AAPM 2013 Imaging Educational Course

Lens of the Eye Dosimetry

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Eye dosimetry

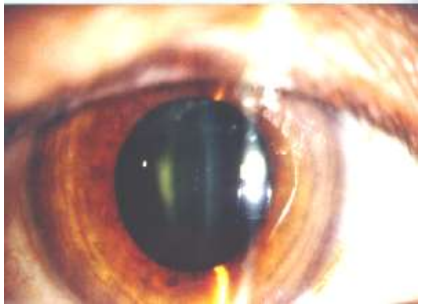
- **Regular eye dosimetry in diagnostic imaging practically does not exist**
- **Accurate assessment of eye lens dose is one of the most important aspects of:**
  - **correlating doses with observed lens opacities among workers in interventional suites**
  - **ascertaining compliance with regulatory limits**

In a single complex procedure, it is possible to accumalate 0.5-1.0 mSv (at the eyes)

With 3 procedures/day it is possible to get 300-600 mSv/year

If radiation protection tools are not used

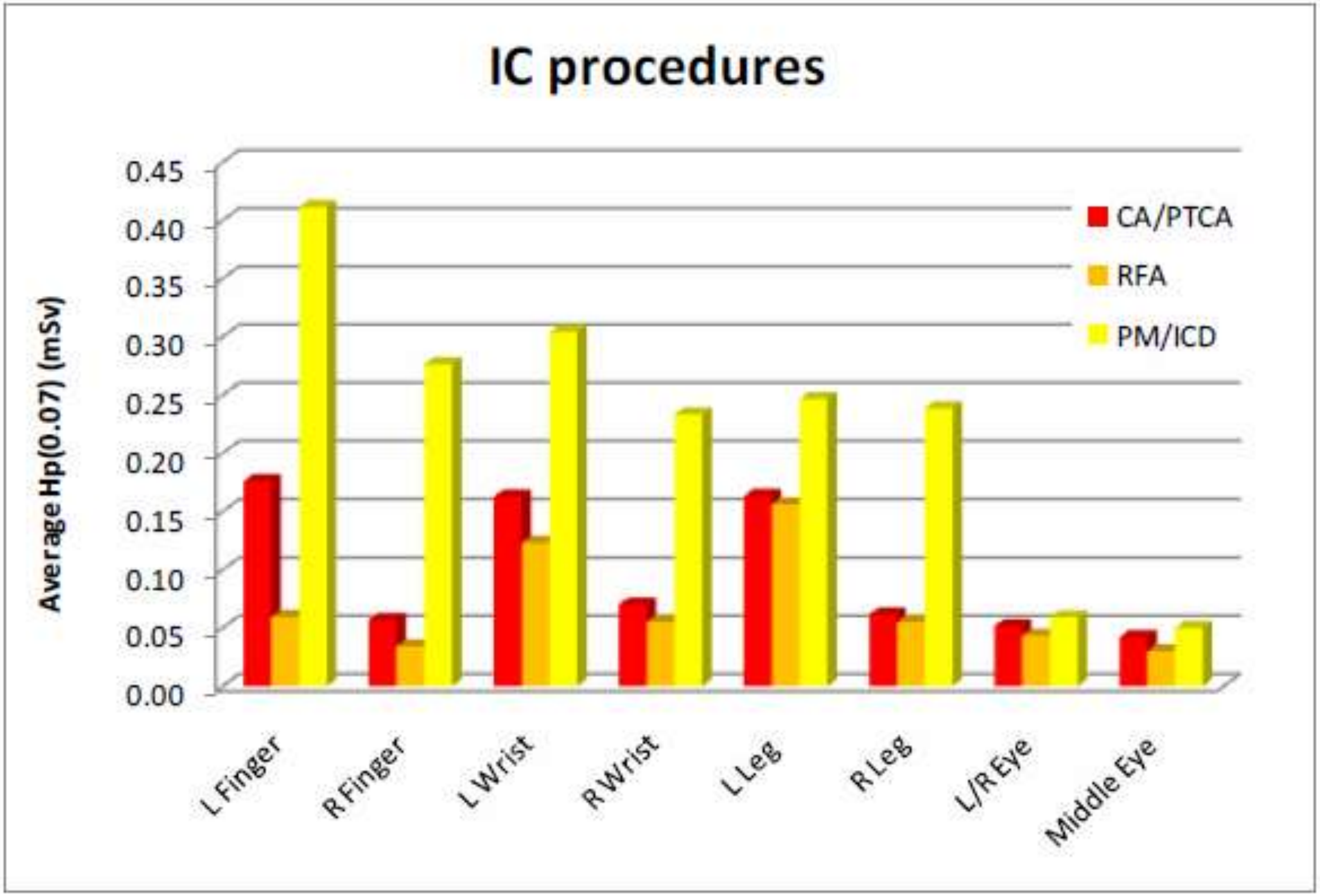
In a few years it could be possible to have lens opacities



ORAMED (Optimization of Radiation protection for Medical staff) Project funded by the EC (2008-2011) http://www.oramed-fp7.eu/

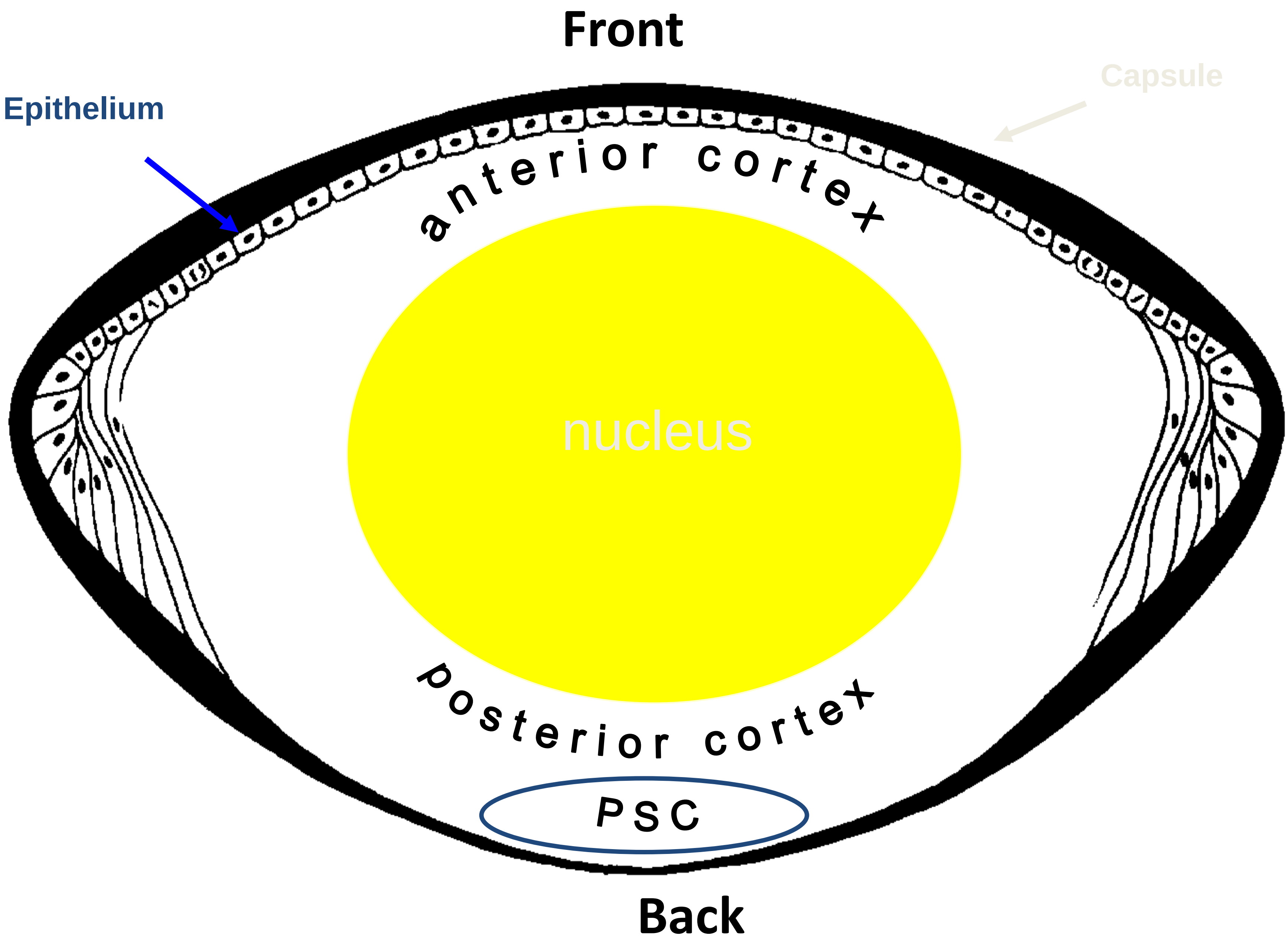
Average Hp(0.07) about 50 µSv for IC procedures

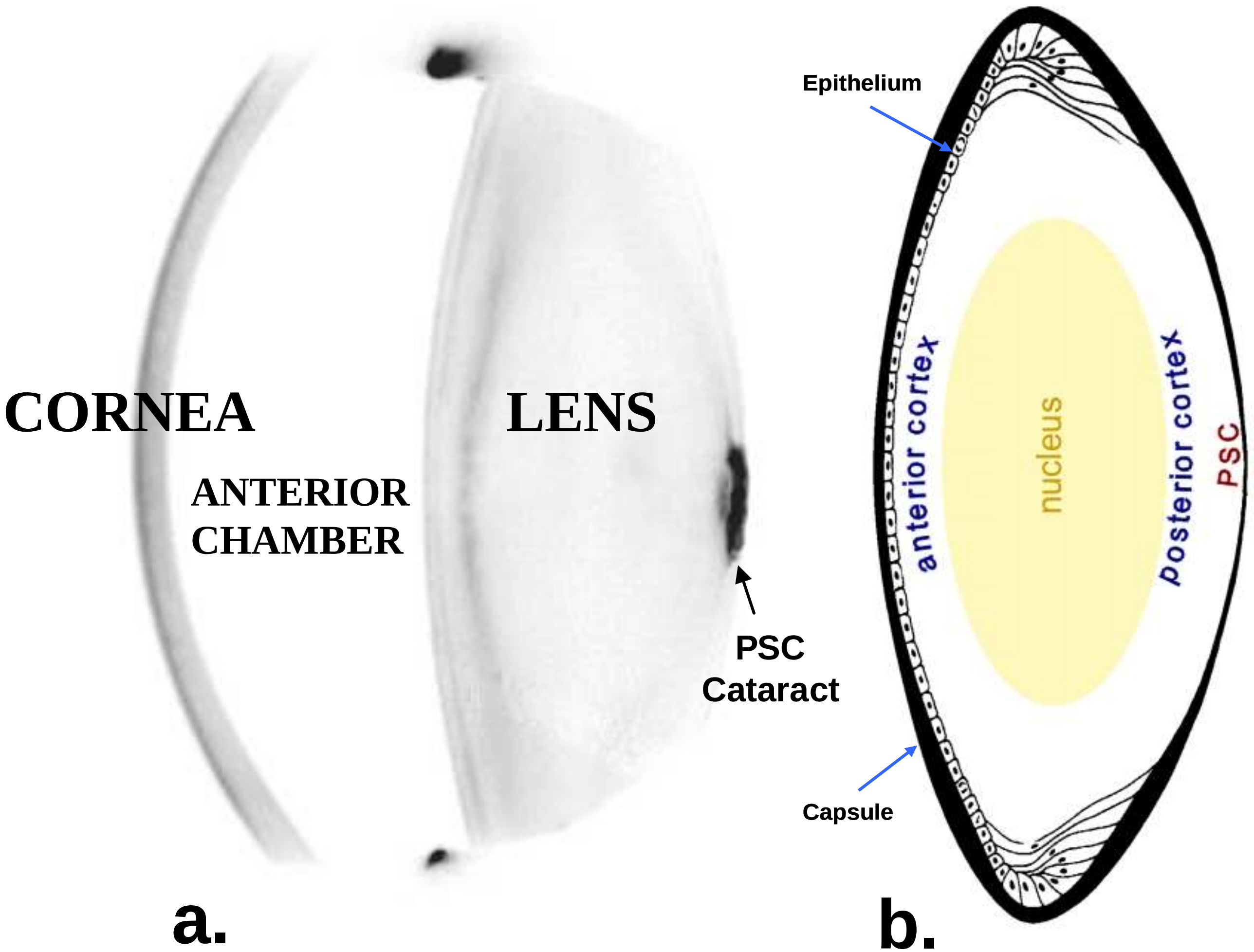
(figure from the final report)



Major Cataract Subtypes

- **Cortical**
- **Nuclear**
- **Posterior SubCapsular (psc)**
- **Mixed**


Front
Capsule
Epithelium
anterior cortex
nucleus
posterior cortex
PSC
Back


CORNEA
LENS
ANTERIOR CHAMBER
PSC Cataract
a.
Epithelium
anterior cortex
nucleus
posterior cortex
PSC
Capsule
b.

Dose metrics

- **The eye lens dose, as organ dose is not directly measurable**
- **According to ICRU the operational quantity Hp (3) is the most appropriate to monitor the eye lens dose, as the lens is covered by about 3 mm of tissue**
- **Proposals to use Hp(0.07) for eye lens dose monitoring**

Current eye dosimetry challenges

- Which personal dose equivalent quantity is appropriate?
- How it can be used routinely for eye lens dose monitoring?
- What is a suitable dosimeter and calibration procedure?
- How to convert radiometric quantities, as fluence, to equivalent dose to the lens?

Possible approaches

Practical dosimetry:

1. **Passive dosimeters**
2. **Active dosimeters**
3. **Retrospective dose assessment using scatter radiation dose levels**
4. **Correlations between patient dose indices and eye doses to the operators**

Passive dosimeters

- **Dedicated passive dosimeter designed to provide the dosimetric quantity Hp(3)**
- **Double dosimetry:**
  - **If a dedicated eye dosimeter is not available, a collar dosimeter calibrated in terms of Hp(0.07)**
    - **Studies that claim that collar dosimeter provide a reasonable and conservative estimate of eye lens dose (within 15%)**
    - **Studies claiming that a dosimeter at collar level would underestimate the absorbed dose to the eye lens for 73 %**

Problems with Passive dosimetry

- **Large number of operators are not wearing personal dosimeters or wear it irregularly**
- **It is generally only one badge with uncertain position on the body**
- **If individual monitoring is provided, is utilised a single dosimeter worn under the lead apron, making any evaluation of ocular radiation dose impossible**
- **Various practices among countries**

Possible approaches

Practical dosimetry:

1. Passive dosimeters
2. Active dosimeters
3. Retrospective dose assessment using scatter radiation dose levels
4. Correlations between patient dose indices and eye doses to the operators

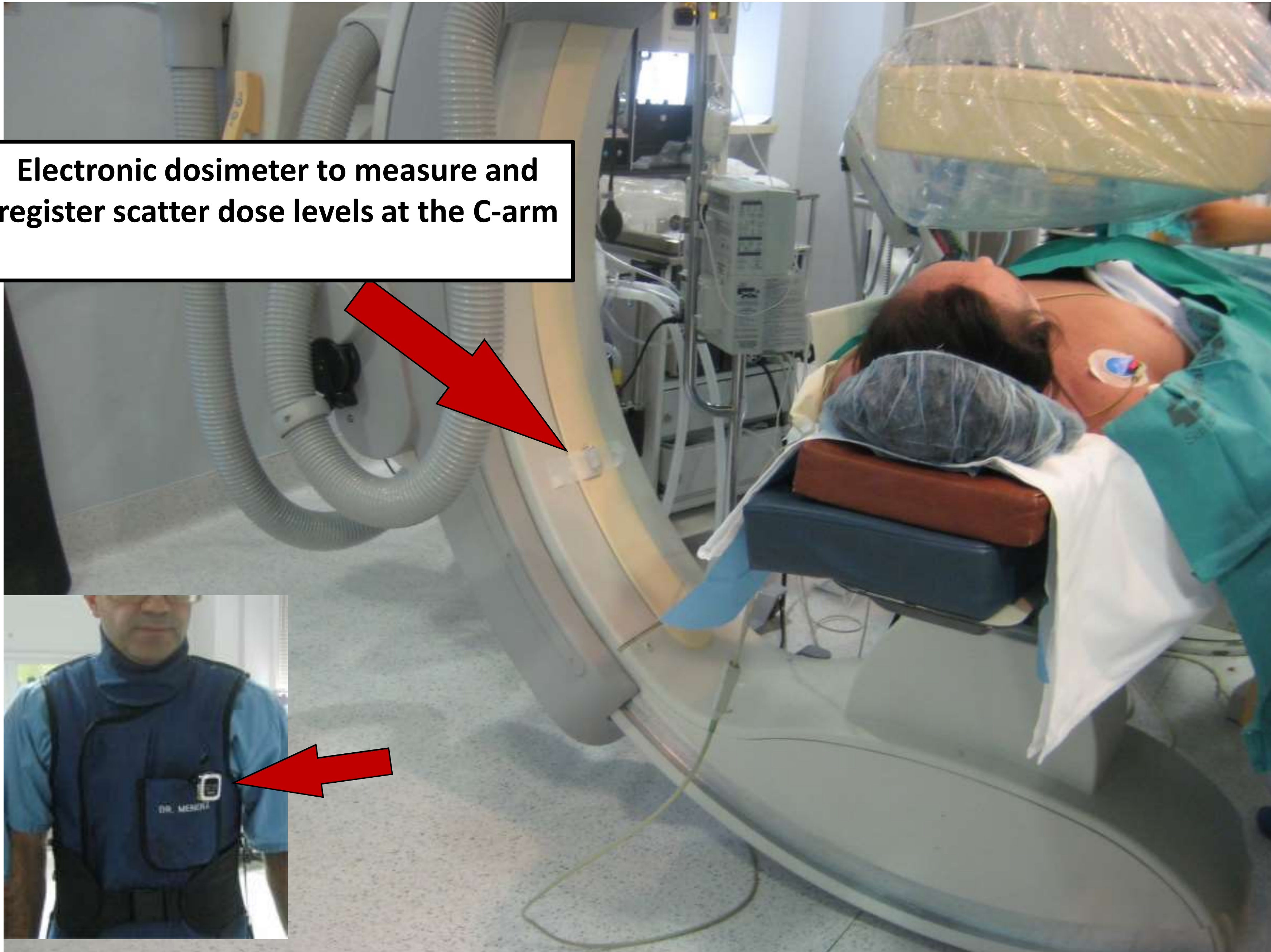
Active dosimeters

- **The most suitable approach for accurate dose assessment in real time**
- **Alarm at dose or dose rate level**

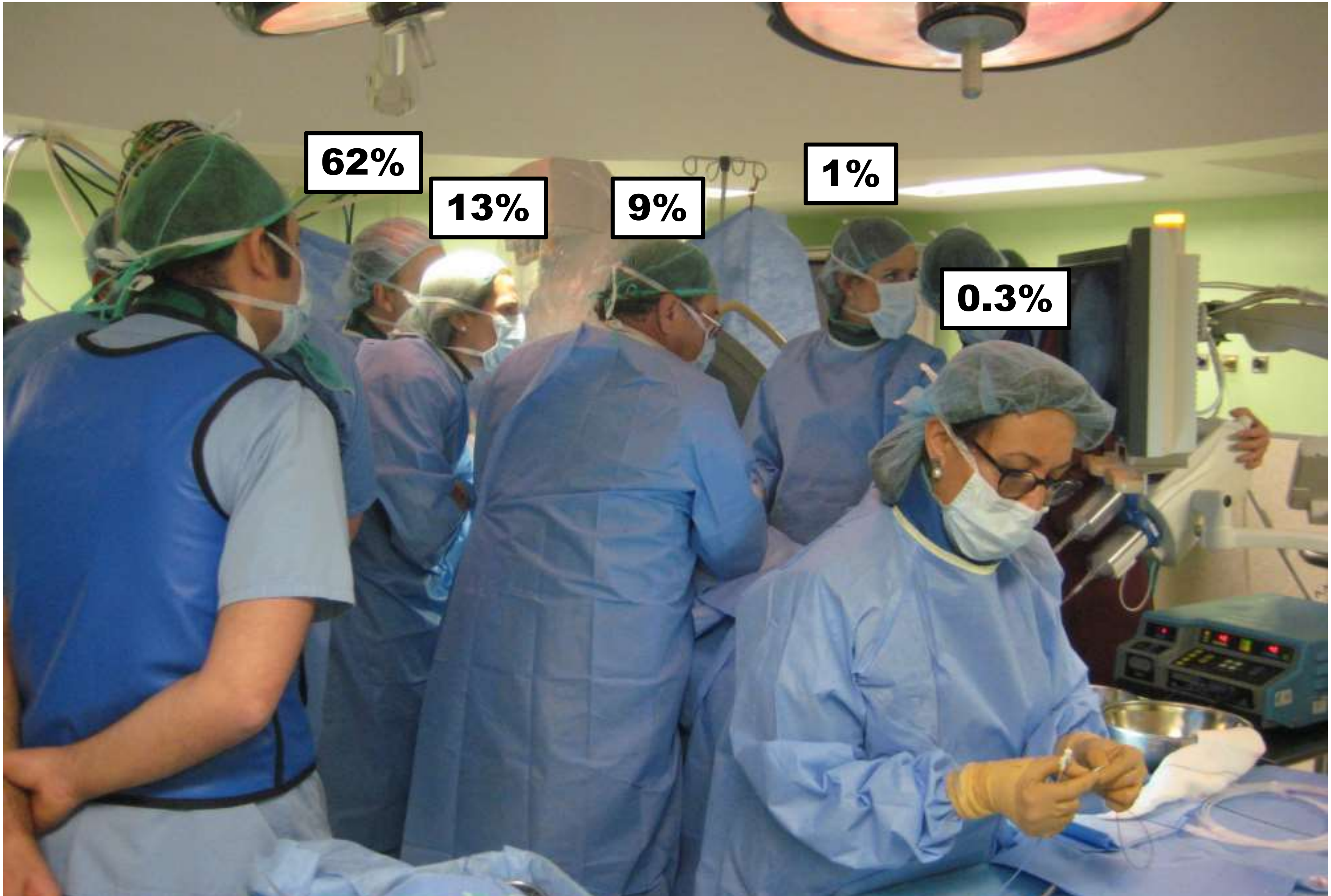
Measuring scatter dose reduction for different goggles
Detector 1 (left lateral goggles not protected)
Detector 2 (central goggles not protected)
Detector 3 (inside goggles, protected)
Detector 4 (shoulder)

Solid stated detectors measuring the scatter dose rate outside (central and left lateral) and inside the goggles (left eye)

Courtesy E. Vano, Madrid



Courtesy E. Vano, Madrid



Vascular surgery procedure % of the scatter dose measured at the C-arm
San Carlos University Hospital Madrid

Courtesy E. Vano, Madrid

SaludMadrid

Hospital Clínico San Carlos
Servicio de Física Medica

Comunidad de Madrid

Example of staff dose report for a single procedure. Note lens doses 0.38-0.53 mSv (33-47% C-arm dose)

Servicio de Física Médica
Informe de Dosimetría Ocupacional

Centro:	Hospital Clinico San Carlos		**Ref:**	
Sala	04 - Hemodinámica		**Clave:**	HCSCCP004
Equipo:	Philips	Velara CVFD rel5	**n/s:**	09004979
Fecha:	06/10/2011		**NHC:**	
Procedimiento:	IMPLANTE VÁLVULA AÓRTICA		**Hora inicio:**	13:39
PDA total (Gy.cm²):	208,00		**Hora de fin:**	17:00
Nº imágenes adquiridas:	1249		**T. escopia (min):**	28
Nº imág. exp. adquiridas:	1249			
Radiofísico:	J.M. Fernández		**Técnico:**	S. Cano
Dosímetros:	Philips Personal Dose Meter			

Máxima dosis ocupacional de referencia en el procedimiento

ID. Dosímetro	940	**Dosis acumulada (μSv):**	1130
Posición del dosímetro:	Arco	**Máxima tasa de dosis (mSv/h):**	22,40

Dosis ocupacionales registradas por el personal

Dosim	Portador	Dosis acum. (μSv)	% del máx.	Tasa máx. (mSv/h)	% del máx.	Uso de medios de PR Dela.	Tiroi.	Gafas	Mam.
892	FAC (Dra.	377	33,4	17,70	79,0	SI	SI	SI	SI
1408	DUE (	527	46,6	22,80	101,8	SI	SI	SI	SI
909	DUE (	2	0,2	0,23	1,0	SI	SI	SI	NO
993	ANEST ( )	17	0,1	0,73	3,2	SI	SI	SI	NO

Courtesy E. Vano, Madrid

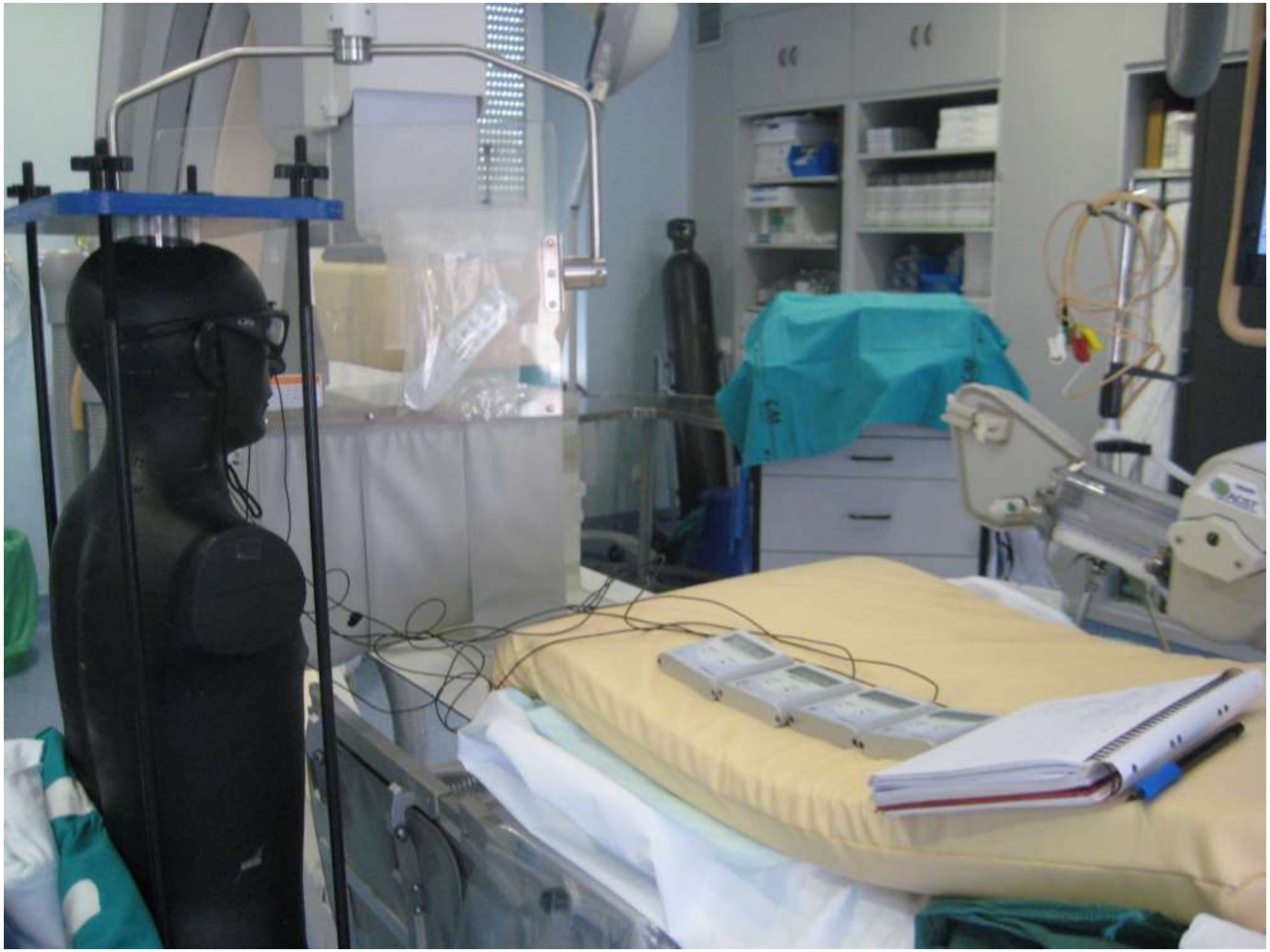
Measuring scatter radiation levels

Courtesy E. Vano, Madrid

Measuring scatter dose reduction for different goggles
(note the correct position of ceiling suspended shielding)

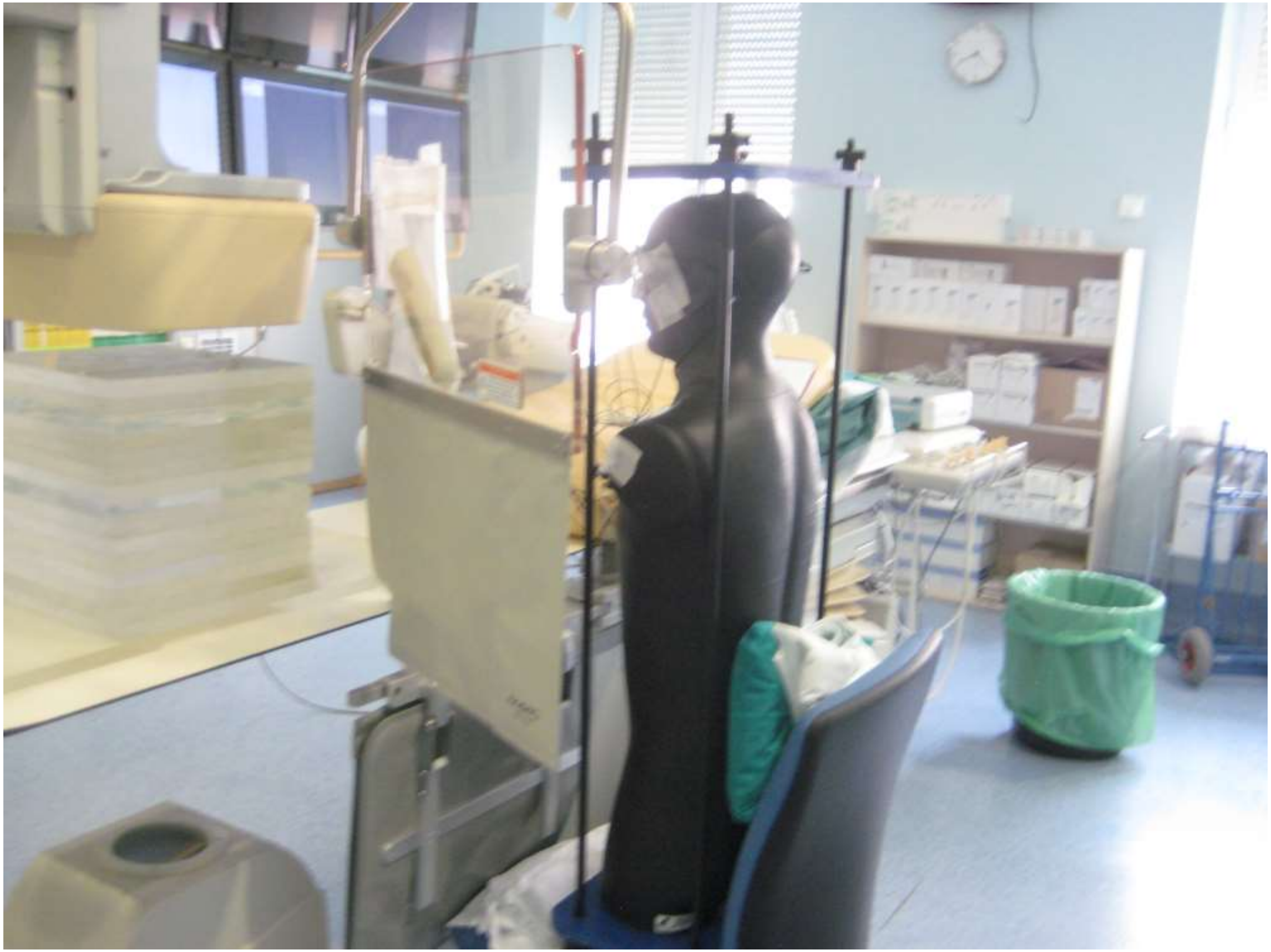
Courtesy E. Vano, Madrid

Measuring scatter dose reduction for different goggles (with correct position of ceiling suspended shielding: Only 4-8 % transmitted)



Courtesy E. Vano, Madrid

Scatter levels (no correct position of the ceiling shielding)



Courtesy E. Vano, Madrid

Scatter levels (no correct position of the ceiling shielding)
In this case: 20-90 % transmitted
(depending of the shielding position)

Courtesy E. Vano, Madrid

Measuring scatter dose reduction for different goggles (frontal protection and lateral protection)

Frontal transmission
5 ± 1 %
(max. 7 min. 4)
Lateral transmission
23 ± 16 %
(max. 48 min. 6)

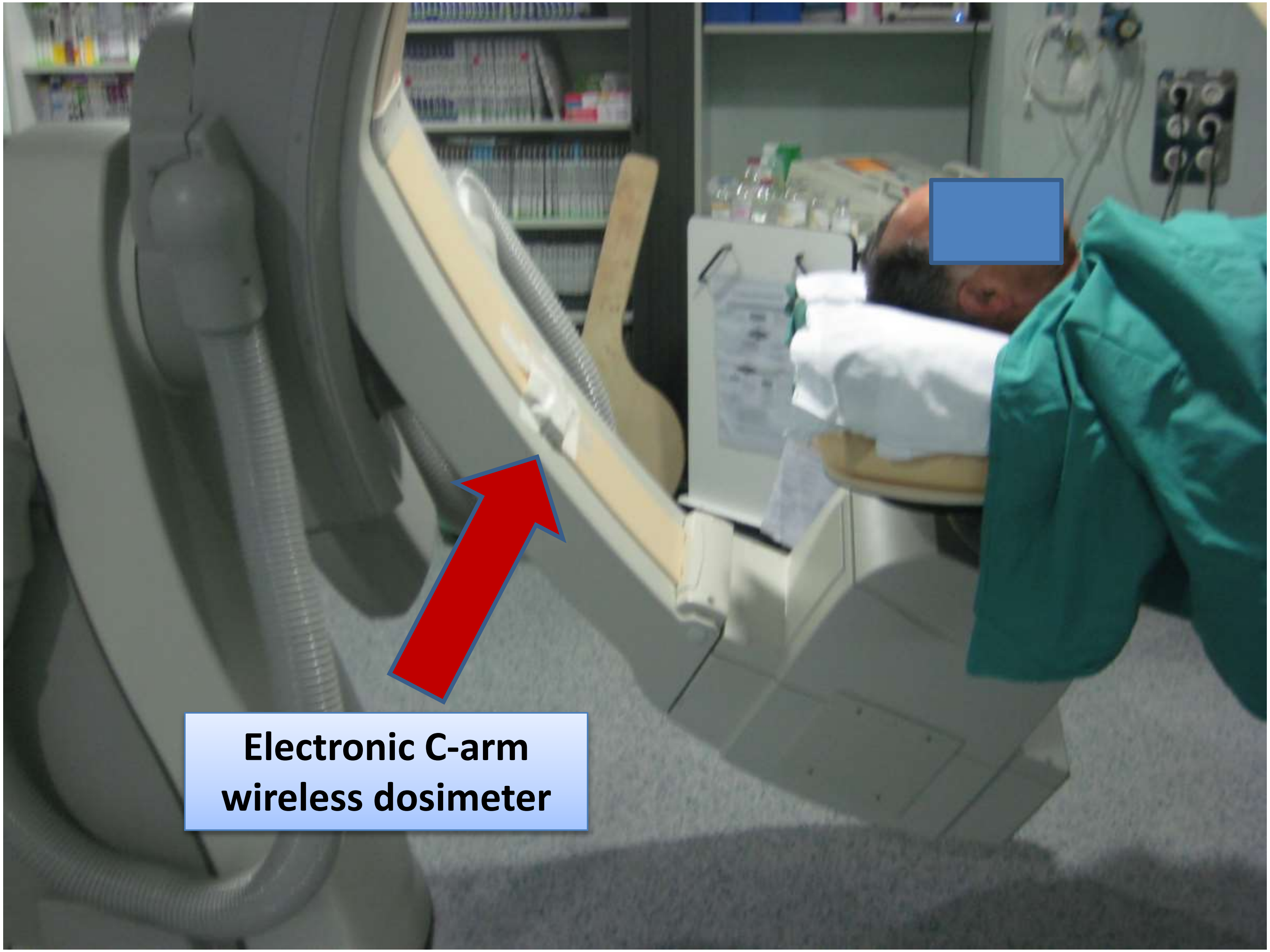
Courtesy E. Vano, Madrid

Complex cardiac procedure
Cardiologist well protected with ceiling screen, goggles and protection under the table.

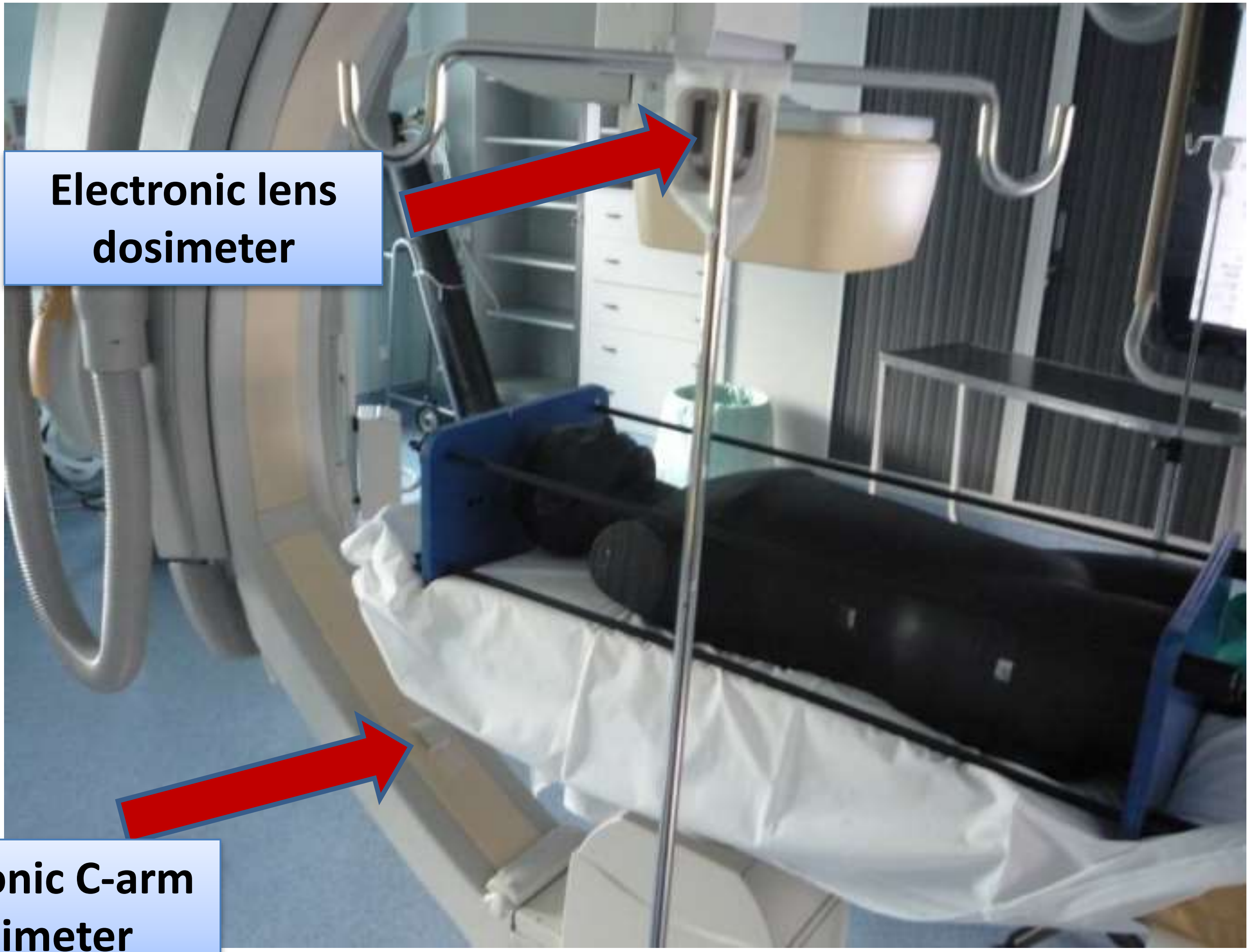
Scatter dose 1000 µSv, behind the screen 100 µSv and behind goggles 10 µSv

Nurse, only goggles, but only a limited time in that position. Only a few µSv BUT ALSO NEED RP TRAINING

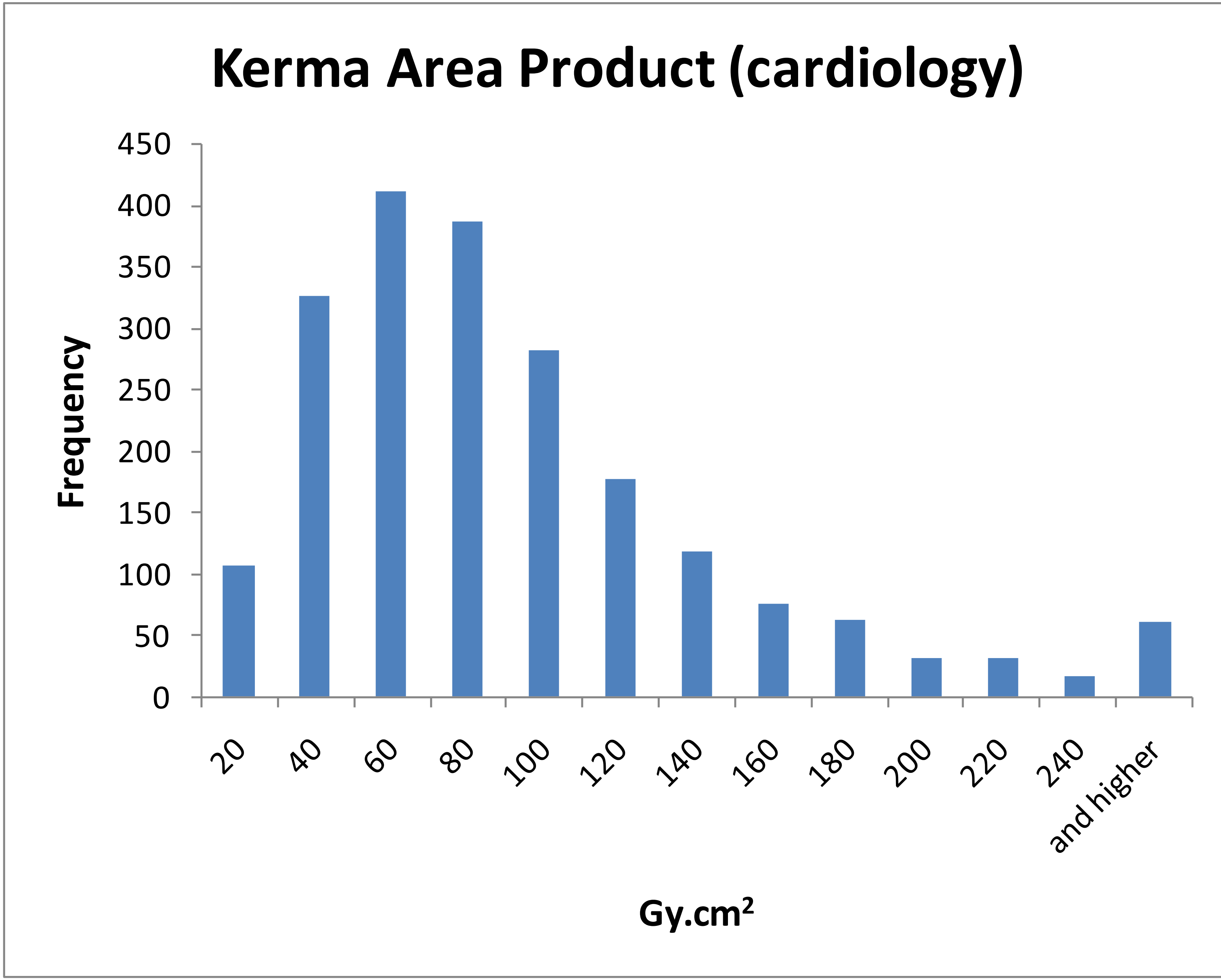
Courtesy E. Vano, Madrid



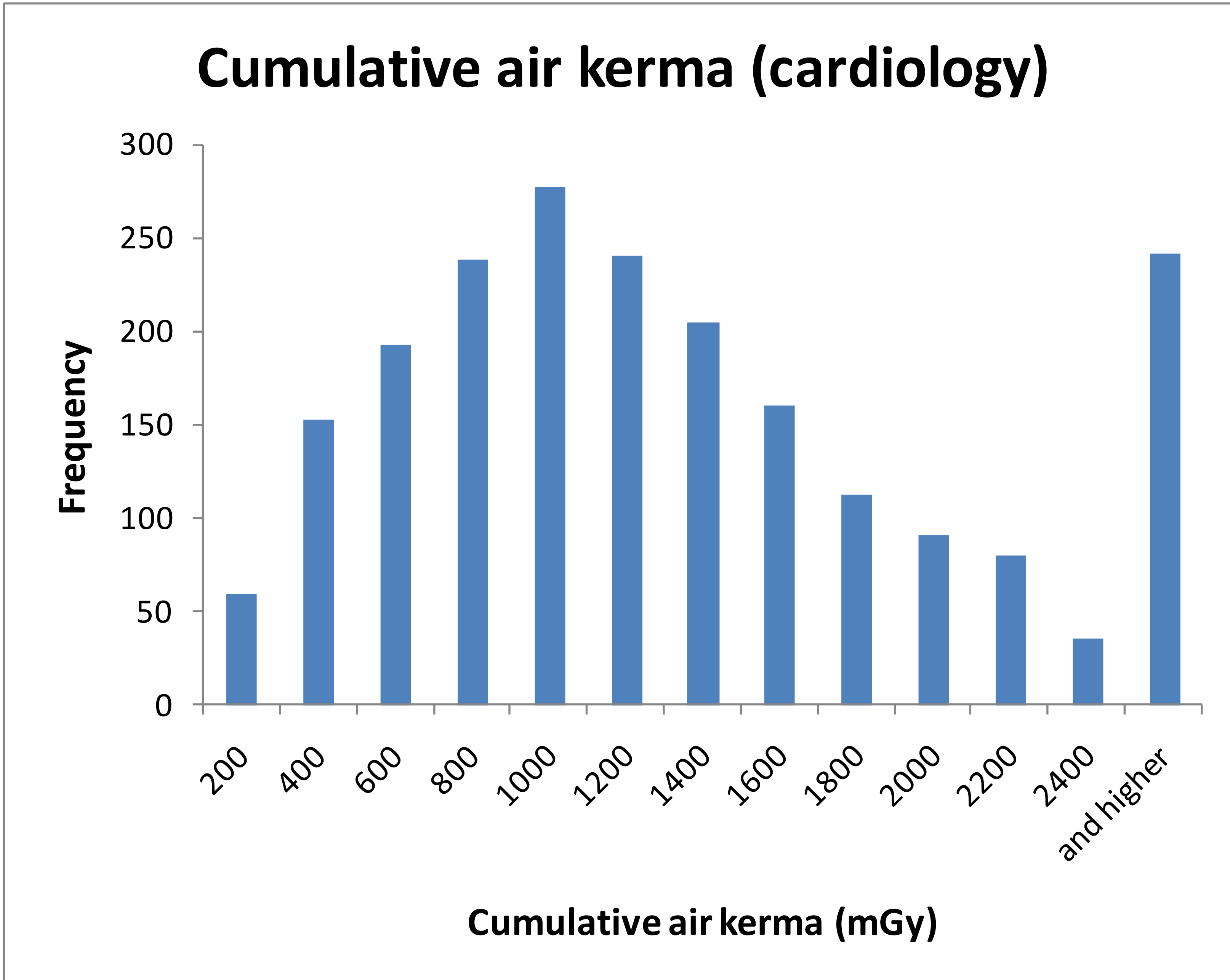
Courtesy E. Vano, Madrid

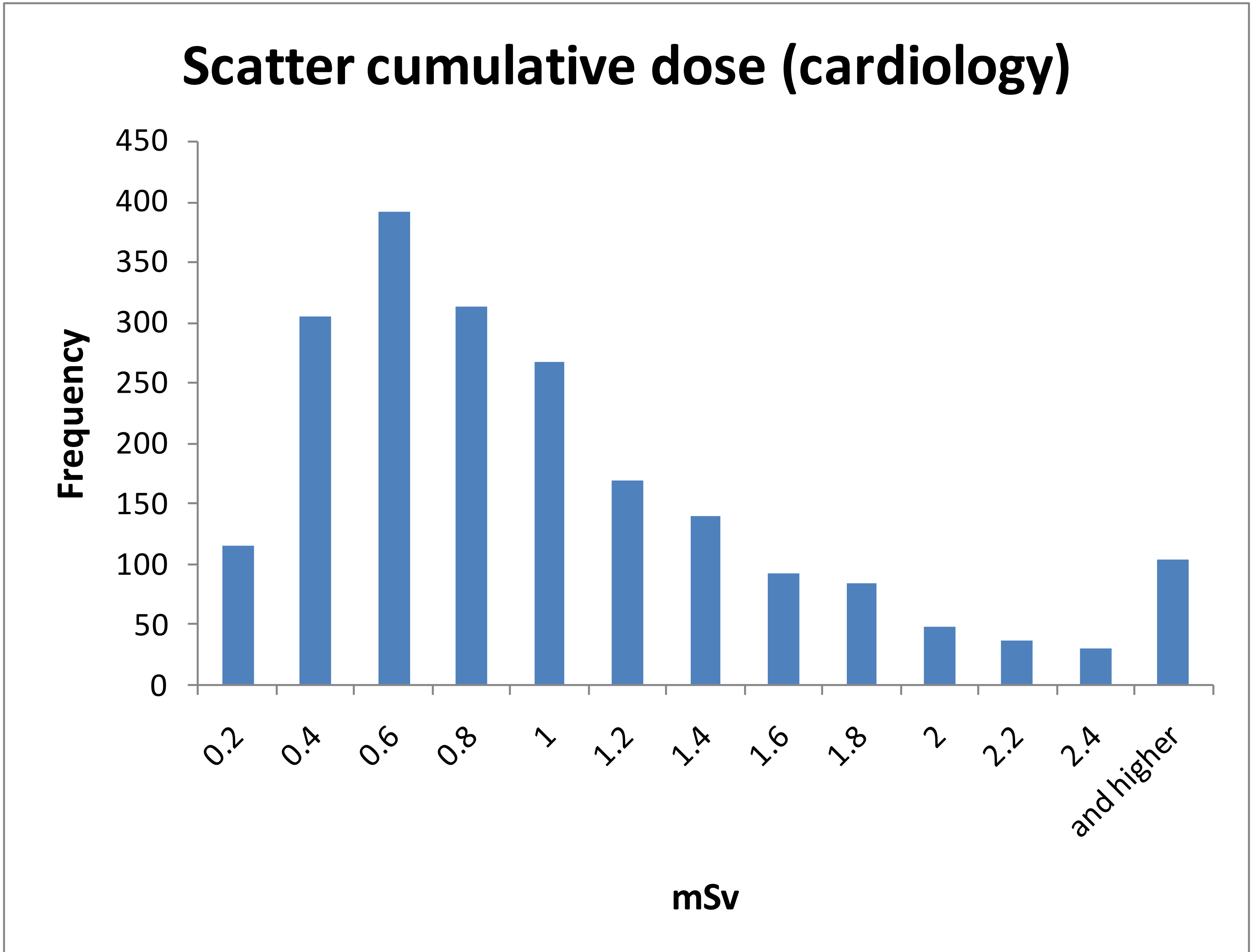


Courtesy E. Vano, Madrid

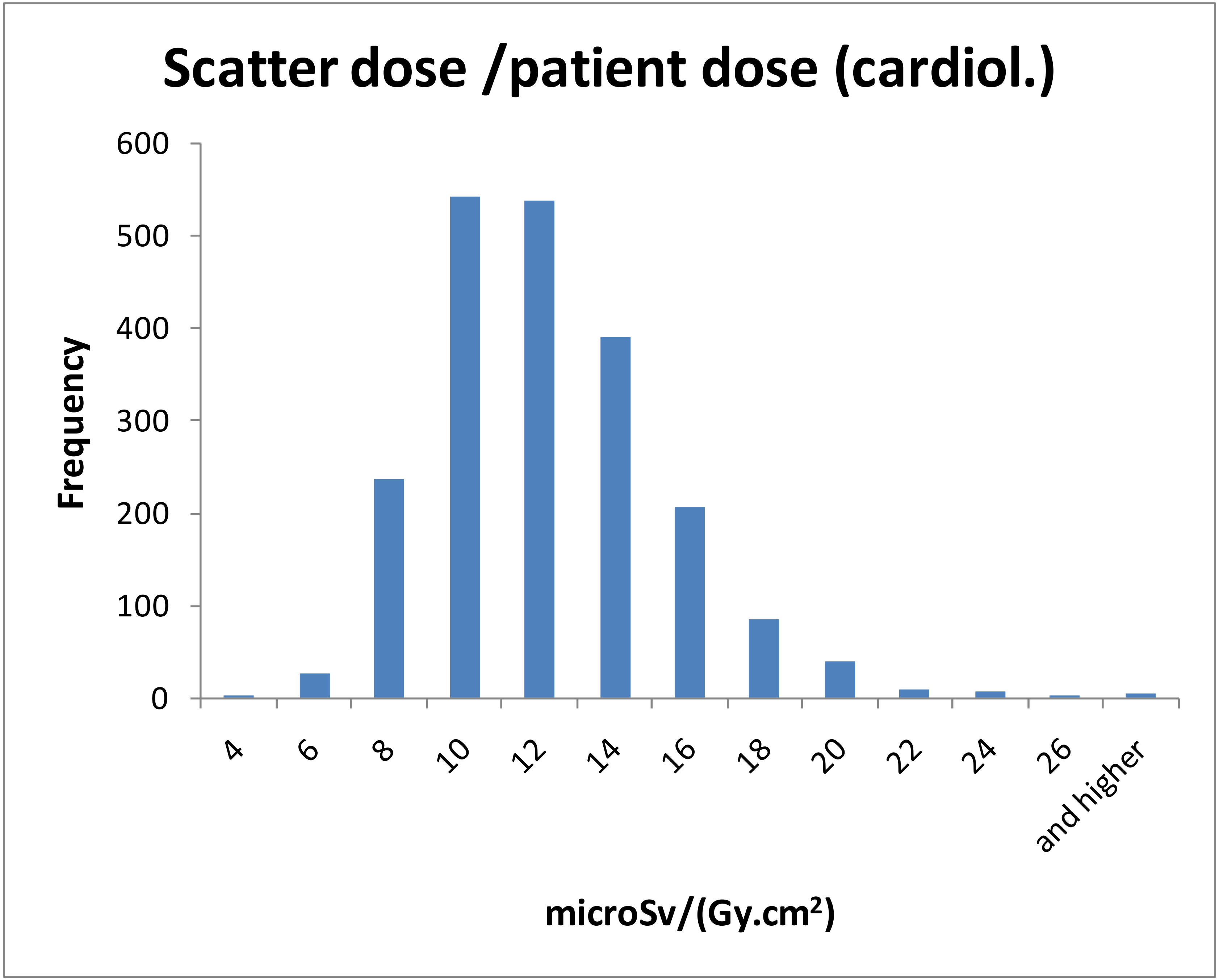


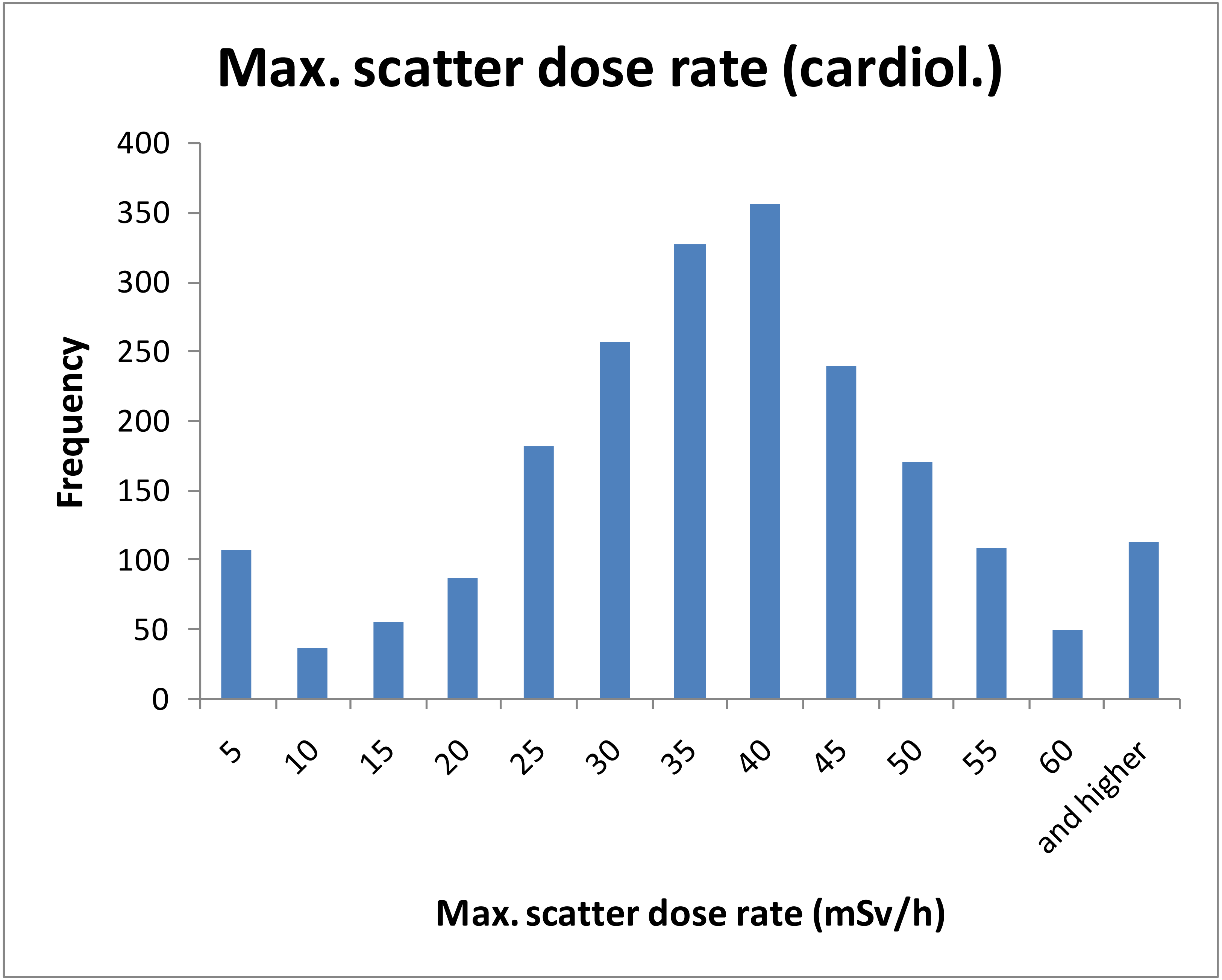
Kerma Area Product (cardiology)
Frequency
450
400
350
300
250
200
150
100
50
0
20
40
60
80
100
120
140
160
180
200
220
240
and higher
Gy.cm2

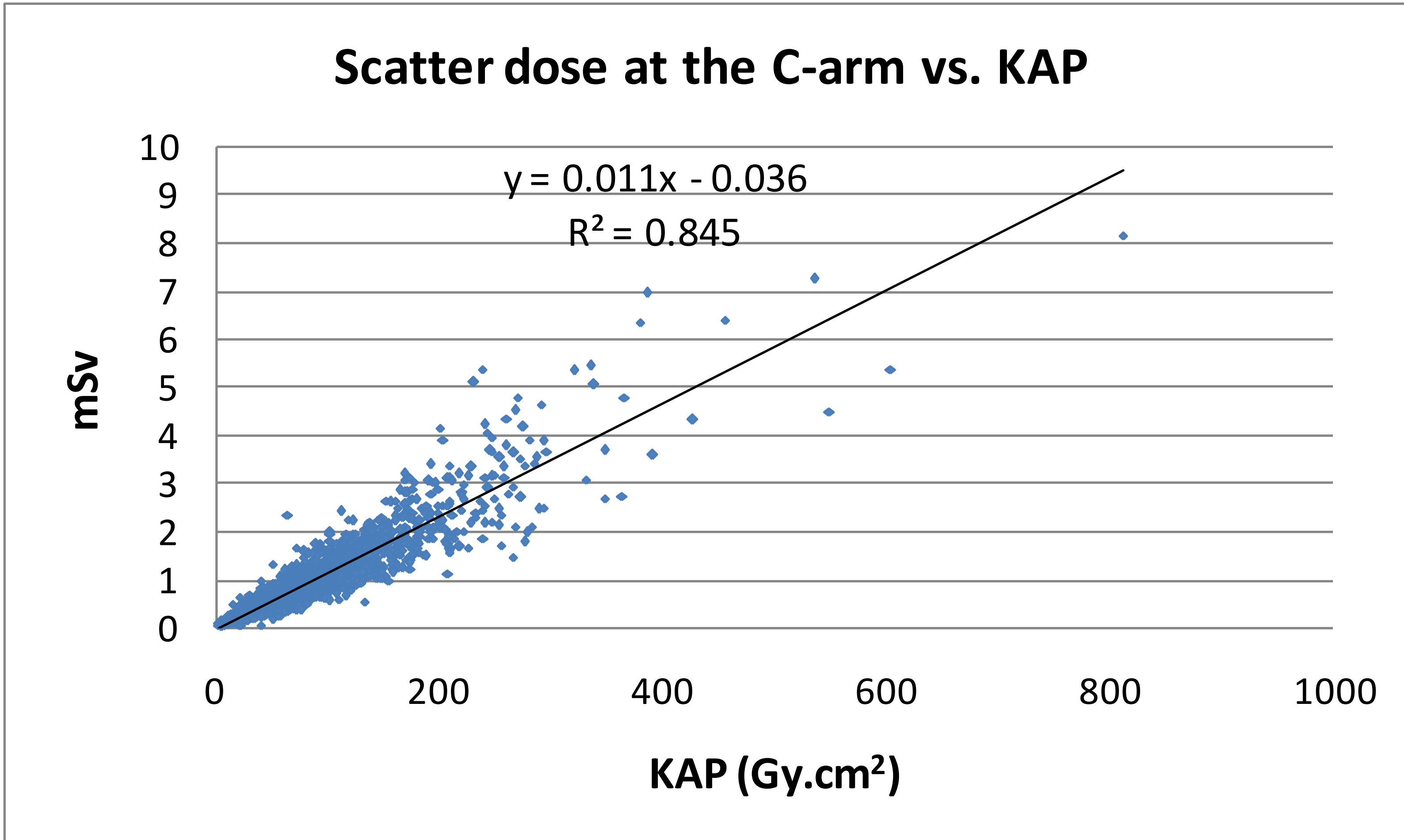

Cumulative air kerma (cardiology)
300
250
200
150
100
50
0
Frequency
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
and higher
Cumulative air kerma (mGy)



Scatter cumulative dose (cardiology)
Frequency
450
400
350
300
250
200
150
100
50
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
and higher
mSv


Scatter dose /patient dose (cardiol.)
Frequency
600
500
400
300
200
100
0
4
6
8
10
12
14
16
18
20
22
24
26
and higher
microSv/(Gy.cm²)


Max. scatter dose rate (cardiol.)
Frequency
400
350
300
250
200
150
100
50
0
5
10
15
20
25
30
35
40
45
50
55
60
and higher
Max. scatter dose rate (mSv/h)



Scatter dose at the C-arm vs. KAP
10
9
8
7
6
5
4
3
2
1
0
mSv
y = 0.011x - 0.036
R² = 0.845
0
200
400
600
800
1000
KAP (Gy.cm²)

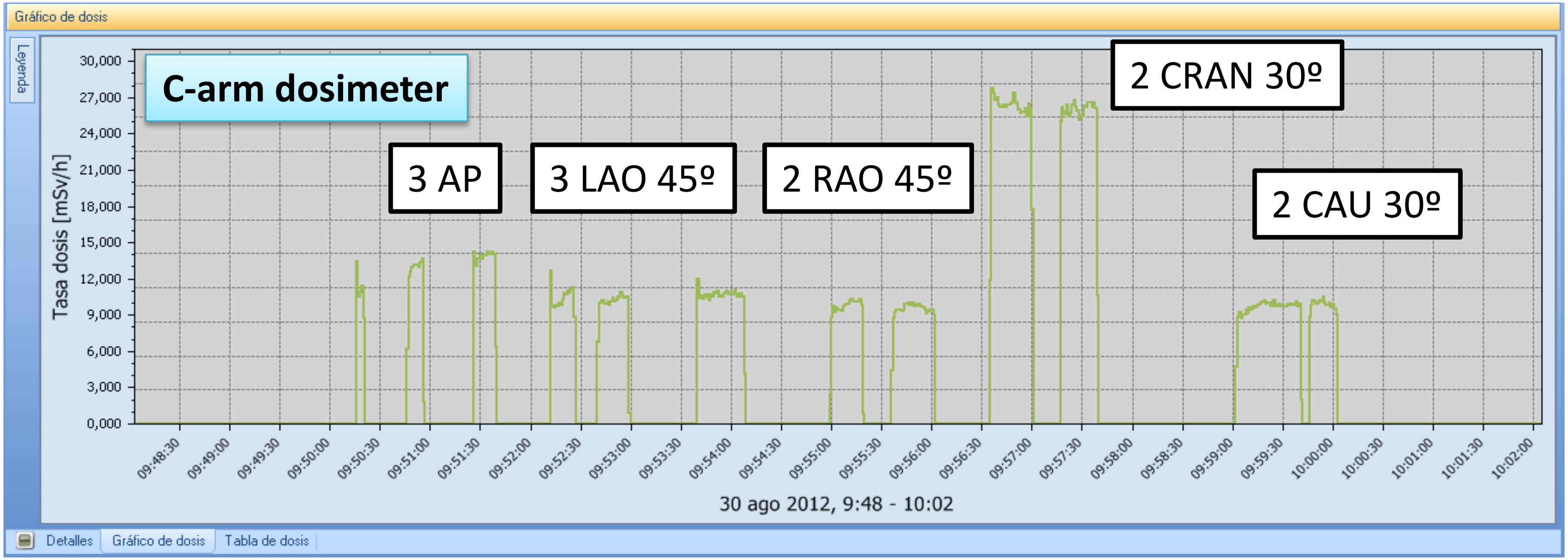


Gráfico de dosis
Leyenda
C-arm dosimeter
3 AP
3 LAO 45º
2 RAO 45º
2 CRAN 30º
2 CAU 30º
Tasa dosis [mSv/h]
30,000
27,000
24,000
21,000
18,000
15,000
12,000
9,000
6,000
3,000
0,000
09:48:30
09:49:00
09:49:30
09:50:00
09:50:30
09:51:00
09:51:30
09:52:00
09:52:30
09:53:00
09:53:30
09:54:00
09:54:30
09:55:00
09:55:30
09:56:00
09:56:30
09:57:00
09:57:30
09:58:00
09:58:30
09:59:00
09:59:30
10:00:00
10:00:30
10:01:00
10:01:30
10:02:00
30 ago 2012, 9:48 - 10:02
Detalles
Gráfico de dosis
Tabla de dosis

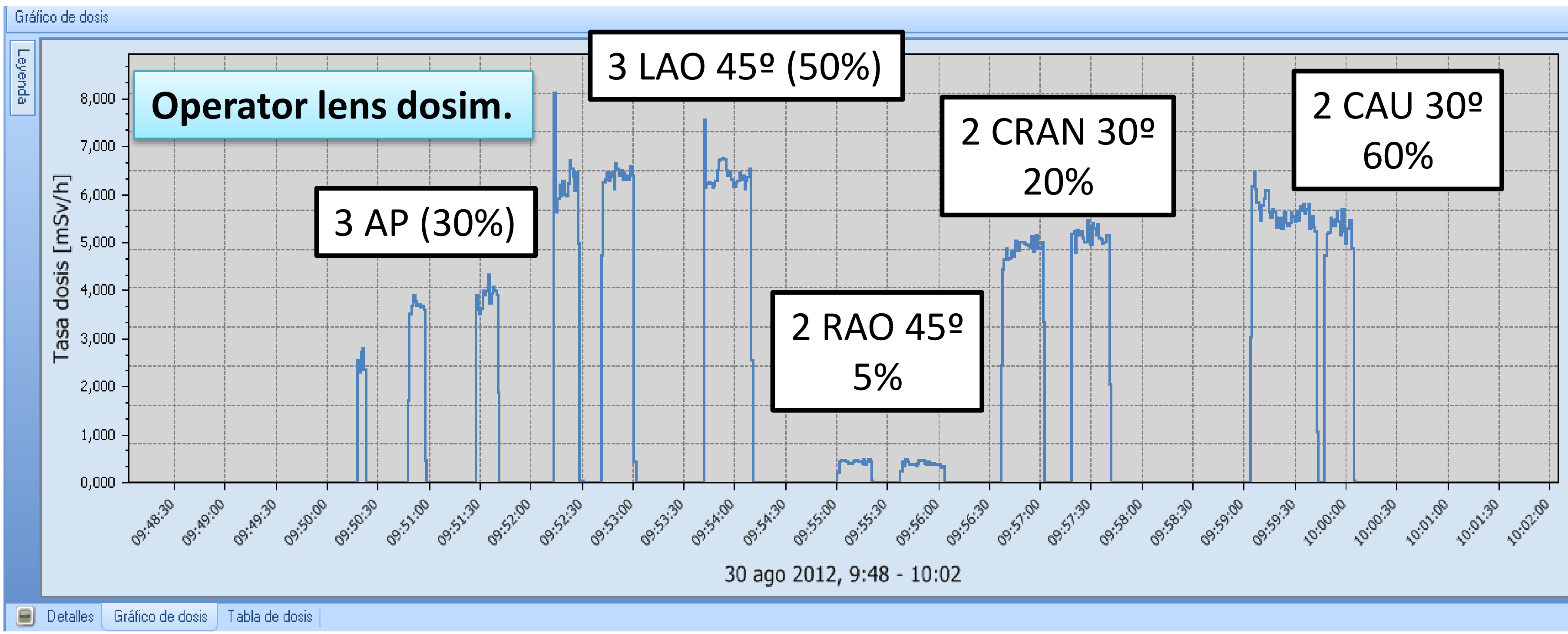


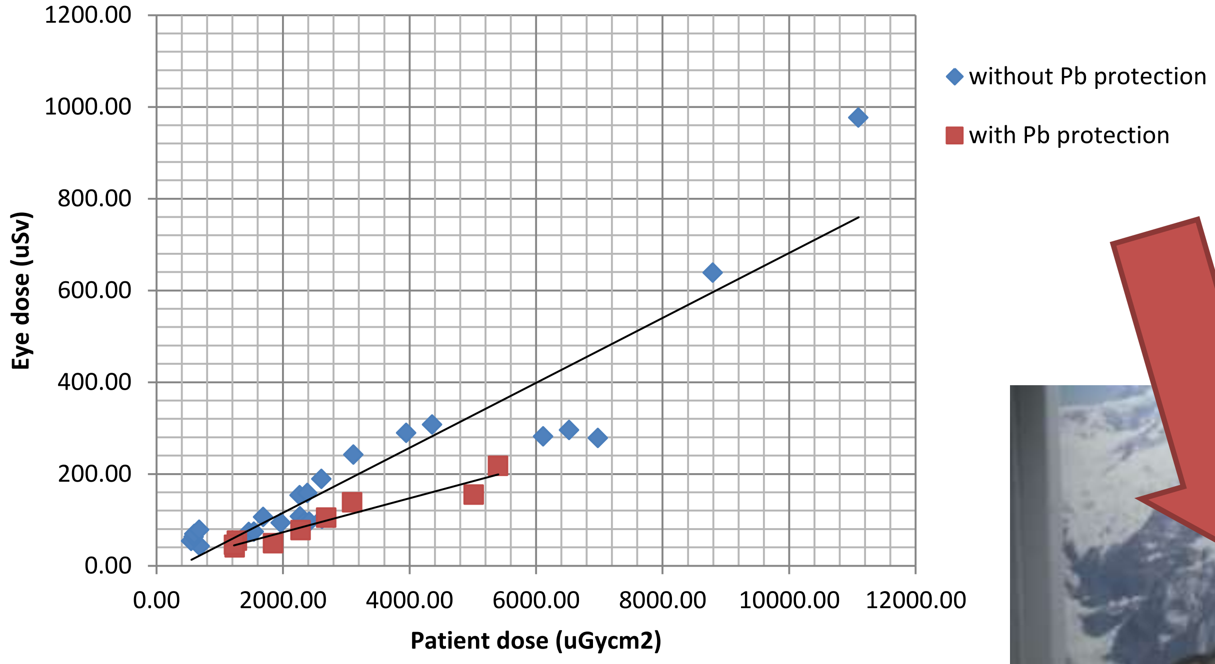
Gráfico de dosis
Leyenda
Operator lens dosim.
3 AP (30%)
3 LAO 45º (50%)
2 RAO 45º
5%
2 CRAN 30º
20%
2 CAU 30º
60%
Tasa dosis [mSv/h]
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0,000
09:48:30
09:49:00
09:49:30
09:50:00
09:50:30
09:51:00
09:51:30
09:52:00
09:52:30
09:53:00
09:53:30
09:54:00
09:54:30
09:55:00
09:55:30
09:56:00
09:56:30
09:57:00
09:57:30
09:58:00
09:58:30
09:59:00
09:59:30
10:00:00
10:00:30
10:01:00
10:01:30
10:02:00
30 ago 2012, 9:48 - 10:02
Detalles
Gráfico de dosis
Tabla de dosis

Typical dose levels

- **CA and PCI: (157±126)μSv with range 0.72-600 μSv for cardiology**
- **Electrophysiology procedures: (30±19) μSv with range 7.7-70 μSv**
- **Gastroenterology interventions (various stenting procedures): (211±202) μSv with range from 42-976 μSv**

Upcoming publication in Health Physics

Gastroenterology interventions (overcoach x-ray tube)



Possible approaches

Practical dosimetry:

1. Passive dosimeters
2. Active dosimeters
3. Retrospective dose assessment using scatter radiation dose levels
4. Correlations between patient dose indices and eye doses to the operators

Retrospective dosimetry

- **Reconstruction of the laboratory workload (types and numbers of procedures)**
- **Usually with questionnaires and the application of many assumptions about past activity (procedures performed, corresponding doses based on previous dosimetric studies and the use of radiation protection tools)**
- **Various uncertainties**
- **Sometimes only possible approach**

Protection tools/activity	Dose modification factor	Remark
Ceiling screen	1.6-2.3	Reduction ratio in terms of Hp(0.07)/KAP for left and middle eye
Ceiling screen	1.8-2.5	Dose ratio without and with ceiling shield
Ceiling screen	54	Dose rate ratio without and with ceiling shield, phantom study
Ceiling screen	38%	Dose reduction by1.0 to 1.5 mm lead equivalent screen
Ceiling screen	20	Dose rate reduction factor
Ceiling screen	2-7	Dose reduction factor for the eye dose
Ceiling screen/upper body shield	40-90%	Dos reduction, depending on upper body shield position
X-ray tube orientation (biplane vsundrecoch)	0.4	Ratio of Hp(0.07)/P_{KA} for biplane and undercouch geometry
X-ray tube orientation (AP vs PA)	7/8.1	Dose ratio for thorax irradiation for femoral/radial access
X-ray tube orientation (AP vs PA)	2-27	Dose ration for factor
X-ray tube orientation (LAO 90°vs RAO 90°)	7.0	Dose ratio for thorax irradiation
Lead glasses	0.13-0.30	Dose ration with and without glasses depending on the type of glasses and x-ray tube orientation, Monte Carlo simulations
Lead glasses	0.2	Dose reduction factor
Lead glasses	2 (1.8-5.3)	Dose reduction factor
Collimation	No influence	Monte Carlo simulations
Beam quality	No influence	Monte Carlo simulations
Access route	2-7	If the shields are properly used, lower dose for femoral access

Dose information for various studies (I)

Model	Value	Unit	Source	Remark
n/a	59	μSv/proc	Tsapaki ate all, PMB, 2004	CA, 5 countries, shoulder dose
n/a	89	μSv/proc	Tsapaki ate all, PMB, 2004	PTCA, 5 countries, Shoulder dose
Philips Optimus M 200 Poly C	260	mSv/y	Vano, et al, BJR, 2006	5000 procedure/y
Philips Integris HM 300	31	mSv/y	Vano, et al, BJR, 2006	5000 procedure/y
Philips Integrtis N-5000	18	mSv/y	Vano, et al, BJR, 2006	5000 procedure/y
Philips Integrtis Allura	3.5	mSv	Kuipers et al, Cardiovas Int Rad, 2008	4 weeks, TLD above the apron
Philps Polydiagnost C2	0.21-0.37	mSv/proc	Steffino, et al BJR 1996	Ceiling screen in place
Not available	0.11	mSv/proc	Pratt and Shaw, BJR, 1993	Ceiling screen and Goggles in place
CGR DG 300	0.014	mSv/proc	Marshall et al, BJR 1995	Eye dose, lead shield
Siemens Angioskop D	0.28	mSv/proc	Calkins et al, circulations, 1991	Eye, Ceiling screen in place
Philips Alura 10FD/20FD. GE Advantix, Philips Intergris 3000/5000, Siemens Axiom bip A	Table 1	Sv//h	Vano et al. Radiology 2008.	Dose rate at 1 m. h=1.6 m for different modes (fluoro. cine..)

Dose information for various studies (II)

Model	Value	Unit	Source	Remark
Philips Integris Allura	3.85	mSv/4 weeks	Kuipers et al, J Inte Card, 2008	TLD dose above the apron, mean value for 7 radiologists
Average 35 institutions	48	mSv/y	Niklason at al, Radiolgy, 1993	972 procedures/y, dose above the apron
Philips Integris 3000, II GE L-U, II	6.55	mSv/month	Williams, BJR, 1997	46 procedures/month, neck dose
Not available	Figure 2.b	µGy/min	Whitby, et al, BJR, 2005	PTCA
Different types of systems, average values	0.5 (IC) 0.15 (nurses)	mSv/proc	Vano et al, BJR , 1998	Without protective tools
Philips Integris V 3000	Figs 3.4,6,7	µGy/min	Whitby, BJR, 2003	Diagrams for PA, RAO, LAO projections
Different units	Table 3	µ Sv/proc	Vano, et al, BJR, 1998	TLD dose, eyes, with and without protective screen
Philips Integris HM 3000	Figs 4.5. 7-11	µGy/min	Morrish et al BJR, 2008	Scatter dose rate for fluoroscopy and acquisition for different projections

Remarks

- Reported eye lens doses:
  - 0.3-11 mGy/study (without use of protective devices)
  - 0.011-0.33 mGy/study (with protective devices)
- Multiple dosimetry quantities: air kerma, H*(10), Hp(10), Hp(3)…)
- Inaccuracy in dose assessment for nurses due to large variability of location and multiple tasks performed

Our Decision

- Typical doses if protective devices are not used
  - *0.5 mGy/procedure for interventional cardiologists*
  - *0.15 mGy/procedure for and nurse*
- This exposure corresponds to a typical procedure of 10 min of fluoroscopy and 800 cine frames

Radiation dose assessment

Typical doses if protective devices are not used:
- *0.5 mGy/procedure for interventional cardiologists*
- *0.15 mGy/procedure for and nurse*

Workload:
- *number of procedures per week*
- *fluoroscopy time*
- *number of cine series per procedure*
- *number of frames per series*

Use of protective devices:
- *ceiling suspended screens (factor: 0.1)*
- *leaded glass eyewear (factor: 0.1)*

Angulations *(factor: 1.8)*
Radial access *(factor: 2.0)*

Dose related parameters (I)

Parameter	Source
Number of years in interventional cardiology	form
Model of fluoroscopy system used (in the past/now)	form
Use of ceiling suspended screens (in % of time period), S	form
Use of goggles (in % of time period), G	form
Workload: number of procedures/week	form
Fluoroscopy time/procedure	form
No of frames/procedure (no of frames/series and series/ procedure)	form

Dose related parameters (II)

Parameter	**Source**	**Value**	**Factor**
Attenuation of goggles, A	literature	90%	$1-\frac{G(1-A)}{100}$
Attenuation of ceiling suspended screen, B	literature	90%	$1-\frac{S(1-B)}{100}$
Distance from isocenter	literature	75 cm	ISL
For particular procedure. for different models of interventional systems at eye level scatter dose: • Dose rate [Sv/h] • Normalized dose rate [Sv/mAs] • Total dose for typical procedure [Sv/study]	literature; different sources to match the model of the system		
Angulations	literature: Vano, 2006 Batsou, 1998 Morrish, 2008	1.8	
Radial access	literature: IAEA, 2004 Vano, 2008	2	

Dose assessment

Scenario	**Calculation**
Information about model of the unit, workload and typical procedure parameters are available	•Scattered dose rate •Correction for distance, use of protective devices, angulation, radial access •Dose ate eye level for typical procedure •Annual dose/dose for the whole period use of a particular system
Information about model and workload is available (procedure parameters are not available)	•Typical exposure parameters from the literature for a particular or similar type if system (10 min fluoroscopy time and 800 cine frames) •Same a previous

Angulation for typical procedure (CA)

	Betsou et al. BJR, 1998	Vano et al. Radiology, 2008.	Average
PROJECTION	TIME (%)	mSv/h	mSv/h
PA	11.50	1.00	0.12
PA CD	0.50	1.00	0.01
PA CR	5.90	1.00	0.06
RAO	7.50	1.00	0.08
RAO CD	15.80	1.00	0.16
RAO CR	4.20	1.00	0.04
LAO	26.30	2.00	0.53
LAO CD	11.90	2.50	0.30
LAO CR	15.10	3.00	0.45
L LAT	1.30	5.00	0.07
	100.00		**1.8**

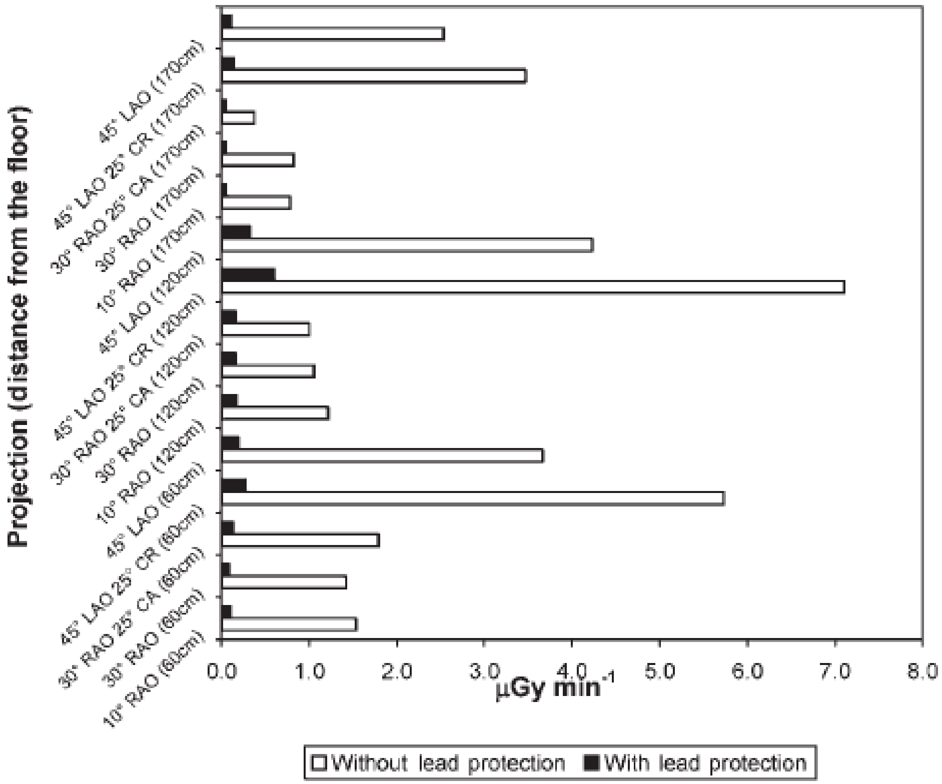


Figure 4. Measurements during fluoroscopy at the 210° position (cardiologist's position) with and without lead protection. RAO, right anterior oblique; LAO, left anterior oblique; CA, caudal; CR, cranial.

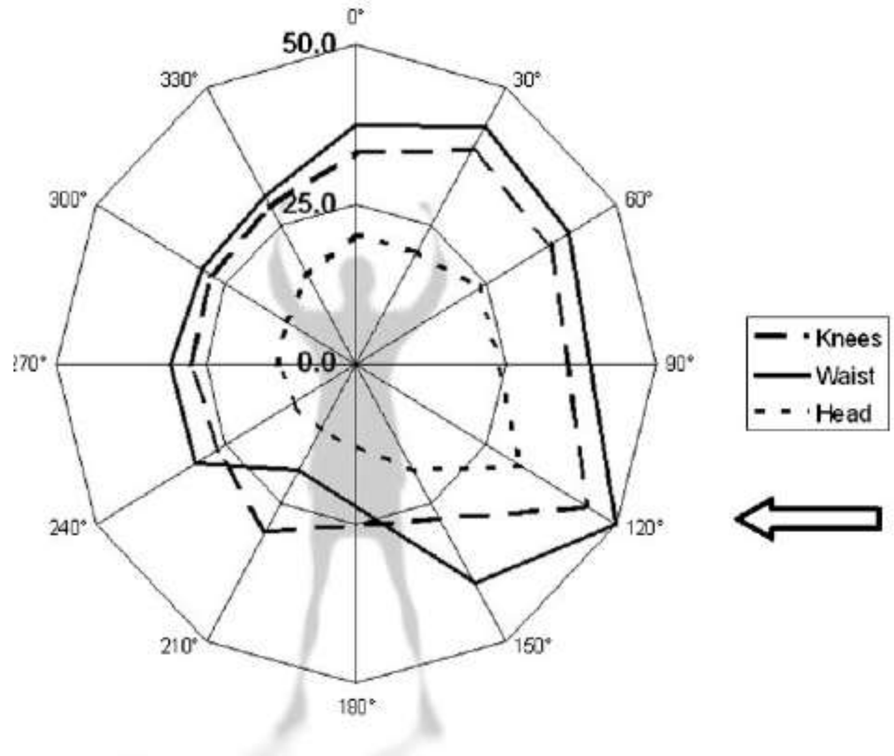


Figure 8. Distribution of scattered radiation from digital acquisition on the 10° right anterior oblique (RAO) projection at 68 kVp. The radial axis shows the dose in μGy min^{-1}, whereas the ionization chamber position is indicated on the circumference. The figure shows the patient position from above, and the arrow shows the direction of the primary beam. Data for points not measured at 90°, 180° and 150° at 60 cm have been interpolated.

O W E Morrish and K E Goldstone

The British Journal of Radiology, January 2008

Possible approaches

Practical dosimetry:

1. Passive dosimeters
2. Active dosimeters
3. Retrospective dose assessment using scatter radiation dose levels
4. **Correlations between patient dose indices and eye doses to the operators**

Correlation of patient’s dose with operators’ eye lens dose

- No clear consensus on the correlation between the patient dose and the dose to the eyes of the medical staff
- Correlation between the eye dose and kerma-area product strongly depends on two main parameters:
  - X-ray tube configuration
  - use of collective radiation protection tools

Eye doses and eye dose normalized to respective kerma-area product for interventional cardiology procedures for position of the first operator

Source	Eye dose (μSv)	Eye dose/ P_{KA} (μSv/(Gycm^2))
Antic et al [10]	121±84 (4.5-370)	0.94±0.61
Donadille et al[48]	52±77 (4-644)	1.0
Kim et all 2008[49]	170-439	/
Vanoet al [50]	170 (53-460)	3.3-6.0
Efstathopoulos et al[19]	13	1.37
Bor et al [44]	72 (32-107)	0.86 (0.46-1.25)
Martin [16]	66 (5-439)	1.0
Vanhavere et al [40]	/	1.0
Pratt et al [47]	15-53	/
Jacob et al [14]	14-439	/
Oydis et al [30]	44 (10-223)	0.6 (0.2-2.6)

Recommendations

- Use of active dosimeter is most appropriate option for periodic assessment
- Passive dosimeter for regular and continuous monitoring of eye dose and compliance with regulatory limits as passive
- If a dedicated eye dosimeter is not available:
  - estimation of eye dose from patient dose

Future challenges

- Development of practical methods for regular monitoring of individual eye doses
- Development of better techniques to estimate eye dose from measurements at some reference points

Thank You

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