Skin dose in interventional radiology

Jonas Andersson
Medical Physics Expert, Associate Professor
Centre for information technology and biomedical engineering (CIMT)

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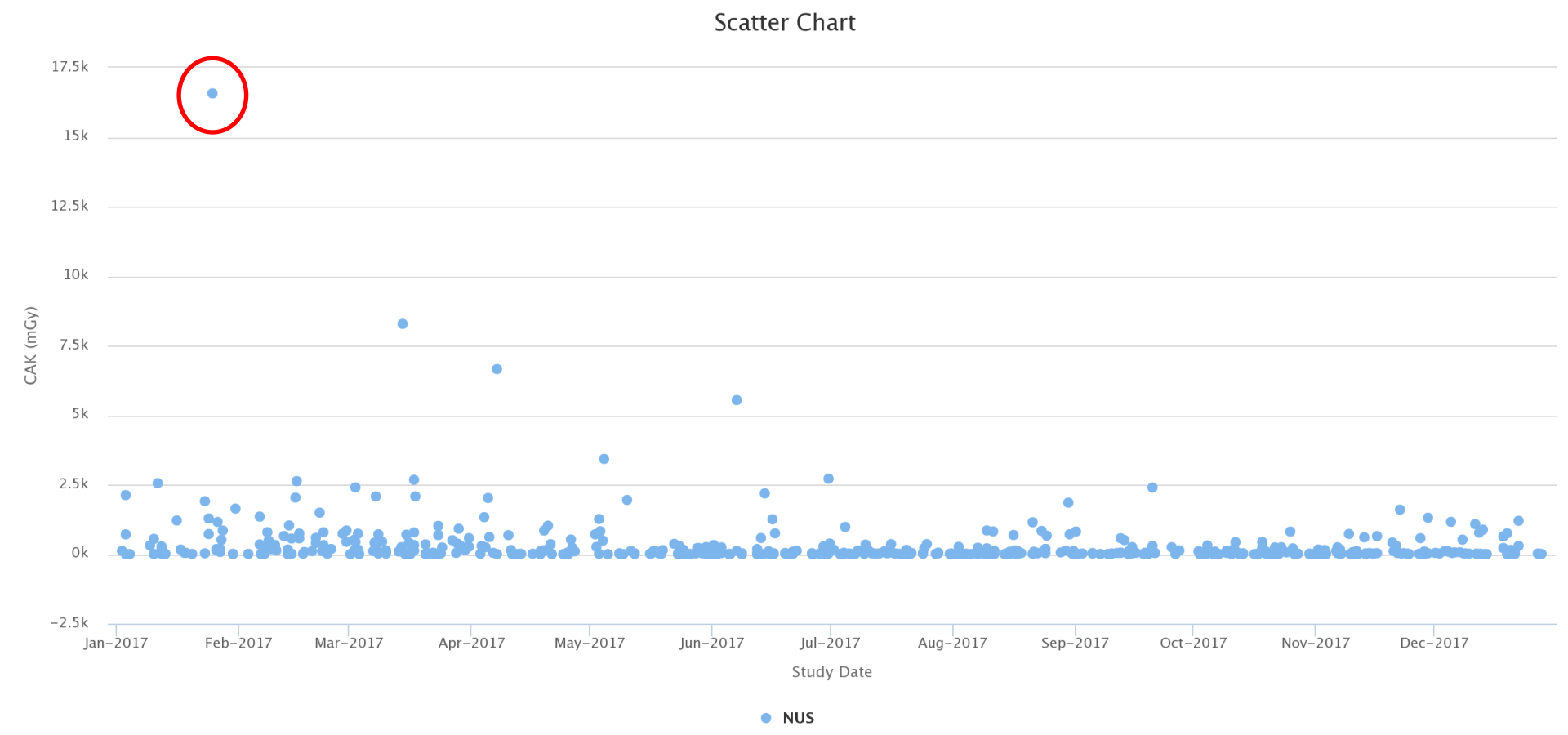

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What could be found in the data?

Total air Kerma 16.57 Gy

- Fluoroscopy 2.75 Gy (74.7 min)
- Exposure 13.82 Gy (12.5 min)

air Kerma spread out over an area due to C-arm angulation

- Highest air Kerma in a projection 13.5 Gy

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The literature (10-15 Gy = trouble, 15+ Gy = necrosis)

What about our patient?

After one month

- Change in tone/blush and scaling skin

After nine months

- Hyper pigmentation

Back to the literature

Miller et al. found that the cumulative air kerma overstated the PSD by 40%–50% and thus cumulative air kerma for a procedure likely represents a conservative surrogate index of PSD for QA reviews.[2] However, Miller et al. also showed the possibility that the tabletop height and image receptor positioning can be such that the cumulative air kerma actually underestimates the PSD received by a patient.[2]

2. Miller DL, Balter S, Cole PE, et al. Radiation doses in interventional radiology procedures: the RAD-IR study: part II: skin dose. *J Vasc Interv Radiol*. 2003;14:977–990.

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Estimation of patient skin dose in fluoroscopy: summary of a joint report by AAPM TG357 and EFOMP

Jonas Andersson[a)]
Department of Radiation Sciences, Radiation Physics, Umeå University, SE-901 85 Umeå, Sweden

Daniel R. Bednarek
State University of New York, 875 Ellicott St, Buffalo, NY 14203-1070, USA

Wesley Bolch
University of Florida, 1275 Center Drive, Gainesville, FL 32611-6131, USA

Thomas Boltz
Orange Factor Imaging Physicists, 4035 E Captain Dreyfus Ave, Phoenix, AZ 85032, USA

Hilde Bosmans
University of Leuven, Herestraat 49, Leuven B-3000, Belgium

Amber J. Gislason-Lee
University of Leeds, Worsley Building, Clarendon Way, Leeds LS2 9JT, UK

Christoffer Granberg and Max Hellstrom
Department of Radiation Sciences, Radiation Physics, Umeå University, SE-901 85 Umeå, Sweden

Kalpana Kanal
University of Washington Medical Center, 1959 NE Pacific Street, Seattle, WA 98195, USA

Ed McDonagh
Joint Department of Physics, The Royal Marsden NHS Foundation Trust, Fulham Road, London SW3 6JJ, UK

Robert Paden
Mayo Clinic, 5777 East Mayo Blvd, Phoenix, AZ 85054, USA

William Pavlicek
Mayo Clinic, 13400 E Shea Blvd., Scottsdale, AZ 85259, USA

Yasaman Khodadadegan
Progressive Insurance, Customer Relation Management, 6300 Wilson Mills Rd.,Mayfield Village, OH 44143, USA

Alberto Torresin
Niguarda Ca'Granda Hospital, Via Leon Battista Alberti 5, Milano 20149, Italy

Annalisa Trianni
Udine University Hospital, Piazzale S. Maria Della Misericordia, n. 15, 33100 Udine, Italy

David Zamora
University of Washington Medical Center, 6852 31st Ave NE, Seattle, WA 98115-7245, USA

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Background: Physicians use fixed C-arm fluoroscopy equipment with many interventional radiological and cardiological procedures. The associated effective dose to a patient is generally considered low risk, as the benefit-risk ratio is almost certainly highly favorable. However, X-ray-induced skin injuries may occur due to high absorbed patient skin doses from complex fluoroscopically guided interventions (FGI). Suitable action levels for patient-specific follow-up could improve the clinical practice.

There is a need for a refined metric regarding follow-up of X-ray-induced patient injuries and the knowledge gap regarding skin dose-related patient information from fluoroscopy devices must be filled. The most useful metric to indicate a risk of erythema, epilation or greater skin injury that also includes actionable information is the peak skin dose, that is, the largest dose to a region of skin.

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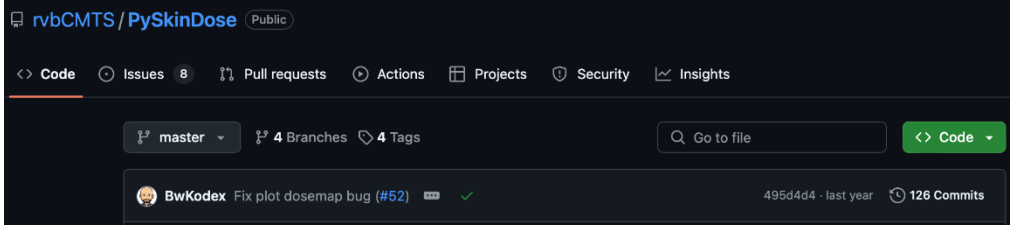
Recently the International Electrotechnical Commission (IEC) stated the importance of skin dose estimation and skin dose mapping by including the concepts in the second amendment of IEC 60601-2-43 ("Particular requirements for the basic safety and essential performance of X-ray equipment for interventional procedures"). Here, the IEC made the difference between air kerma mapping and skin dose mapping very clear.[3]

1.B. An open-source framework for discussion and evaluation of skin dose

PySkinDose, an open-source Python™ package for RDSR-based skin dose estimation is used throughout this report as a source of practical examples.[7,8] This system translates air kerma at the PERP to estimate entrance skin dose for all irradiated surfaces on computational phantoms. The phantoms are oriented with the X-ray source by geometric parameters found within the RDSR, and conversion from air Kerma at the PERP to skin dose is further supported by correction factors found in literature, as well as a limited number of in-clinic measurements, which are discussed in this report (e.g., validation of the coordinate system, table and pad transmission etc.).[7,8] The output of the software is an estimation of skin dose and a visual indication of skin dose distribution mapped onto an anthropomorphic or a cylindrical phantom. The real position of the phantom on the tabletop can be taken into account. A variety of voxelized phantoms can be incorporated in PySkinDose.

There are many available software solutions for skin dose estimation (both commercial and in-house custom developed), which are also discussed in this report, but the strength of PySkinDose is the open-source format that makes it a good choice for a transparent discussion on models for estimating skin dose together with DICOM information.



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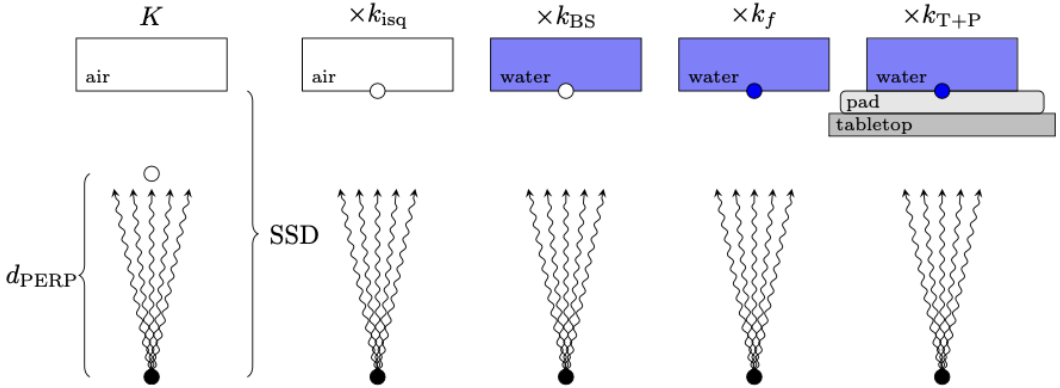


FIG. 4. Step-by-step correction of the FGI device indicated K to a skin dose estimate according to Eq. (5). The location of the measurement point is indicated with a white dot or a blue dot, respectively, depending on whether the measurement point is considered air or water equivalent.[7,8] [Color figure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

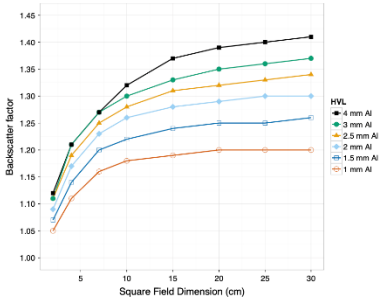
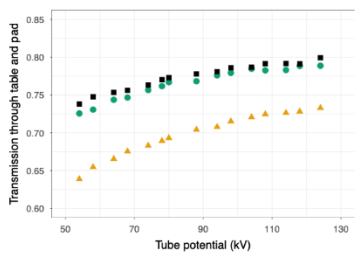


FIG. 5. Backscatter factors as a function of dimension of a square field at the entrance surface of a water phantom for different HVLs.[36] [Color figure can be viewed at wileyonlinelibrary.com]

TABLE III. Mass energy-absorption coefficients relative to air.[47]

Energy (keV)	Soft Tissue	Muscle	Eye Lens	Cortical Bone	Compact Bone
10	1.052	1.047	0.940	5.652	3.937
15	1.051	1.046	0.931	6.288	4.359
20	1.051	1.046	0.926	6.682	4.610
30	1.051	1.047	0.925	6.962	4.792
40	1.056	1.053	0.939	6.596	4.576
50	1.064	1.061	0.967	5.700	4.016
60	1.073	1.071	0.998	4.604	3.320
80	1.087	1.086	1.046	2.865	2.225
100	1.095	1.094	1.071	1.972	1.654
150	1.100	1.100	1.089	1.275	1.221



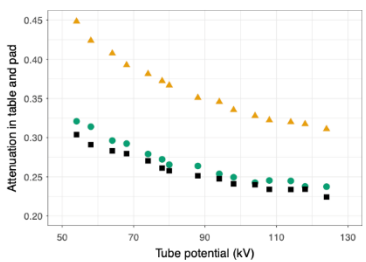


FIG. 8. Examples of measured tabletop and pad attenuation and transmission.[54] Left: the ratio of beam intensity transmitted through the tabletop and pad to the intensity measured in air, as a function of kV for the three spectral filters. Right: $\mu_T t_T + \mu_P t_P$ shown as function of kV for three different spectral filters [Color figure can be viewed at wileyonlinelibrary.com]

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

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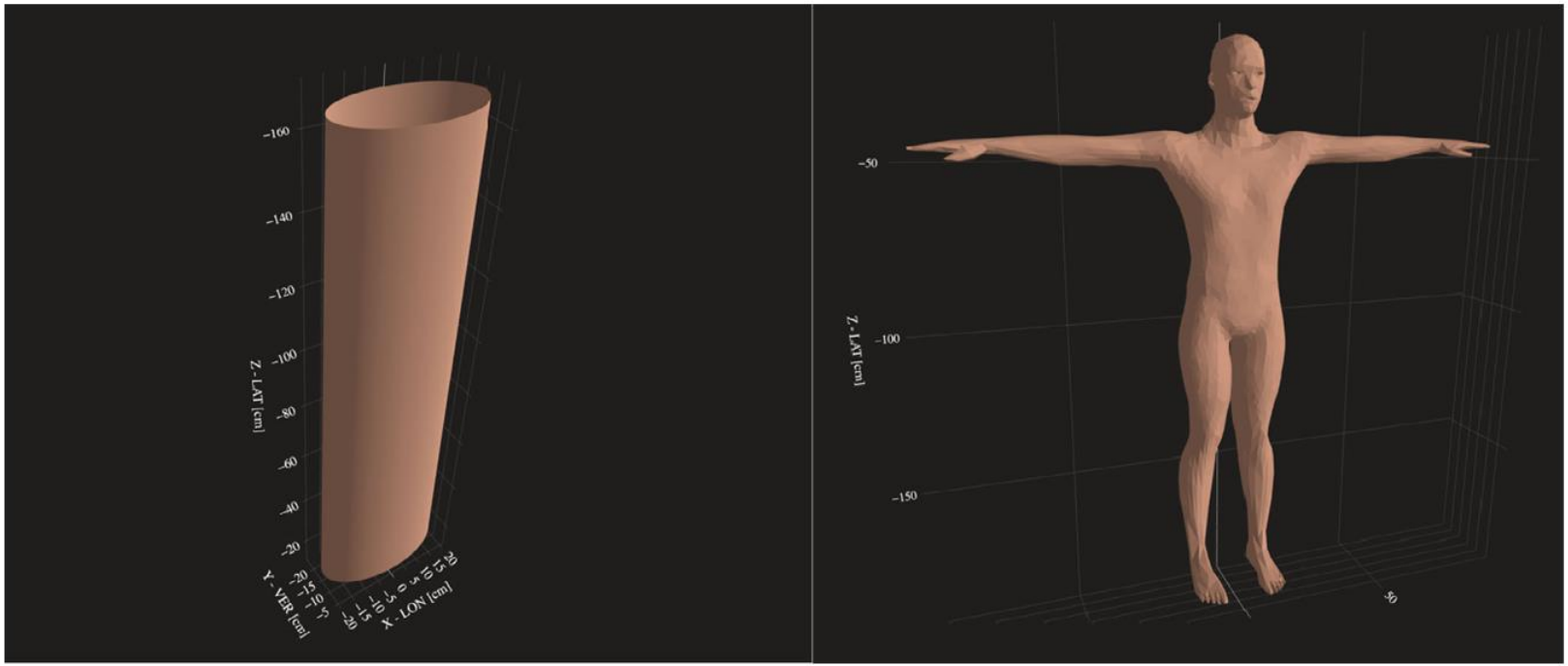

FIG. 12. Example of patient phantoms for skin dose mapping. Left: A cylindrical phantom with elliptic cross-section. Right: A human-shaped phantom, constructed with the MakeHuman® software.[59] Both phantoms are available in PySkinDose.[8] [Color figure can be viewed at wileyonlinelibrary.com]

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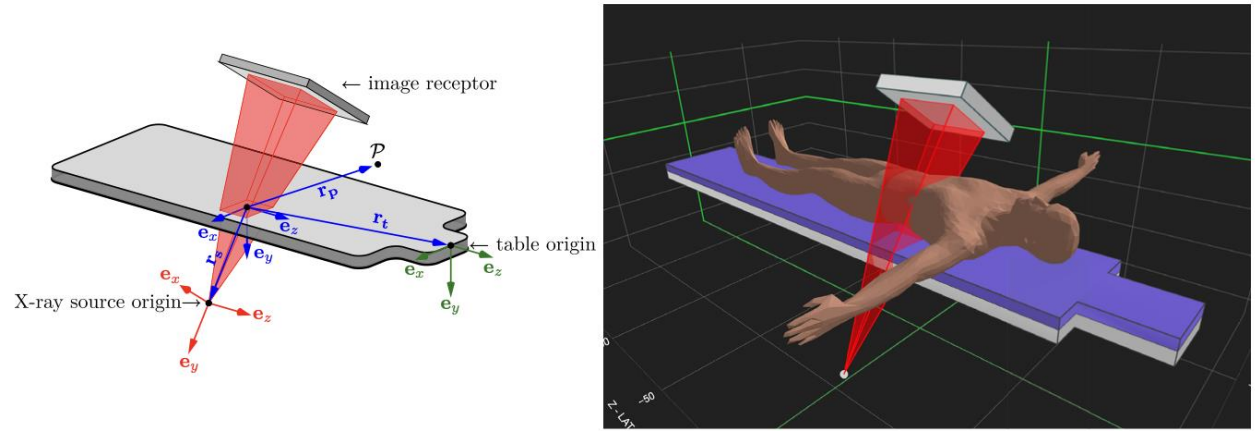

FIG. 14. *Left:* Illustration of three Cartesian coordinate systems, with origin fixed at the X-ray source (red), the tabletop (green), and the isocenter of the C-arm (blue). The red coordinate system is used to define the location of the X-ray beam from beam-related parameters in the RDSR structure, while the green coordinate system is used to define the position of the patient support table, upon which the user-defined patient phantom is positioned. *Right:* Illustration of the same geometry, when conducting skin dose mapping with PySkinDose, where the patient and the X-ray beam have been defined in separate coordinate systems and transformed to a common space which enables skin dose mapping.[8] The position and orientation of the patient phantom, in relation to the tabletop, needs to be specified by the user. [Color figure can be viewed at wileyonlinelibrary.com]

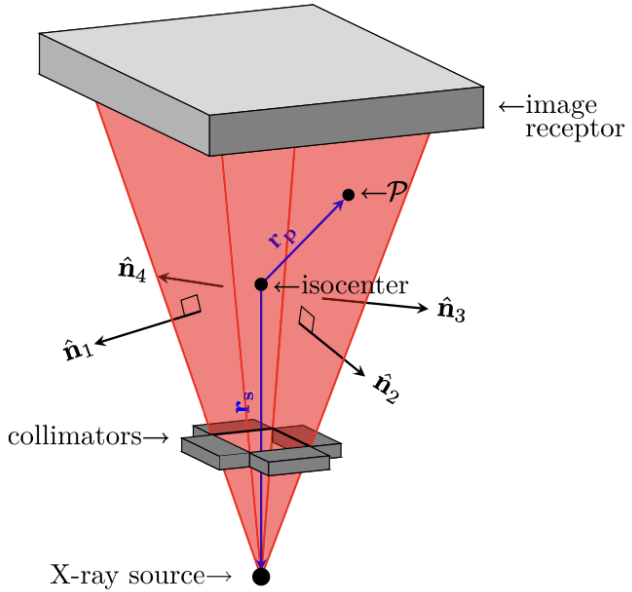

FIG. 15. Illustration of the X-ray beam-patient intercept algorithm.[8] The algorithm calculates the signed distance from the skin patch to all of the four sides that delineate the X-ray beam. [Color figure can be viewed at wileyonlinelibrary.com]

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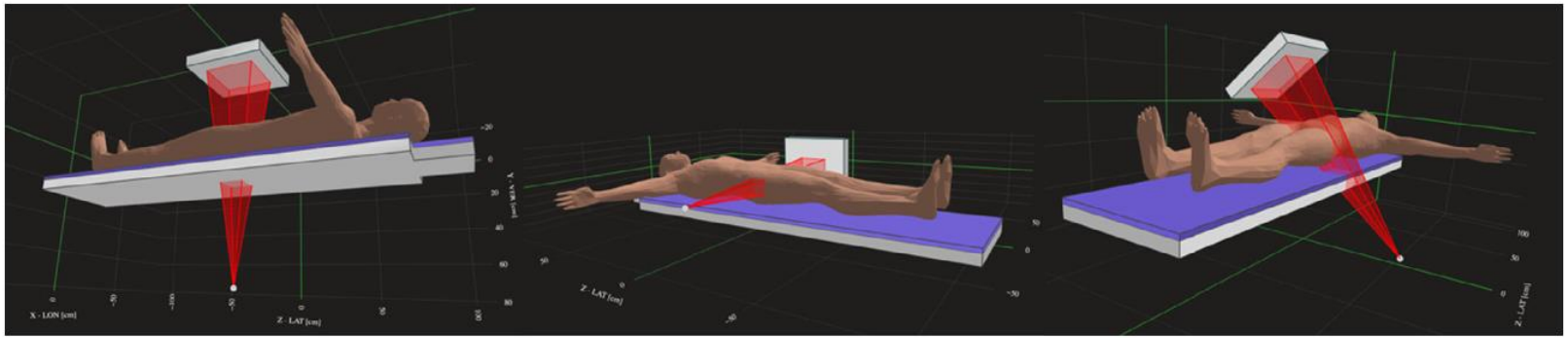

FIG. 16. Illustration of the importance of applying the tabletop and pad correction factors on a skin patch level. Left: Normal incidence posterior projection, in which all irradiated skin patches should be corrected for tabletop and pad attenuation. Middle: LAO projection, where no patches of skin should be corrected for tabletop and pad attenuation. *Right:* RAO projection, where parts of the X-ray beam are covered by the tabletop and pad.[8] [Color figure can be viewed at wiley onlinelibrary.com]

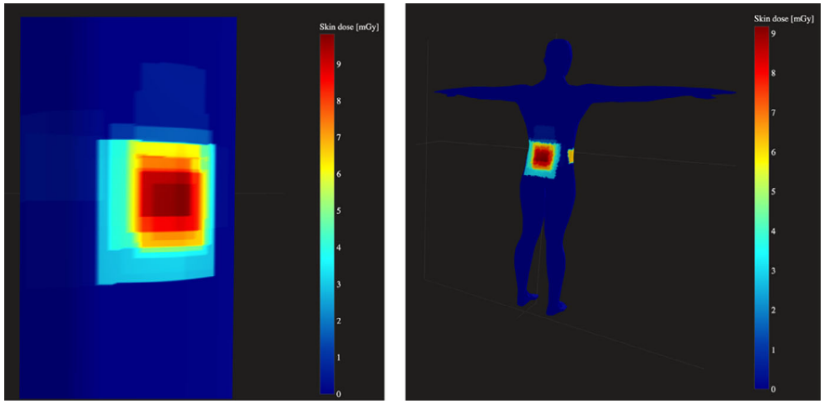

FIG. 18. Illustration of dose maps calculated from RDSR data Left: Calculated with a cylindrical phantom and Right: A human-shaped phantom.[8] The PSD estimate equals maximum absorbed skin dose to any of the skin patches on the patient phantom. [Color figure can be viewed at wileyonlinelibrary.com]

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When should you do QC of digital data?

Tenders

- Require formal DICOM compliance
- Request RDSR/other data for QC

Installation

- Test in DMS/unity test

Software upgrades

- Test in DMS/unity test

Decommissioning

- Migrate data and delete

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Who should do the work?

- Medical physicists
- Biomedical engineers
- Manufacturer engineers
- System admins
- IT-safety professionals

- Radiology equipment manufacturers
- DMS manufacturers

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Report all incidences/deviations!

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Report summary and recommendations

1. Air kerma at the reference point together with physical corrections and RDSR data and computational phantoms can achieve meaningful estimates of skin dose.
2. Use the AAPM TG125 test routine to understand the FGI equipment.
3. More work is needed to understand the uncertainties associated with skin dose estimates, which should be reported with 95% confidence intervals.

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Report summary and recommendations

4. Real-time monitoring of skin dose should be used with care during procedures, the primary task is patient outcome.

5. There is a need for better naming conventions for standardised procedures.

6. There are gaps in available DICOM information, which could further advance accuracy and mitigate uncertainty in skin dose estimates.

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