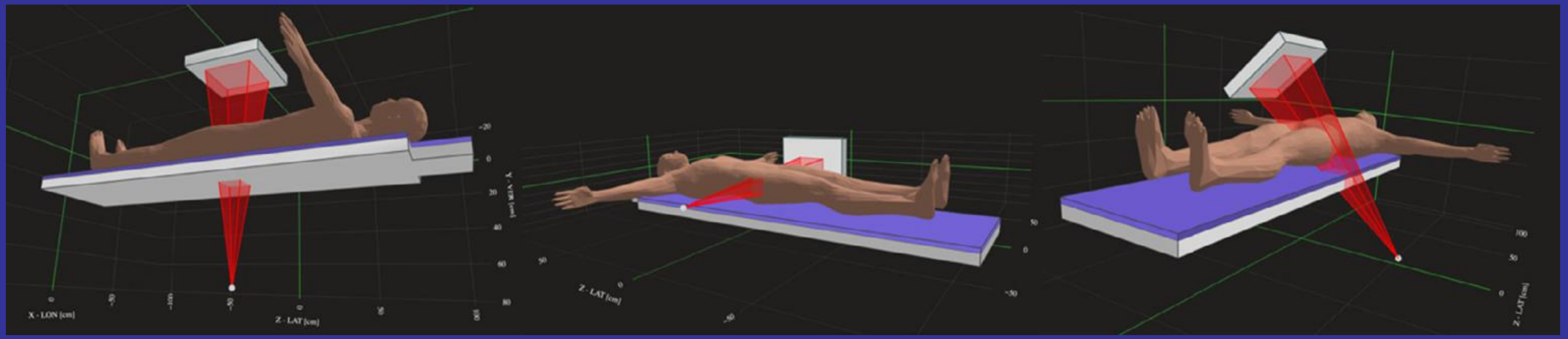
Once the X-ray beam and the patient skin phantom have been positioned in the same coordinate system, the next step is to calculate which patches of skin are hit by the X-ray beam. This is done to select the irradiated area for skin dose calculation.

The X-ray beam to patient intercept determination can be conducted by a variety of different algorithms. A straightforward approach is to implement an algorithm that calculates the signed distance from each skin patch, to all of the four planes that build up the extent of the pyramid shaped X-ray beam.

Calculating X-ray Beam to Table/Pad Intercept

A further important factor for skin dose mapping is the ability to determine if the X-ray beam passes through the tabletop and pad prior to when it hits a given patch of skin. This information is needed in order to apply tabletop and pad correction factors on a skin patch level for each irradiation event.

Three scenarios to consider:

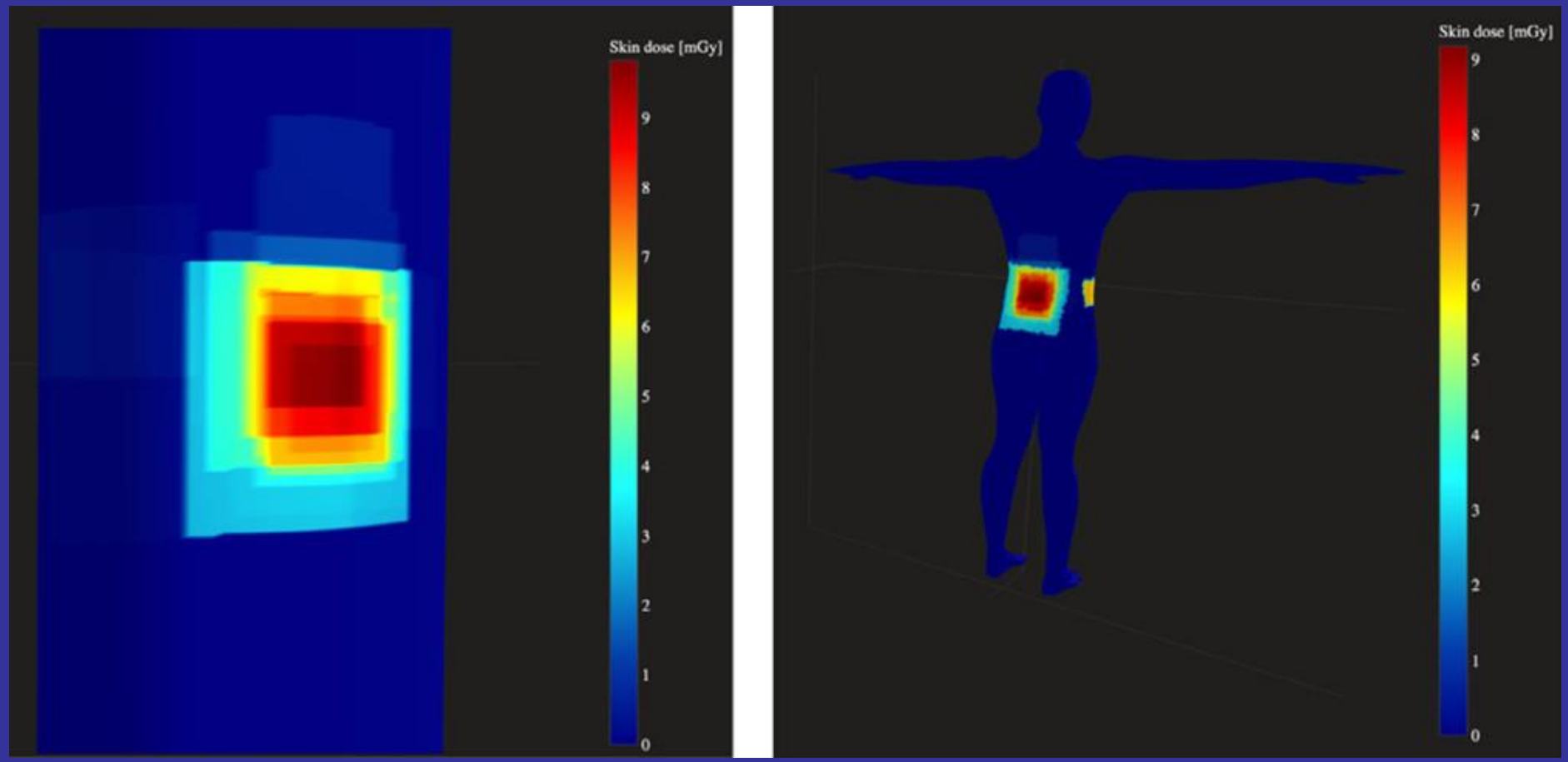


***All** skin patches require T+P attenuation*

***No** skin patches require T+P attenuation*

***Some** skin patches require T+P attenuation*

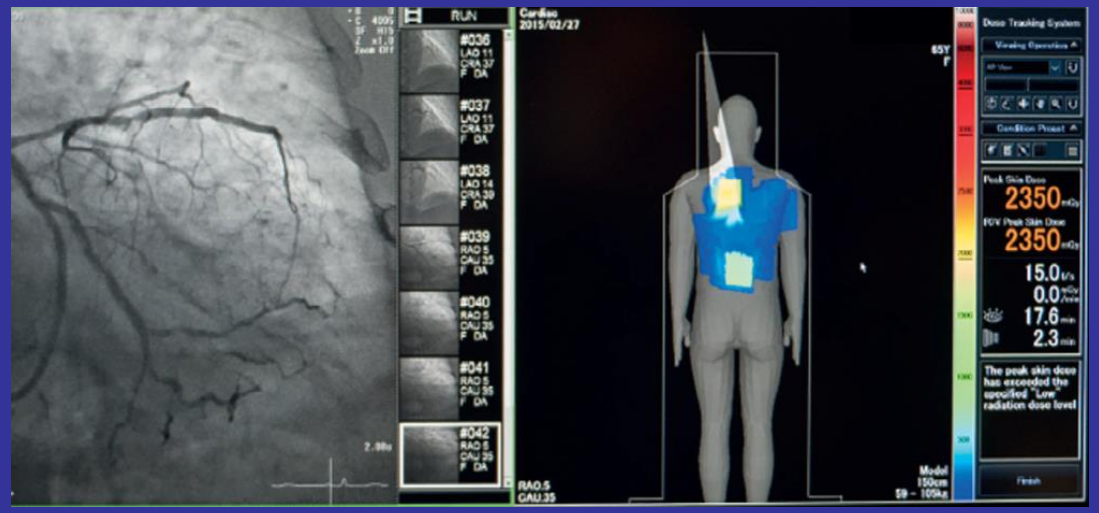
Skin dose mapping and localization of the PSD

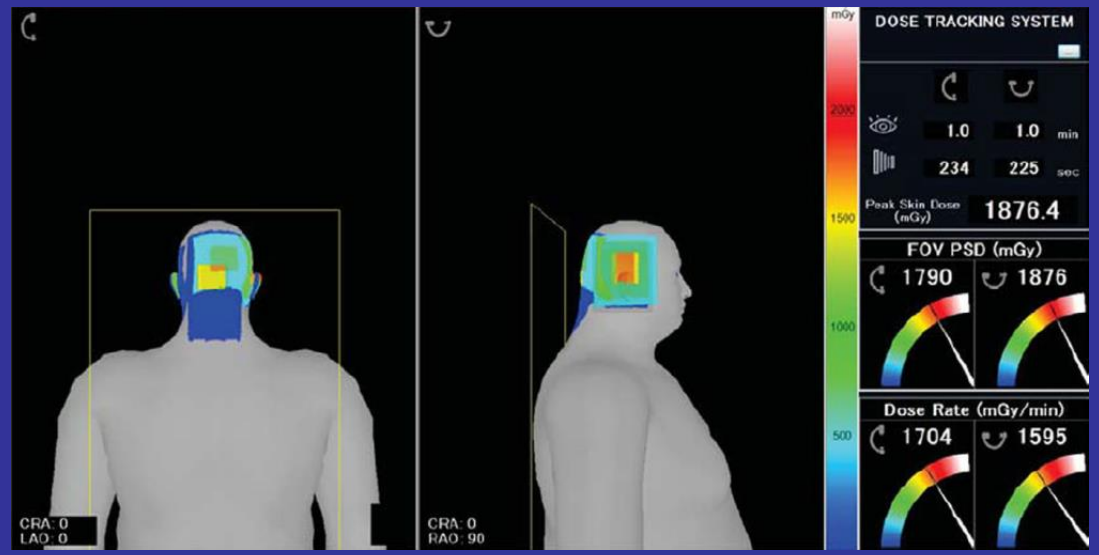


PySkinDose – **Cylindrical Phantom**

PySkinDose – **Human-Shaped Phantom**

Skin dose mapping and localization of the PSD





Two examples of commercial skin dose mapping software that provides real-time display

Skin dose map is incremented following each irradiation event of the fluoroscopically guided intervention

Warning in the report's Conclusions:

Regarding real-time monitoring of skin dose during FGI procedures, it should be noted that, while solutions might aid operators in choosing projection angles and collimation settings to reduce PSD, this aspect of a procedure should not get a disproportionally large degree of attention from operators – their primary task is to perform a clinically successful procedure.

Sources of Uncertainty

- For skin dose estimates from FGI procedures to yield robust and actionable information within healthcare the associated uncertainties must also be known and understood.

- There is presently no comprehensive discussion in the literature regarding uncertainties in patient skin dose estimates, nor do commercially available software solutions communicate uncertainty with skin dose estimates.

- A reasonable goal would be to express skin dose and PSD estimates as expected mean values with the 95% confidence interval.

Sources of Uncertainty – Physical Corrections

TABLE IV. Identified uncertainties associated with basic skin dose estimates, employing only physical corrections, from FGI device procedures

Source	Description	Magnitude of Error
Air kerma (K) at the PERP	a. Measurement performed by a medical physicist. b. Required tolerances by IEC and FDA.[15,24]	a. ±5%, inclusive of ±2 standard deviations. b. Up to ±35%, stated tolerances provided by the manufacturers.[15,24]
X-ray Beam Size (Area) at the PERP	Correction for beam size. See the Report of AAPM Task Group 190.[14]	An error with the beam size affects P_{KA}, which propagates to K for FGI devices with KAP-meters. An area that is wrongly stated as too large can cause overlapped irradiated areas when performing skin dose mapping (Section 4.2).
Tabletop and Pad Attenuation	Attenuation of primary beam by the tabletop and pad, which depends upon kV, added filtration, as well as angle of beam incidence on the tabletop.	25% to 45%.
Forward Scatter from Tabletop and Pad	Forward scattered X rays from the tabletop and pad.	8% to 12% of the primary beam.

TABLE IV. Identified uncertainties associated with basic skin dose estimates, employing only physical corrections, from FGI device procedures

Source	Description	Magnitude of Error
Backscattered X rays for Soft tissue	X rays that are backscattered to the skin of the patient.	5% to 50%, depending on field size and beam quality. Up to 15% for cortical bone directly beneath the skin.
Backscattered X rays for Phantoms	Differences noted with back scatter corrections obtained using different phantom materials.	Up to 10%, depending on the actual phantom material.
Distance Correction to Skin Surface – Actual Patient versus Computational Model	Inverse square law from the X-ray source to patient. Large patients and lateral projections may be expected to cause the largest variations.	±20%, depending on the relative position of X-ray source and irradiated patient skin area.
Conversion of Skin Exposure to Skin Dose	Conversion of air kerma to absorbed skin dose.	Up to 4%, depending on X-ray beam energy.
Non-uniformity of the X-ray Beam	Correction for non-uniform irradiation of the patient skin, for example, from the heel effect and use of wedge compensation filters.	Up to 15%, depending on incident beam area on patient skin.

Sources of Uncertainty – Skin Dose Mapping

TABLE VI. Identified uncertainties associated with skin dose mapping estimates from FGI procedures

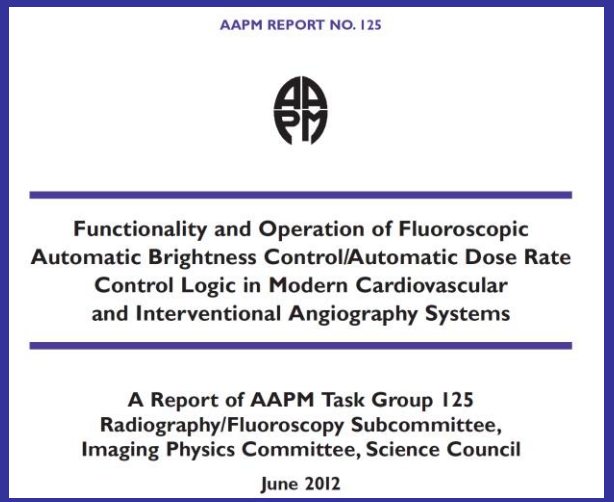
Source	Description	Magnitude of Error
Computational Phantom Type and Format	A statement is needed on which computational phantom was used, together with characteristics: • Human like or cylindrical/ elliptical phantom. • Computational phantom height and weight. • Model number or another descriptor. • Size of the smallest skin patches on the phantom.	Dependent upon phantom agreement with actual patient. If patient is supine and the X-ray tube is under the tabletop, the uncertainty may be described using Table 4.1.
Computational C-arm Models	If a virtual C-arm is used to estimate skin dose, the element matching should be stated. Further important information associated with uncertainty include: • SID matching to the actual FGI device. • Determination of X-ray beam shape (square or rectangular). • Longitudinal and lateral tabletop position movement for locating the X-ray beam on the phantom.	Aspects associated with identifying the irradiated patches of the phantom skin should be noted.
Matching a Patient with a Computational Phantom	Patient size will affect accuracy of skin dose estimates, particularly with angled C-arm projections. Data on patient to phantom match should be presented.	10% to 15%
Patient Location on the Tabletop	A statement on the method used for locating the actual patient on the tabletop, for example, 15 cm from the top of the head to the end of the tabletop. Patient movement or position change during the procedure must also be taken into account.	NA
C-arm Angulation During an Irradiation Event	RDSR provide the start angle for each irradiation event, but not the stop end position. Only images sent to PACS store the C-arm angulation and tabletop locations in DICOM image header tags.	The assumptions used in the beam location on the patient should be stated. For example, all irradiation events list the start location as irradiated during an entire sequence.
Resolution of Skin Dose Regions and X-ray Beam Collimation	No agreement exists for the needed resolution.	NA

Summary and Recommendations

- All software solutions for estimating skin dose should supply (at least) one reference phantom with a reported confidence value for a nominal 1 Gy exposure.

- Medical physicists should verify air kerma at the PERP (AAPM TG125) Understanding and optimization of clinical protocols.

- The uncertainties discussed are not comprehensive. More work is needed, please contribute to the literature!


AAPM REPORT NO. 125

Functionality and Operation of Fluoroscopic Automatic Brightness Control/Automatic Dose Rate Control Logic in Modern Cardiovascular and Interventional Angiography Systems

A Report of AAPM Task Group 125
Radiography/Fluoroscopy Subcommittee,
Imaging Physics Committee, Science Council

June 2012

Summary and Recommendations

- We need software solutions to estimate PSD (commercial, non-commercial, and open-source). Note the difference between post-procedure (RDSR/image header data) and real-time. Balance between ALARA against getting the clinical job done!

- We need better naming conventions for standardized procedures to achieve specificity in skin dose per procedure type and complexity. Also, standardization of units and color schemes for robustness (communication, multi-vendor environments).

Summary and Recommendations

- The gaps in available DICOM information should be filled to achieve more reliable estimates of PSD. Continued collaboration with MITA, FDA, IEC, and the DICOM community is essential to advance knowledge.

- MPs should verify FGI device RDSR as part of commissioning, acceptance testing, and following software upgrades.

- Familiarity with DICOM content and software for PSD estimation may be considered as added competence requirements for MPs.

Thank you for your attention!

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