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Joint ICTP/IAEA Advanced School on Dosimetry in Diagnostic Radiology and its Clinical Implementation

11 - 15 May 2009

Dosimetry in Interventional Radiology

Renato Padovani
EFOMP

Joint ICTP-IAEA Advanced school on Dosimetry in Diagnostic Radiology:
And its Clinical Implementation
11 - 15 May 2009; Miramare, Trieste, Italy

Dosimetry in interventional radiology

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Introduction

- Introduction to interventional radiology
- Dosimetry in IR
  - Code of Practice
  - Skin dosimetry methods

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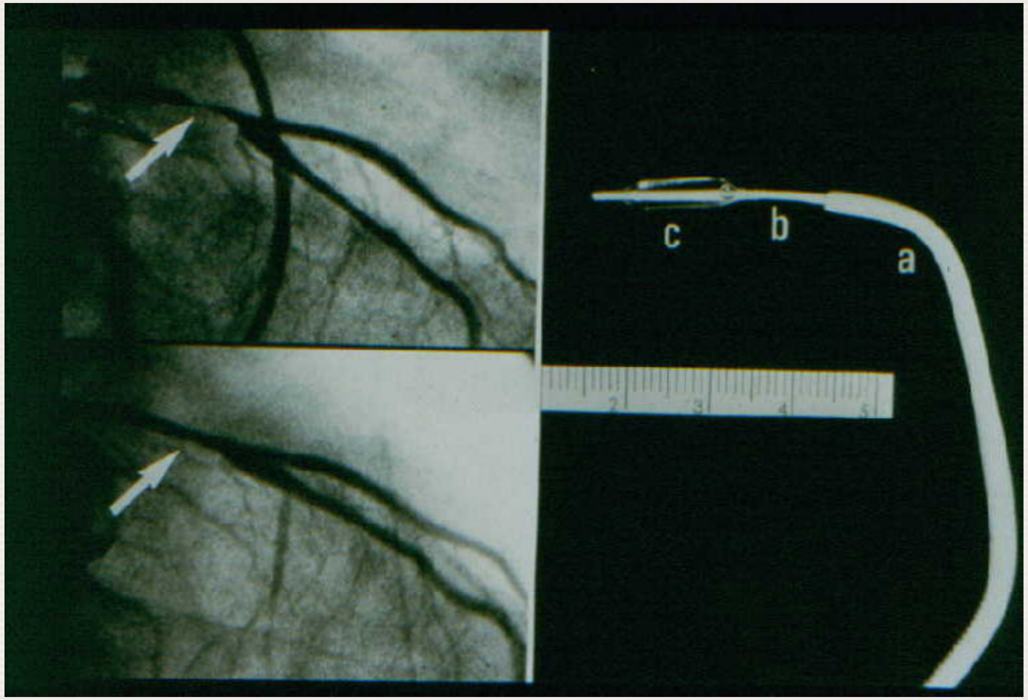
Interventional era started in 1977

- Gruntzig, Zurich
- Crude catheters
- Long fluoroscopy
- Many cine runs
- Big increase in radiation to staff and patients

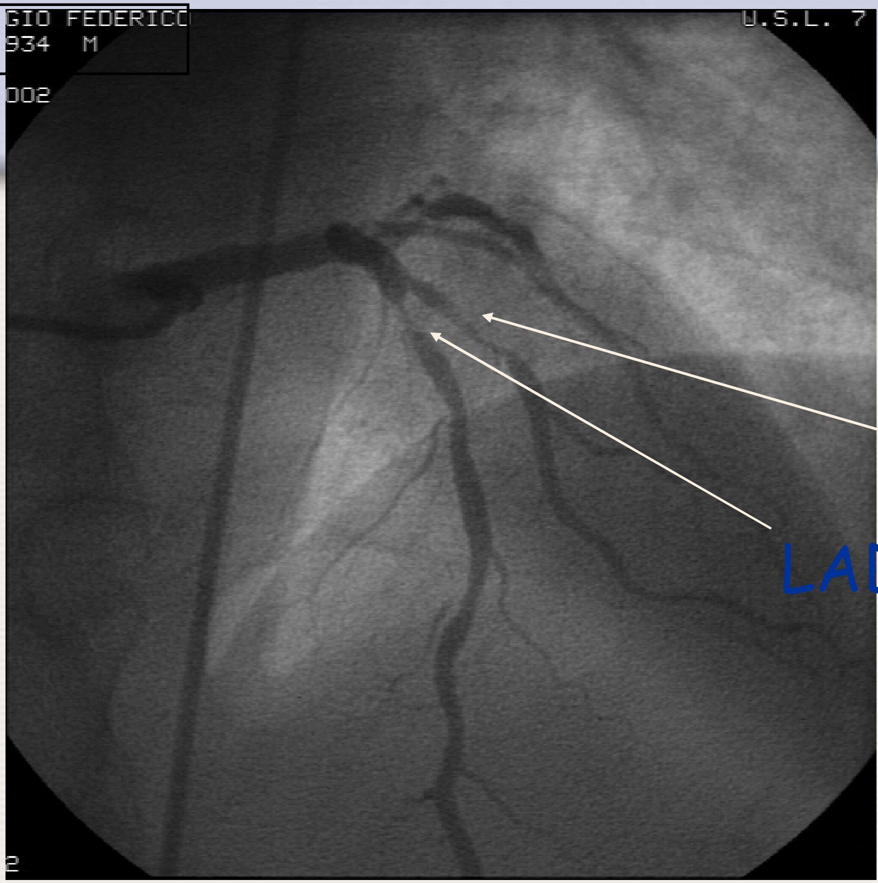


Interventional radiology: guided fluoroscopy

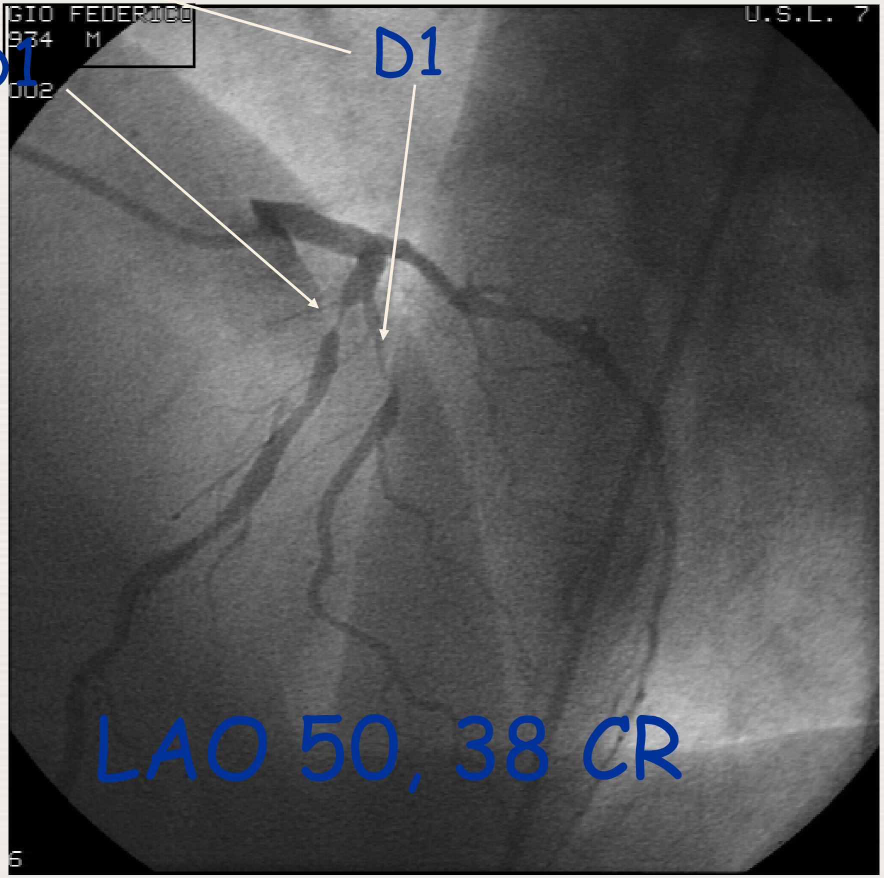
Interventional cardiology

PTCA

Case: bifurcation lesion



AP, 38 CR



LAO 50, 38 CR

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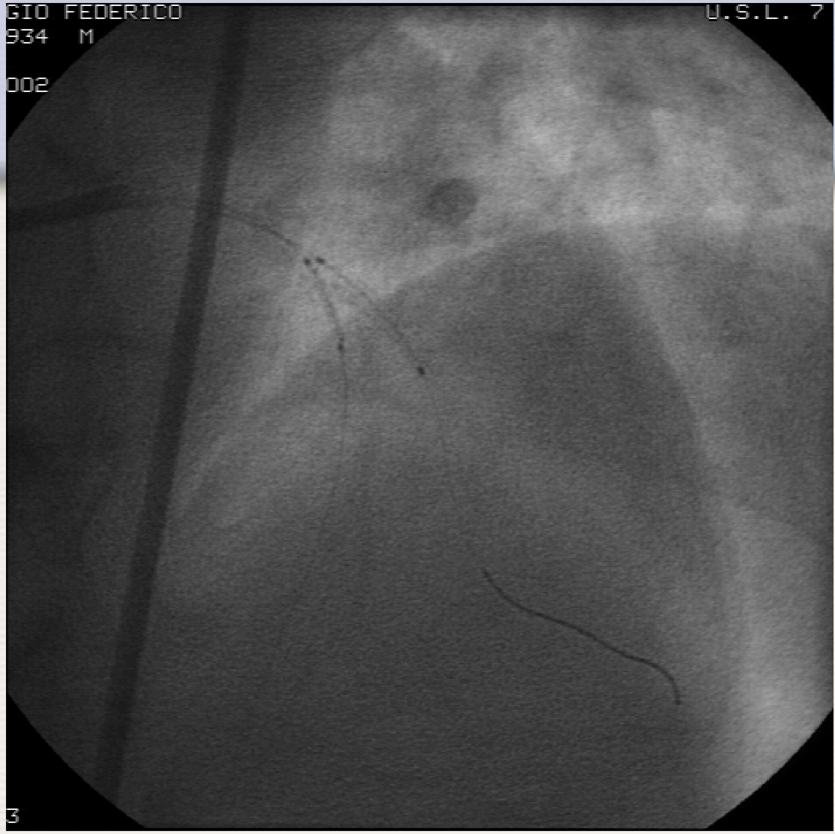
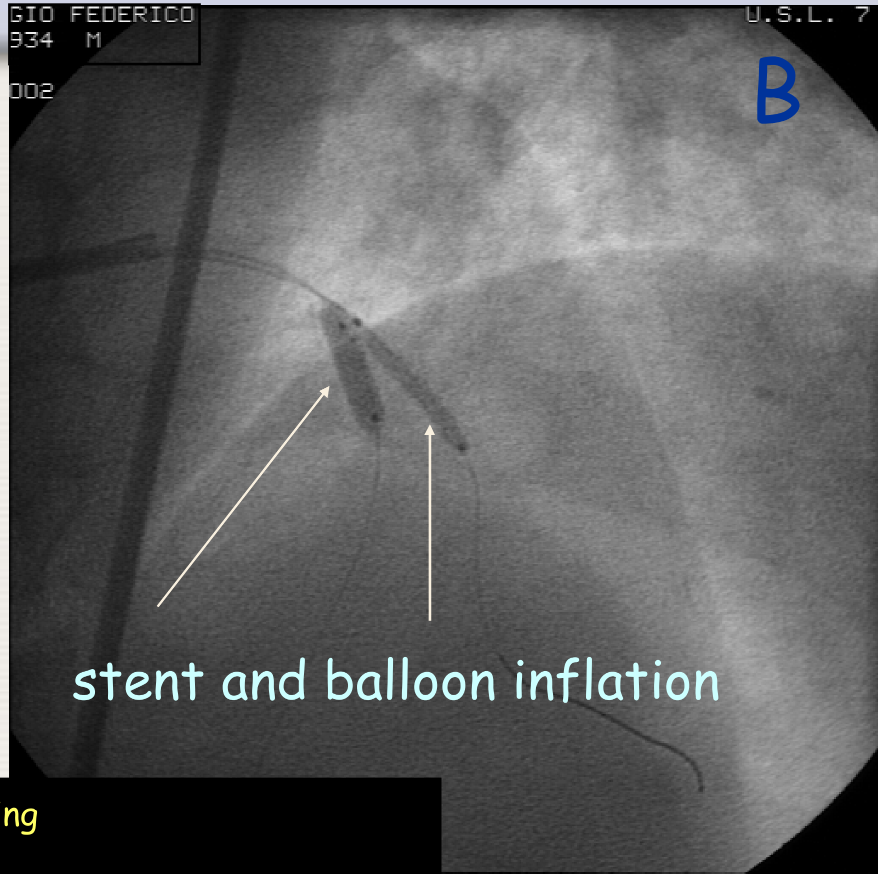
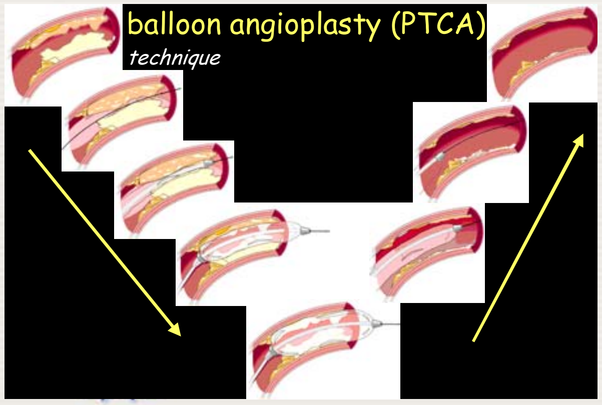
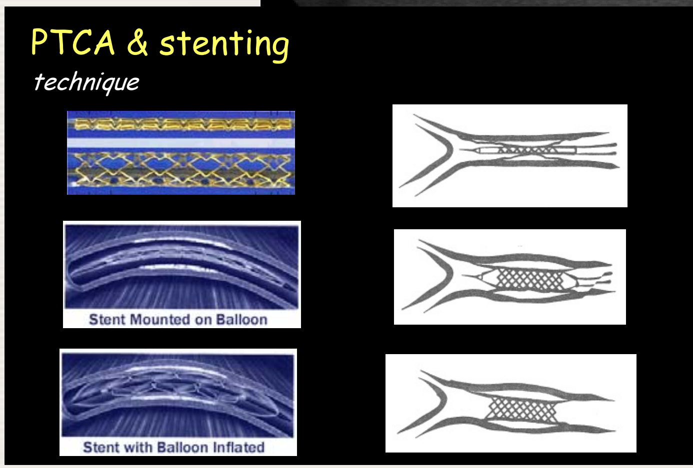
Case 1 bifurcation lesion



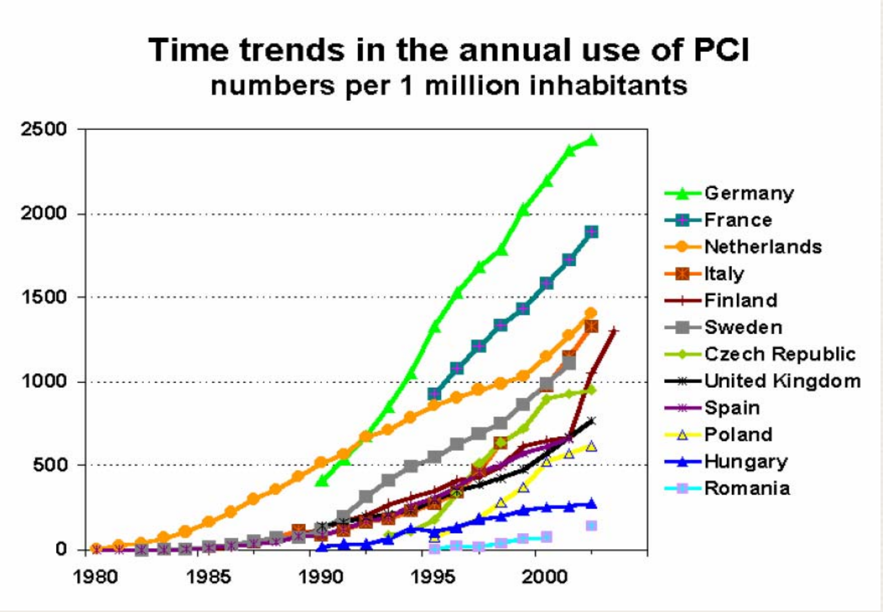






The frequency of procedures in Europe

- Number of diagnostic and interventional cardiac procedures (PCI) per million inhabitants in European countries is continuously increasing
- Practice is not uniform across Europe



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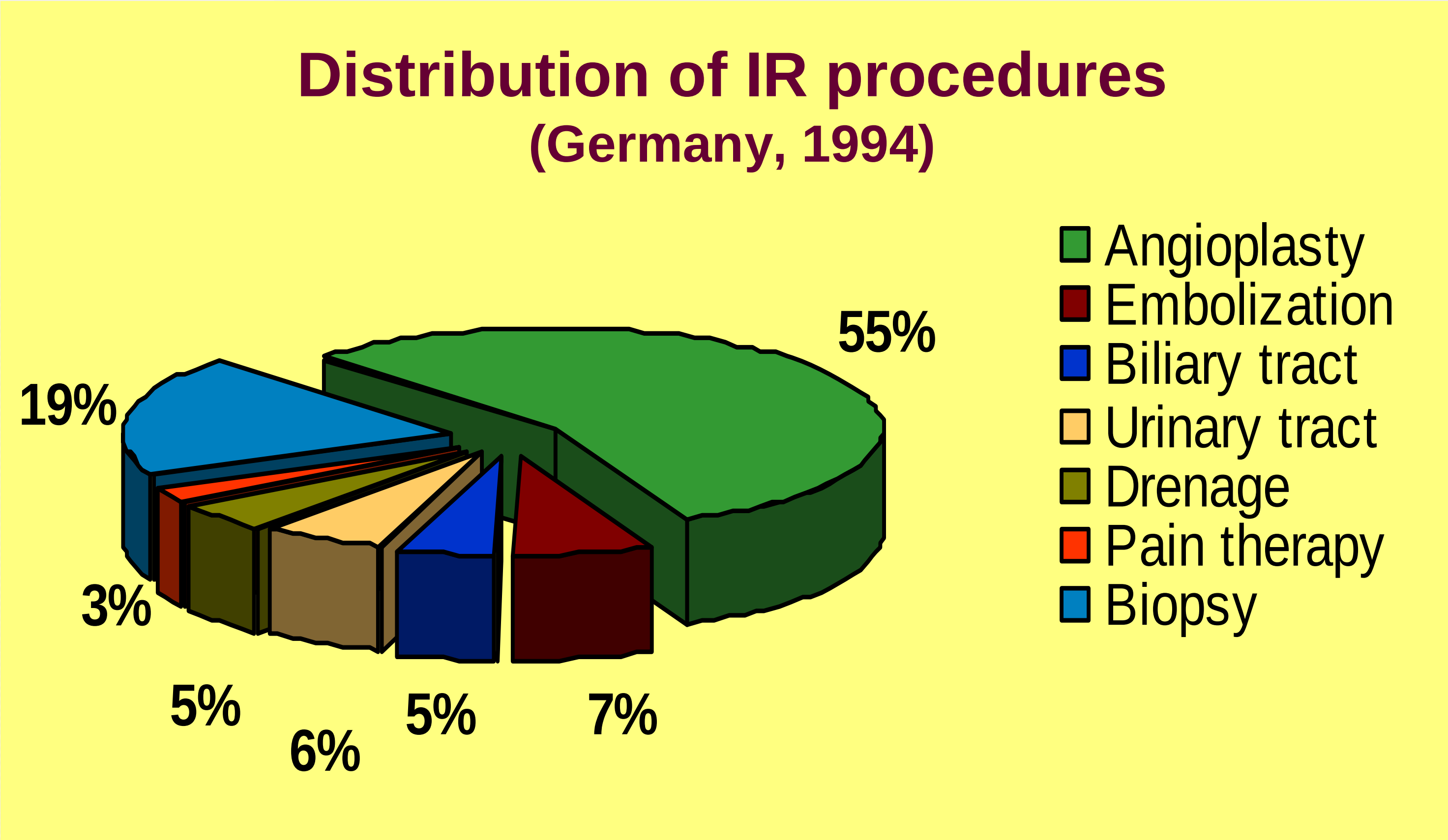
The practice: type of procedures



Most of them are fluoroscopy guided procedures

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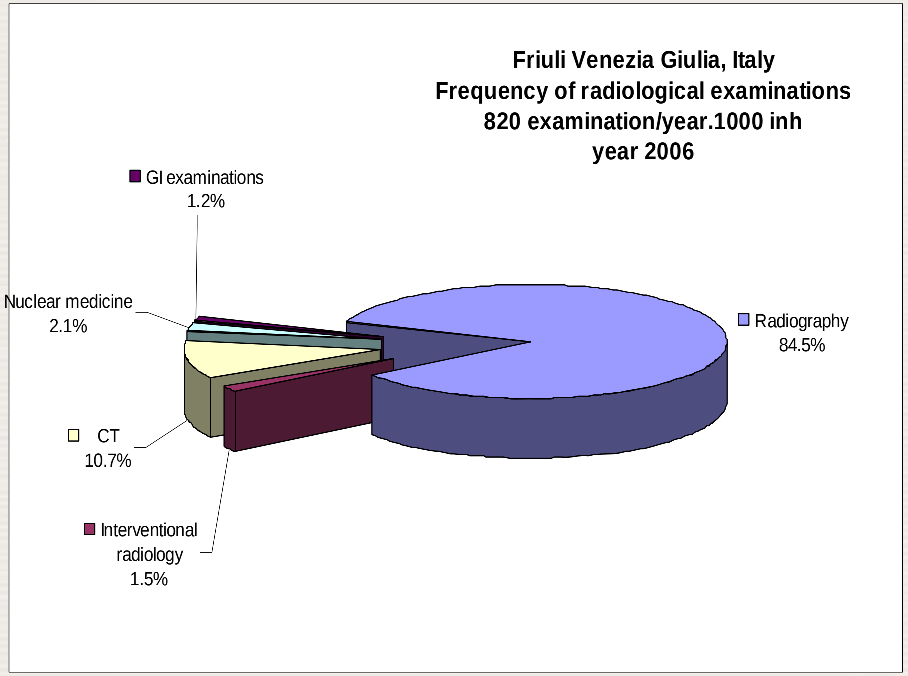
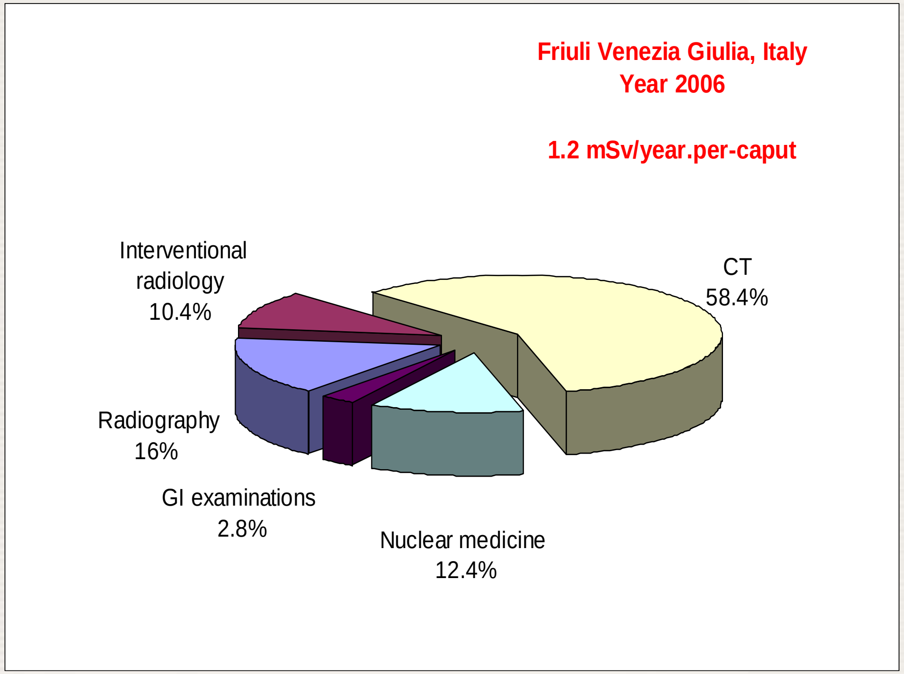
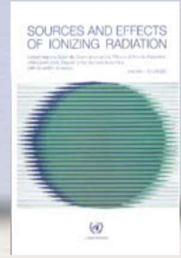
Frequencies and contribution to the collective effective dose of IR





R.Padovani & others, North-east Italy, 2006

Patient dose range
in angiographic procedures
(UNSCEAR 2000)



Angiographic Procedure	*Technique*	*Fluoro time (min)*	*KAP ($Gy.cm^2$)*	*Effective dose (mSv)*
Coronary	Cine film	3.6 – 9.8	16.1 - 98	2 – 15.8
	Digital cine	5.7	47.7	9.4
Cerebral	DSA/conventional	1.2 – 36	12 – 120	2.7 – 23.4
Abdominal	Hepatic (DSA)	2.3 – 28.6	28 – 279	4 – 48
	Renal DSA	5.5 - 21	41 - 186	6 - 34
	Renal angiogr.	0.5 – 9.3	17 – 327	2.8 – 11.5

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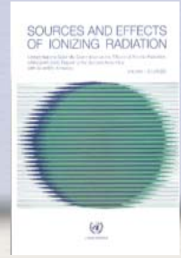
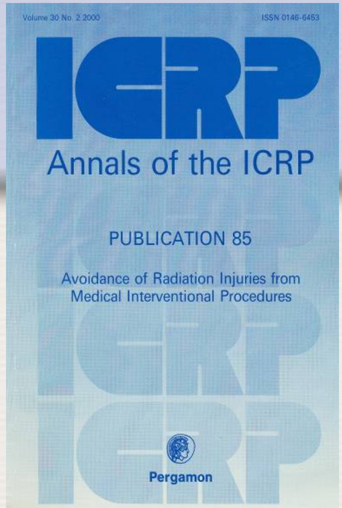
Patient dose range in interventional procedures (UNSCEAR 2000)



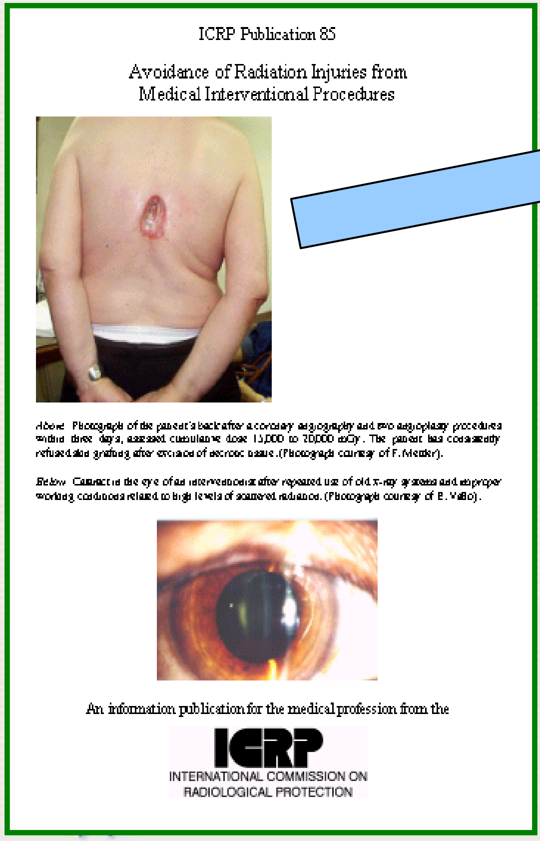
Interventional procedures	*Localized dose to skin (Gy)*	*Fluoro time (min)*	*KAP (Gy.cm^2)*	*Effective dose (mSv)*
PTCA	0.05 - 5	3 - 92	20 - 402	7.5 - 57
PTA	0.4	5 – 68	5 – 338	10 – 12.5
TIPS	0.4 – 5	9 – 115	7 - 1131	2 - 181
RF ablation	0.1 – 8.4	3 - 195	7 – 532	17 – 25
Embolization	0.2 – 0.5	1 – 90	7 – 918	6 – 43

ICRP recognise as ‘high dose’ procedures, giving potentially high skin doses:

- **Embolisation: aneurysm and arteriovenous malformation**
- **Angioplasty (cardiac = PTCA)**
- **Radiofrequency ablation**
- **Transjugular intrahepatic porto-systemic shunt (TIPS)**



✓ICRP report 85 (2001): Avoidance of Radiation Injuries from Interventional Procedures


ICRP Publication 85

Avoidance of Radiation Injuries from Medical Interventional Procedures

Above: Photograph of the patient's back after a coronary angiography and two angioplasty procedures within three days, assessed cumulative dose 15,000 to 20,000 mGy. The patient has consistently refused skin grafting after excision of necrotic tissue. (Photograph courtesy of F. Mettler).

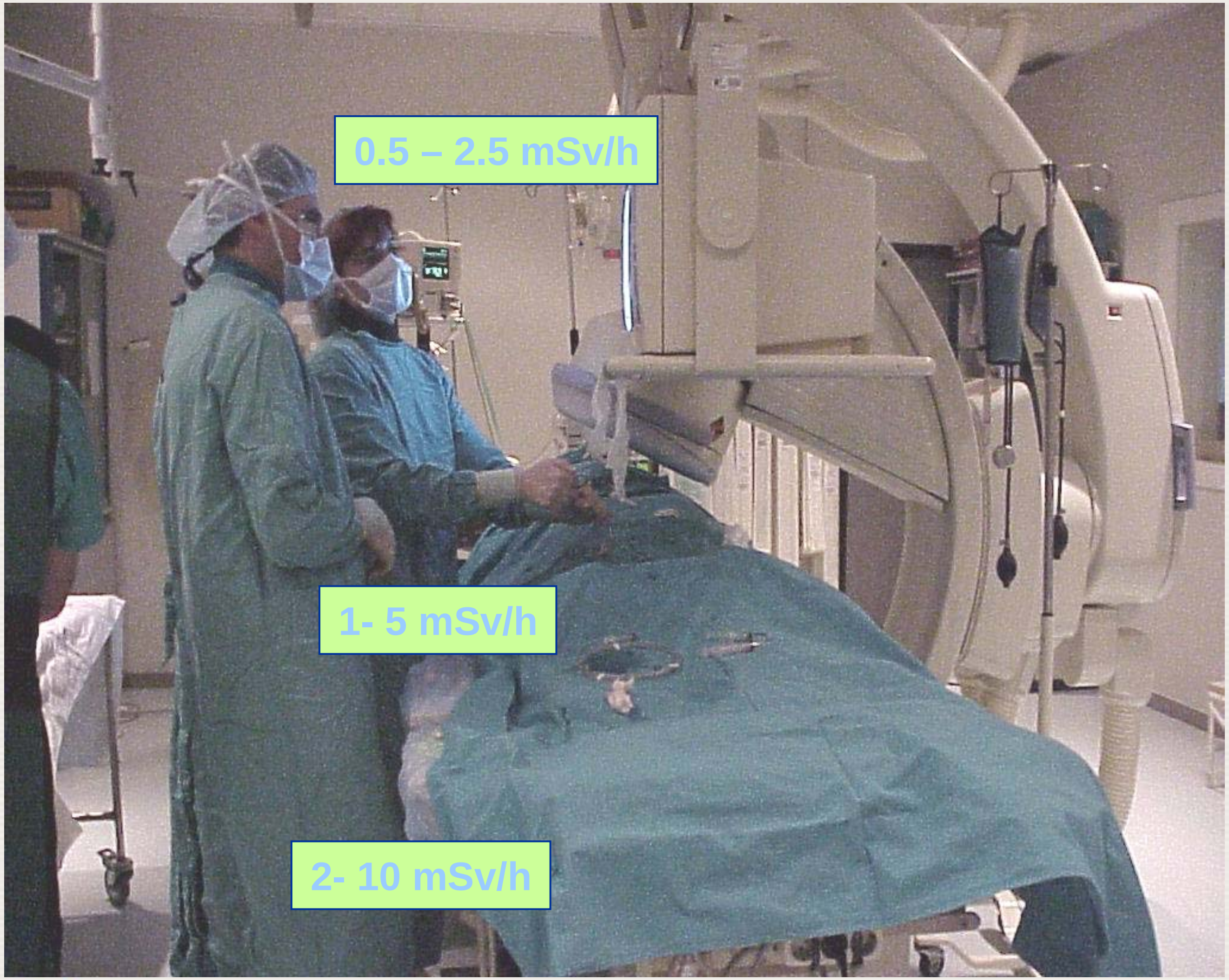
Below: Cataract in the eye of an interventionist after repeated use of old x-ray systems and improper working conditions related to high levels of scattered radiation. (Photograph courtesy of E. Vañó).

An information publication for the medical profession from the

ICRP
INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

Photograph of the patient's back 21 months after a coronary angiography and two angioplasty procedures within three days; the assessed cumulative dose was 15 - 20 Gy (Photograph courtesy of F. Mettler).

Staff: high exposure work area



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Patient dosimetry in IR

1. Dosimetry for quality assurance
   - Air kerma area product (KAP, P_{KA})
2. Dosimetry for stochastic risk evaluation
   - dose equivalent to selected organs
   - effective dose
3. Dosimetry to prevent deterministic effects of radiation (maximum skin dose assessment)
   - Maximum skin dose (MSD or $D_{skin,max}$)

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Code of Practice

(8.5 Fluoroscopy)

- Since no standardized method exists, recommendations on how to measure the maximum entrance surface air kerma in interventional procedures will not be given in this Code of Practice.

(Appendix VI)

- Deterministic effects only occur in diagnostic radiology in special circumstances when the local dose is very high. The most important example is the high skin dose which can arise during interventional procedures using X rays.

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Code of Practice (cont.)

- The assessment of absorbed dose to the most exposed area of the skin is essential in complex interventional procedures
- Knowledge during the procedure of the skin dose is necessary to avoid deterministic effects or to reduce their severity
- Knowledge after the procedure of the skin dose is necessary in order to decide which patients require follow-up

- The determination of the skin dose to the most exposed area is not easy since exposure parameters and projection angle change during the procedure
- The most exposed area cannot be predicted in most cases

Code of Practice (Appendix VII)

- In fluoroscopy guided interventional procedures, the air kerma–area product, P_{KA}, offers a convenient quantity for monitoring patient exposure.
- In order to estimate the peak skin absorbed dose it is necessary to have a detector that registers the skin dose at many points

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Code of Practice (Appendix VII)

- Real time measurements are possible with detectors located on or near the skin but these cannot generally provide complete dose mapping

- Two alternative approaches to estimate the maximum possible incident air kerma:
  - Measurements at a Interventional Reference Point (IEC-60601-2-43) as a point on the central ray of the X ray beam which is 150 mm from the isocentre of the radiological equipment in the direction of the X ray tube. The cumulative air kerma at the IRP may overestimate the maximum incident air kerma
  - Measurements of P_{KA} can provide an indication of the maximum possible incident air kerma if the focus to skin distance and field area are recorded

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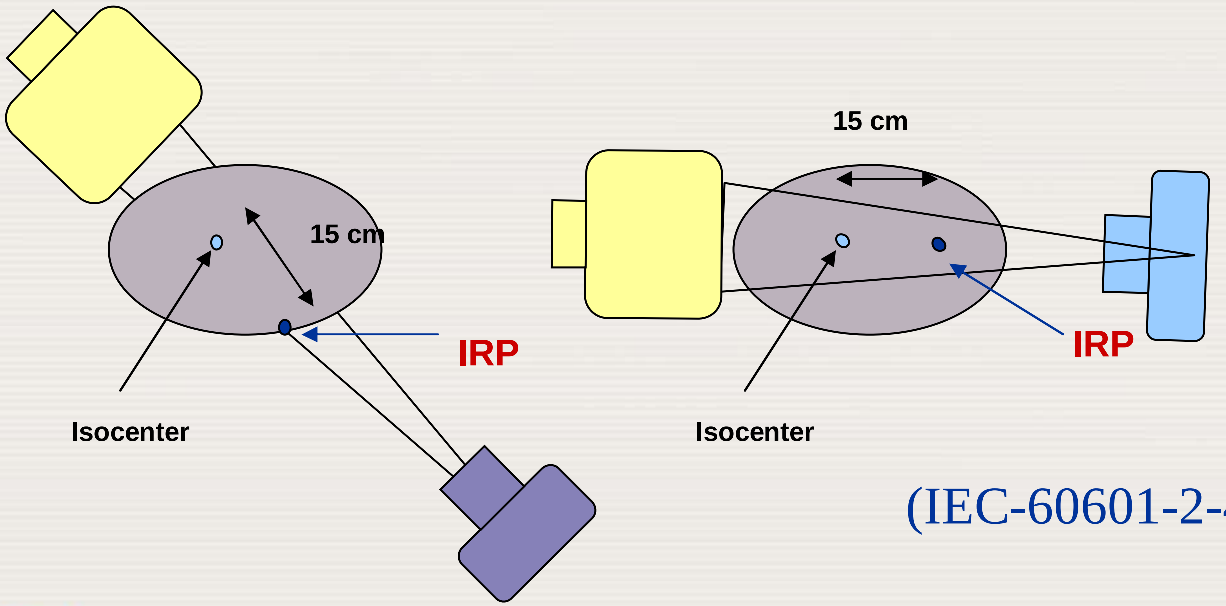
Interventional Radiology Point (IRP)

Cumulative ESAK to Interventional Radiology Point (IRP) measured with a flat ion chamber or calculated by the system and displayed in the angio room



(IEC-60601-2-43)

Patient dosimetry to prevent deterministic effects (skin injuries)

- Dosimetric quantity:
  - Maximum skin dose (MSD)

  - Real time measurement/evaluation of MSD
    - Point or area detectors
    - Cumulative dose at IRP (interventional radiology point)
    - Calculation from technical data
  - Off line methods
    - Area detectors: TLD array, slow films, radiochromic films
    - From KAP and CD measurement

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Method for MSD evaluation: TLD grid

(Thomas W. Slowey, K&S)

- **80 LiF TLD’s**
- **Attached to polyethylene carrier**
  - **8 x 10 chip matrix**
  - **4 cm x 4 cm grid spacing**

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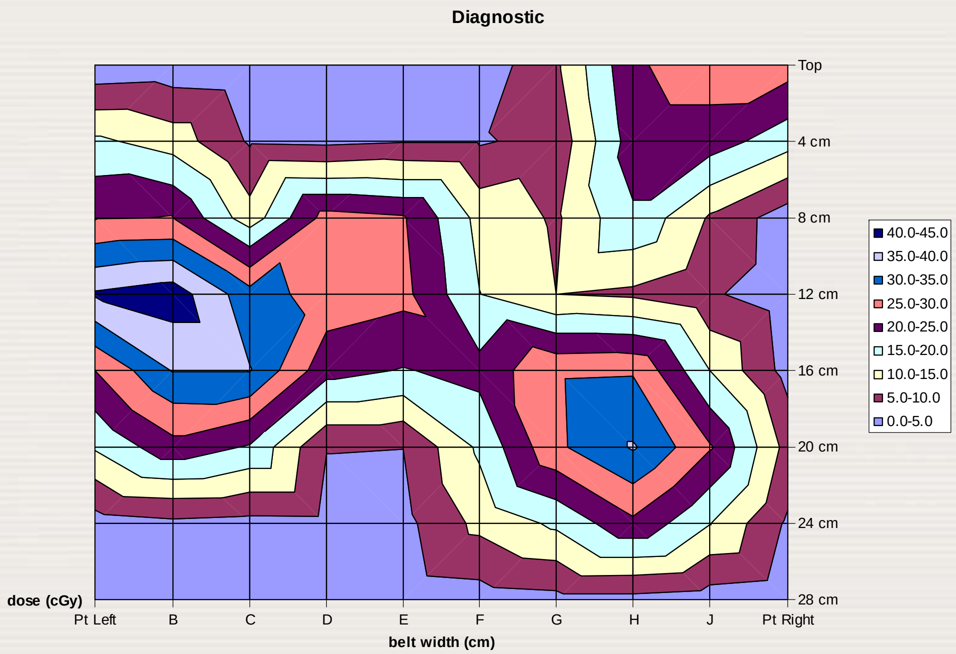
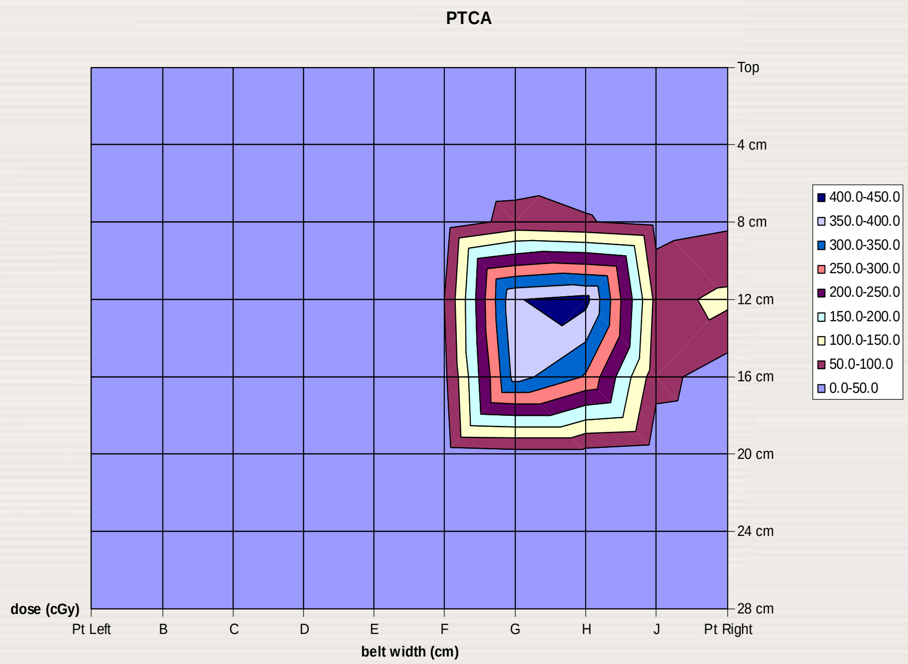
Method for MSD evaluation: TLD grid

- 22 CVL studies: 18 studies 0.1 – 0.45 Gy
- Fluoro Time Range: 1.3 - 53.7 min.
- Max Dose Range: 0.07 – 2.52 Gy
- Area of Dose > 0.2 Gy: 32 - 328 sq cm



- 13 PTCAs: 6 PTCA > 1 Gy
- Fluoro Time Range: 2 - 51 min.
- Max Dose Range: 0.22 – 4.16 Gy
- Area of Dose ≥ 1 Gy: 32 - 160 sq cm



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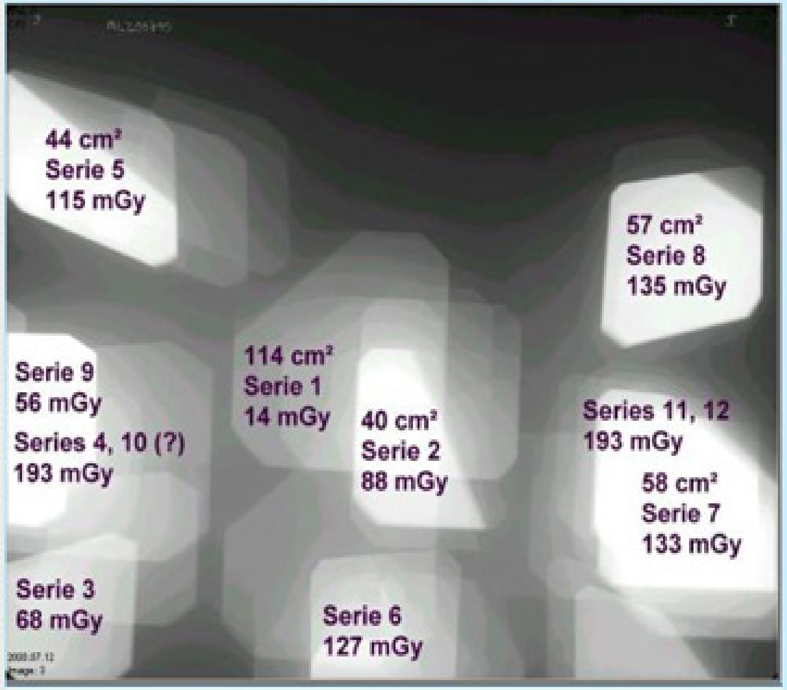
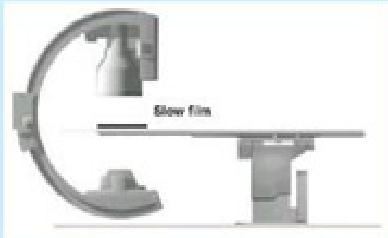
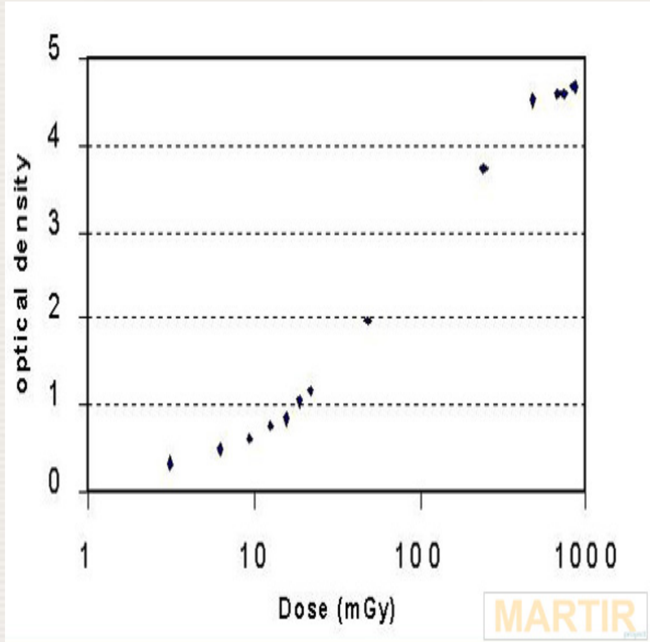
Method for MESAK evaluation: slow film method

Slow film method (Vano E et al. Patient dosimetry in interventional radiology using slow film systems. Br J Radiol 1997; 70: 195-200)



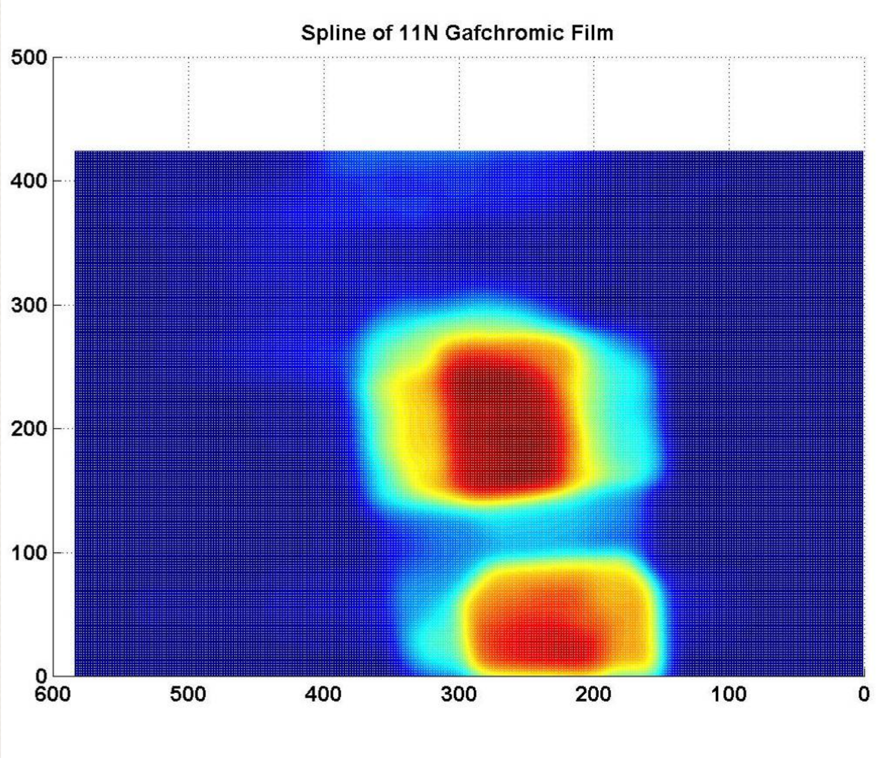




Method for MESAK evaluation: radiochromic large area detector

Example: Radiochromic films type Gafchromic XR R 14”x17”

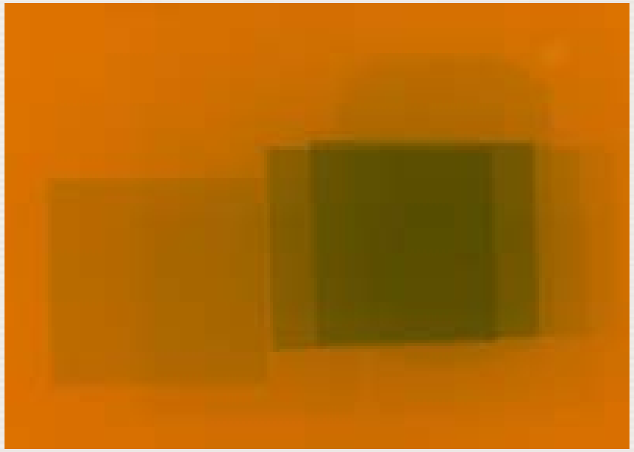
- usefull dose range: 0.1-15 Gy
- minimal photon energy dependence (60 - 120 keV)
- acquisition with a flatbed scanner:b/w image, 12-16 bit/pixel
  or, measure of OD measurement with a reflection densitometer



Benefits of radiochromic films

- The radiochromic film:
  - displays the maximum dose and its location
  - shows how the total dose is distributed
  - provides a quantitative record for patient files
  - provides physician with guidance to enable safe planning of future fluoroscopically guided procedures
  - improves fluoroscopic technique and patient safety

Example of an exposed radiochromic film in a cardiac interventional procedure



Evaluation methods of radiochromic

1. Rapid semi-quantitative evaluation with comparison chart

2. Quantitative measurements with:
   a. Densitometer (point measurements)
   b. Digital flat bed scanner

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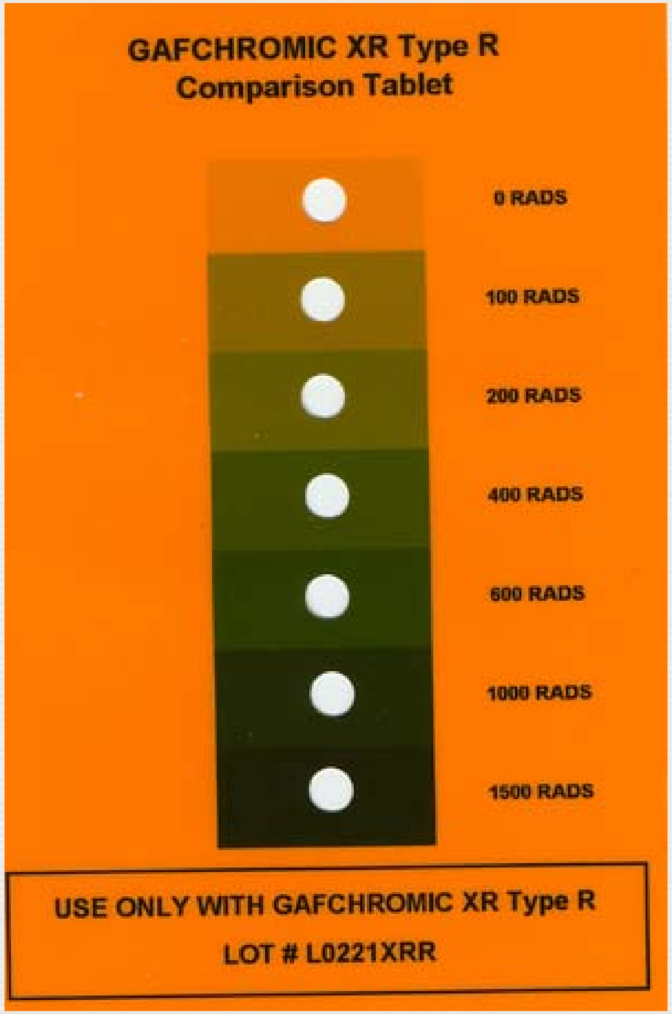
1. Rapid semi-quantitative evaluation

- For each batch number (lot #) of gafchromic film a Comparison Tablet is provided
- A simple direct comparison of the Comparison Tablet with the exposed film allows to estimate the maximum dose



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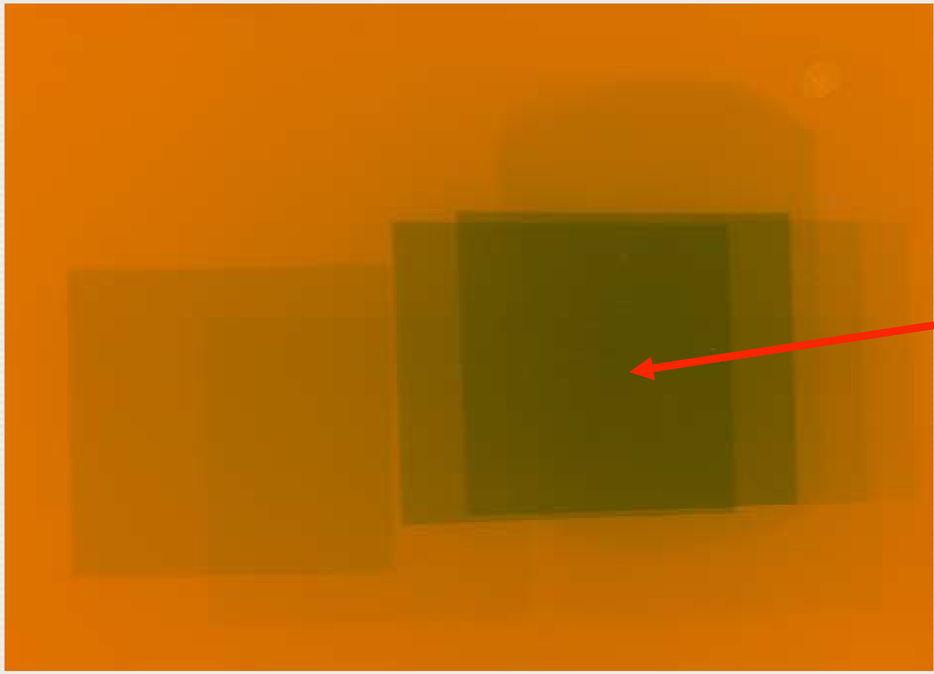
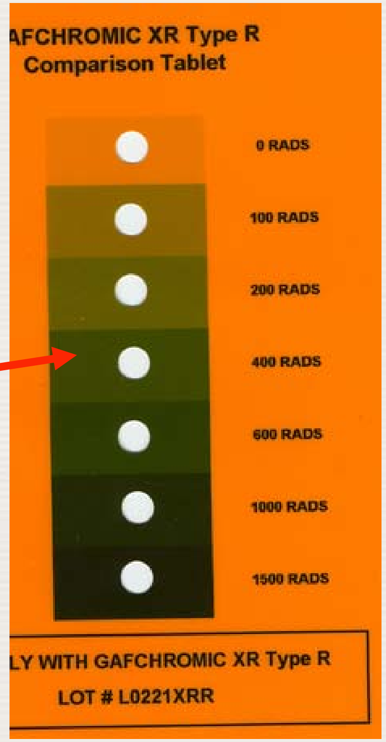
Rapid semi-quantitative evaluation: example

- In the reported example we easily can recognise that the darkness area of the film, corresponding to the skin area that has received the maximum local dose, has an Optical Density that correspond at about 4 Gy





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2.a - Quantitative measurements with spot densitometer

2.a Spot measurements with reflective densitometer

- Spot reflective densitometer reading the Optical Density (OD) of the gafchromic film in the red region is an easy, accurate and fast method for skin dosimetry and for the estimation of the maximum local skin dose

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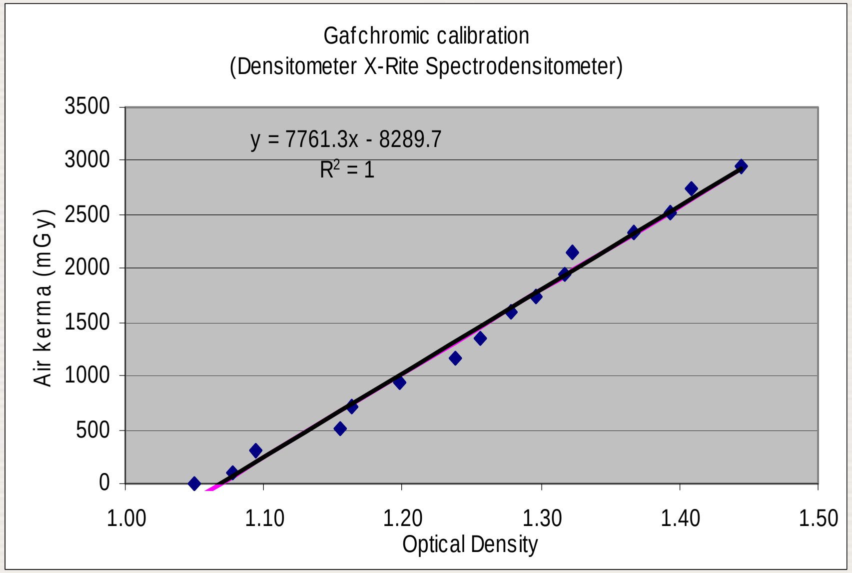
Calibration procedure for radiochromic film

- Each piece of gafchromic is read with the reflection densitometer (typical results are reported in the table)
- Air kerma vs. OD are interpolated in an Excel sheet
- The resulting calibration curve (a straight line in this case) is adopted for the patient dose calculation
- In the example: ESD (mGy) = -8290 + 7771*OD

OD	Air kerma (mGy)
1.050	0
1.077	103
1.094	310
1.155	517
1.163	724
1.198	949
1.238	1161
1.256	1346
1.279	1601
1.297	1732
1.317	1936
1.323	2140
1.367	2325
1.393	2521
1.409	2749
1.444	2942



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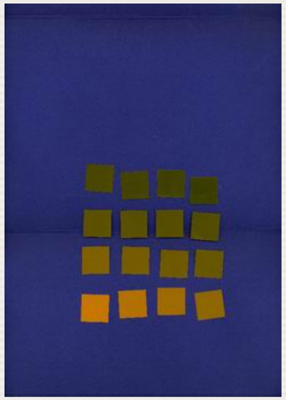
2. Quantitative measurements with flat bed scanner

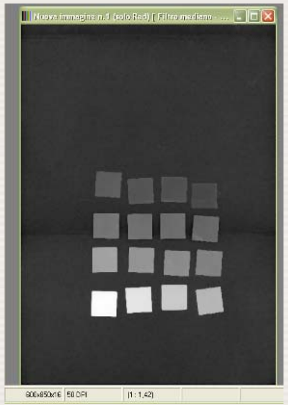
2.b OD measurements with a colour flat bed scanner

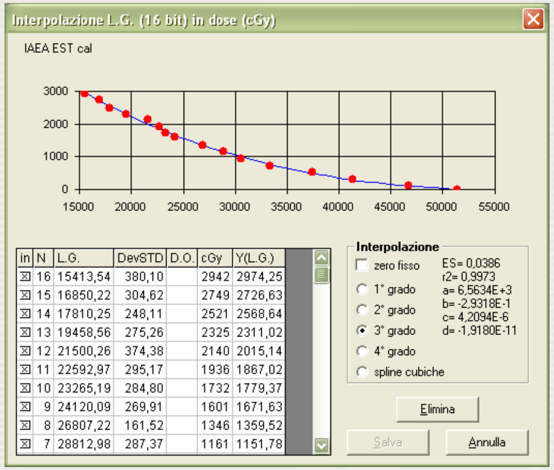
- A colour flat bed scanner can be used to digitise an exposed gafchromic film.
- The dosimetric system, including the scanner, the acquisition parameters and the image processing methodology, has to be properly tested and calibrated.

2.B Calibration procedure for radiochromic film

- The red component of the image is selected (in RGB format the image has red, blu and green components) because the maximum light absorption is in the red region of the spectrum.
- Manually, or with a dedicated software, a ROI is created inside each piece and the mean OD calculated.
- Finally, a calibration curve is calculated; a cubic curve is usually adopted.







in	N	L.G.	DevSTD	D.O.	cGy	Y(L.G.)
☒	16	15413,54	380,10		2942	2974,25
☒	15	16850,22	304,62		2749	2726,63
☒	14	17810,25	248,11		2521	2568,64
☒	13	19458,56	275,26		2325	2311,02
☒	12	21500,26	374,38		2140	2015,14
☒	11	22592,97	295,17		1936	1867,02
☒	10	23265,19	284,80		1732	1779,37
☒	9	24120,09	269,91		1601	1671,63
☒	8	26807,22	161,52		1346	1359,52
☒	7	28812,98	287,37		1161	1151,78

In the example: (i) in the table the grey levels (GL) vs air kerma values (AK) (ii) the coefficients of the cubic interpolating curve: $AK=6.563*10^{3}-0.2932*GL+4.209*10^{-6}*GL^{2}-1.918*10^{-11}*GL^{3}$

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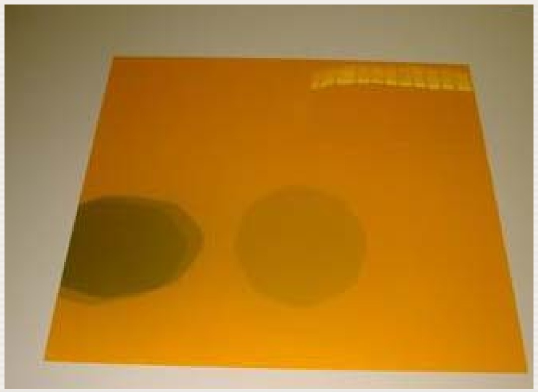
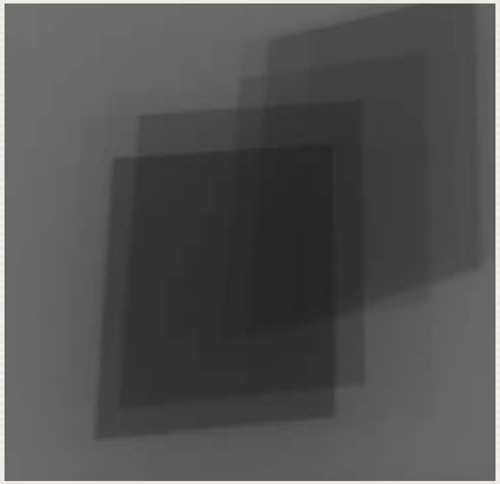
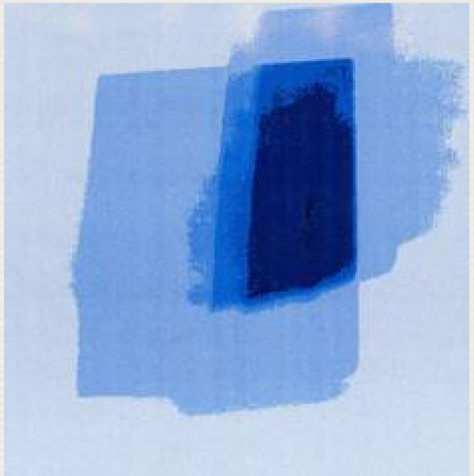
Patient skin dose evaluation (I)

- The patient film is acquired with the scanner in manual mode, with the parameters registered/stored in the calibration procedure.
- The red component of the image is selected.
- The image can be smoothed with a 5x5 filter.
- The red levels (GL) of the extracted image is converted to entrance dose to air applying the calibration curve.





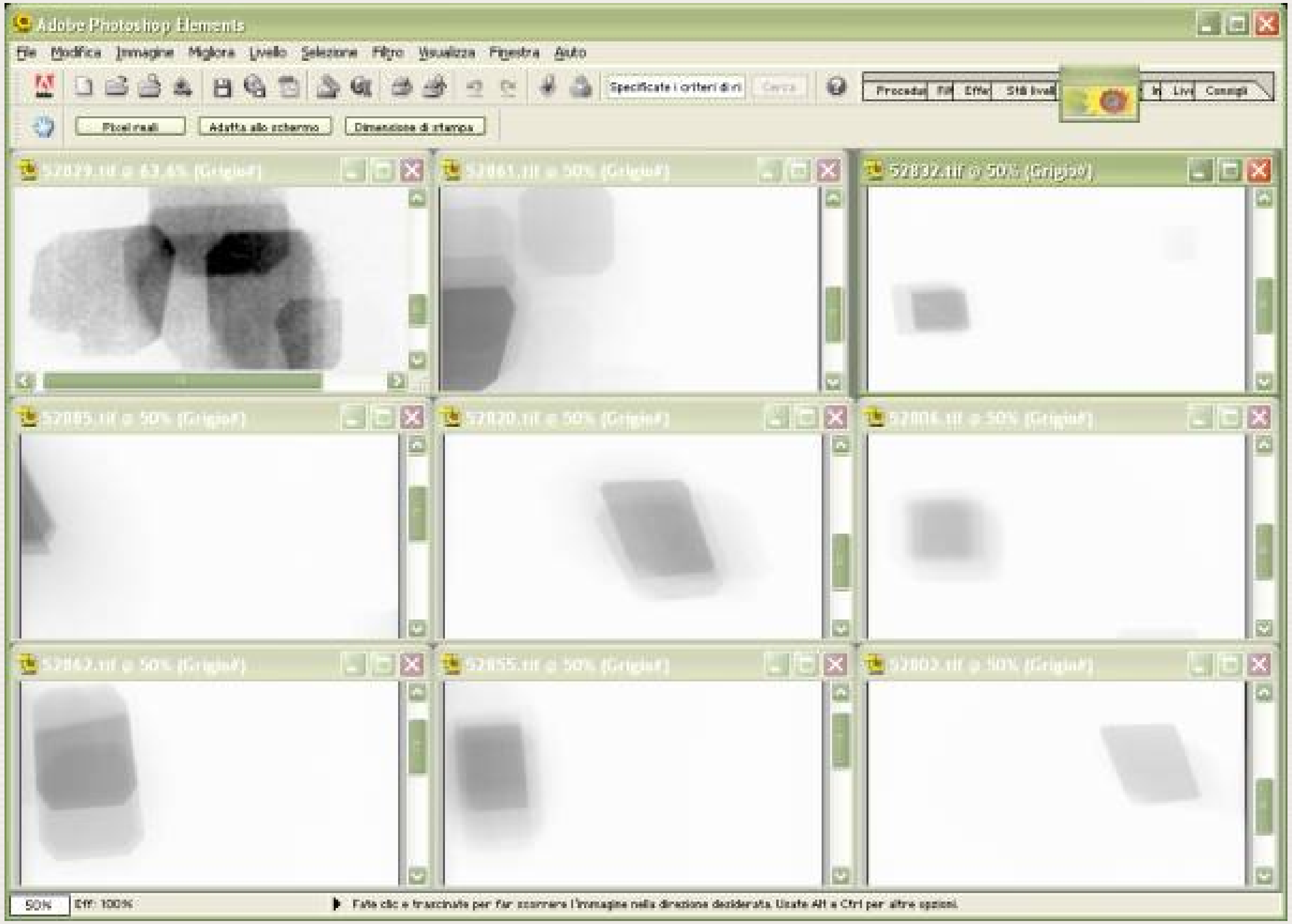


Patient dose evaluation and evaluation accuracy

Examples of patient skin dose distributions in PTCA procedures

Accuracy of dose evaluations:

- comparing MSD evaluated with the different quantitative methodologies described, differences of less than 10% are expected.



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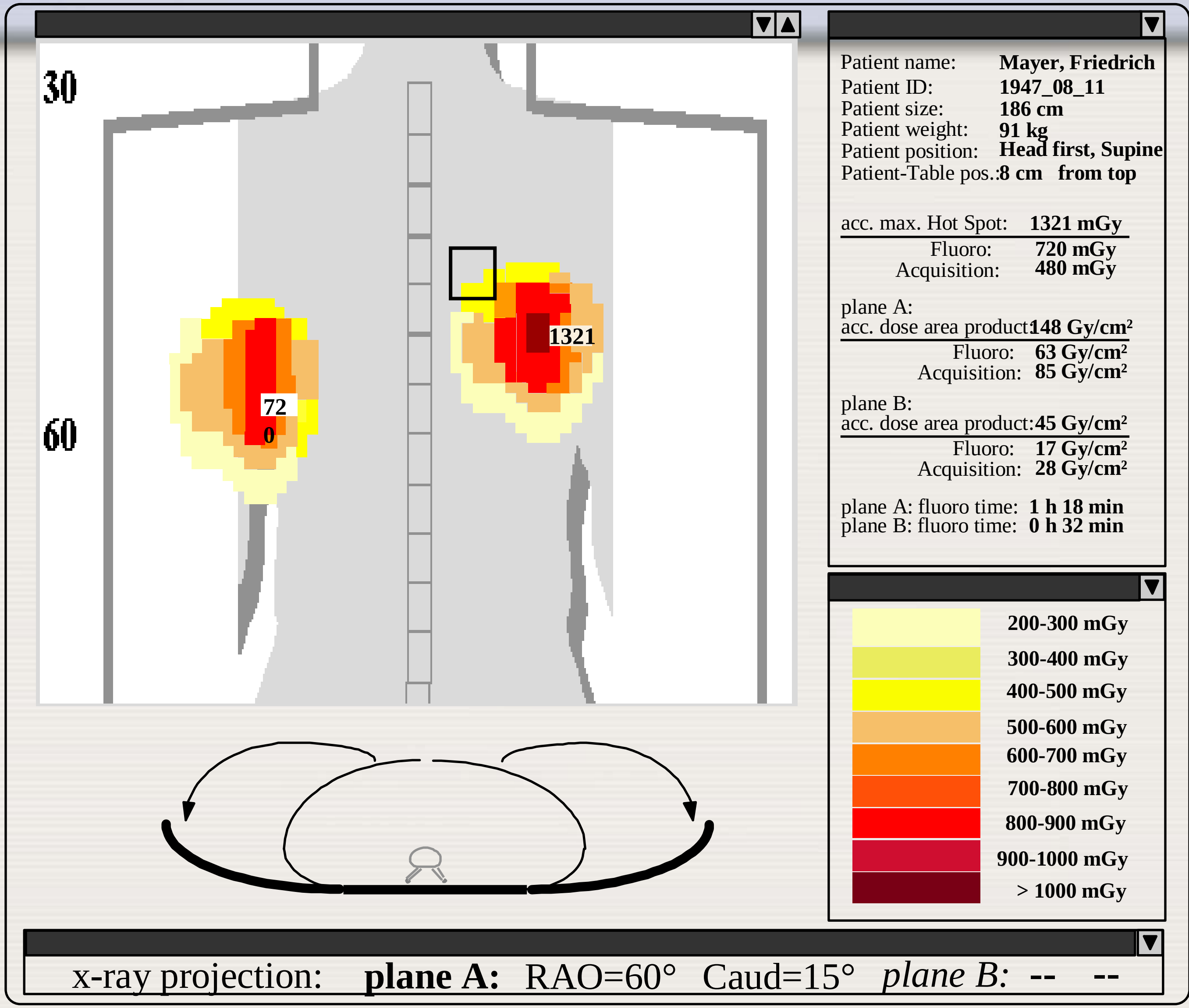
Monitoring of skin dose in high dose procedures (IAEA survey)

- Radiochromic films used to measure patient skin dose in a sample of 392 interventional procedures in a IAEA international study
- In 52 procedures (7.4%) the PSK > 2 Gy, 15 proc. > 4 Gy
- maximum PSK 6.6 Gy; 38 PTCA, 6 RF ablation, 1 neuro and 6 hepatic embolisations
- 39 occurred at two hospitals !

MSD evaluation: computational method

- **CAREGRAPH (Siemens)**

  Dose Distribution



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P.J.Marsden, Y.Washington, J.Diskin

Method for MSD evaluation: MSD/KAP factors

- Skin doses in IR and IC
  - Measurements of dose rates for different type of procedures, field size, orientation, continous/pulsed fluorosocpy
    - Extended assessment of *KAP/ESD factors* for different procedures/field size/orientations
    - Possible use of *ESD/KAP factor* to estimate skin dose, in alternative to more direct methods of skin dose measurements

Method for MSD evaluation:
MSD/KAP factors for cardiac procedures

Projection	MSD/KAP ($mGy/Gycm^2$) vs field size		
	23 cm	15 cm	11 cm
PA	4.67	7.63	10.93
RAO 30^0 + 25^0 CAU	4.11	6.64	9.33
RAO 10^0 + 10^0 CAU	4.13	6.37	9.53
Lateral	7.64	12.43	17.39
LAO 45^0	3.56	5.73	7.86
LAO 45^0 + 25^0 CAU	3.55	6.08	8.27
RAO 30^0	3.02	5.00	7.21

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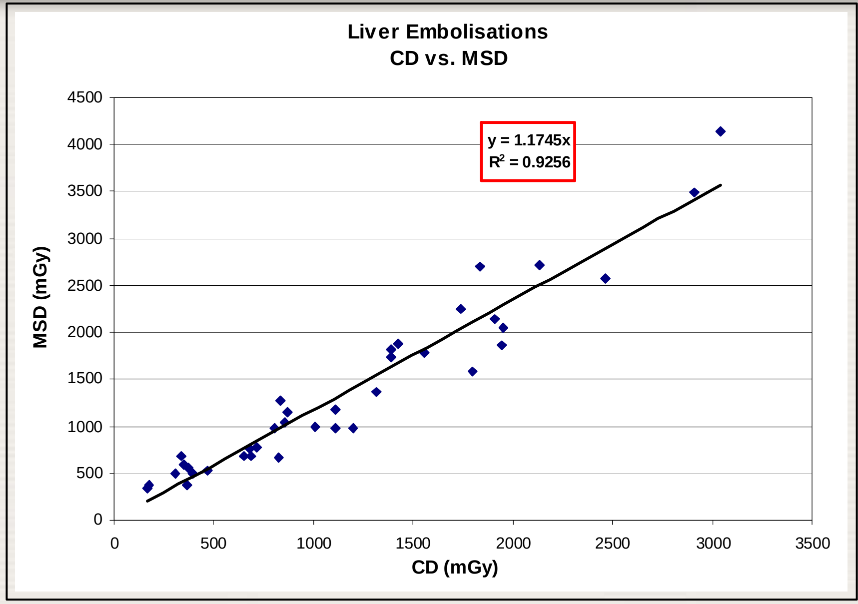
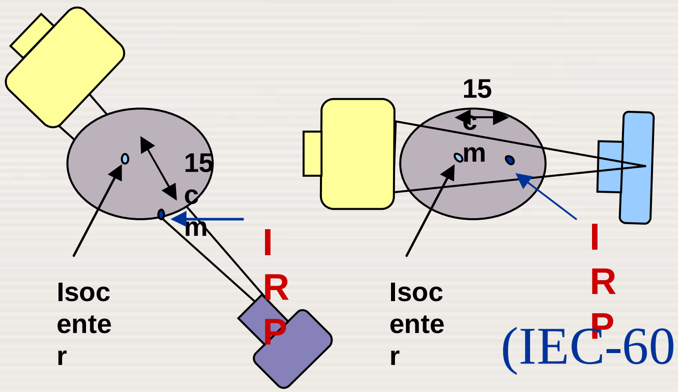
MSD vs. Cumulative air kerma

- In some procedures, CD is well correlated with maximum (peak) skin dose
- CD can be a good indicator of doses higher than the thresholds for skin injures
- A “trigger value” of 2000 mGy for CD can be adopted to alert interventionalists the threshold for skin erythema could be reached
- A follow-up protocol can be adopted



About 20% of patient > 2 Gy at the skin (Udine, 2008)



(IEC-60601-2-43)

Recommendations to reduce the probability of skin injuries in IR

- Periodic monitoring of skin doses on high dose procedures
- A “trigger value” in term of KAP or CD to IRP should be adopted to alert interventionalist
- A follow-up protocol should be introduced for patients could have received high skin doses

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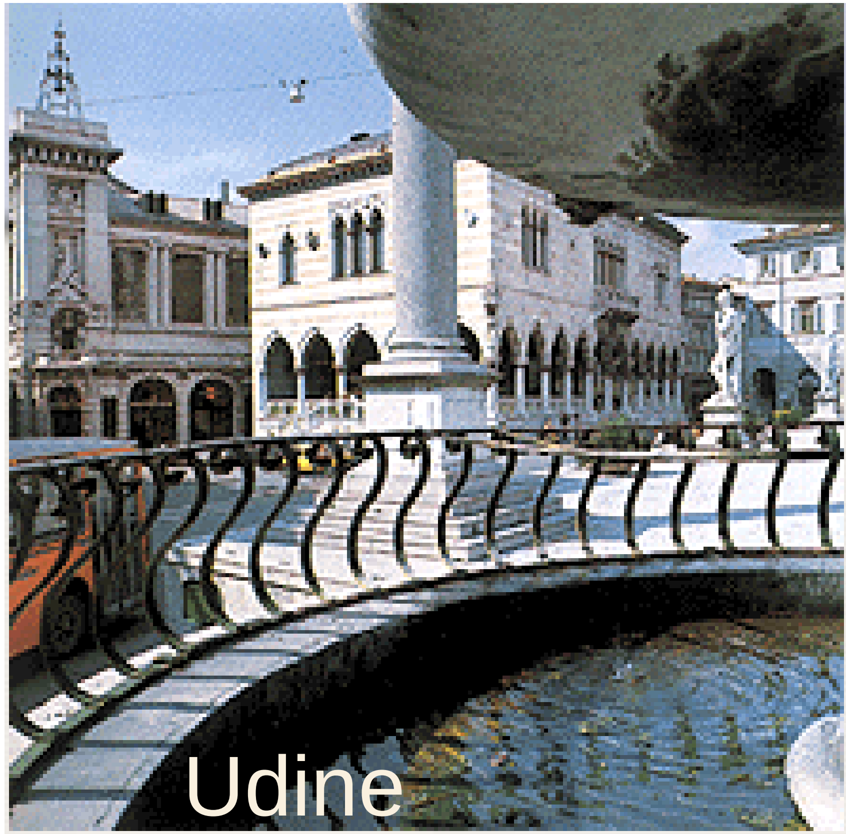

Friuli-Venezia Giulia region