Radiation Exposure and Risks to Patients and Staff During Selected Non-Cardiac Interventional Procedures: Pernambuco, Brazil Experiences

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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

Studies Performed in Recife- PE

Cerebral Angiography: 158 Adults
15 Children

Cerebral Embolization: 70 Adults

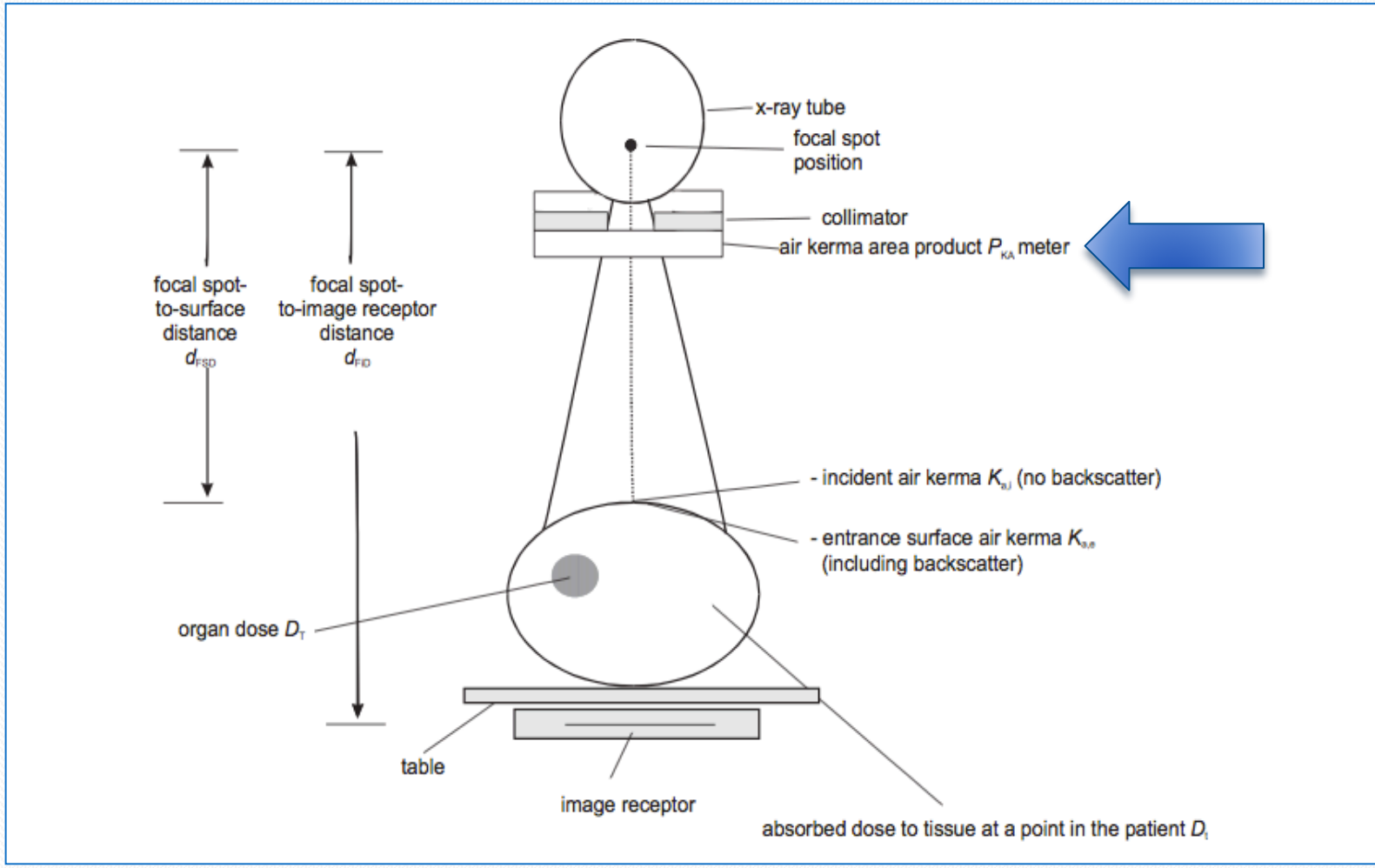
Hepatic Chemoembolization: 55 adults (3 hospitals)

Prostatic Artery Embolization: 5 adults

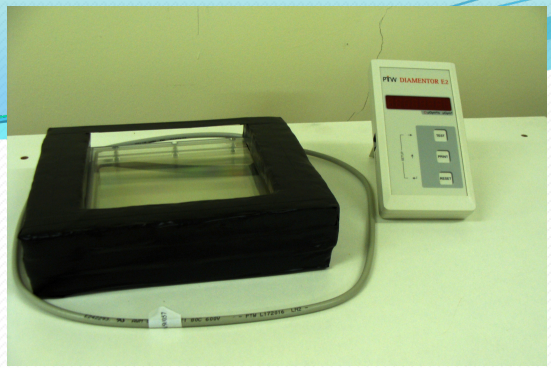
Dosimetric and Geometric Quantities for Determination of Patient Dose (ICRU 74, 2005)

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.

The accuracy of the display can be checked directly or indirectly

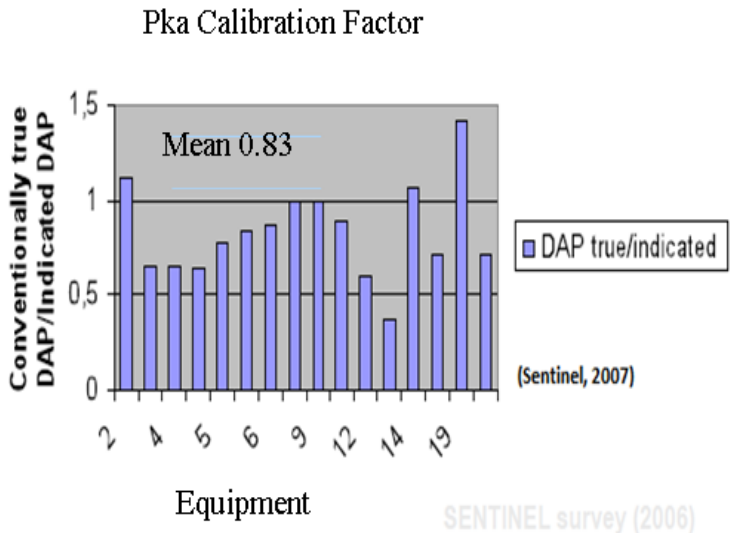


PKA (DAP) Display on control

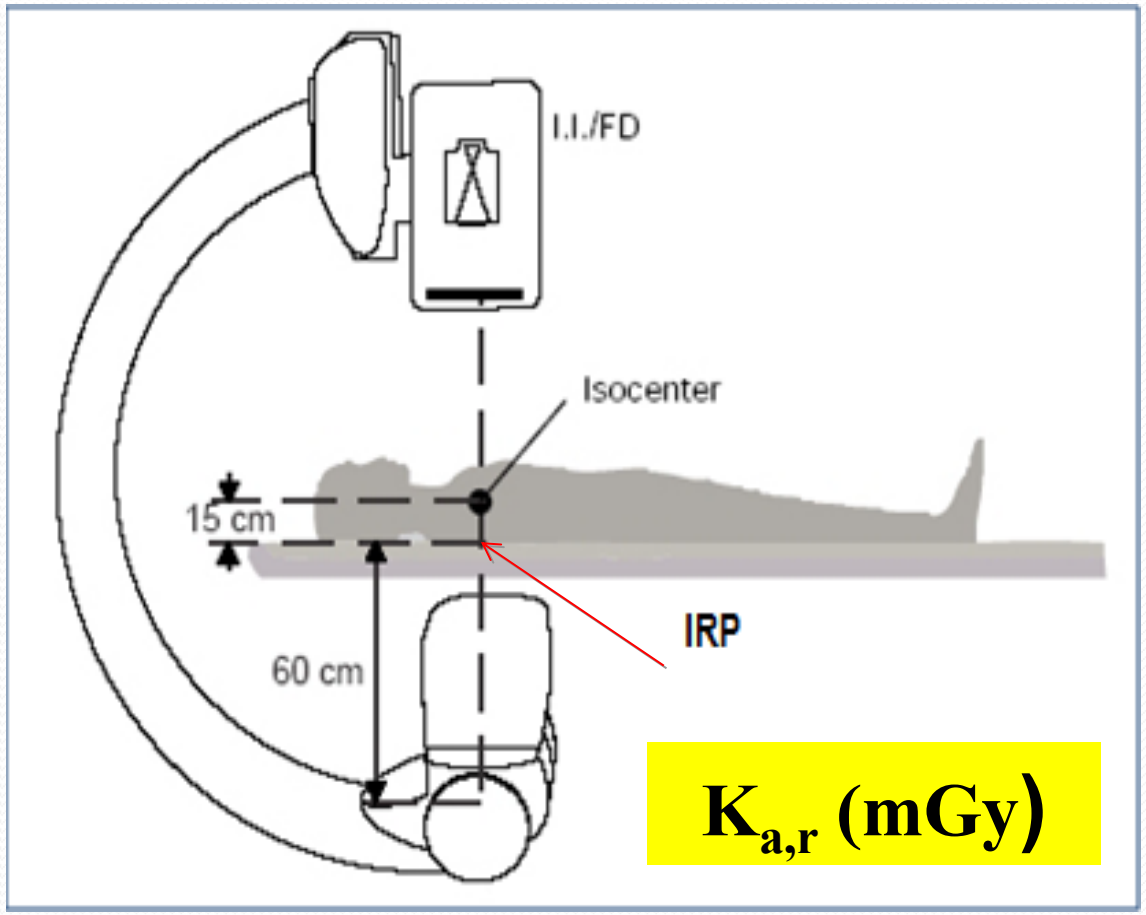


Calibration PKA chamber

$$P_{KA} = k_a * K_Q * F_{P,T} * A$$



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



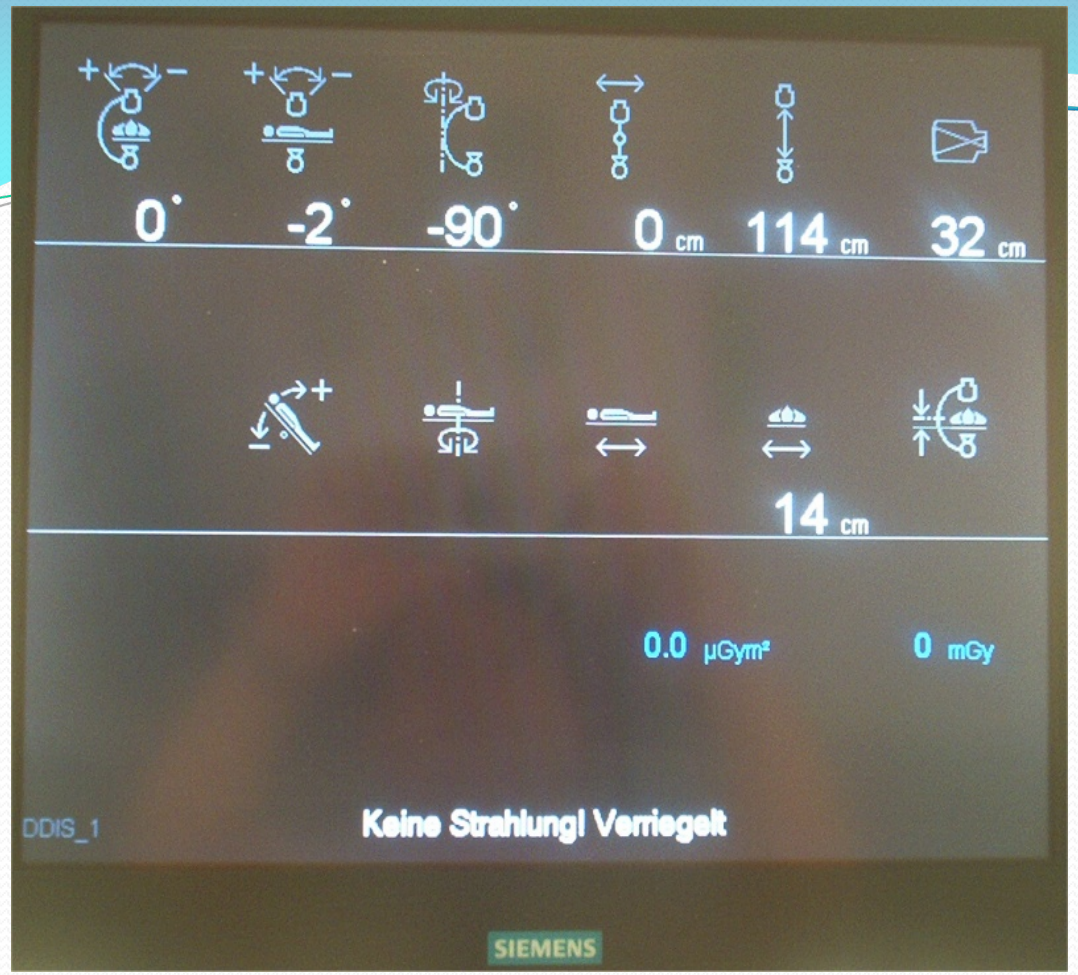
The accuracy of the $K_{a,r}$ display is checked with an ion chamber

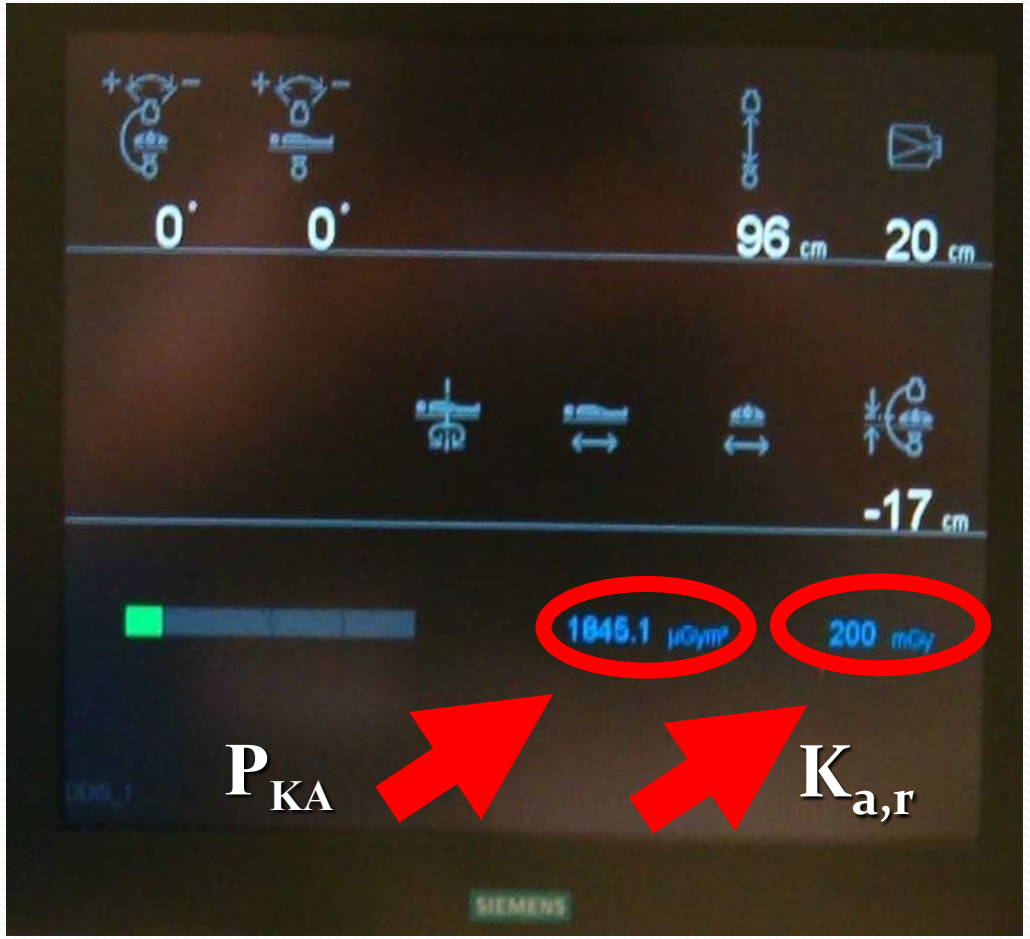
Tolerance ± 35 % for > 100 mGy

$K_{a,r}$ approximates $K_{a,e}$ for patients undergoing body interventions such as cardiac and hepatic procedures, but overestimates it for patients in cerebrovascular interventions.

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

Room Monitor Displays (Siemens System)





P_{KA} Tolerance ± 35 % for > 2.5 Gy cm²

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 cm²; Fluoroscopy Time: 60 min (NCRP)

Threshold doses for approximately 1% morbidity incidence

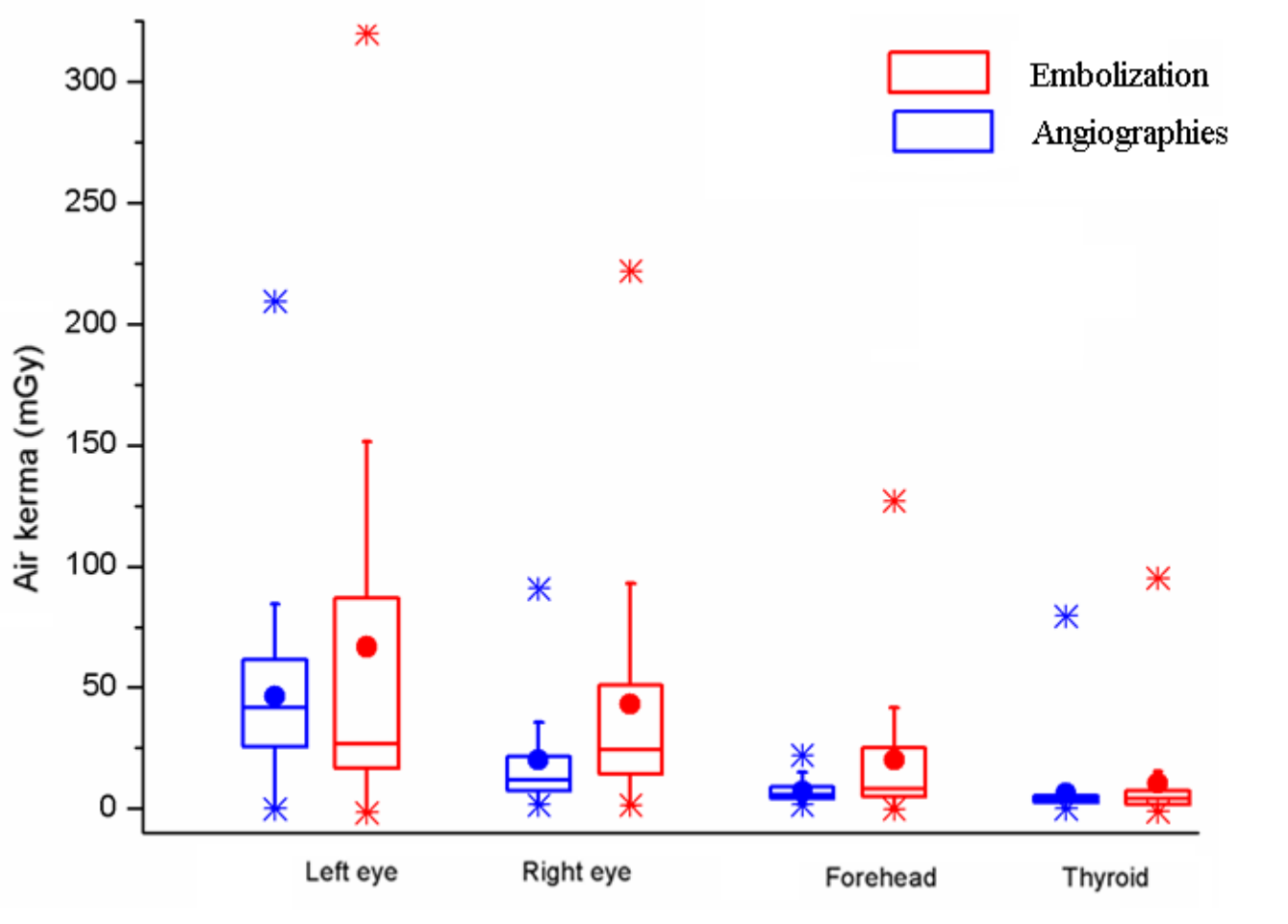
ICRP 118 , 2012

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

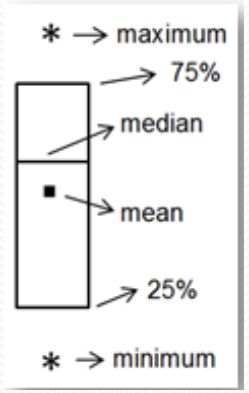
- PATIENT DOSIMETRY

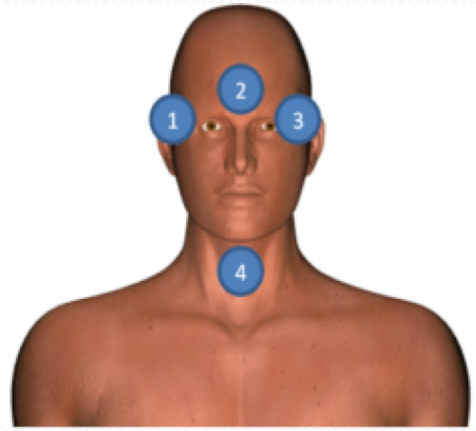
- P_{KA} and $K_{a,r}$: showed at equipment display
- Radiochromic film: dose distribution estimated on patient’ s skin
- TLD dosimetry in some body regions

Adult patient doses received during cerebral procedures performed in Recife

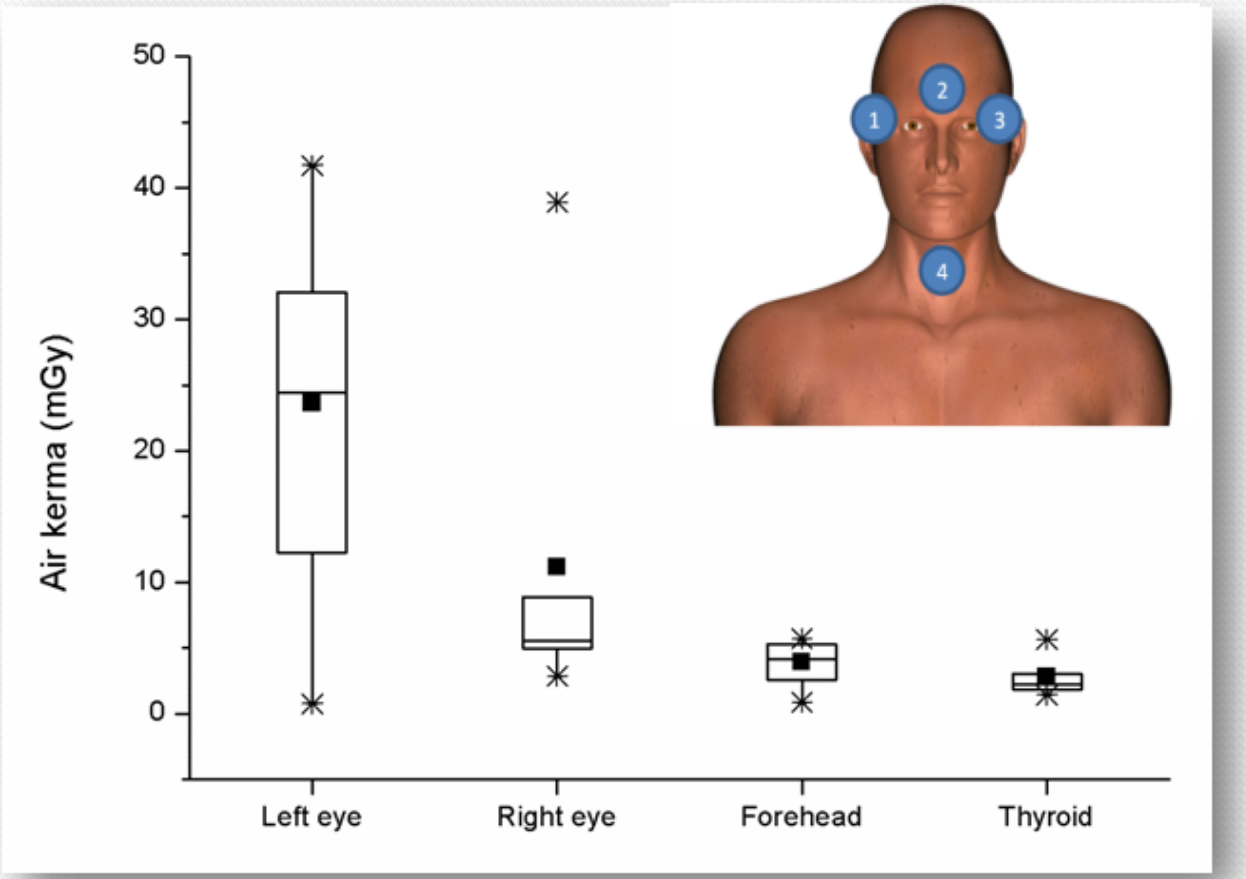


Dosimeters:
TLD-100



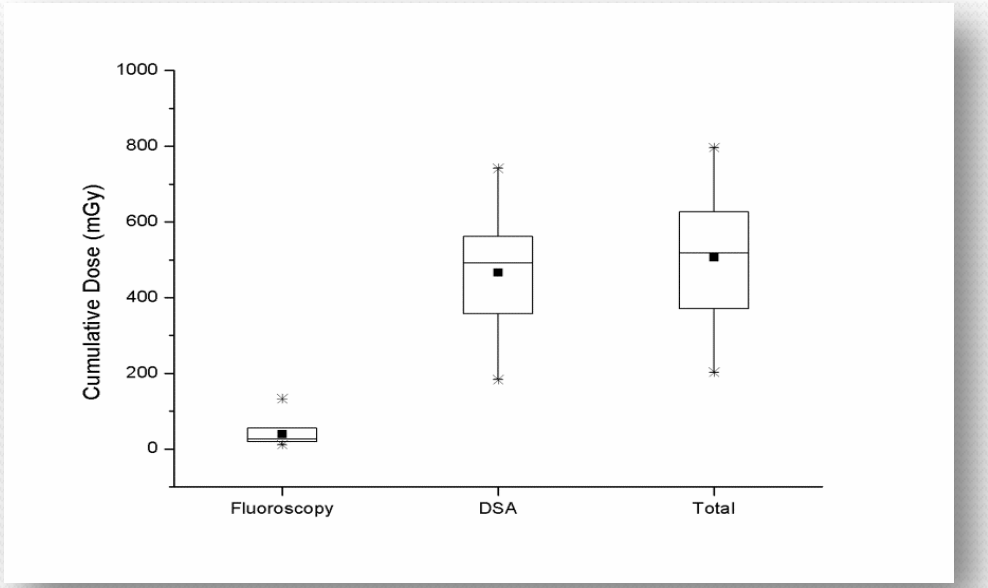


Paediatric patient doses received during cerebral procedures performed in Recife



Distribution of the skin air kerma in the region of left and right eyes, forehead and thyroid

- Patients: Data for 15 patients (7 female and 8 male), 3 to 15 years old.
- Procedures: 13 patients cerebral angiographies and 2 patients embolization neuroradiology procedure



Reference cumulative dose for fluoroscopy , DSA and total neuroangiographic procedure

P_{KA} and $K_{a,r}$ Values for Cerebral Angiographies

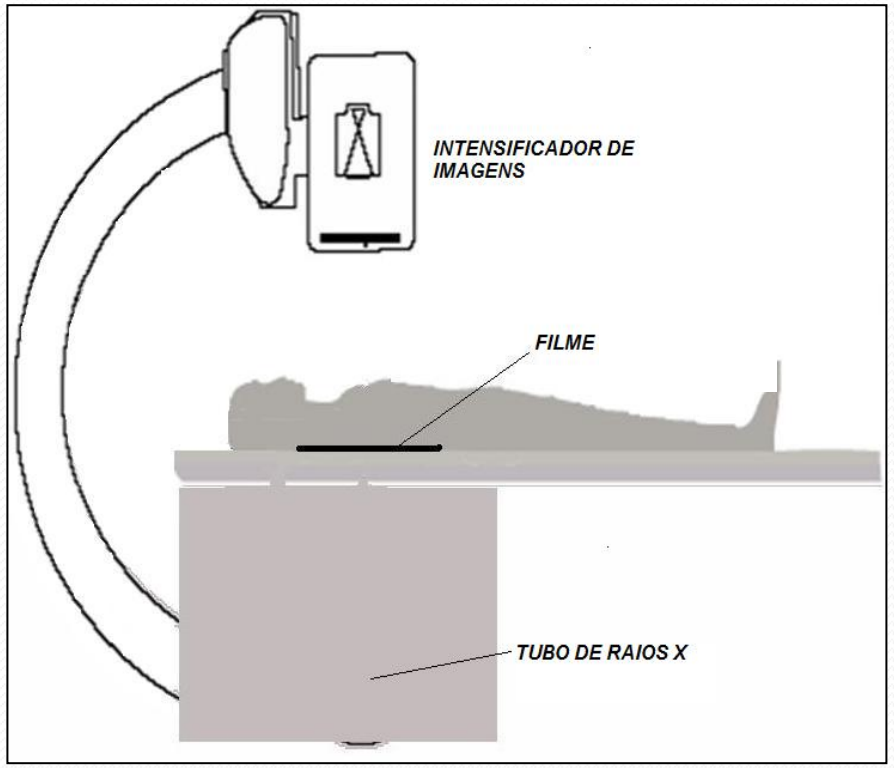
Pediatric Patient

		P_{KA} (Gy.cm²)			$K_{a,r}$ (mGy)		
		Min.	Mean	Max.	Min.	Mean	Max.
Mode of exposure	Fluoroscopy (n = 13)	1,3	**3,7**	7,5	12	**33**	56
	DSA (n = 11)	16,7	**46,5**	81,4	183	**455**	709
	DSA + 3D (n = 2)	69,9	**73,9**	77,9	562	**652**	741
complete procedure (n = 13)		18,8	**53,6**	88,3	203	**519**	796

Adult Patient

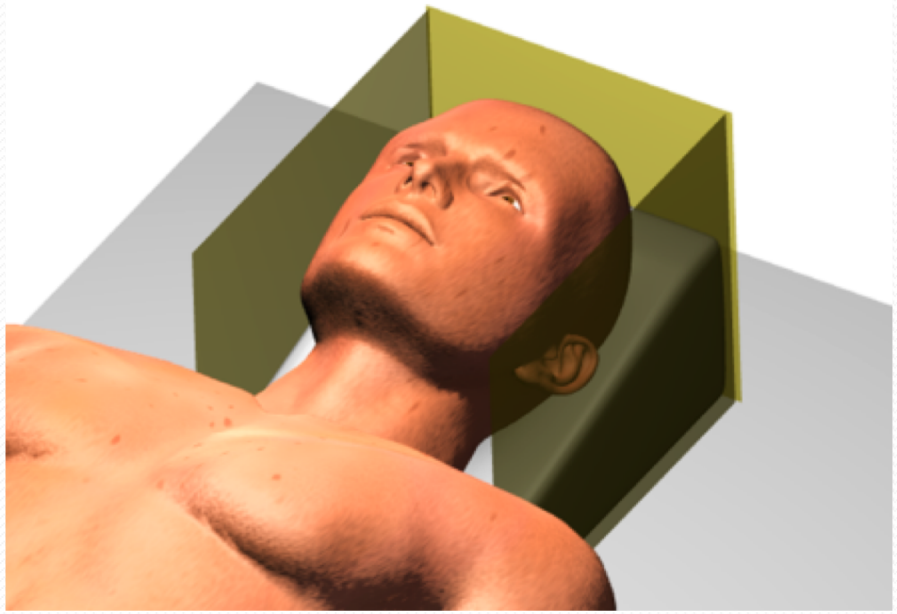
		P_{KA} (Gy.cm²)			$K_{a,r}$ (mGy)		
		Min.	Mean	Max.	Min.	Mean	Max.
Mode of exposure	Fluoroscopy n = 158)	1,9	**12,2**	97,4	21	**111**	1180
	DSA (n = 97)	14,3	**57,9**	237,5	212	**626**	1912
	DSA + 3D (n = 61)	29,8	**70,6**	122,4	294	**706**	1649
complete procedure (n = 158)		16,3	**75,1**	251,7	233	**768**	2829

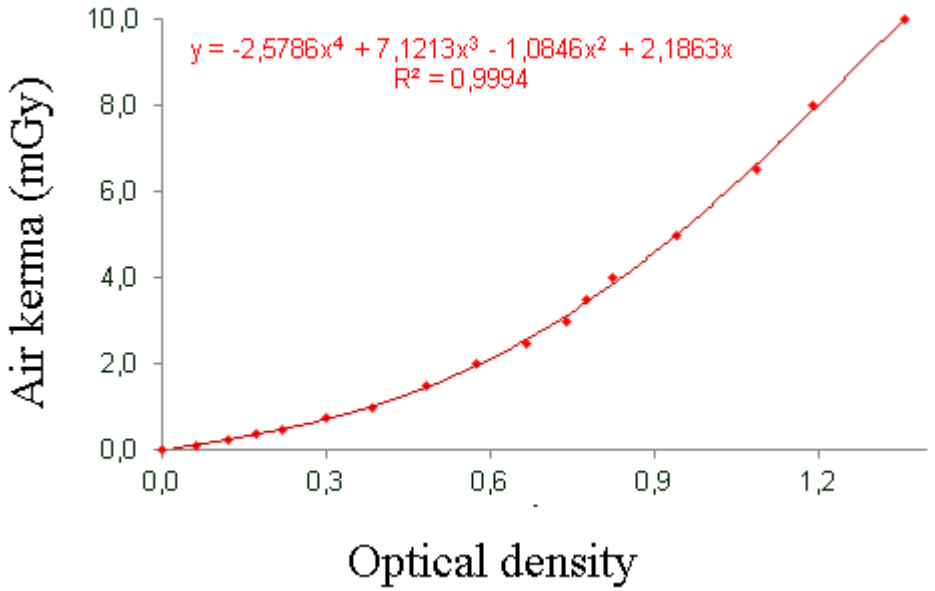
In Interventional Exams, Maximum Skin Dose and P_{KA} can be Determined with Film: Silver Halide and Radiochromic

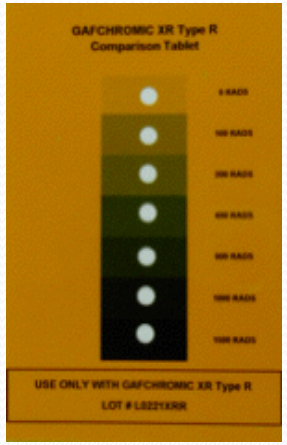


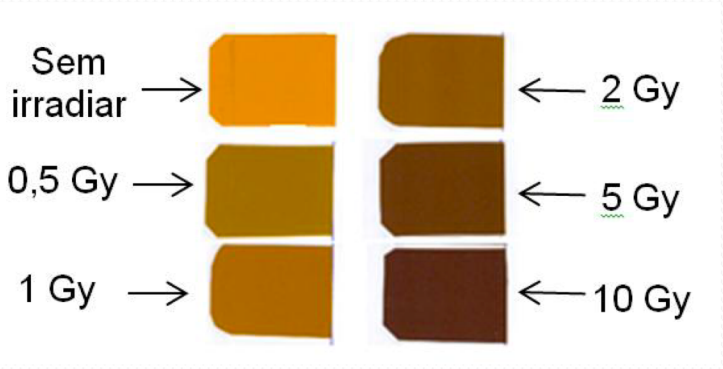
Film Position (Cardio)

Radiochromic films



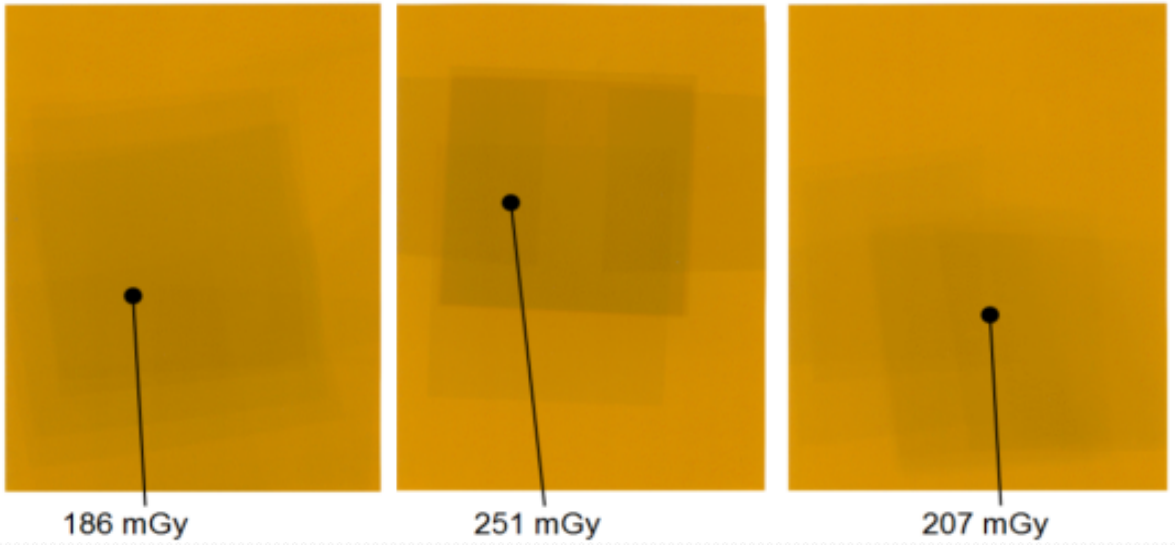


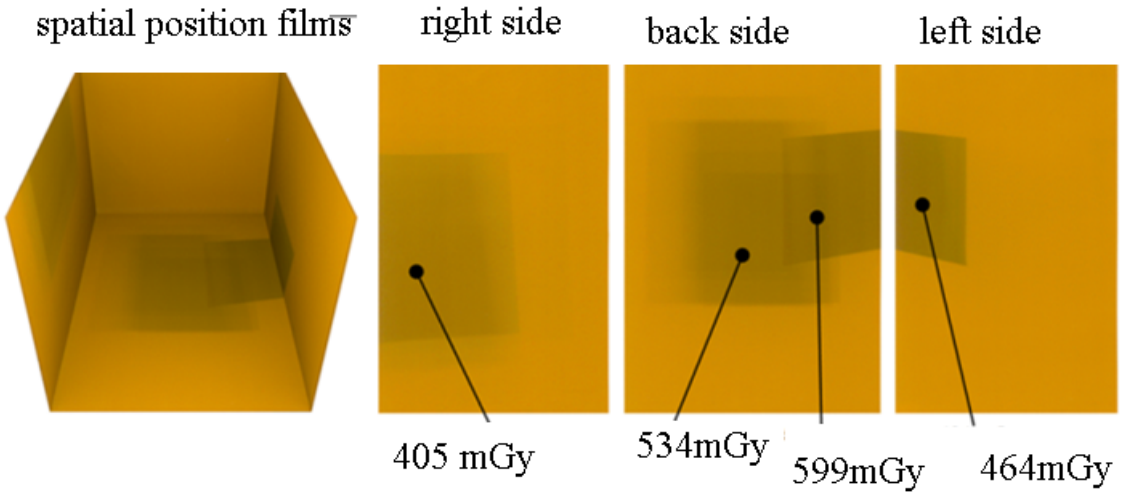


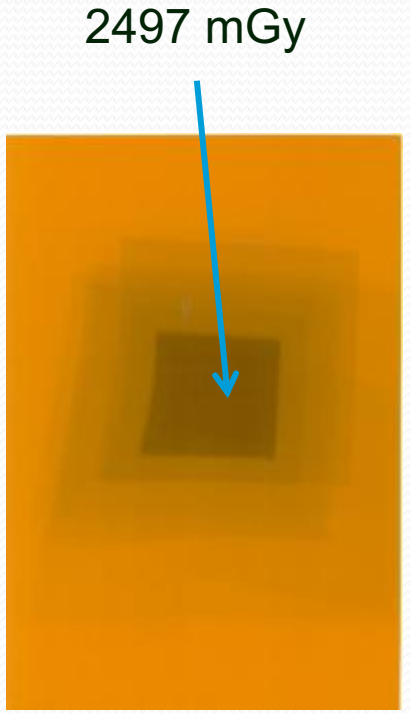


Maximum Skin Dose

Cerebral angiographies



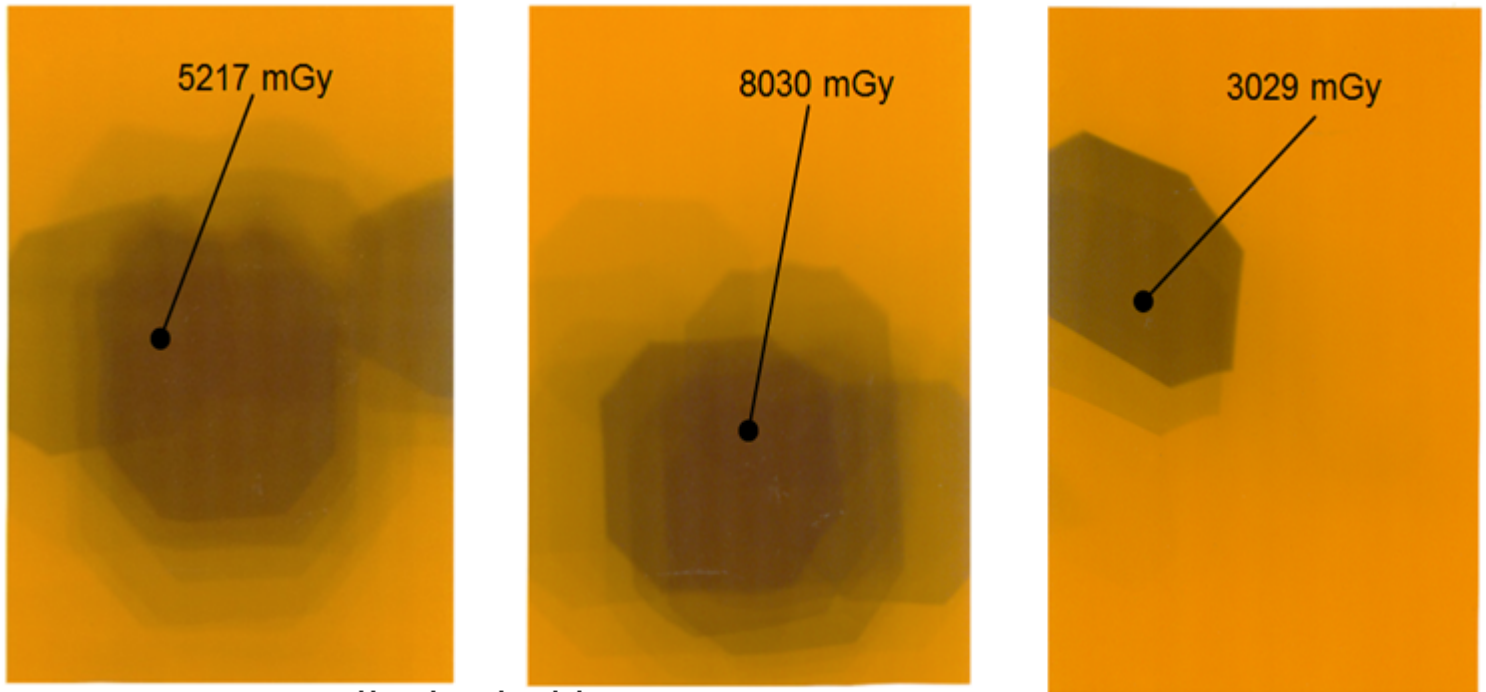




Cerebral Embolizations

N. Lunelli, 2012

Maximum Skin Dose - Results
Neuroradiology Interventions



Film back side

Vascular malformation

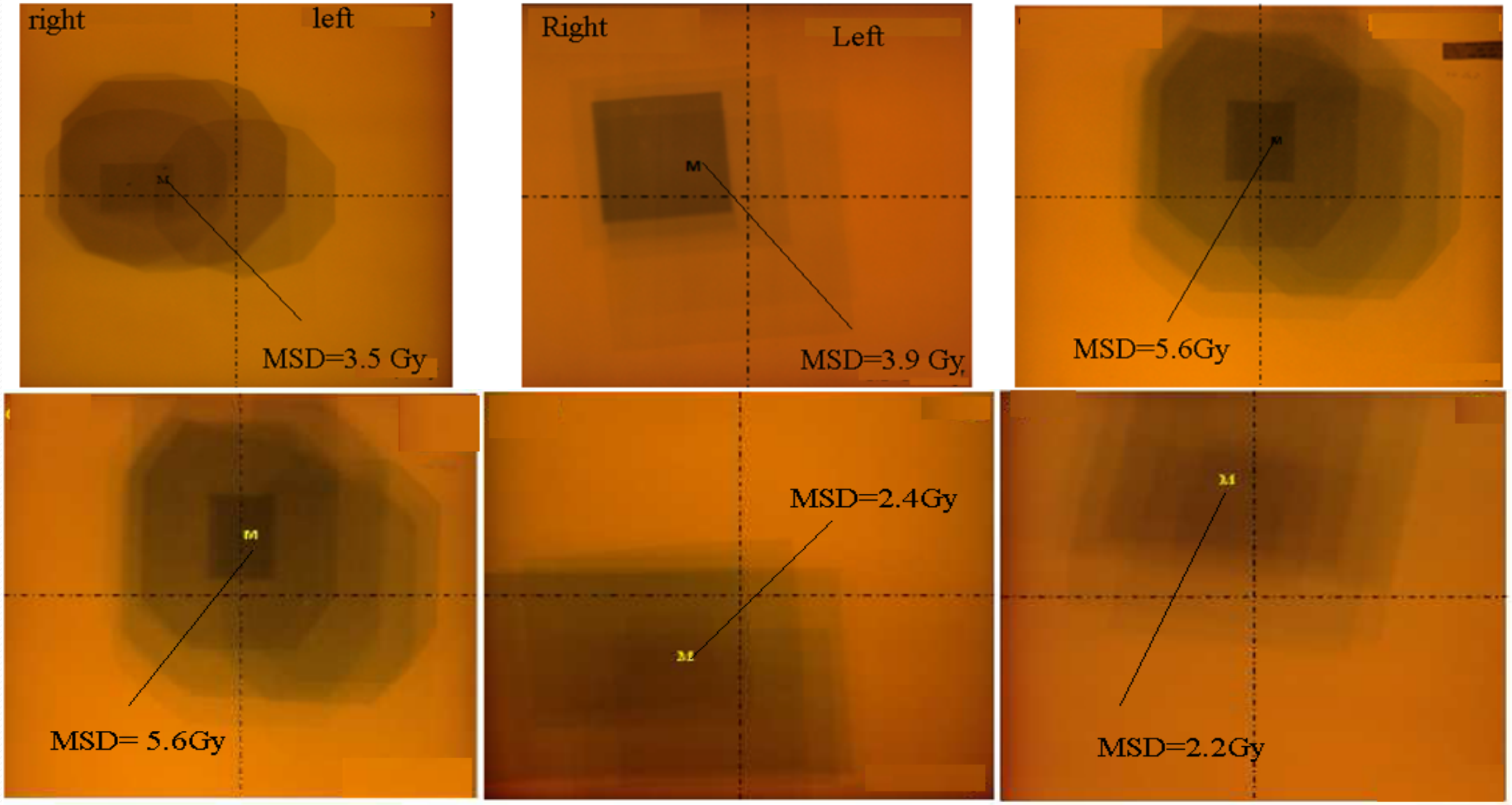
Vascular malformation

Aneurysm - left side

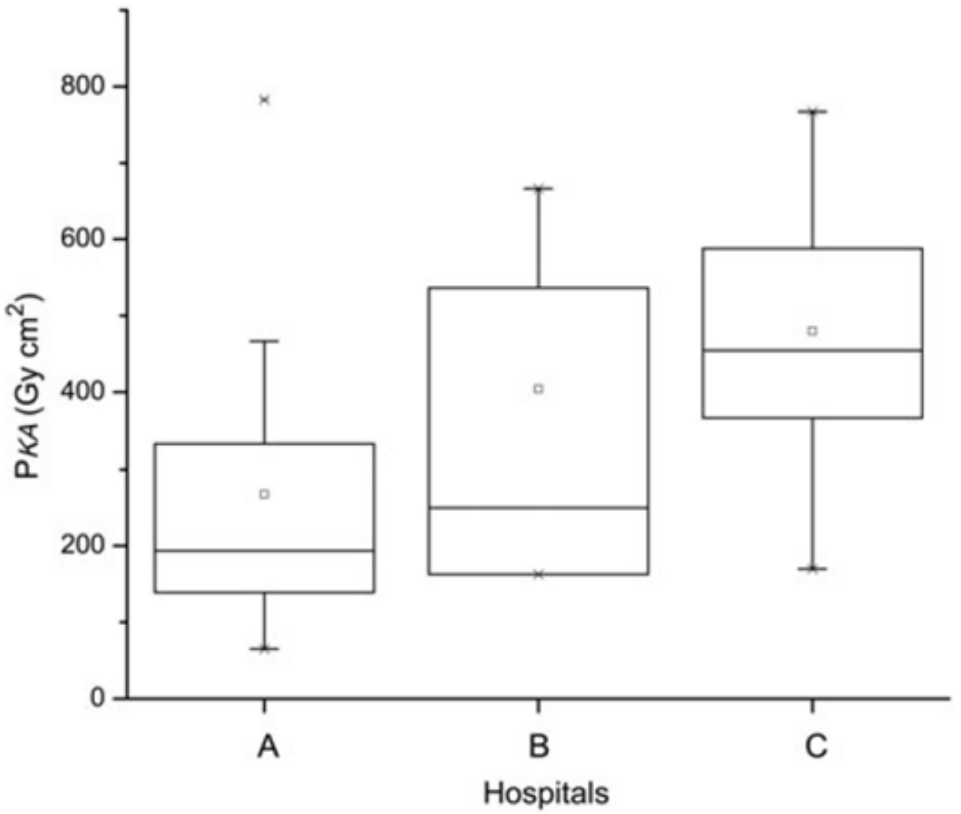
Reaction in the patient – MSD=8030 mGy

N. Lunelli, 2012

Maximum Skin Dose - Results
Hepatic Artery Chemoembolization



Hepatic Artery Chemoembolization Results



Distribution of P_{KA} across procedures and hospitals.

H.J. Khoury et al, 2015

Prostatic Artery Embolization Results

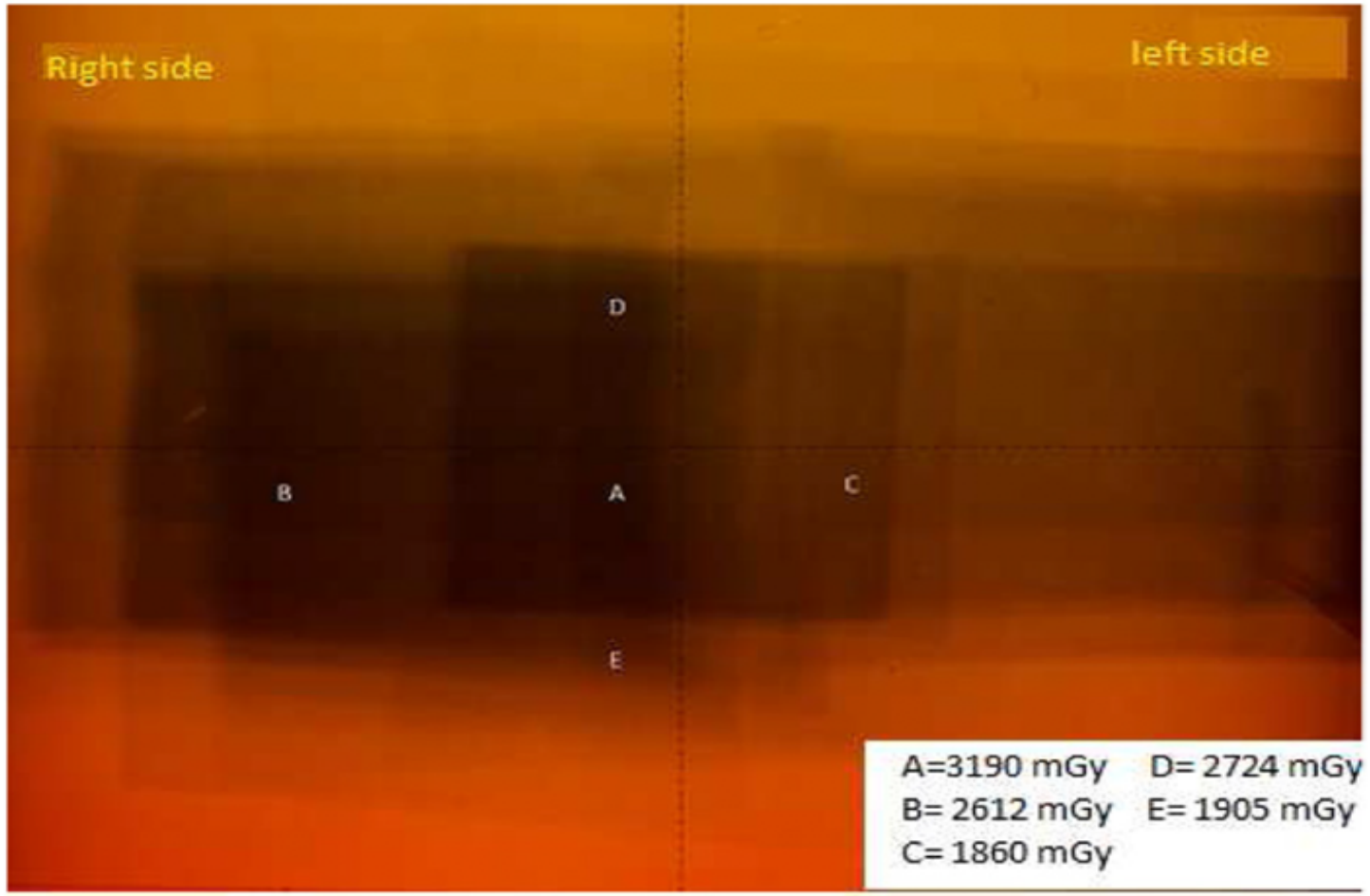
Fluoroscopy time, acquisition images, total and partial P_{KA} values per procedure.

Procedure	Fluoroscopy time (min)	Acquisition images (runs)		P_{KA} (Gy · cm^2)			
		DSA	3D CBCT	Fluoroscopy (%)	DSA (%)	CBCT (%)	Total
1	38.4	598 (21)	396 (2)	118.2 (16)	577.4 (77)	52.7 (7)	748.3
2	25.5	458 (25)	397 (2)	81.4 (13)	489.7 (79)	48.1 (8)	619.2
3	36	447 (18)	—	142.9 (27.1)	384.7 (72.9)	—	527.7
4	25.3	486 (13)	—	68.1 (17)	333.7 (83)	—	401.9
5	20.4	575 (23)	—	43.3 (13)	279.2 (87)	—	322.6
Mean	29.1	512.8 (20)	396.5 (2)	90.8 (17.2)	409 (79.8)	20.2 (3)	523.9

—CBCT mode not used.

W.J. Garzon et al., 2016

Prostatic Artery Embolization Results



Patient skin dose distribution and radiation field beam variation observed on a radiochromic film used during a PAE procedure.

W.J. Garzon et al.,

Prostatic Artery Embolization Results

PSD, cumulative air kerma, and DI for each PAE procedure in this study.

		Ka,r (mGy)				
Procedure	PSD (mGy)	Fluoroscopy (%)	DSA (%)	CBCT (%)	Total	DI
1	3008	1008 (17.7)	4496.9 (79.2)	169 (3)	5674	0.53
2	3190	774.5 (15.7)	3995.5 (81.1)	154 (3.1)	4924	0.65
3	2500	1299 (25.1)	3884 (74.9)	—	5183	0.48
4	2380	810.7 (22)	2948.2 (78)	—	3758	0.63
5	2293	522.4 (14)	3214.7 (86)	—	3737	0.61
Mean	2674	882.9 (18.9)	3707.9 (79.8)	64.6 (1.2)	4655.2	0.58

—CBCT mode not used.

W.J. Garzon et al., 2016

Medical Staff Dosimetry

TLD-100 chips attached next to the eyes, close to the thyroid (over apron-collar), on the thorax under the apron, at the hands in the region of the pulse, and at the feet.

The effective dose to the staff was estimated using the algorithm of von Boetticher .

$$E = 0.84H_{p,u}(10)+0.051H_{p,o}(10)$$

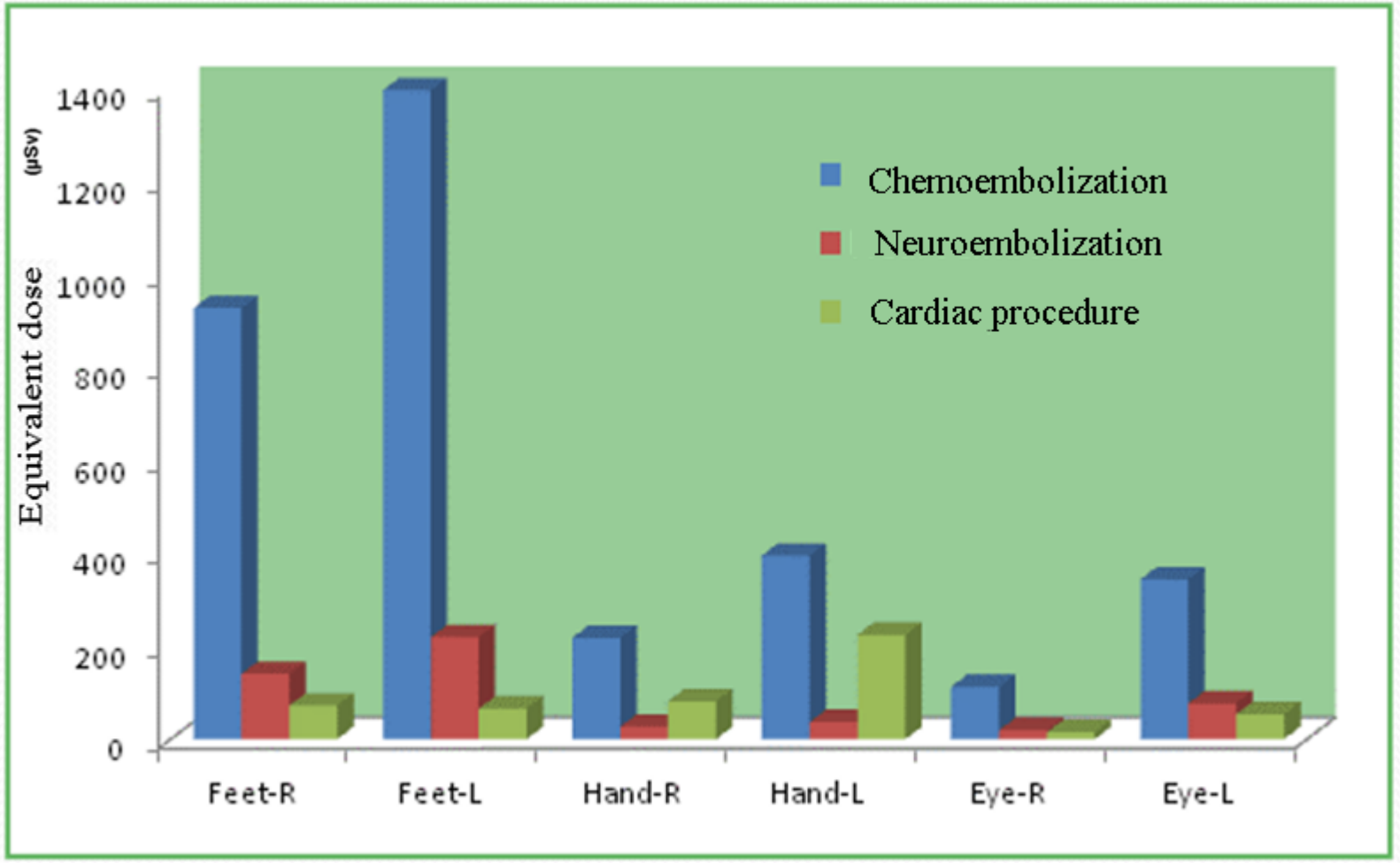
Where: $H_{p,u}$ is the dosemeter reading under the apron

$H_{p,o}$ is the dosemeter reading over the apron

Monitored Regions	Operational Quantity
Eyes	Hp(0.07); Hp (3)
Neck (Over the thyroid shield) Thorax (Under the apron)	Hp(10)
Hands (pulse area) Knees Feet	Hp(0.07)

Position of the TLDs on the physician's body surface

Occupational Dosimetry
Cerebrovascular Aneurysms & Embolizations



N. Lunelli et al 2012

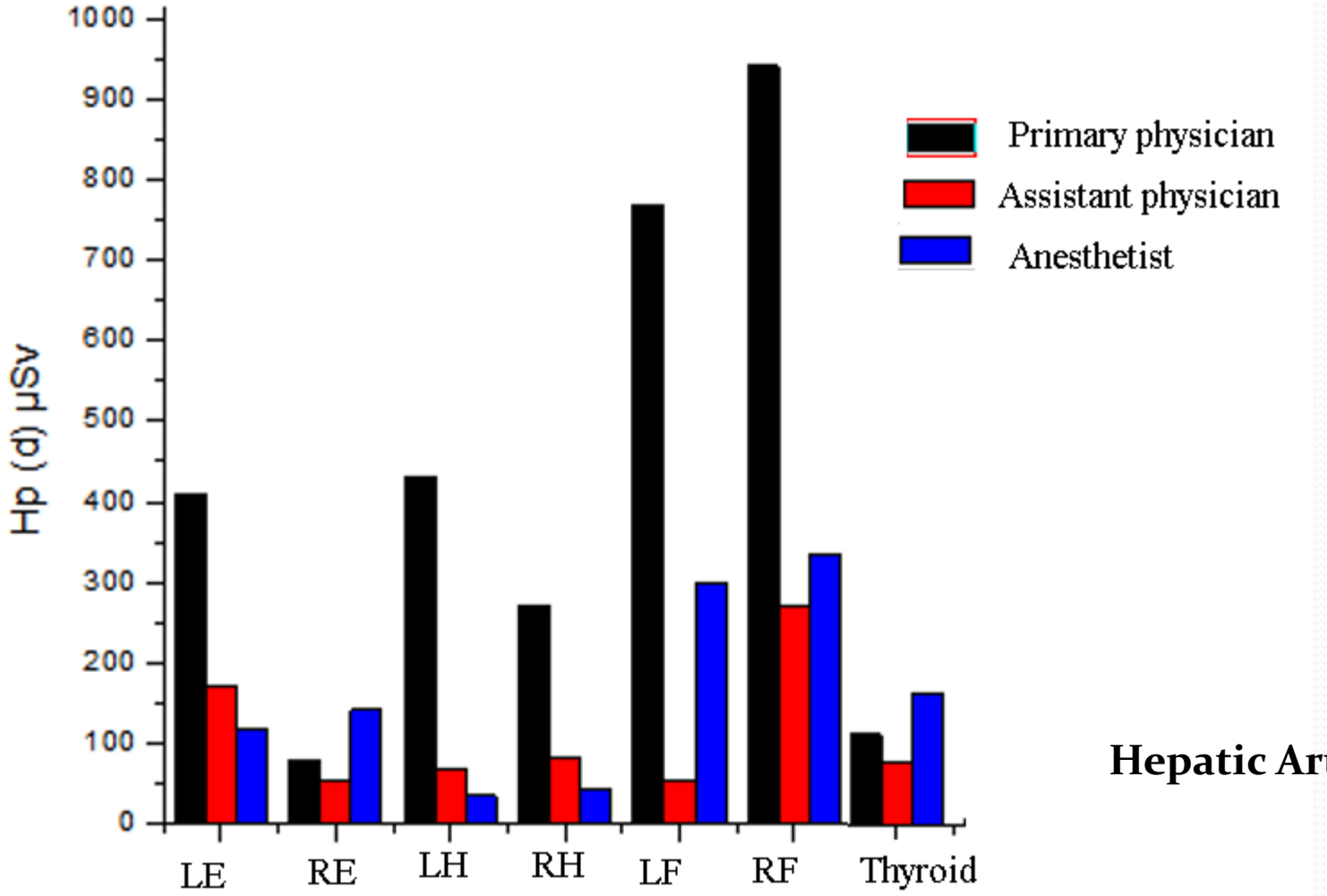
Prostatic Artery Embolization

Mean, minimum and maximum Hp(3), Hp(0.07) and Hp(10) values measured on the physician per location and procedure.

	Hp(3) (μSv)			Hp(0.07) (μSv)				Hp(10) (μSv)	
Monitored location	Glabella	Left eyebrow	Right eyebrow	Left wrist	Right wrist	Left foot	Right foot	Chest (under apron)	Neck (over collar)
Mean	441	478	196	720	357	2099	1167	7	246
Minimum	321	341	80	377	218	94	145	2	104
Maximum	673	798	367	1286	545	4026	1935	11	347

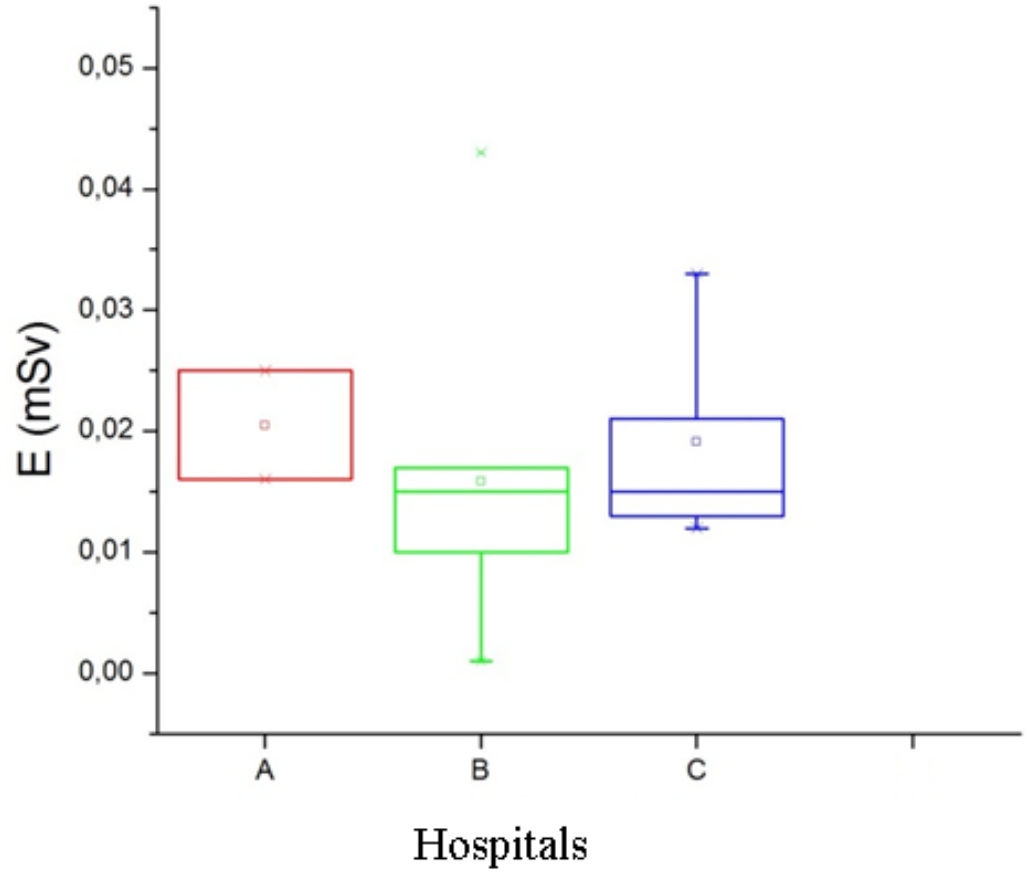
W.J. Garzon et al., 2016

Mean values of Hp (d) in several regions of the main physician and the medical staff



Hepatic Artery Chemoembolization

Physician Effective Dose / Procedure
Hepatic Artery Chemoembolization



W.J. Garzon 2015

Estimation of annual values of main physician's effective dose and equivalent dose

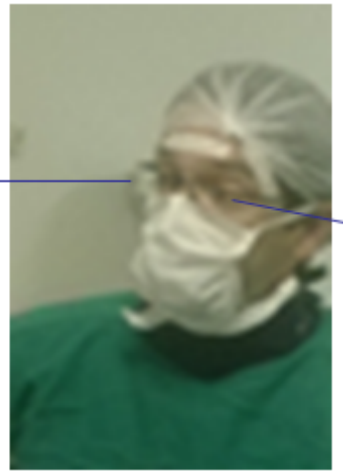
- Considering that the doctor performs about 150 embolization per year

	Limit value	Annual Dose (mSv)	
	Annual	Garzon et al,2015	Kong et al., 2013
Efective dose	20	2.55	3.16
Lens of eyes	20	41.40	9.27
Hands	500	54.15	***
Feet	500	133.5	***

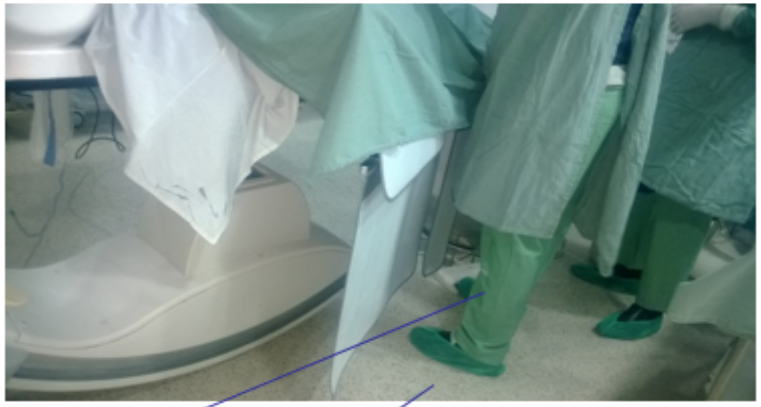
W.J. Garzon 2015

Teaching the Hospitals Radiation Protection

Good practice - using shield devices



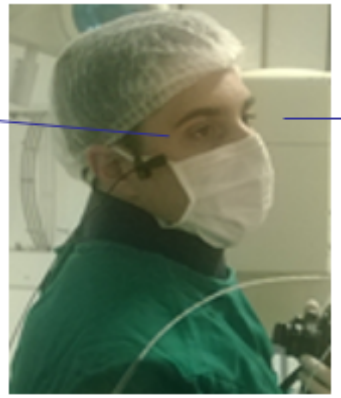
72%



80%

246,4 µSv 319,5 µSv

Without shield devices



1007 µSv 1608,6 µSv

Measurements with radiochromic film and TLDs are very time consuming. But the methodology can be used to validate the

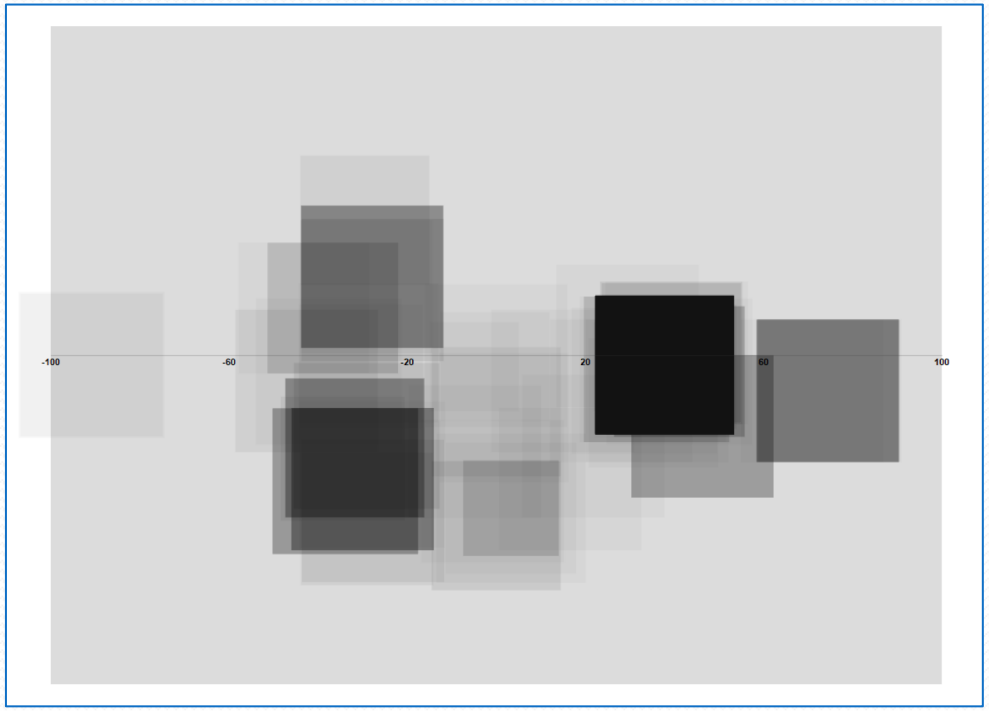
DICOM Standards

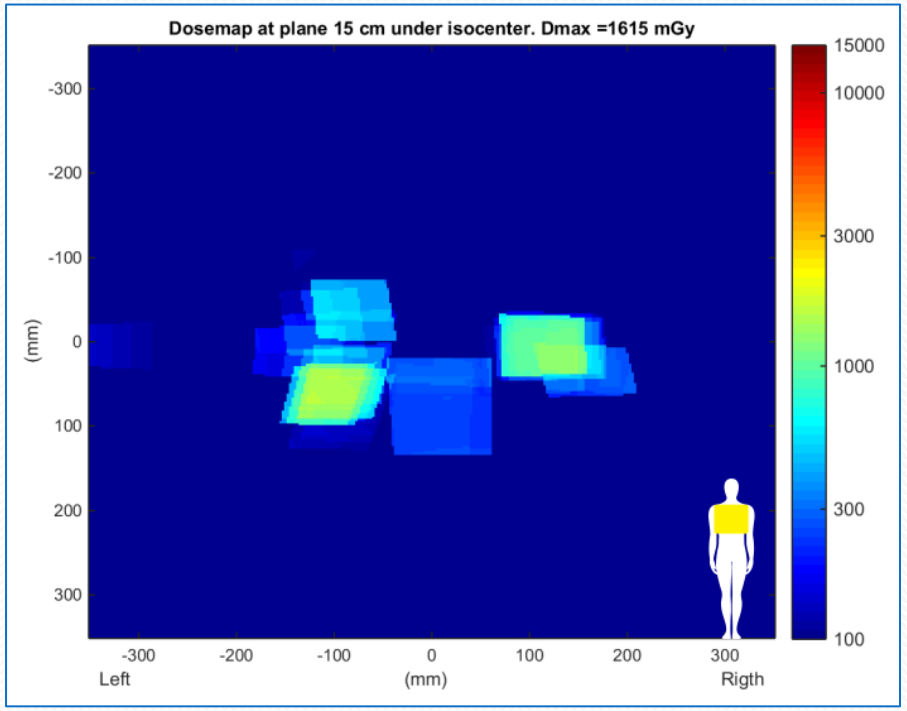
- DICOM Header
- DICOM Services
  - e.g. modality performance procedure step (MPPS)
- Radiation Dose Structured Report (RDSR)
- Patient-RDSR (P-RDSR)

Skin Dose Maps

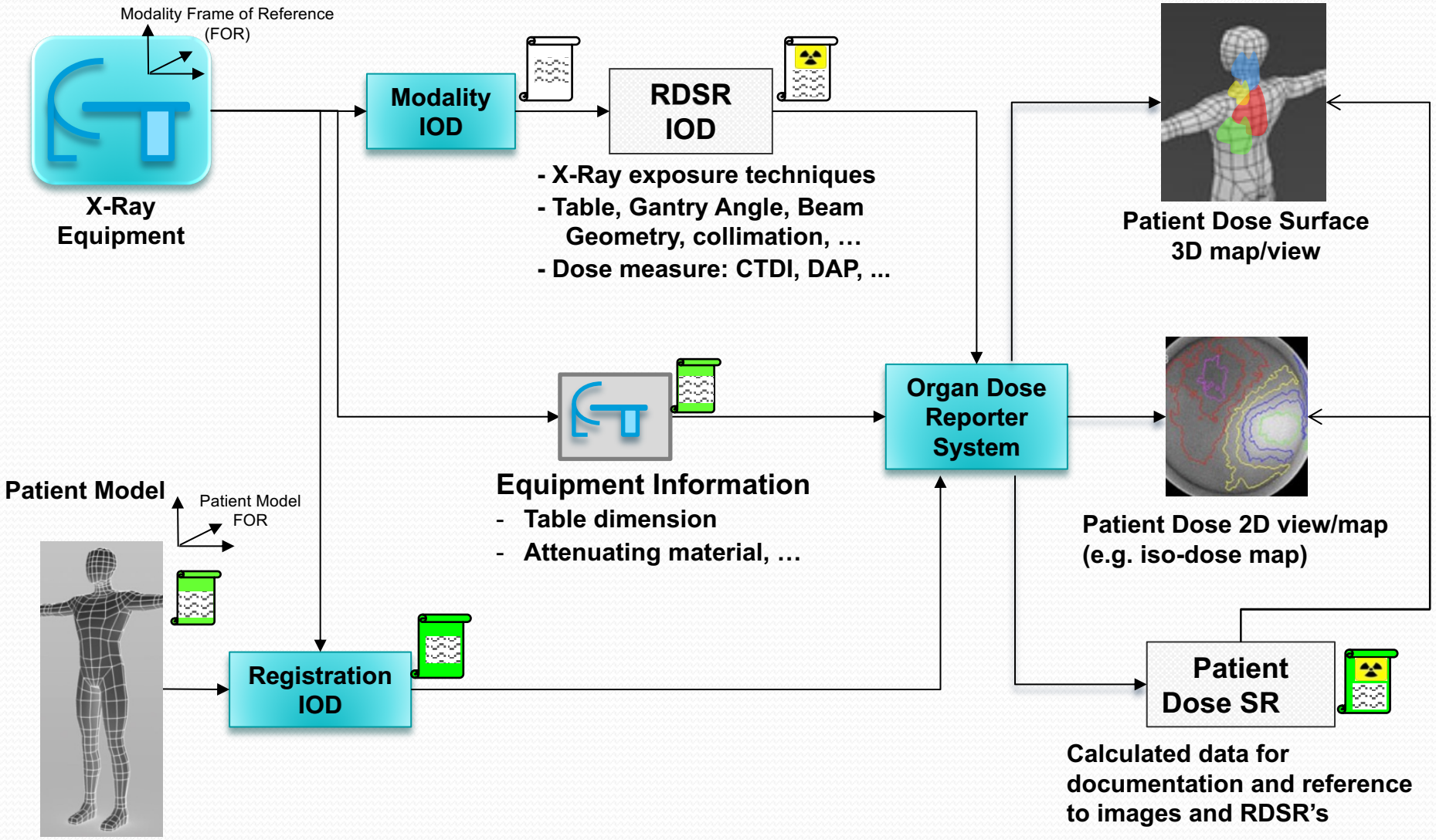
(JM Fernandez-Soto et al., 2016)

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.





Patient Dose Determination: Data Flow Requirements



Signifies part of Supplement 191 Patient RDSR