Novel Approaches to Patient Dosimetry Measurements in Radiotherapy and Interventional Radiology: The role of in vivo dosimetry. Part 2

Interventional Radiology

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Fluoroscopically-guided Interventions
Interventional Radiology

- Cardiology
- Neurology
- Vascular Surgery
- Urology
- Orthopedic Surgery
- Obstetrics and Gynecology
- Gastroenterology and Hepato-biliary System
- Anesthesiology and Pain Management

Interventional Procedures

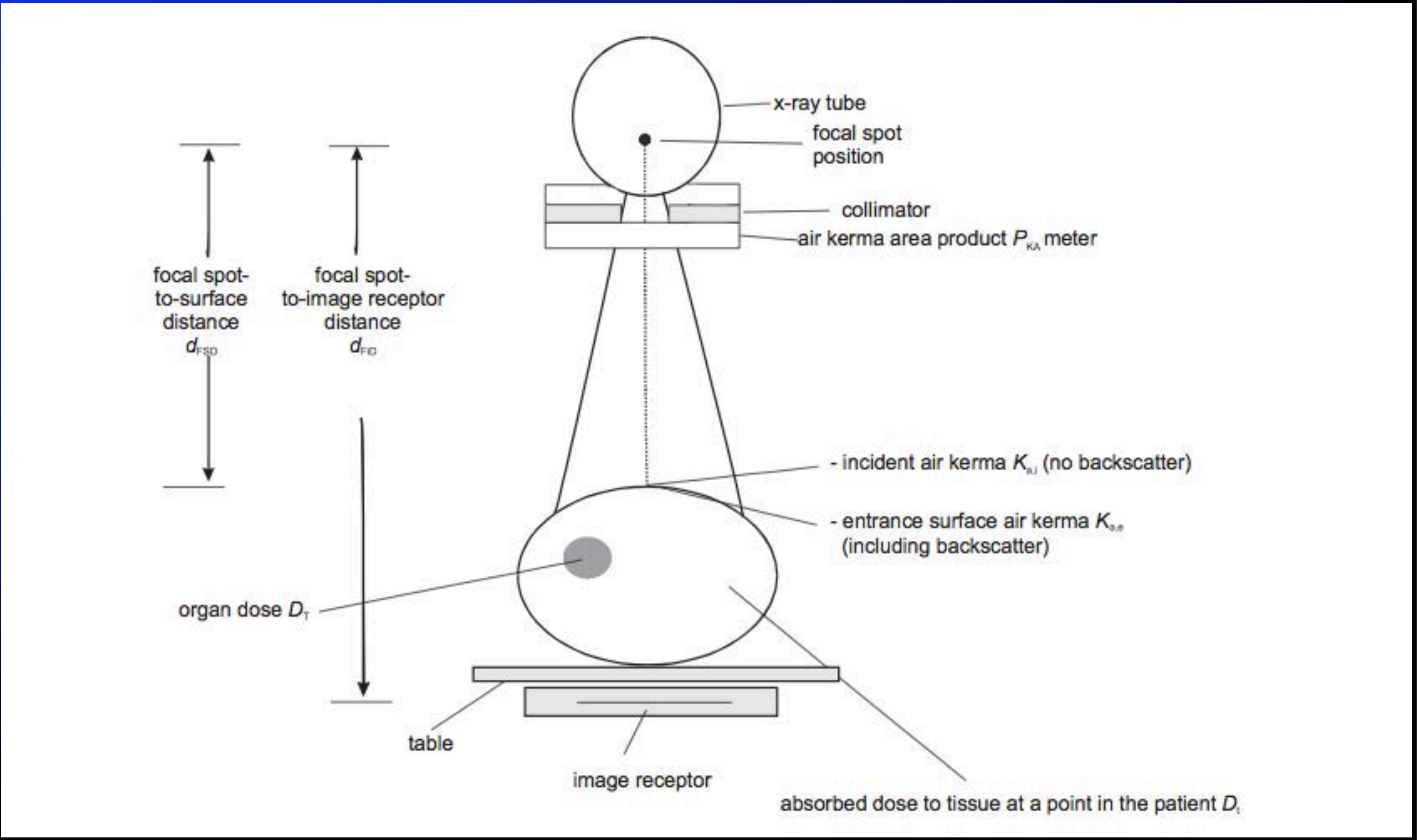
Diagnostic

Therapeutic

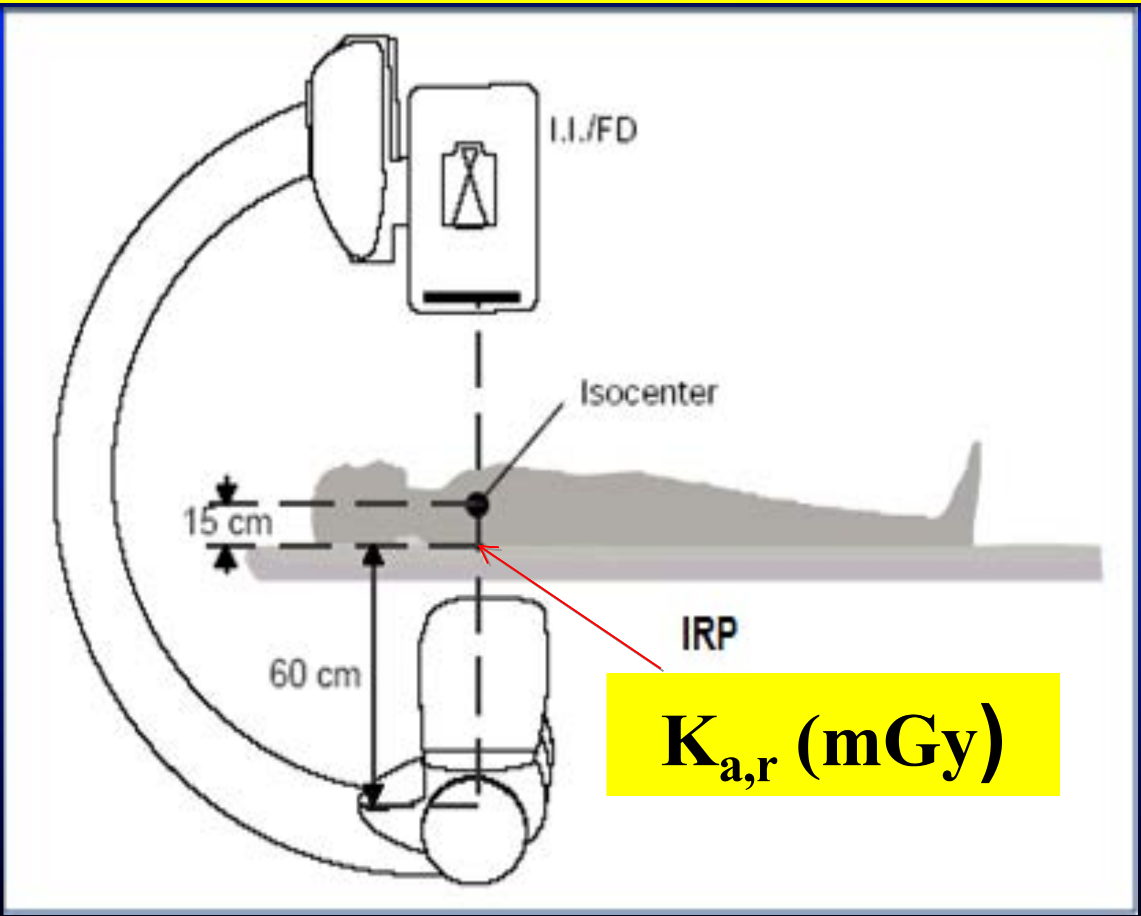

Artis
zee

Dosimetric and Geometric Quantities for Determination of Patient Dose (ICRU 74, 2005)

P_{KA} represents the integral of air kerma across the entire x-ray beam emitted from the x-ray tube. Its units are Gy cm^2.



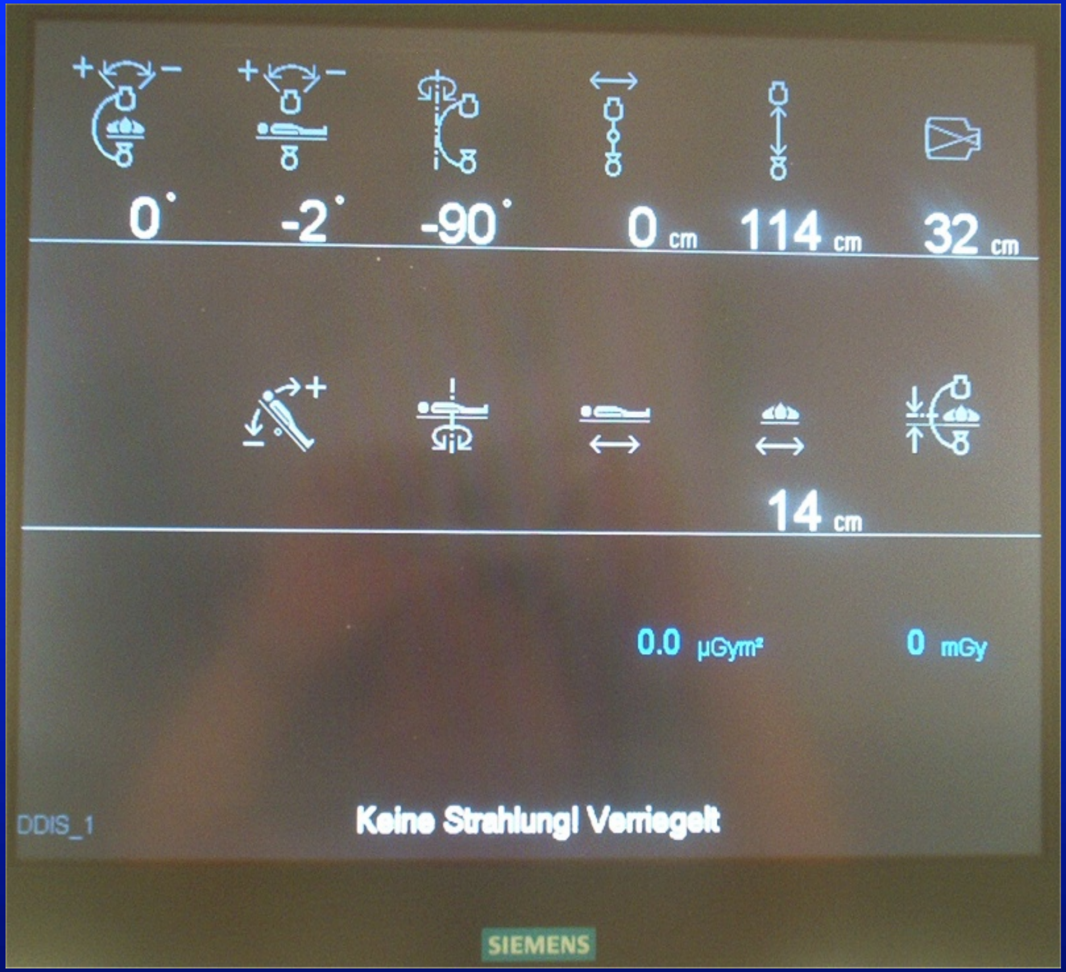
($K_{a,r}$)
"Interventional reference point", "Cumulative reference point air kerma", "Cumulative dose", "Patient entrance reference point"

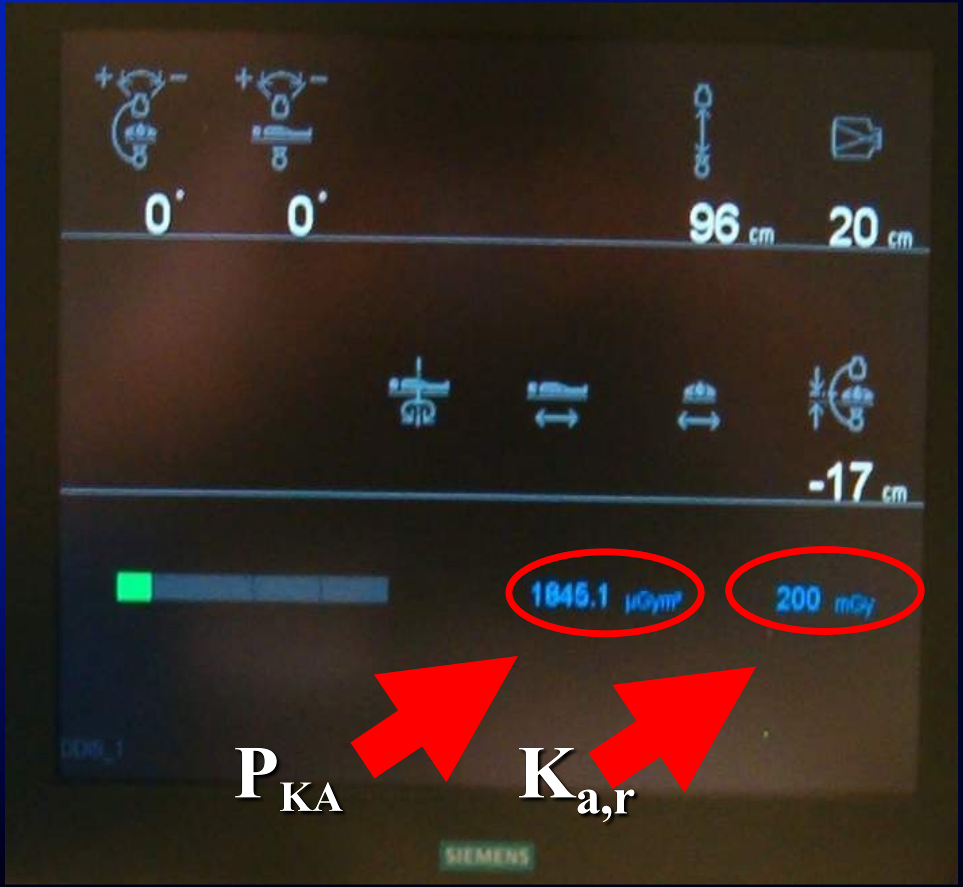


$K_{a,r}$ approximates $K_{a,e}$ for adult patients undergoing cardiac interventions, but overestimates it for patients in cerebrovascular interventions.

IEC 60601-2-43, 2000 & NCRP 168, 2010

Room Monitor Display (Siemens System)

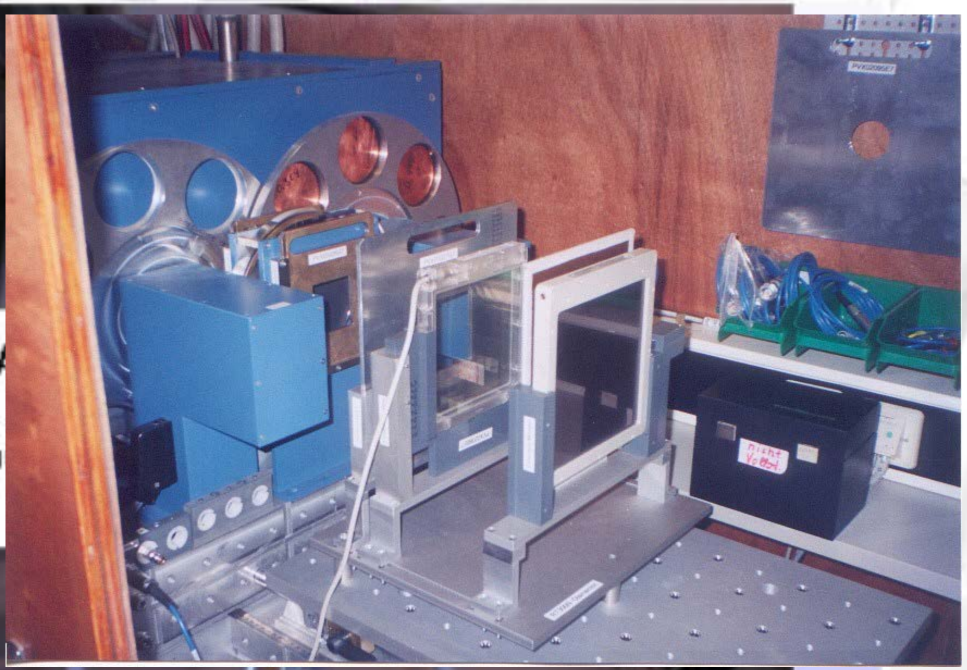




Radiation Measurements
In air
In/On Phantom
On Patient

Radiation Instrumentation
Ion Chamber
Film: Silver Halide and Radiochromic
Diodes
TLD, OSL

DIRECT



Determination of P_{KA}

INDIRECT

X Ray tube output
Imaging parameters

$K_{a,i}$

Rad area

P_{KA}

Manufacturer’s calibration: <10% uncertainty

HJ Khoury, 2009

IAEA NAHU No. 24

DOSIMETRY IN DIAGNOSTIC RADIOLOGY FOR PAEDIATRIC PATIENTS

2013

TABLE 3. UNCERTAINTIES FOR FLUOROSCOPY MEASUREMENTS

	Scenario 1	Scenario 2	Scenario 3
Description of scenario Uncertainty ($k = 2$) in dosimetric quantity due to:	Determination of entrance surface air kerma rate $\dot{K}_e$ using a phantom, applying air density and beam quality correction	Determination of entrance surface air kerma rate $\dot{K}_e$ using a phantom, no manual corrections applied	Measurement of P_{KA} during patient fluoroscopy, P_{KA} chamber calibrated in situ
Intrinsic error of dosimeter	3.2%	3.2%	>3.2%
Calibration coefficient N_{K,Q_0}	1.6%	1.6%	1.6%
Long term stability of dosimeter reading	1%	1%	1%
Difference in beam qualities between calibration and clinical use	3%	6%	>20%
Field size/field inhomogeneity	2%	2%	5%
Distance measurements and correction	4%	4%	—
Scatter radiation	3%	3%	—
Kerma rate[a]	5%	5%	5% or greater
In situ calibration of P_{KA} chamber	N/A	N/A	7.5%
Difference in table attenuation compared to in situ calibration point due to varying beam hardness (under couch systems)	N/A	N/A	15%
Air density correction:	0.2%	2%	2%
Pressure	0.5%	2%	5%
Temperature			
Electromagnetic compatibility and humidity; other uncertainties estimated <1% each	2%	2%	2%
Backscatter factors	5%	5%	N/A
Combined expanded (2σ) uncertainty in K_e or P_{KA}	10%	12%	24%

[a] Instruments should be checked for the range of dose rates over which their calibration is valid, and an appropriate uncertainty determined.

Tolerances

- FDA(2009)
  - $K_{a,r}$ shall not deviate > ± 35% for > 100 mGy
- IEC(2000)
  - $K_{a,r}$ shall not deviate > ± 50% for > 100 mGy
  - P_{KA} shall not deviate > ± 50% for > 2.5 Gy-cm^2
- IEC(2010)
  - $K_{a,r}$ shall not deviate > ± 35% for > 100 mGy
  - P_{KA} shall not deviate > ± 35% for > 2.5 Gy-cm^2

B. Schueler, 2010

Protection Dosimetry – Interventional Radiology

- **Stochastic Effects**
  - **P_{KA}**

Diagnostic Reference Levels in terms of P_{KA}

- **Deterministic Effects**
  - **Maximum (Peak) Organ Dose**
    - **Skin**
    - **Eye Lens**

Patient Follow-up

Peak Skin Dose: 3 Gy (ICRP, NCRP), **15 Gy** (U.S. TJC)

Cumulative Air Kerma: 5 Gy; P_{KA}: 500 Gy cm^2; Fluoroscopy Time: 60 min (NCRP)

Threshold doses for approximately 1% morbidity incidence

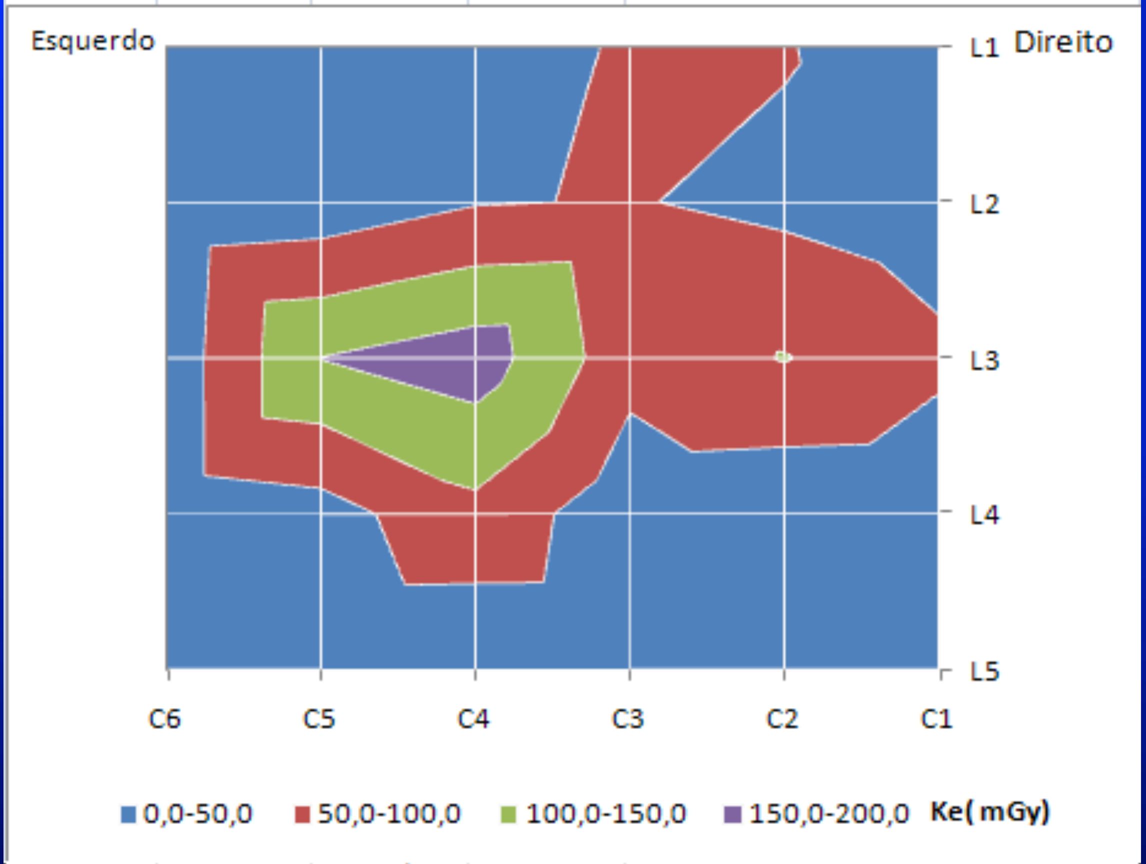
ICRP 118 , 2012

Effect	Organ/tissue	Time to develop effect	Acute exposure (Gy)	Highly fractionated (2 Gy per fraction) or equivalent protracted exposures (Gy)	Annual (chronic) dose rate for many years (Gy y^{-1})
Main phase of skin reddening	Skin (large areas)	1-4 weeks	<3-6	30	NA
Skin burns	Skin (large areas)	2-3 weeks	5-10	35	NA
Temporary hair loss	Skin	2-3 weeks	~4	NA	NA
Late atrophy	Skin (large areas)	> 1 year	10	40	NA
Telangiectasia @ 5 years	Skin (large areas)	> 1 year	10	40	NA
Cataract (visual impairment)	Eye	>20 years	~0.5	~0.5	~0.5 divided by years duration

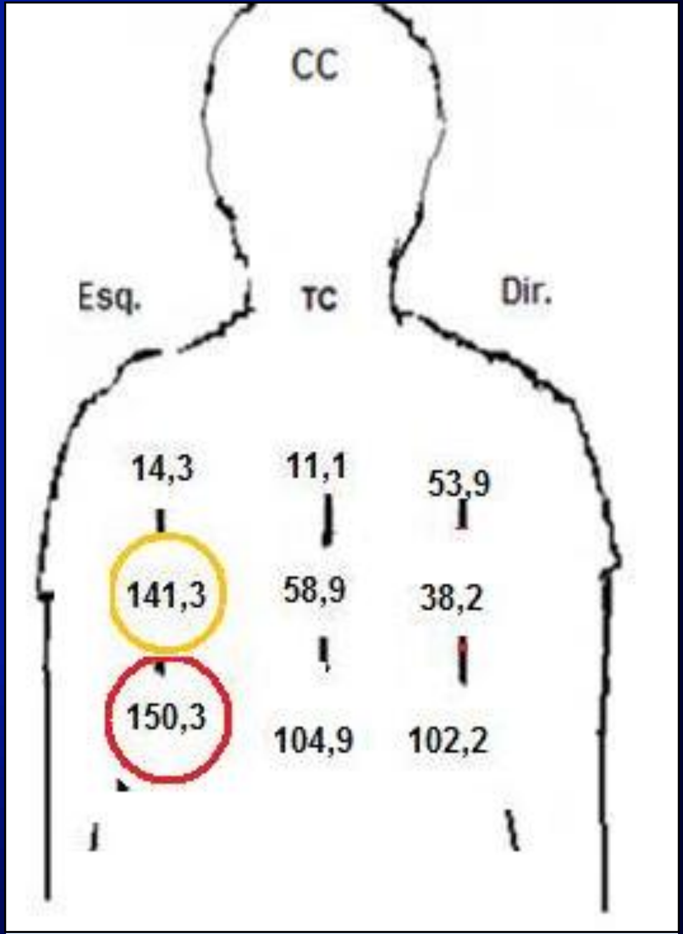
Organ Dose Determination

- Direct Radiation Measurements
- Table Look Up
- Calculations from Fluoro System Dose Metrics
  - and/or 'Dose Report'
- Monte Carlo Simulations using Patient and Radiation Transport Modeling
- DICOM information
  - DICOM Header
  - DICOM Services
    - e.g. modality performed procedure step (MPPS)
  - Radiation Dose Structured Report (RDSR)
  - Patient-RDSR (P-RDSR)

Skin Dose Measurements - TLD



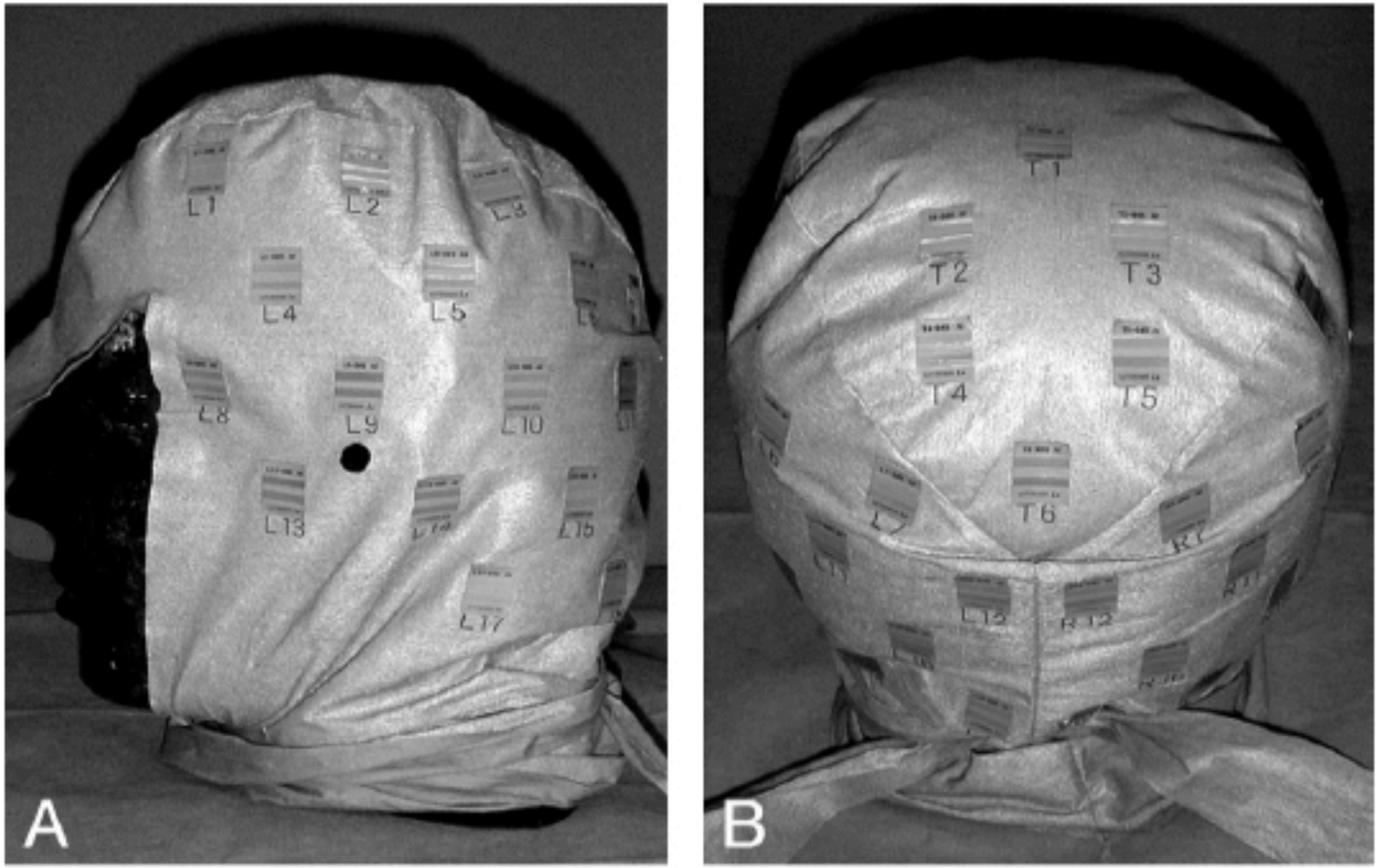
Matrix of TLDs placed on a sheet under a patient undergoing a cardiac interventional procedure



TLDs placed directly on a patient's back

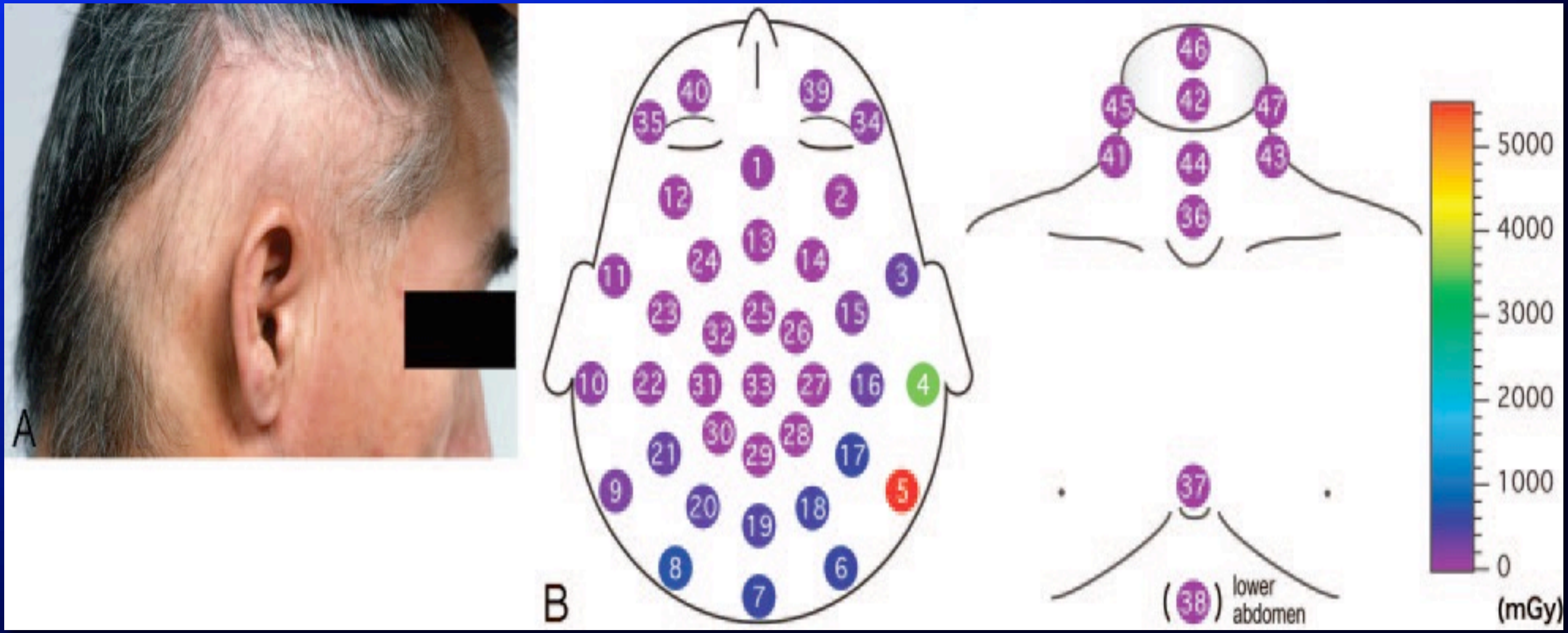
Silva et al., 2009

Placement of Radiosensitive Indicators
Skin Dose Assessment - Neuroembolization



Suzuki AJNR 29 Jun-Jul 2008

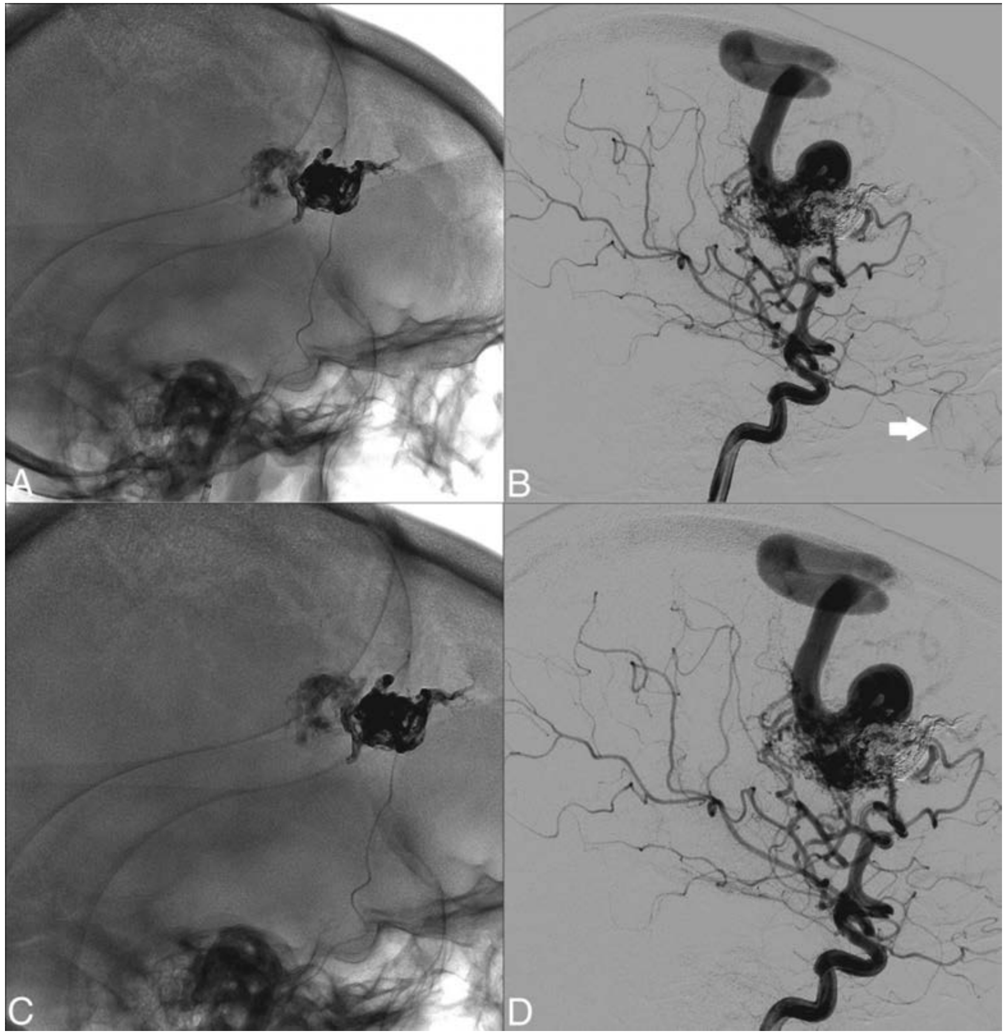
Matrix of Photoluminiscent Dosimeters



Cerebral embolization

Moritake et al, 2008

A and B, Nonoptimal lateral projection without and with subtraction where the left eye is irradiated.



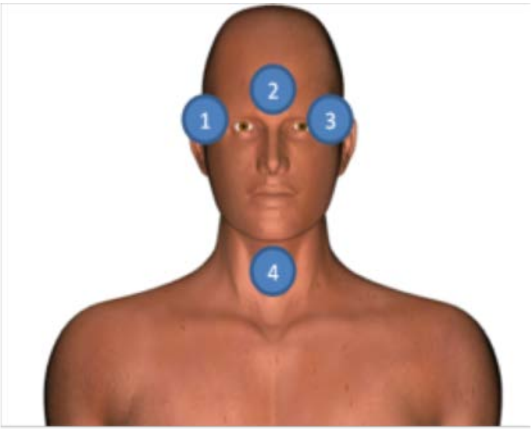
R.M. Sánchez et al. AJNR Am J Neuroradiol 2016;37:402-407

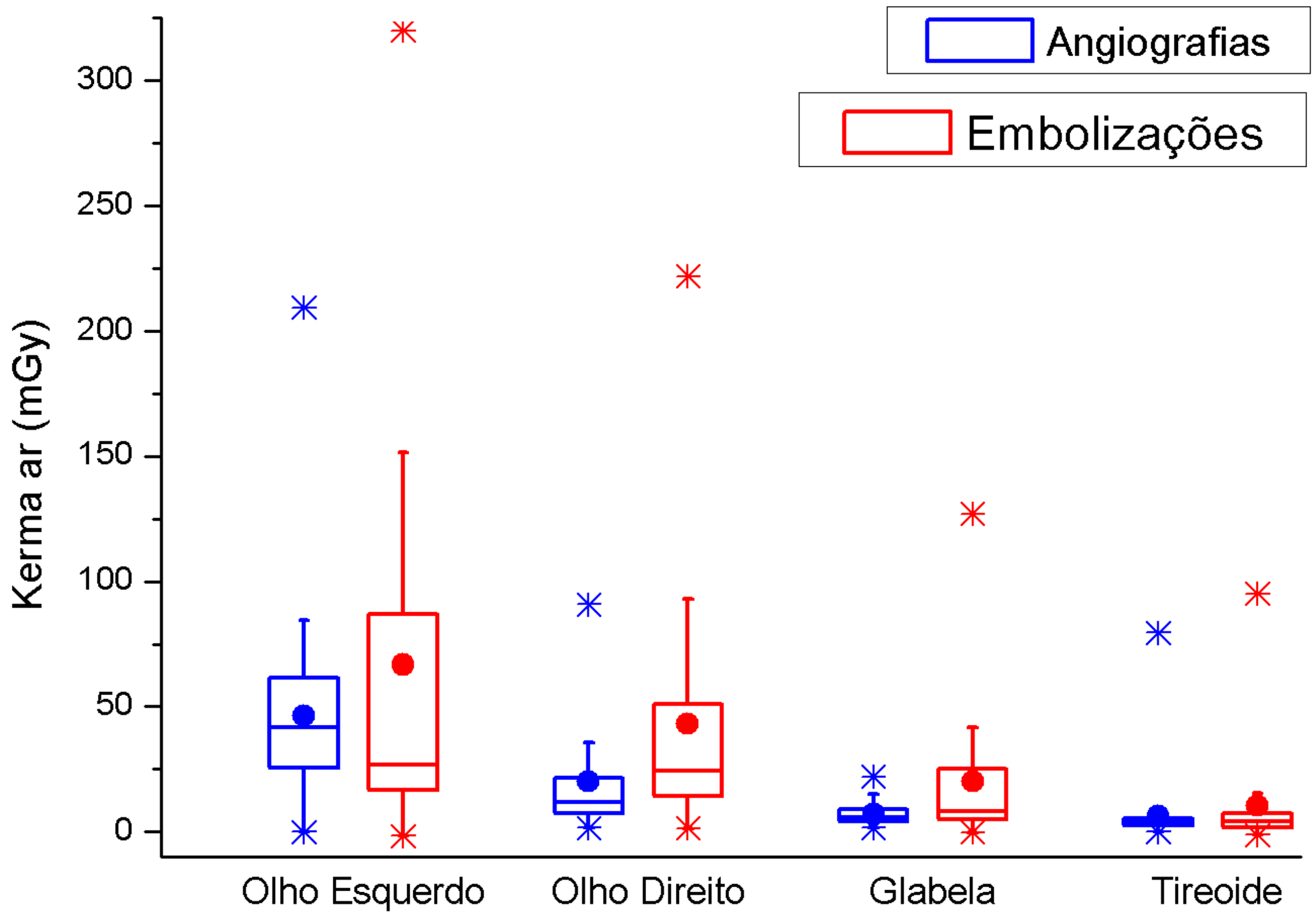
AJNR AMERICAN JOURNAL OF NEURORADIOLOGY

Position of the OSL dosimeters on patient eyes.

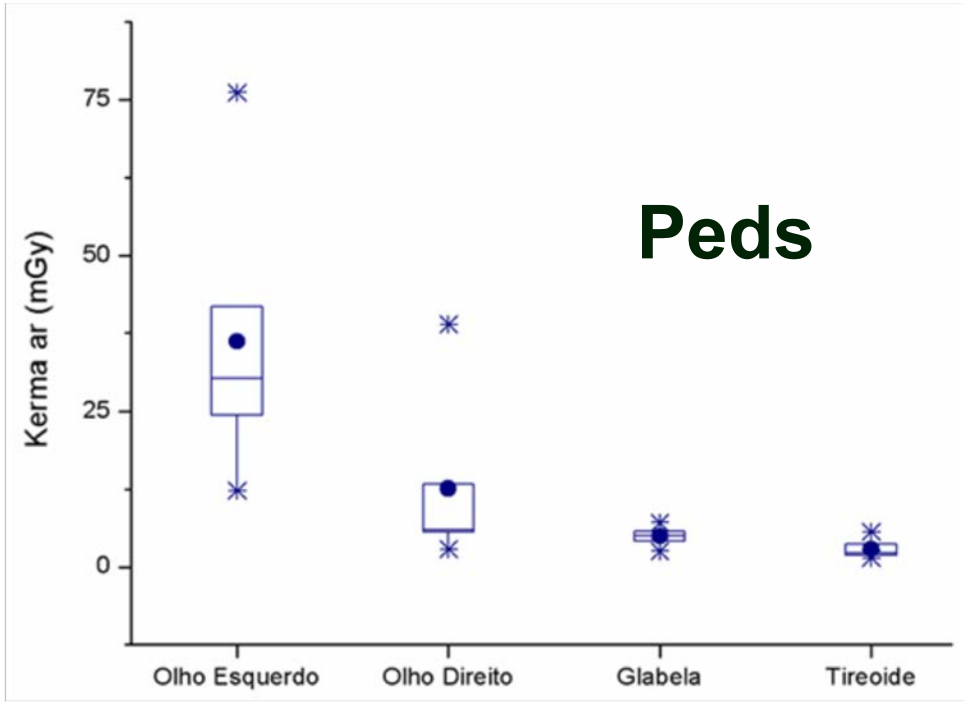
R.M. Sánchez et al. AJNR Am J Neuroradiol 2016;37:402-407

TLDs nos órgãos





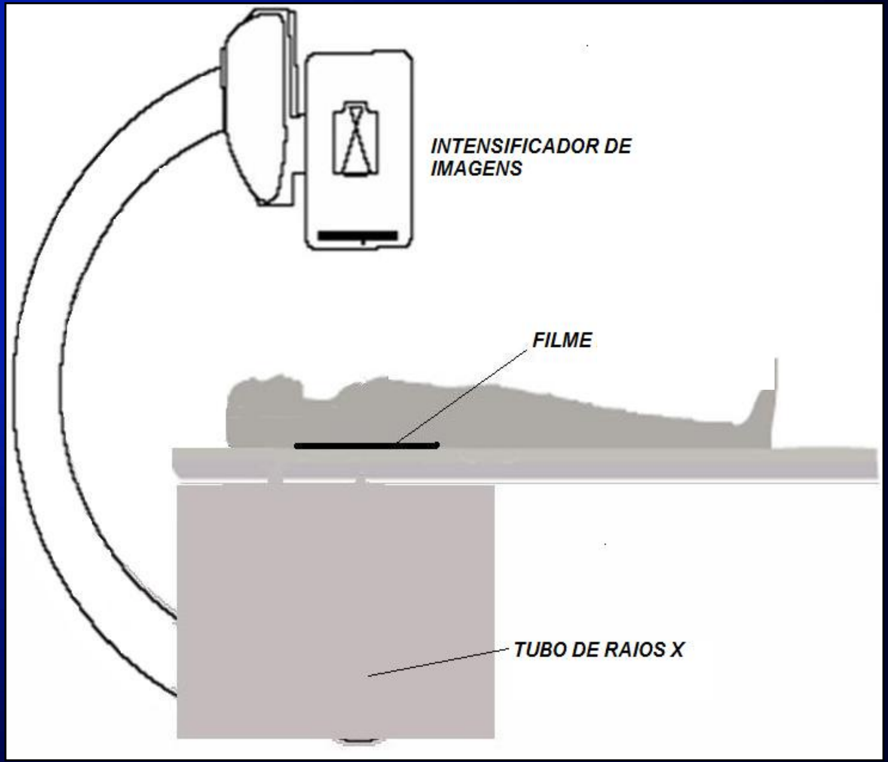
Adultos



Peds

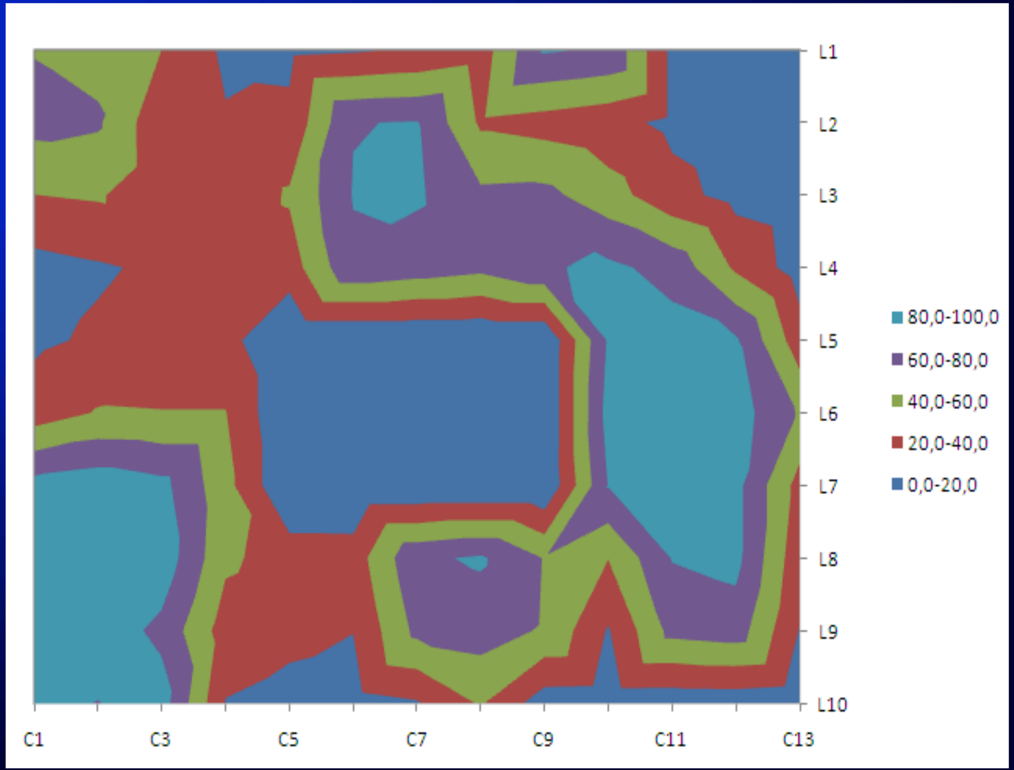
N. Lunelli, 2012

In Interventional Exams, Maximum Skin Dose and P_{KA} can be Determined with Film: Silver Halide and Radiochromic



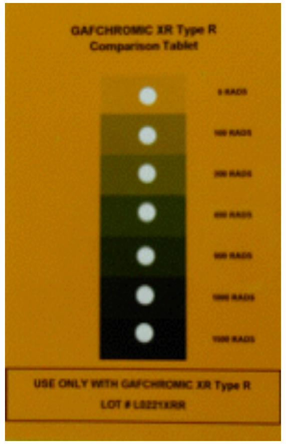
Film Position (Cardio)

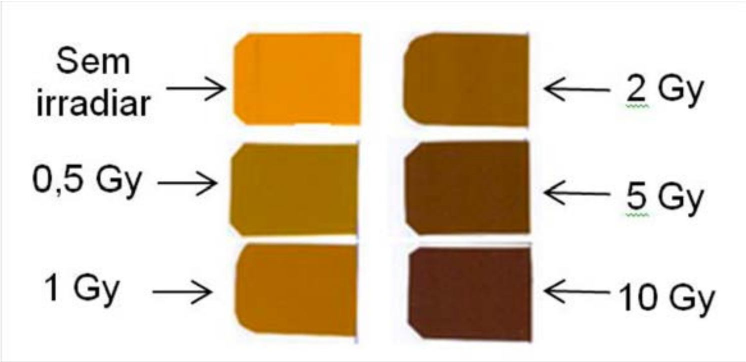
Measurements with Silver Halide Film



Silva et al., 2009

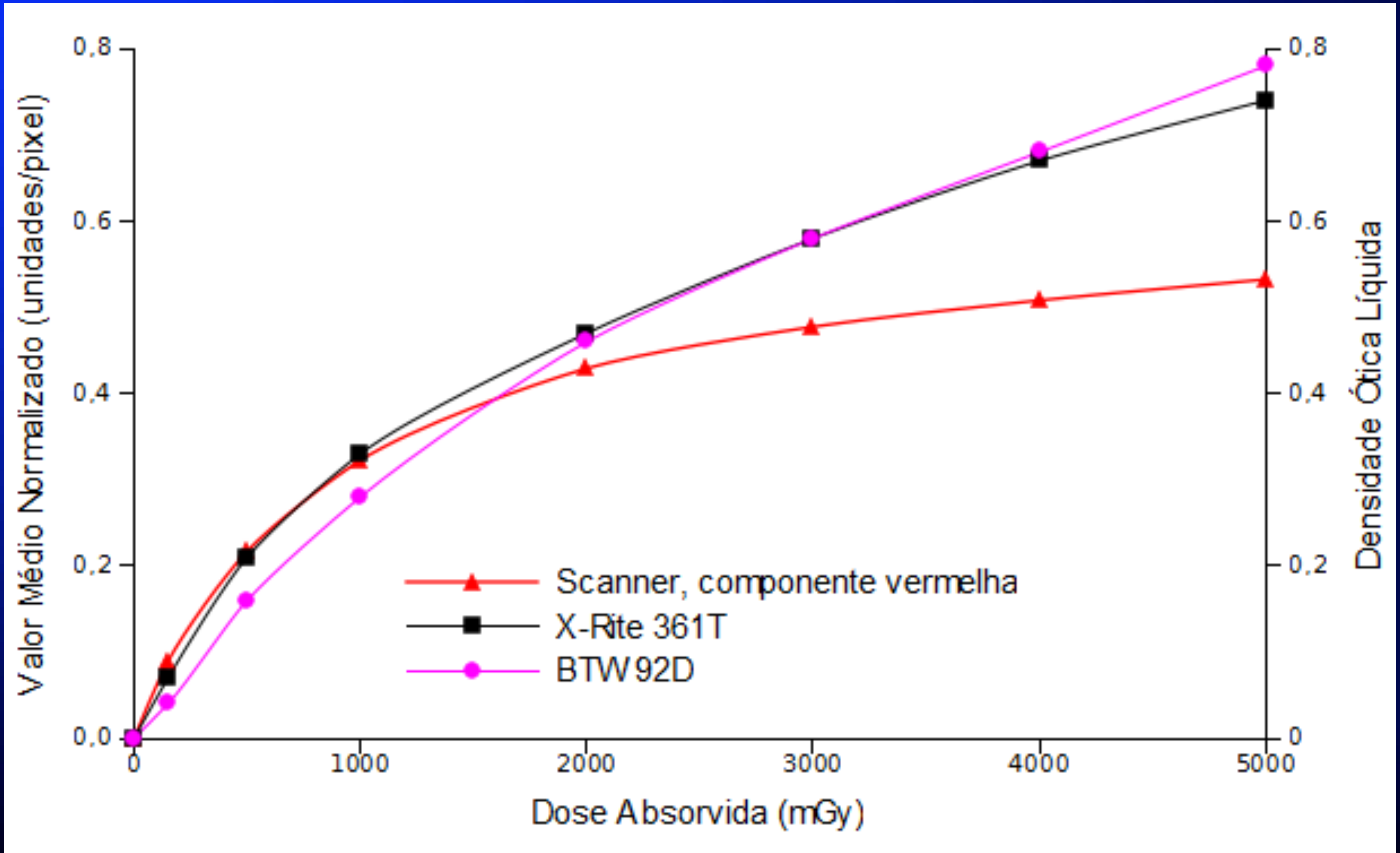
Filmes Radiocrômicos (Neuro)





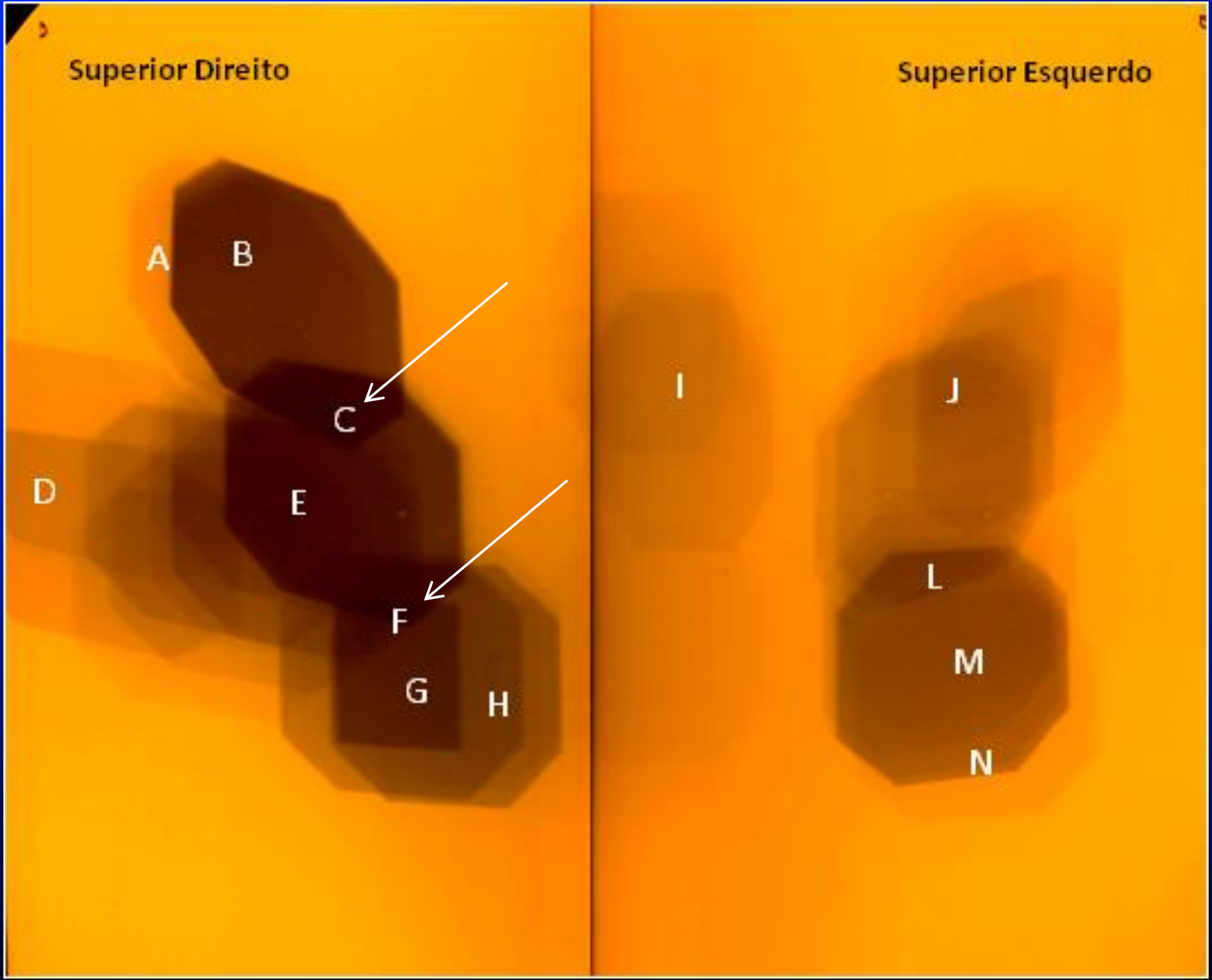
N. Lunelli, 2012

Curvas de Calibração com scanner e densitômetros



Silva et al., 2009

Coronary Angioplasty Results



Silva et al., 2009

Loc	Dose (Gy)
A	0,43
B	2,27
C	3,92
D	0,57
E	3,56
F	3,97
G	2,28
H	1,39
I	0,41
J	0,9
L	1,39
M	1,22
N	0,28

Neuroradiology Interventions - Results

Malformação Vascular – Posterior | Malformação Vascular – Posterior | Aneurisma – Lado esquerdo

N. Lunelli, 2012

Skin Dose (D_T) Calculations

$$K_{a,e} = K_{a,r}\, f_{table}\, (SRD/SSD)^2\, BSF$$

$$D_T = K_{a,e} \left(\frac{\mu_{en,T}}{\rho} \Big/ \frac{\mu_{en,a}}{\rho} \right) \simeq K_{a,e}\, 1.06$$

$K_{a,e}$: Entrance surface Air Kerma

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

f_{table}: Table and pad attenuation factor

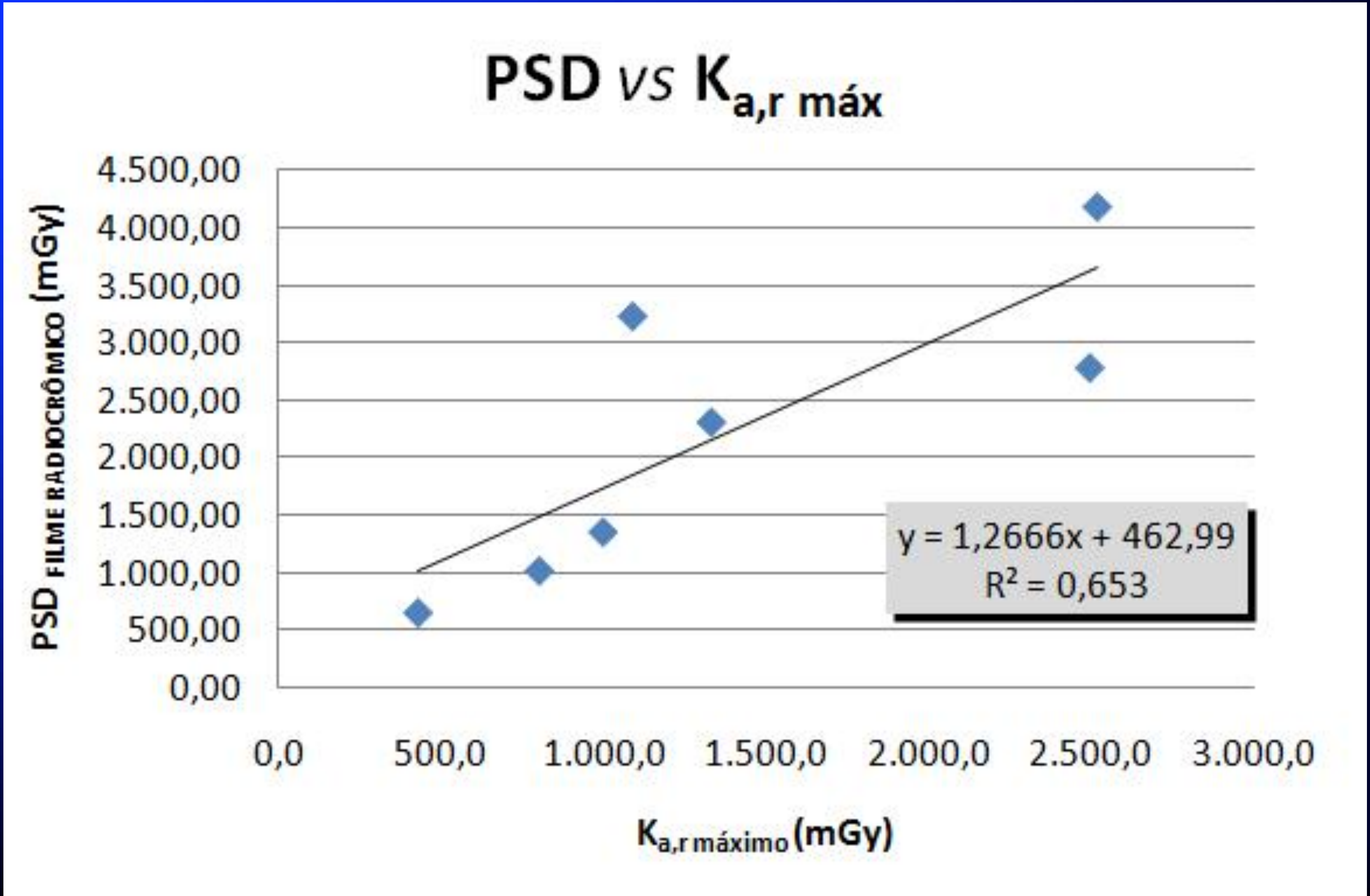
SRD: Source-reference distance

SSD: Source-entrance surface distance

BSF: Back scatter factor

$\mu_{en,T}/\rho$: Skin mass energy absorption coefficient

$\mu_{en,a}/\rho$: Air mass energy absorption coefficient



Silva et al., 2009

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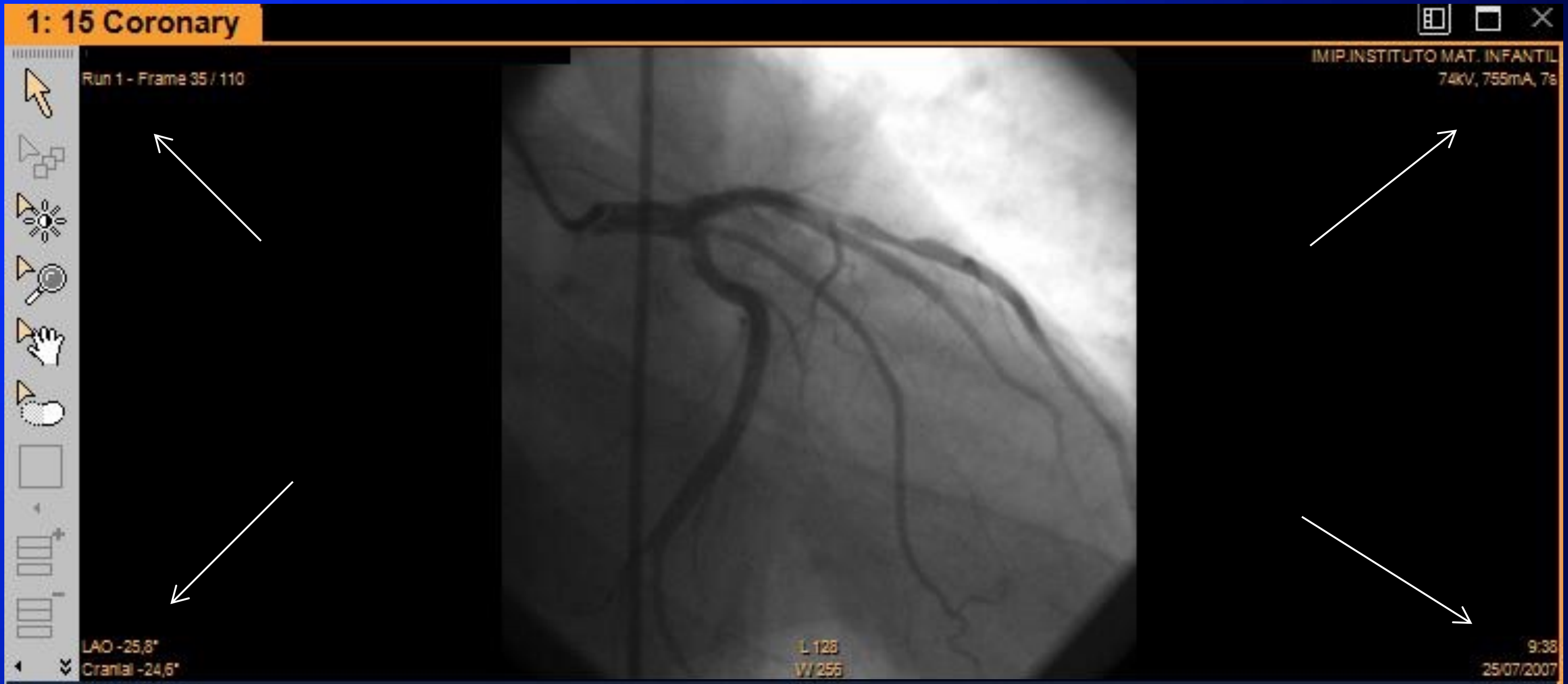


DICOM Information

Tag	Attribute Name	Attribute Value
(0010,0020)	Patient ID	2891
(0010,0030)	Date of Birth	15/09/1951
(0010,0040)	Patient Sex	M
(0018,0060)	kVP	74
(0018,1020)	Software Versions	7.7.1, 5.3.1, 3.3.2
(0018,1030)	Protocol Name	15 Coronary
(0018,1063)	Frame Time	66,666664
(0018,1066)	Frame Delay	0
(0018,1110)	Distance Source to Detector	1149
(0018,1150)	Exposure Time	7
(0018,1151)	X-ray Tube Current	755
(0018,1155)	Radiation Setting	GR
(0018,1162)	Intensifier Size	169,99998
(0018,1500)	Positioner Motion	STATIC

Silva et al., 2009

DICOM RDSR from Philips (rooms 3-4 San Carlos Hospital)

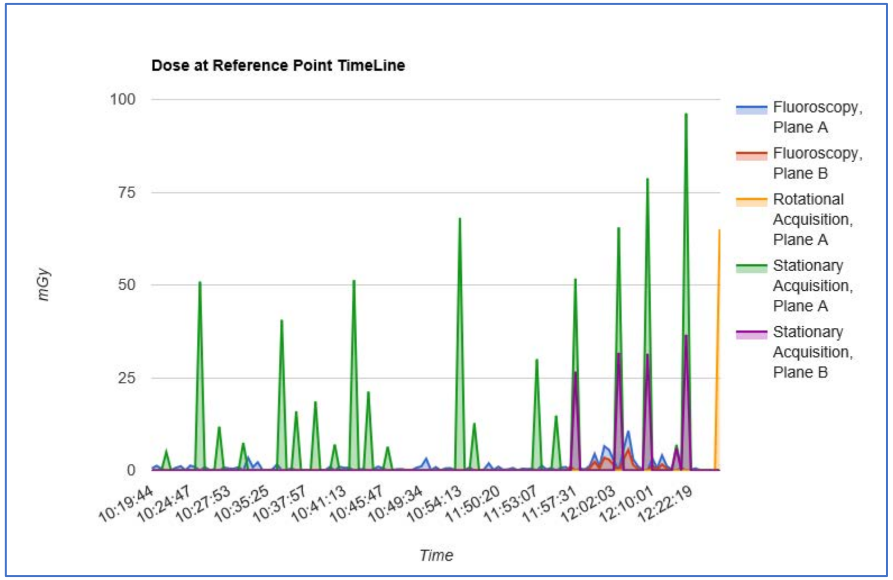
Radiation Dose Structured Report 67: pages, 30 runs of fluoro + 10 runs of cine; all technical, dose and geometry details included (part 3 Fluoro example)

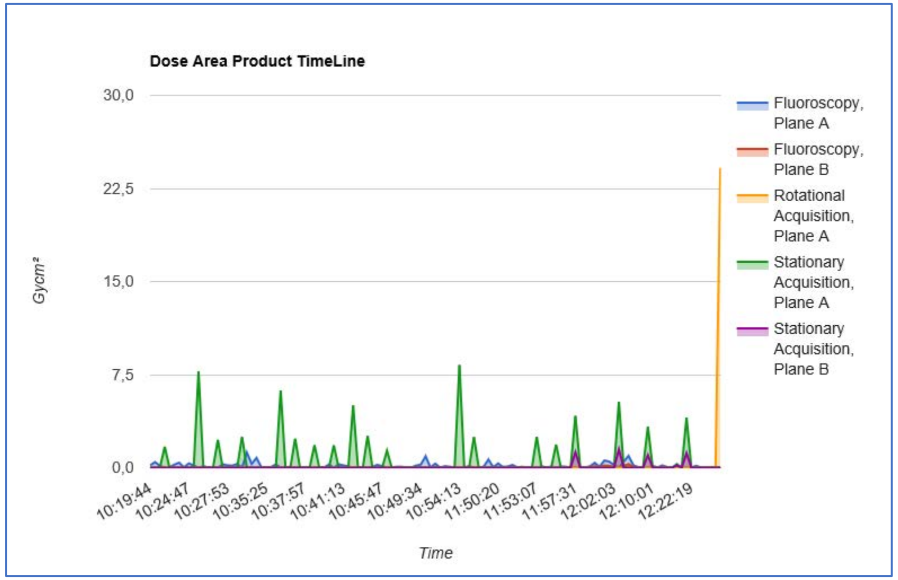
Irradiation Event X-Ray Data
Acquisition Plane : Single Plane
Date Time Started : 2013-08-12, 12:51:07.958
Irradiation Event Type : Fluoroscopy
Reference Point Definition : 15cm below BeamIsocenter
Irradiation Event UID :
1.3.46.670589.28.3711502481496.20130812125107317.1
Dose Area Product = 1.8E-06 Gy.m2
Dose (RP) = 0.00017185537709Gy
Positioner Primary Angle = 1.6 °
Positioner Secondary Angle = -0.1°
X-Ray Filters
X-Ray Filter Type : Strip filter
X-Ray Filter Material : Copper or Copper compound
X-Ray Filter Thickness Minimum = 0.9 mm
X-Ray Filter Thickness Maximum = 0.9 mm
X-Ray Filters
X-Ray Filter Type : Strip filter
X-Ray Filter Material : Aluminum or Aluminum compound
X-Ray Filter Thickness Minimum = 1 mm
X-Ray Filter Thickness Maximum = 1 mm

Fluoro Mode : Pulsed
Pulse Rate = 7.5 pulse/s
Number of Pulses = 11no units
X-Ray Tube Current = 120 mA
Distance Source to Isocenter = 765 mm
KVP = 97.97 kV
Pulse Width = 9.2 ms
Irradiation Duration = 1.466 s
Patient Table Relationship : headfirst
Patient Orientation : recumbent
Patient Orientation Modifier : supine
Target Region : Chest
Number of Frames = 11no units
SubImages per Frame = 1 no units
Wedges and Shutters
Bottom Shutter = 82.5mm
Left Shutter = 82.5mm
Right Shutter = 82.5mm
Top Shutter = 82.5mm
Beam Position
Longitudinal Beam Position = 1562mm
Beam Angle = 0 °
Table Height Position = 920 mm

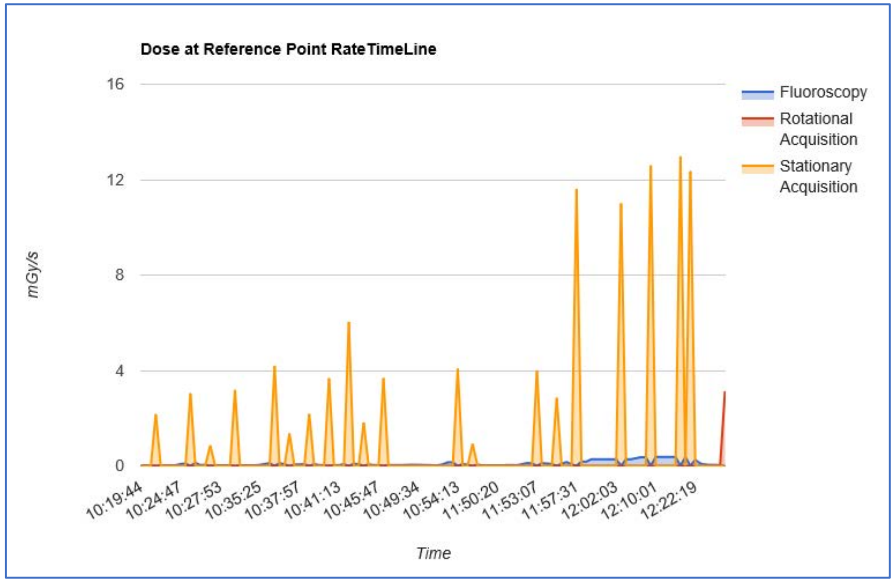
E. Vañó, 2018

Study level – summary of a procedure II





Sample of the graphical representation of DICOM RDSR data of a neuro-interventional study carried out in a bi-plane cath-lab, that allows to see the different fluoroscopy and acquisition modes used during the procedure.



J.M. Fernandez-Soto et al., 2016

DICOM RDSR

X Ray Data Irradiation Events

Date equals 23/12/2015. Time equals 10:42:26. Acc Number equals 14949329. Description equals Cardiaca. DAP (cGycm²) equals 419,14. RP Dose (mGy) equals 9.330,50.

Acquisition Protocol	Time	Irradiation Type	DAP (cGycm²)	RP Dose (mGy)	Primary Angle	Secondary Angle	kVp	Tube Current (mA)	Exposure Time (ms)	Isocenter (mm)	Fluoro Mode	Pulse Rate	Pulses	Pulse Width (ms)	Table Height (mm)	Irradiation Duration (s)	Frames	Images per Frame	Target Region
	12:17	Stationary Acquisition	1,14	31,02	30,5	-2,5	93	764,8	0	765		0,0	0	8,1	860	2,00	30	1	Chest
	12:17	Fluoroscopy	0,02	0,48	30,5	-2,5	120	120,0	0	765	Pulsed	7,5	8	10	860	1,07	8	1	Chest
	12:17	Stationary Acquisition	0,21	5,50	30,5	-2,5	86	833,0	0	765		0,0	0	7,6	860	0,40	6	1	Chest
	12:18	Fluoroscopy	0,12	2,76	30,5	-2,5	120	120,0	0	765	Pulsed	7,5	48	10	860	6,40	48	1	Chest
	12:18	Fluoroscopy	0,19	4,25	30,5	-2,5	120	120,0	0	765	Pulsed	7,5	80	10	860	10,67	80	1	Chest
	12:18	Fluoroscopy	0,01	0,20	30,5	-2,5	113	120,0	0	765	Pulsed	7,5	4	10	860	0,53	4	1	Chest
	12:18	Fluoroscopy	0,06	1,43	30,5	-2,5	112	120,0	0	765	Pulsed	7,5	31	10	860	4,13	31	1	Chest
	12:18	Stationary Acquisition	1,22	33,02	30,5	-2,5	84	853,2	0	765		0,0	0	7,4	860	2,47	37	1	Chest
	12:18	Fluoroscopy	0,05	1,27	30,5	-2,5	119	120,0	0	765	Pulsed	7,5	28	10	860	3,73	28	1	Chest

Standard dose report

Nº secuen. | Nº imágenes | | Tiempo hh:mm | Velocidad-ips | kV | mA mAs | ms | PDA [mGycm^2] | Ka [mGy] | Rotación | Angulación | DFI [cm] |

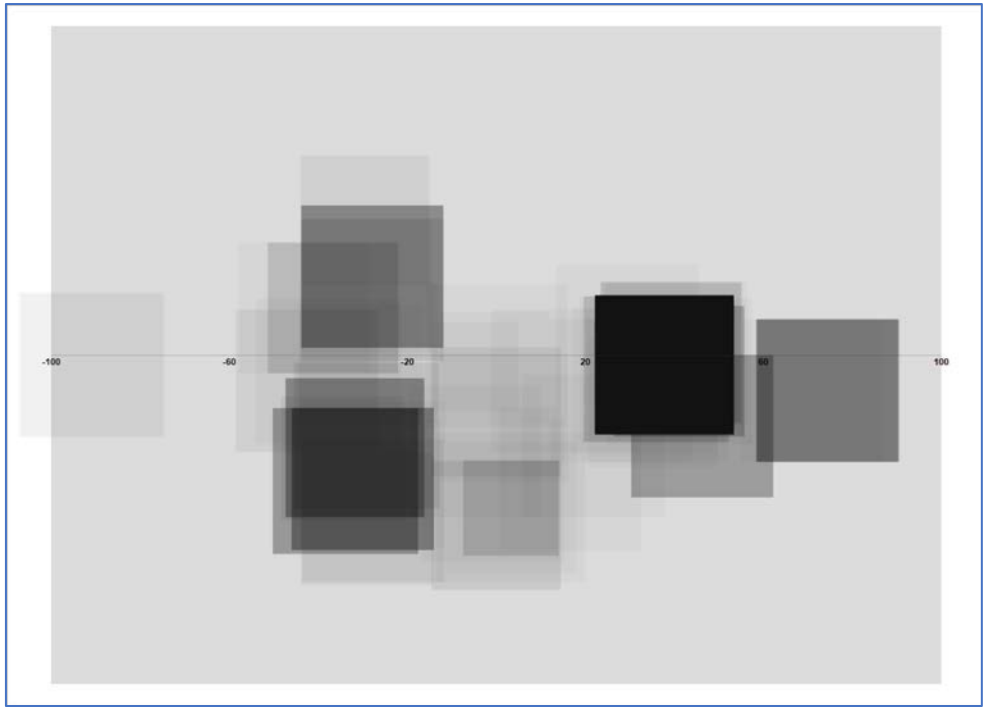
20 | 30 | Coronaria izda 15 ips | 12:17 | 15 | 93 | 2
OAI 31 | CRAN 3 | 107 |
21 | 6 | Coronaria izda 15 ips | 12:17 | 15 | 86 | 833 | 8 | 214 | 5.50
| OAI 31 | CRAN 3 | 107 |
22 | 4 | Fluoroscopia | 12:18 | 7.5 | 113 | 14 | | 9.0 | 0.20 |
OAI 31 | CRAN 3 | 107 |
23 | 37 | Coronaria izda 15 ips | 12:18 | 15 | 84 | 853 | 7 | 1216 | 33.02
| OAI 31 | CRAN 3 | 107 |

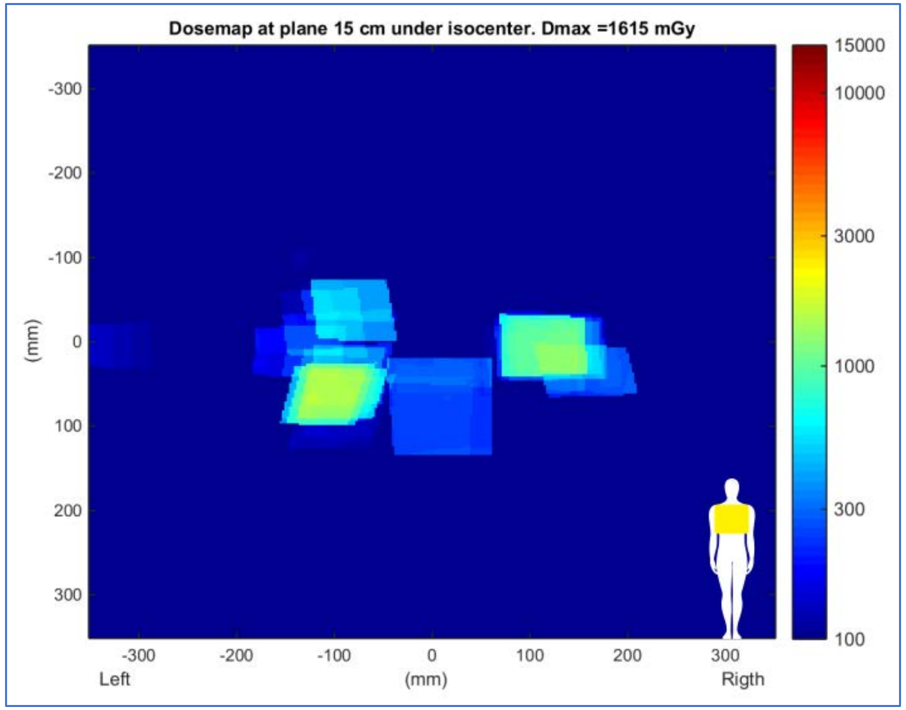
E. Vañó, 2018

Skin Dose Maps

(JM Fernandez-Soto et al., 2016)

Sample of a radiochromic film image placed at the patient back in an interventional cardiology procedure (right) and two types of dose maps obtained from the DICOM RDSR for the same procedure. This also allows the estimation of the maximum dose at the skin entrance.





Supplement 191 Patient Dose SR

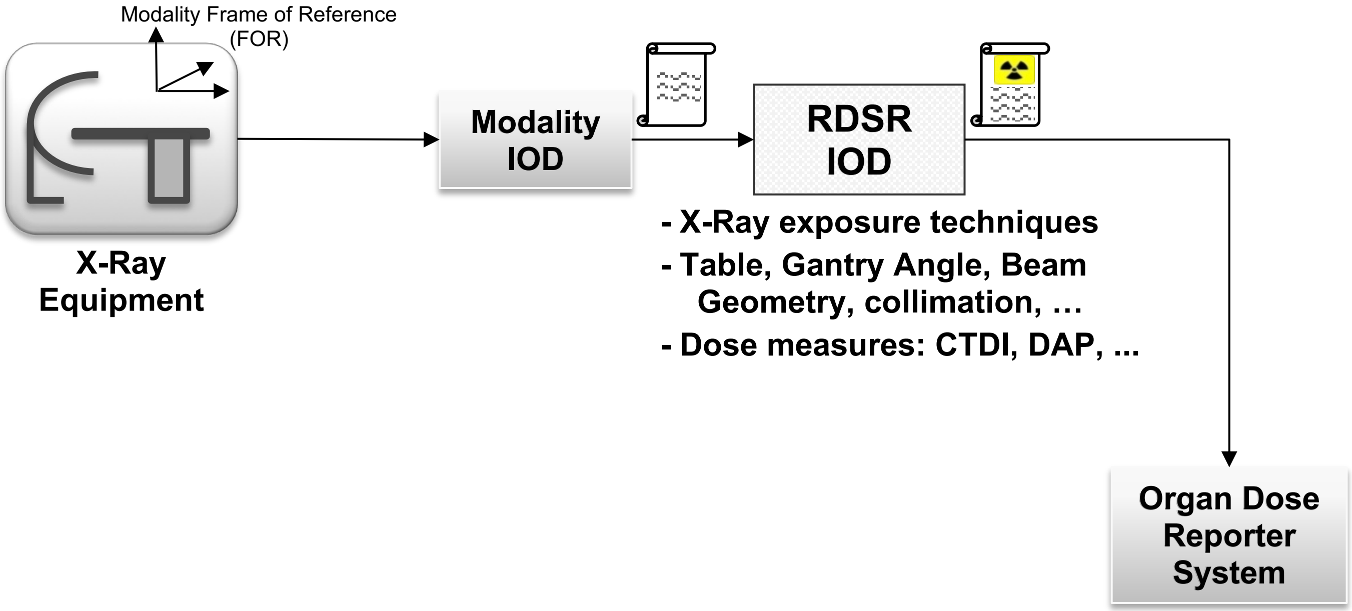
- Current Radiation Dose SR contains only information about the x-ray system or information the x-ray system can determine, e.g.:
  - radiation output, geometry, x-ray source, detector system, etc.

- Estimation of patient/organ dose requires knowledge of:
  - Radiation beam characteristics that interact with patient
  - Models of the patient/organs
  - Models of radiation interaction within the patient

- Methods to do patient dose estimations are being developed and improved continuously
  - storage of these estimations in a different object would allow more versatile utilization of the data

D. Pelc, 2016

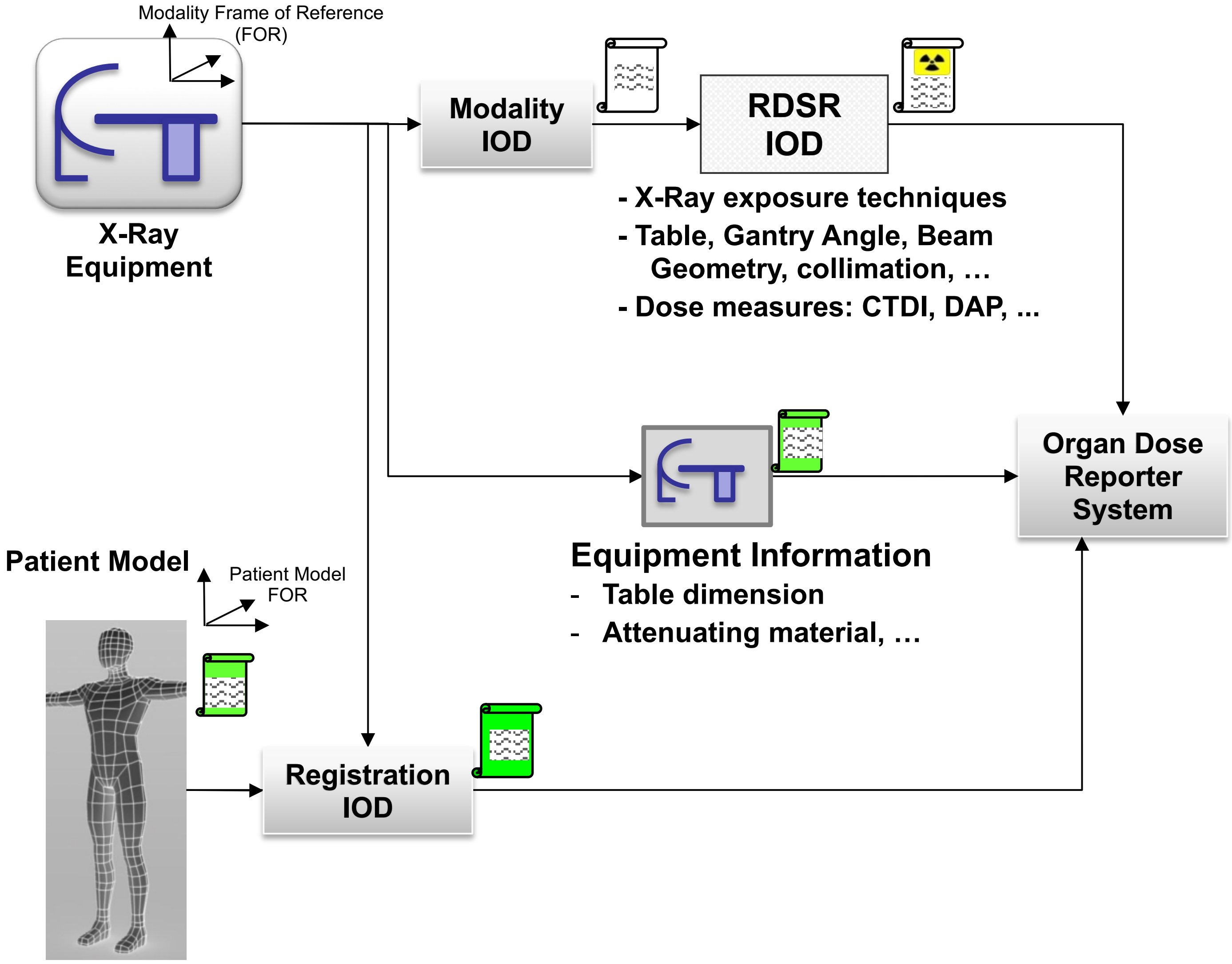
Patient Dose Determination: Data Flow Requirements



Signifies part of Supplement 191 Patient RDSR

D. Pelc, 2016

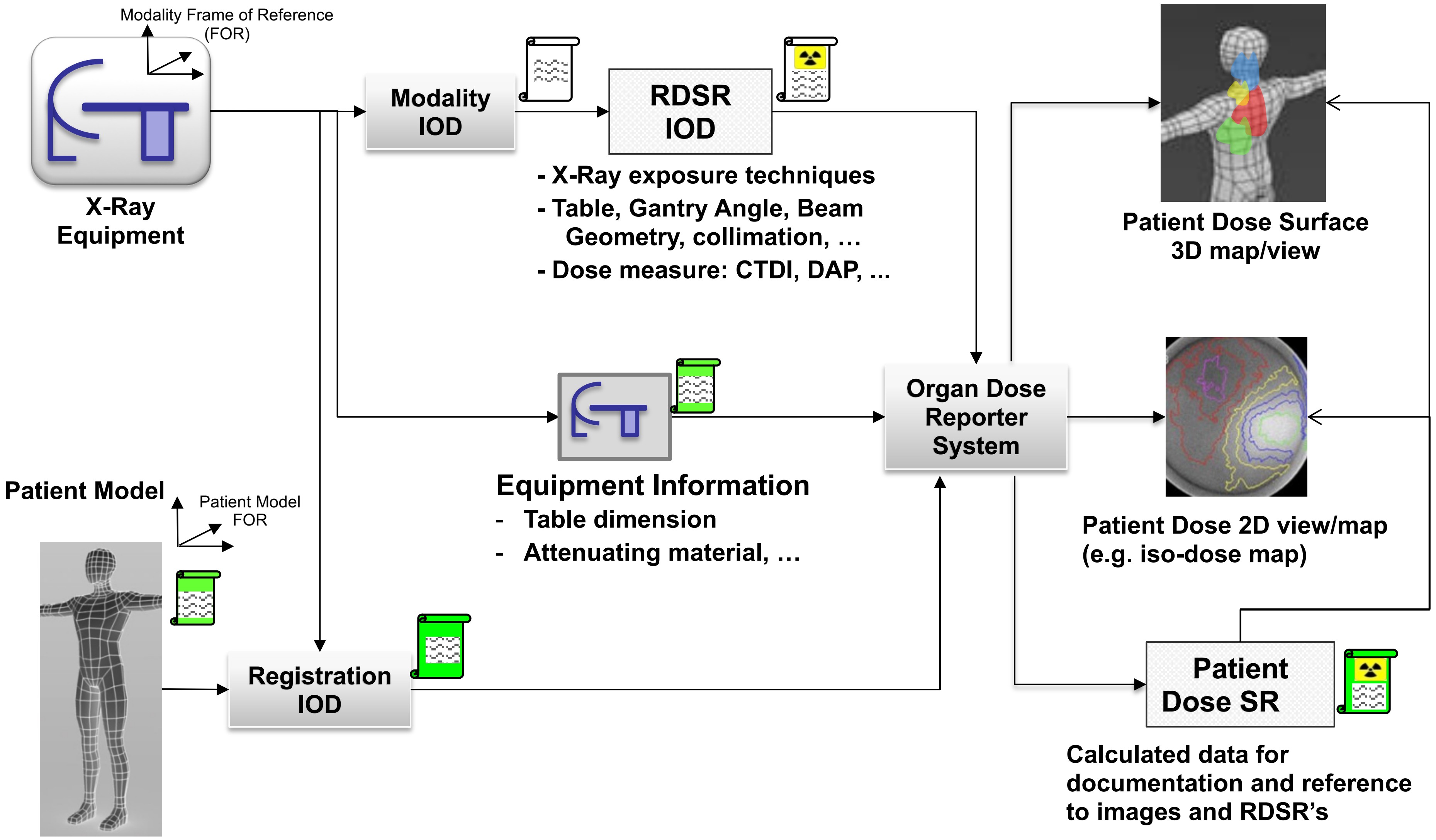
Patient Dose Determination: Data Flow Requirements



Signifies part of Supplement 191 Patient RDSR

D. Pelc, 2016

Patient Dose Determination: Data Flow Requirements



Signifies part of Supplement 191 Patient RDSR