EURADOS European Radiation Dosimetry Group

Occupational exposure of the eye lens in interventional procedures: how to assess and manage radiation dose

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HUG Hôpitaux Universitaires Genève

13th EURADOS Winter School, Florence , 30 January 2020

Introduction

- Radiation-induced eye injuries are matter of current research interest
- Evidence on eye injuries associated with exposure to ionizing radiation*
- The duration of the latency period is inversely dependent on dose
- ICRP
  - *Decrease the threshold for the eye lens from 5 Gy to 0.5 Gy (0->0.8 Gy)*
  - *Decreased the dose limit form workers 150 mSv ->20 mSv*
- **ICRP Publication 113 and 120 (interventional procedures)**

(IAEA RELID; Vano, 2013; Vano 2010; Kleiman, 2011…)

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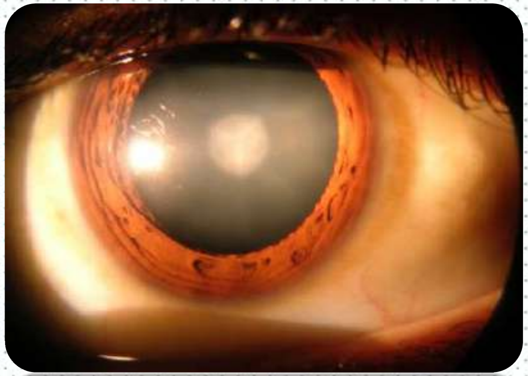
Eye dosimetry: Why is it important?

- Important for correlation of observed radiation effects with dose
- Contribute to better radiation protection
- Verification of compliance with regulatory dose limits

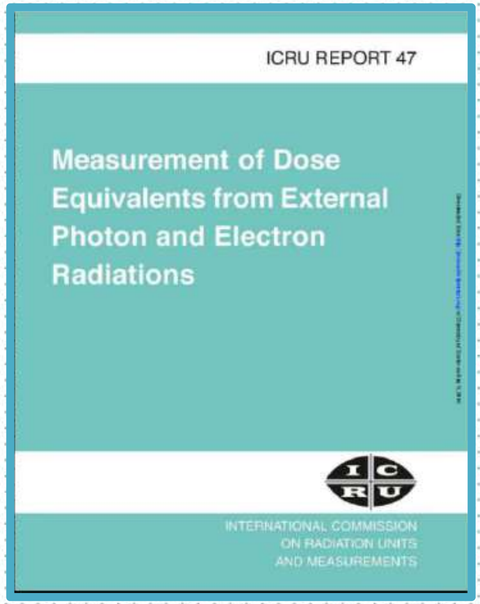
Eye dosimetry in medical filed

- **Eye dose in fluoroscopy guided procedures** in radiology, cardiology and other areas (orthopedics, urology, anesthesiology, vascular surgery, CT fluoroscopy, gastroenterology…)
- **Eye dose in nuclear medicine**
- Photon and beta radiation



Motivation for this review

- Eye lens dosimetry is currently not well established
  - Hp(3) hardly used in practice
  - Accuracy and practicality in medical field



ICRU 47, search "eye", only 4 times in general phrases, as " … for one of the organs, lens of the eye, or skin", or… " 0.07 mm for the skin and 3 mm for the eye are employed with analogous notation"

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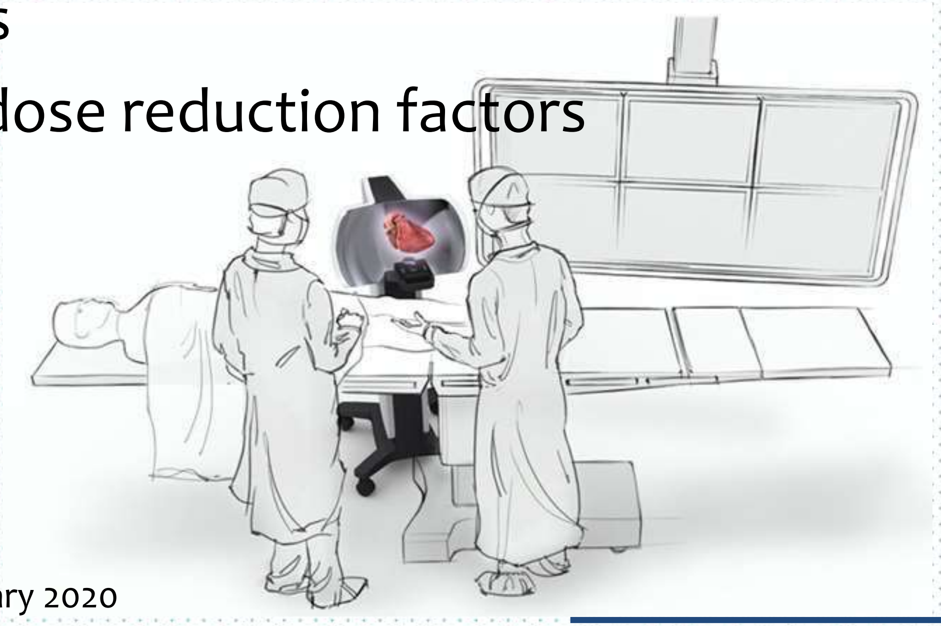
Objective

- To review:
  - Eye lens dose levels in clinical practice that may occur from the use of ionizing radiation in fluoroscopy-guided interventional procedures
  - Eye lens dose monitoring arrangements and dose assessment methods
  - Impact of potential dose reduction factors



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A problem: Eye lens dose assessment

- Active research area
- Clinical studies
  - to review the methodology for assessing eye lens dose levels
  - to investigate monitoring arrangements using different types of dosimeter
  - to study correlation of eye lens dose with patient dose indices
  - to perform retrospective eye lens dose assessment

Matter of increasing research interest

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Approaches to eye dosimetry

Passive dosimetry

Active dosimetry

Retrospective dosimetry

Scatter dose levels

Correlation between patient dose indices and eye dose

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Dosimetric quantities

- **Hp(3)** *(ICRU 39, 1985)*
- Hp(0.07) can be used for eye dose assessment (*Vanhavere, 2011; Lie, 2009; Martin, 2011; Domeinik, 2011, IAEA, 2013*)
  - Adequate for photons, not OK for beta radiation (*Behrens, 2012*)
- Hp(10) sometimes is the only available option
  - Hp(3)/Hp(10) in NM 0.7-1.1 (*Kopec, 2011*)
  - Hp(10) badge on the left side of the body at collar level (*Farah, 2013*)

Type of radiation	Area monitors		Individual dosimeters	
	active	passive	active	passive
Photon and beta particles	IEC 60846-1 [48] $H'(0.07)$ and $H^*(10)$	IEC 62387 [49] $H'(0.07)$ and $H^*(10)$	IEC 61526 [50] $H_p(0.07)$ and $H_p(10)$	IEC 62387 [49] $H_p(0.07)$, $H_p(3)$, and $H_p(10)$
Neutron	IEC 61005 [51] $H^*(10)$	---		ISO 21909 [52] $H_p(10)$

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Passive dosimetry

- Dedicated individual dosimetry designed to provide Hp(3)
  - **Calibration in terms of Hp(3)** *(Bordy, 2011; Daures, 2011; Behrens, 2011; Ferrari, 2007; Gualdrini, 2011…)*
  - **Type test for eye dosimeters** *(Bordy, 2011; Bilski, 2011)*
- Double dosimetry
  - Chest levels under the apron
  - Collar level above the apron

Double dosimetry

- Collar level over the apron -> eye dose assessment (ICRP 139, 2018)
- **Eye dose = Collar dose x F, F = 0.75 (0.4-0.9)**
- Hp(3)/Hp(0.07) at collar level within ± 15% (>50 µSv)*
- Practical issues
  - *Unavailable double dosimetry*
  - *Unknown position of the dosimeters*
  - *Irregular or erratic use, overuse*
  - *Variability in practice among the countries*

**Vanhavere, 2011*

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Active dosimetry

- Direct monitoring of eye dose
- Small detectors clipped onto spectacles
- Dose assessment in real time
- Dose per procedure
- Operational radiation protection
- May not be adequate for legal dosimetry ?

Dosemeters have to be tested and suitable for use in clinical environment: beam quality, dose rate, pulsed radiation
(Struelens, 2011, Hupe 2018, ICRP 139, 2019)

Dosimetry in real time

- **Ambient monitors (C-arms)** *(Omar, et al, JRP,2017)*
- Scatter dose levels in real time *(Vano, et al, Rad Meas 2011):*
  - Educational role
  - Backup to personal dosimetry
  - Retrospective information and cumulative dose
  - Assessment of working habits, staff comparison
  - Correlation of dose rate with cumulative dose to staff
  - Correlation to patient dose for different procedures

Dosimetry in real time

- **Computational dosimetry**
  - Backup to personal dosimetry
  - Auditing the regular and proper use of personal dosimeters
  - Assessing the need for additional protection
- **Computational technologies (not requiring dosimeters) together with personnel position sensing to assess personnel doses (ICRP 139, 2018)**

Issues with passive and active dosimeters

- Ideally, dosimeters should be type tested and calibrated in terms of Hp(3) using an appropriate phantom
- The best position:
  - On the side of the head nearest to the radiation source
  - Behind the glasses (not very convenient)
  - Above the glasses (correction factor)
- However,…

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Issues with passive and active dosimeters

- Must not interfere with the wearer's vision
- Use of 3 or more dosemeters (reliability and consistency ?)

- If the radiation field is well known, Hp(3) can be estimated by the use of dosimeters calibrated in terms of Hp(0.07) and Hp(10) (ICRP 139, 2018)

Appropriate dosimetry arrangements:
accuracy vs practicality

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Retrospective dose assessment

- General assumptions on scattered dose levels
  1. Correlation to patient dose
  2. Scatter dose rate and typical exposure parameters (mainly in H*(10))
- Position of the operator and other staff members (modifying factors 0.2-1.0)
- **Large uncertainty** (order of magnitude):
  - Technical and physical factors, social desirability and memory bias…
  - Protective tools and their use…
  - **Validation by means of measurements** is needed *(Pirchio et al, 2014)*

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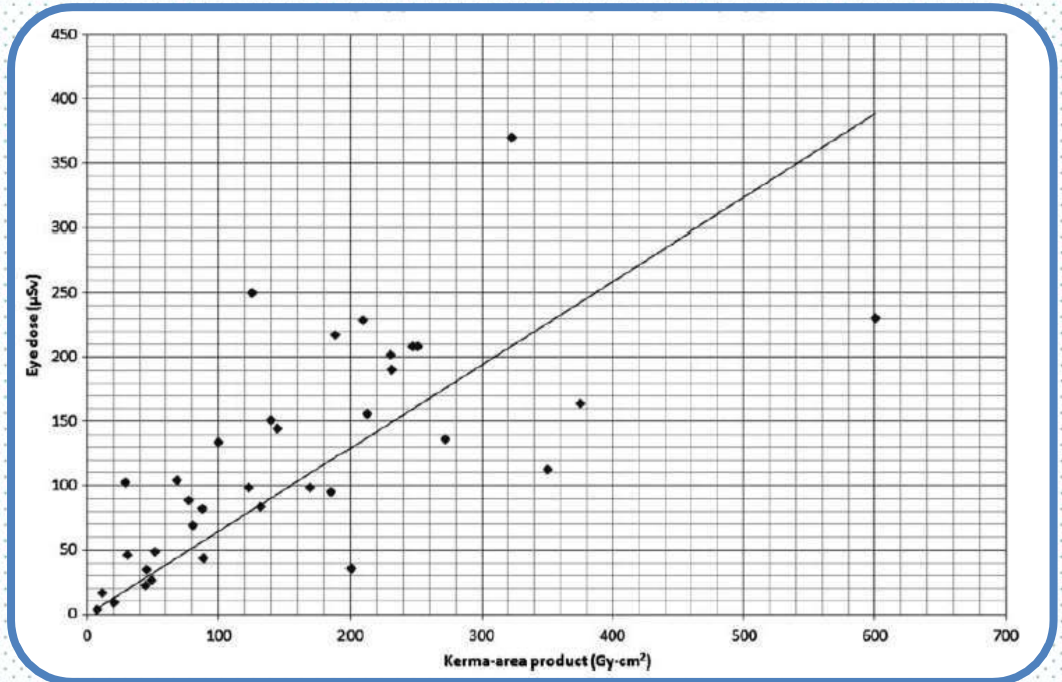
Correlation of eye dose with patient dose

- Normalized eye dose per unit KAP based on local practice, as dominant influencing factors are *(Antic, 2012; Krim 2011;…):*



X ray tube configuration, beam collimation, access route

Use of protective tools

If kept constant, correction is of practical use

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Eye dose normalized to respective KAP for interventional cardiology procedures for position of the first operator

Refernce	Eye dose (µSv)	Eye dose/ P_{KA} (µSv/(Gycm^2))
Antic, 2012	121±84 (4.5-370)	0.94±0.61
Donadille, 2011	52±77 (4-644)	1.0
Kim, 2008	170-439	-
Vano, 1998	170 (53-460)	3.3-6.0
Vano, 2013	-	10-11 (unprotected)
Efstathopoulos, 2012	13	1.37
Bor, 2009	72 (32-107)	0.86 (0.46-1.25)
Martin , 2009	66 (5-439)	1.0
Vanhavere, 2011	-	1.0
Pratt , 1993	15-53	-
Jacob , 2013	14-439	-
Koukorava, 2011	-	1.0
Duer, 2010	35±32 (pre year)	4.2 (unprotected)
Lie, 2008	23 (10-230)	0.4 (0.2-2.6)
Vano, 2009	-	7 (unprotected)

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Correlation of eye dose with patient dose

- Useful as a surrogate measure of eye dose if measured dose using eye dosimeter is unavailable

Typically, 1 Gy·cm^2 to the patient resulted in:

10 µSv to the unprotected eyes of the primary operator

1 µSv when protective tools are used

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Retrospective dose assessment

- Related to a "typical" procedure and **anticipated scatter dose:**
  - Consider past activity of an individual
  - Accuracy of information provided and assumptions made
  - Dose reduction factor due to use of protective tools (static *vs* clinical conditions)

Professional group	Cumulative dose	Reference
Cardiologists	25-1600 mSv	Jacob, 2012
Cardiologists	0.1-18.9 Sv	Vano, 2013
Cardiologists and support staff	0.1 to 21 Sv	Ciraj-Bjelac , 2010
Cardiologists and support staff	0.1-27 Sv	Vano, 2010

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Current status of eye lens dose levels

- Eye doses vary considerably
  - Various dose methodologies and dose assessment approaches
  - Various combinations of protective tools
  - Reported mainly for the first operator and in some cases for nurses and radiographers

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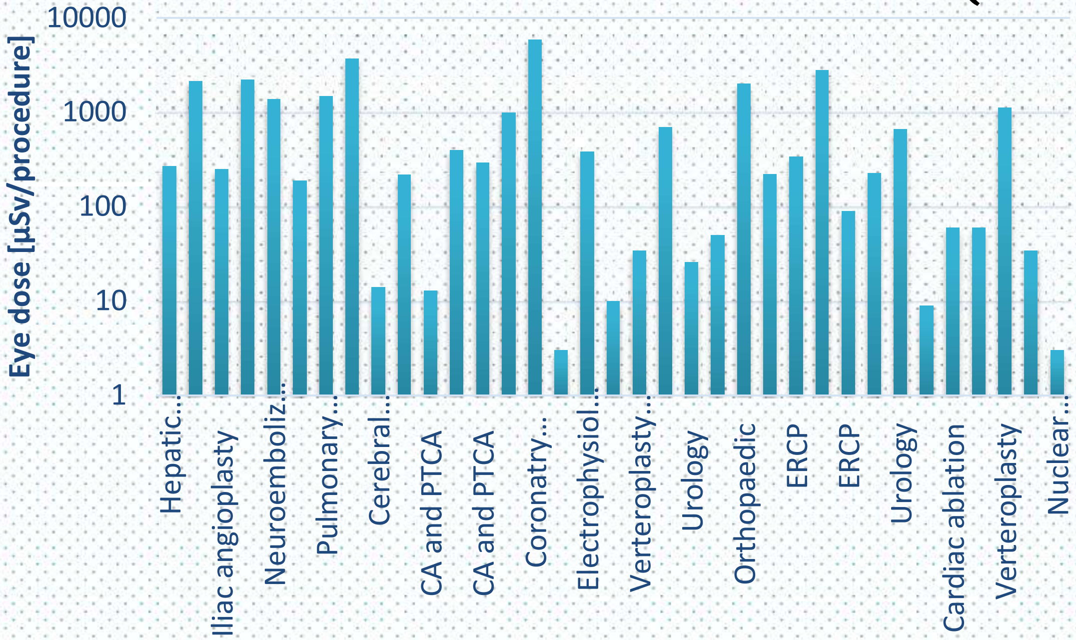
Current status of eye lens dose levels

Total dose

- range from less than **0.1 to 1100 µSv**

Dose rate

- from **1 to 22 mSv/h** (fluoroscopy)
- from **12 to 235 mSv/h** (DSA)



Max/Min : 2000

Typical dose levels

Table 1. Typical measured eye lens dose levels and eye lens dose normalized to respective kerma-area product in interventional radiology procedures with additional information about the use or not of protective tools

Type of Procedure	Eye Lens Dose per Procedure (µSv)	Eye Lens Dose / P_{KA} (µSv/Gy cm^2)	Measurement Details	Reference
Various interventional radiology procedures, with protective tools	47 (0-557)	1.19	25 procedures, few cases per procedures	[15]
Hepatic chemoembolization	270-1,070 / 16-64 (unprotected / protected)	-	With phantom, different acquisition modes	[36]
Iliac angioplasty	250-1,110 / 15-66 (unprotected / protected)	-		[36]
Neuroembolization (head)	1,380-5,600 / 83-336 (unprotected / protected)	-		[36]
TIPS creation	410-1,860 / 25-112 (unprotected/ protected)	-		[36]
Anesthethesiology, various procedures	44	0.278-1.305	Simulations, 31 cases	[37]
Gastroeneterology, ERCP	90/10 (unprotected, overcouch/undercouch)	0.98-1.4/14-21 (unprotected, undercouch/overcouch)	62 cases	[38]
Vascular surgery, EVAR	10 (unprotected)	-	149 cases	[39]
Urology, various procedures	26 (unprotected)	-	20 cases	[40]
Urology, percutaneous renal calculus removal	100 (unprotected)	-	102 cases	[41]
Orthopedic surgery, various procedures	50 (unprotected)	-	204 cases	[42]
CT fluoroscopy, various procedures	7-48	-	220 cases	[17]
CT-guided interventions	3.5 (0.2-39.9)	-	89 cases	[16]
Various procedures	-	0.47-0.84	1,300 cases	[43]

Note: EVAR = Endovascular aneurysm repair; ERCP = Endoscopic retrograde cholangio-pancreatography; P_{KA} = kerma-area product; TIPS = Transjugular intrahepatic portosystemic shunt.

Ciraj-Bjelac, O, JACR ,2016

Typical dose levels

Table 2. Typical measured eye lens dose levels and eye lens dose normalized to respective kerma-area product in interventional cardiology procedures with additional information about the use or not of protective tools

Type of Procedure	Eye Lens Dose Per Procedure (μSv)	Eye Lens Dose / P_{KA} (μSv/Gy cm^2)	Measurements Details	Reference
Interventional cardiology, first operator, various procedures, dose with protective tools	121 ± 84 (4.5-370)	0.94 ± 0.61	35 cases	[13]
	52 ± 77 (4-644)	1.0	646 cases	[44]
	3.3-1,040	-	Literature survey, phantom and clinical, 3-1,532 cases per survey	[34]
	170 (53-460)	3.3-6.0	83 cases	[45]
	13 (0-61)	1.37	7 cases	[15]
	72 (32-107)	0.86 (0.46-1.25)	166 cases	[14]
	66 (5-439)	1.0	Literature survey, 26 studies included	[12]
	-	1.0	1,300 cases	[32]
	15-53	-	164 cases	[46]
	23 (10-230)	0.4 (0.2-2.6)	144 cases	[47]
	35 ± 32 (per year)	4.2	using collar dosimeter	[48]
Interventional cardiology, first operator, various procedures, dose without protective tools	-	10-11	EPD, 1,969 cases	[49]
	300-2,500	3.2-3.4	Multicentric phantom study, different complexities	[35]

NOTE: EPD = electronic personal dosimeter; P_{KA} = kerma-area product.

Ciraj-Bjelac, O, JACR ,2016

Factors influencing dose to the eye lens

Patient related factors

- Clinical problem (fluoroscopy time and number of images)
- Size of the patient

Equipment related factors

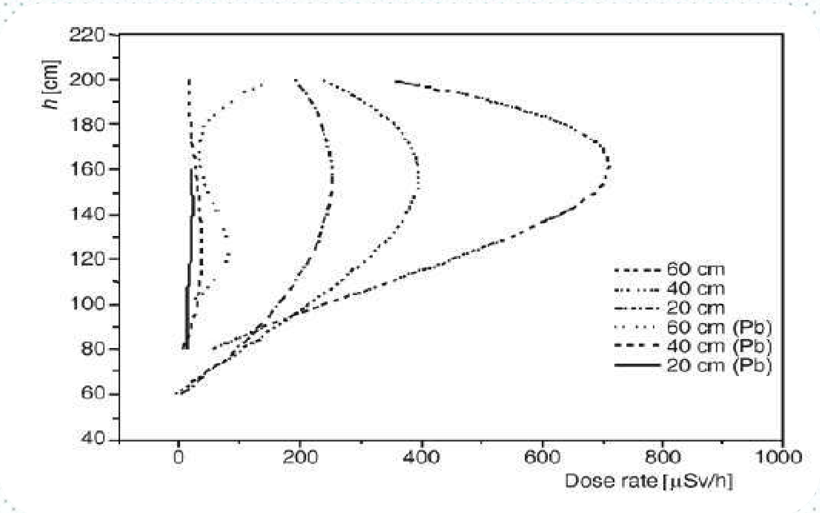
- Geometry of the X ray tube (undercouch/overcouch)
- Use of biplane systems
- Performance characteristics of X ray system, including the settings
- The scatter radiation distribution

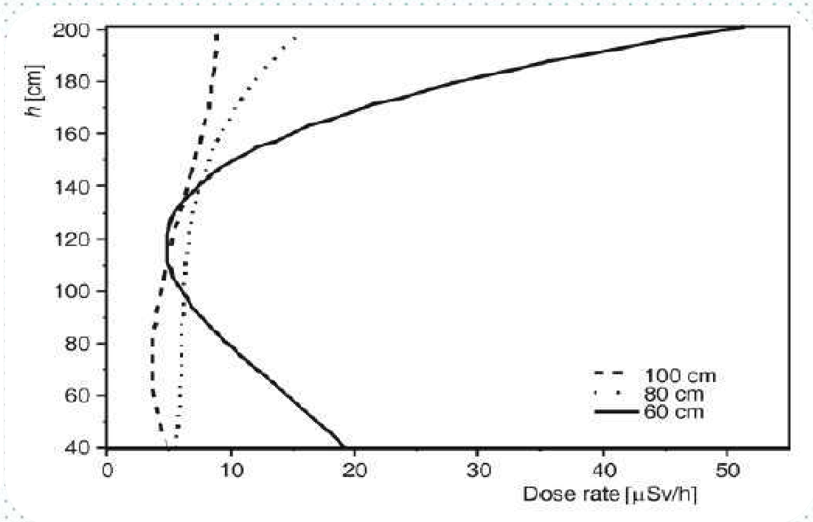
Practice related factors

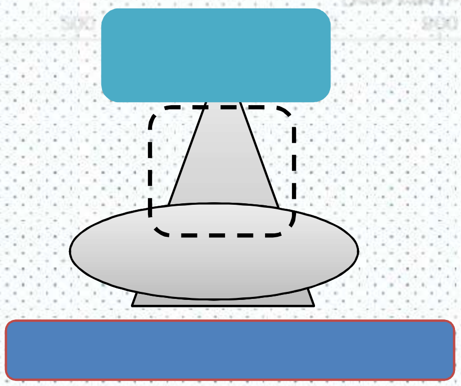
- Use of protective tools
- Position vs. x-ray tube and patient, projections used, exposure setting, collimation, access route…
- Workload and physician's experience and skill

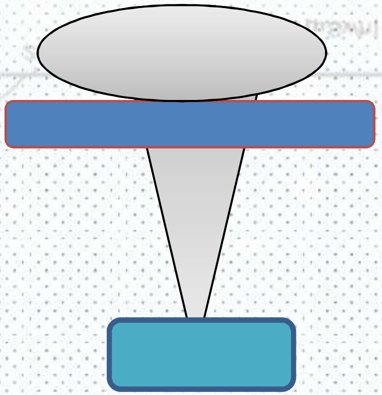
X-ray tube geometry & scatter radiation

Favorable undercouch configuration: **dose reduction factor: 2-27** (Carinou, 2011)









Ciraj-Bjelac et al, NT&RT, 2009

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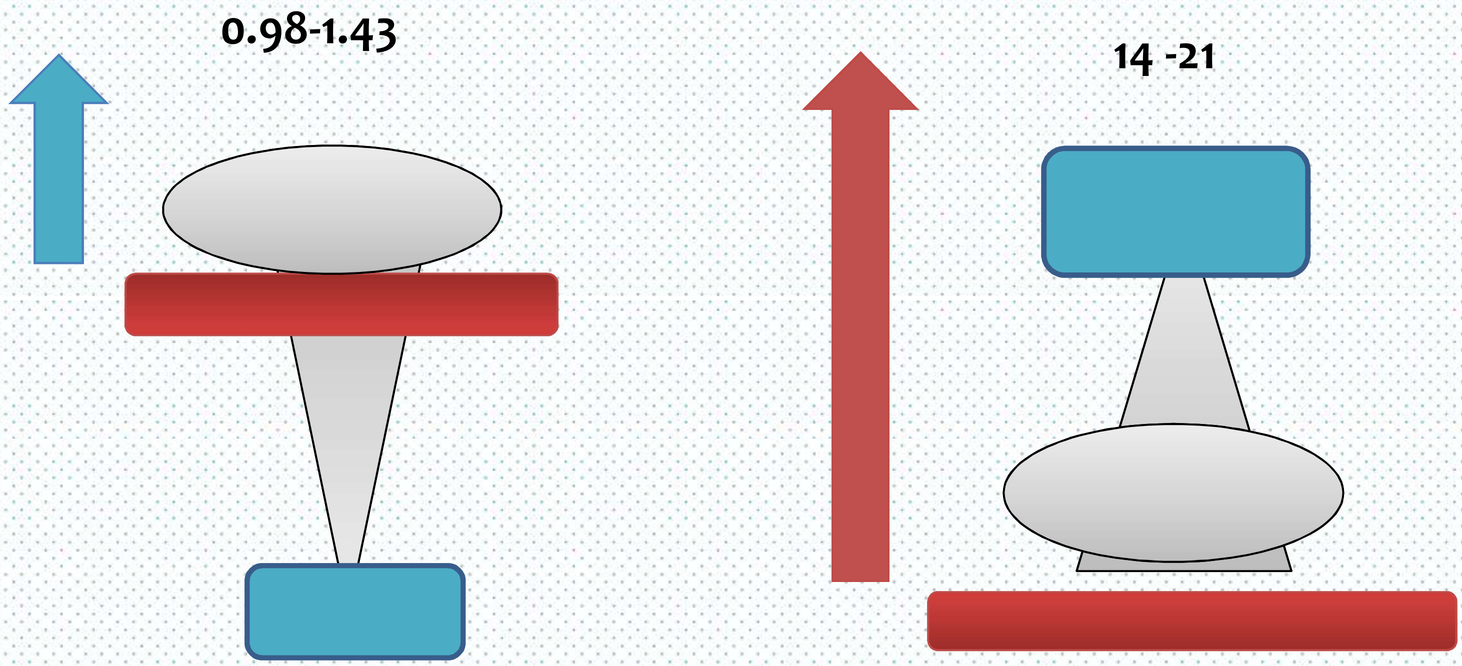
X-ray tube geometry & eye dose

- ERCP (O'Conor et al, 2013)
- Hp(3)/KAP (μSv/Gycm²):



Endoscopic retrograde cholangiopancreatography (ERCP)

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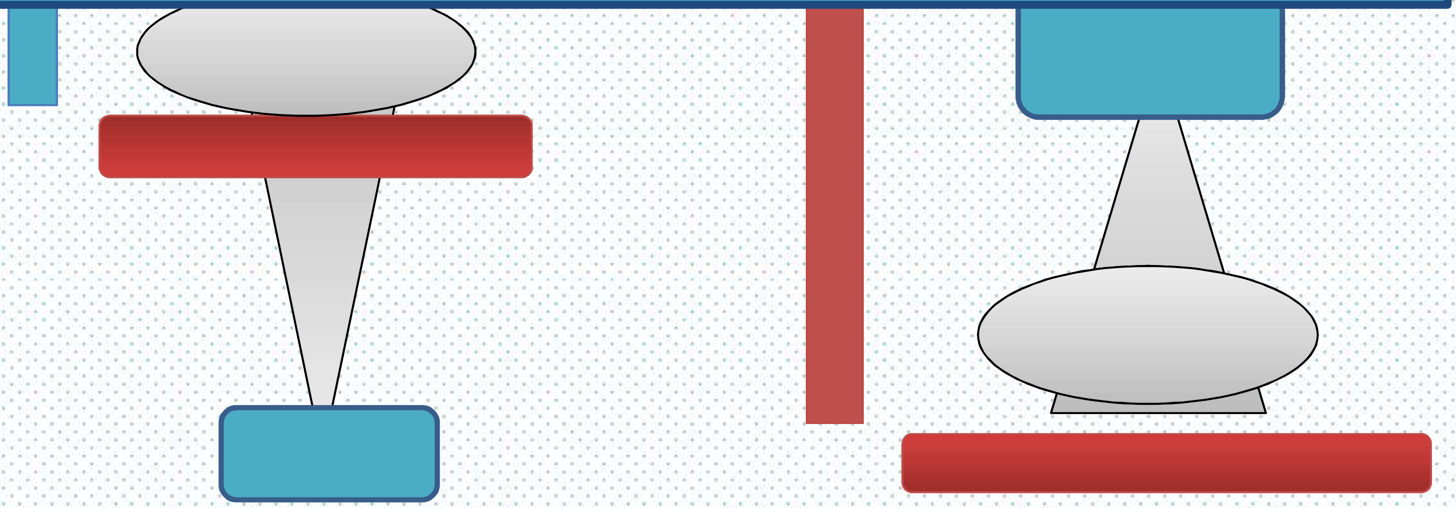
X-ray tube geometry & eye dose

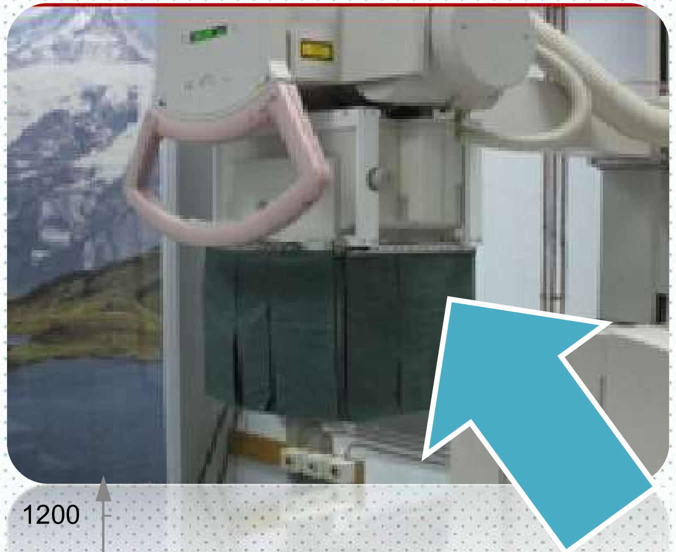
- ERCP (O'Conor et al, 2013)
- Hp(3)/KAP (μSv/Gycm^2):

The highest values are related to the overcouch x-ray tube geometry and the absence of ceiling suspended screens and glasses

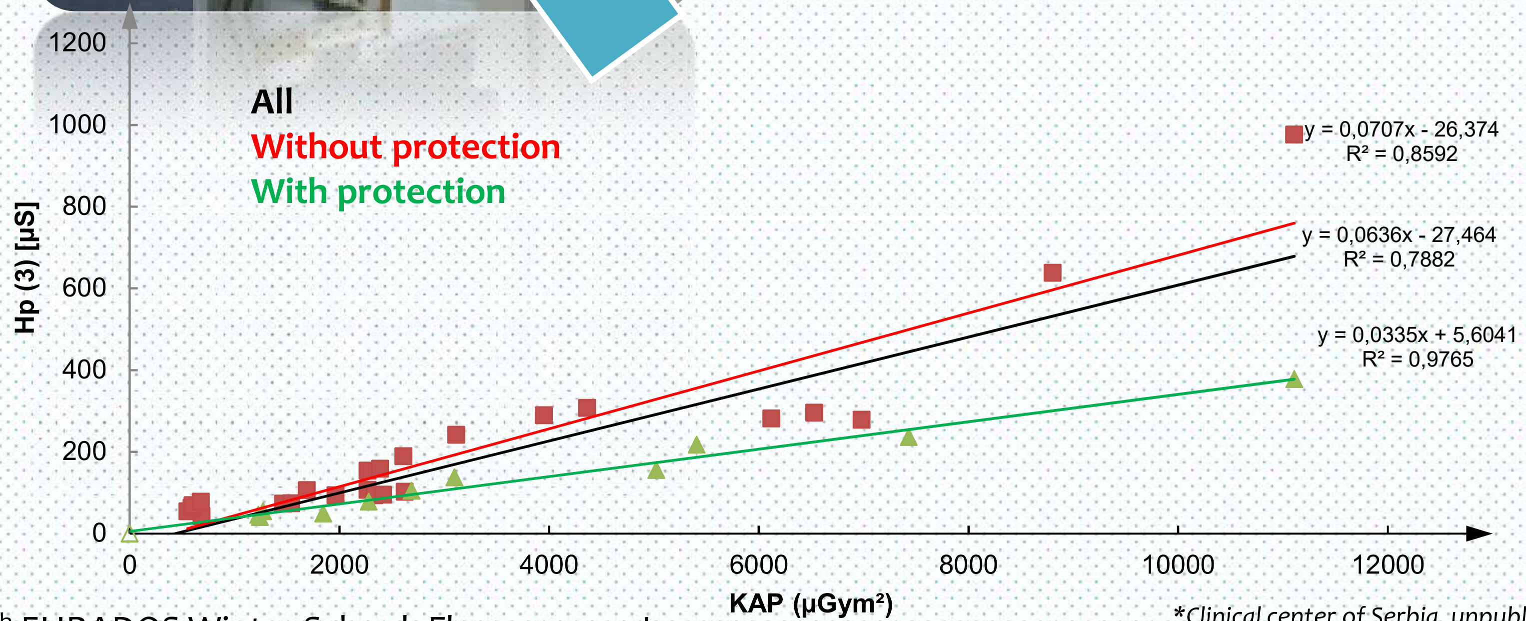


Endoscopic retrograde cholangiopancreatography (ERCP)

Protective tools @ overcoach geometry



Gastrointestinal procedures: scenting and enteroclysis*
*Clinical center of Serbia, unpublished data



*Clinical center of Serbia, unpublished data

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Practice related factors: protective tools

Use of ceiling screens

- Positioned just above patients and position of the operator behind
- **Dose reduction factor: 2-7***
- For LLAT projection move the screen towards the operator (x-ray tube)**
- Biplane systems: additional lateral shielding


*Carinou, E, et al, 2011, **Koukorava, C, et al, 2014*

Lead glasses, properly fitted

Key factors:

- Position and head of orientation
- Beam projection
- Scatter radiation from gaps beneath the glasses and BS from the head
- **Dose reduction factor: 1.4 – 10***
- **Important: large glass with lateral coverage and good fit to face**

Efficiency of protection tools

- Strong dependence on orientation and design, factor 1.4-9, (Sturchio, 2013)
- Rule of thumb:
  - *Use of leaded glasses alone reduced the lens dose rate by a* ***factor of 5 to 10****; scatter-shielding screens alone reduced the dose rate by a* ***factor of 5 to 25****. Use of both simultaneously is even more efficient than either used alone, reducing the dose rate by* ***factor of 25 or more.***

Should be used by staff members in the interventional room

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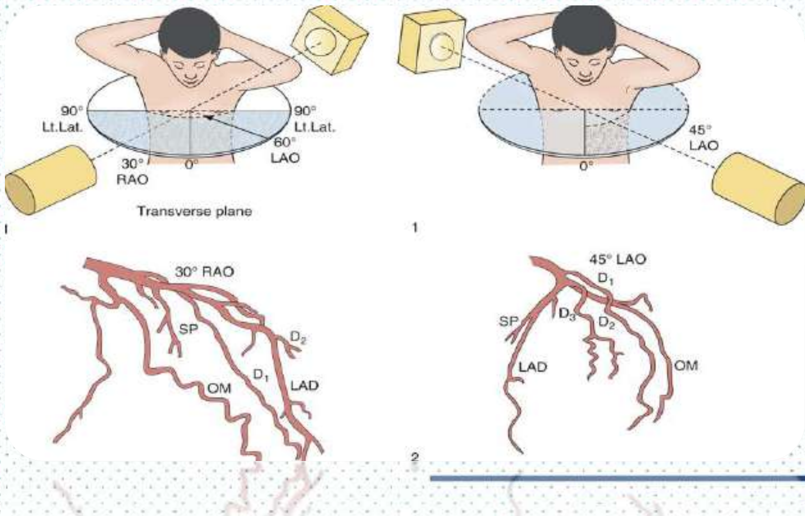
Practice related factors

Position of the operator

- Largely determined by the procedures performed
  - Radial vs femoral access in cardiology procedures
  - Percutaneous procedures in interventional radiology
- Radial artery route vs femoral access route
- **Dose difference by a factor 2-7 (Carionu, 2011)**

X-ray tube angulation

- Technique related factors
- **Left lateral projection associated with higher doses (Kong, 2014)**
- Not well defined geometry



Dose management strategy

- Use of **protective tools**, undercoach x-ray tube geometry, keep away from the X ray tube and patient
- Maintaining **x-ray equipment in optimum operating condition** (pulsed fluoroscopy, minimizing fluoroscopy time, limiting radiographic images, collimation and reduced use of magnification)
- **Training** in radiation protection (use of active dosimeters and awareness of the radiation dose levels)

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Eye lens monitoring arrangements

- Number of situations requiring specific eye lens monitoring is likely to increase

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Estimation of dose levels

Prior to routine individual monitoring

- Need for IM?
- Method?
- Interval of routine monitoring?

→

Workplace monitoring
Literature data
Simulations
Individual monitoring for a limited time

When is monitoring needed?

- Recommendation of dose monitoring (*Martin, 2011*):
  - 1-2 mSv/month, initial monitoring to establish dose levels
  - 2-3 mSv/month, regular monitoring should be considered
  - >3 mSv/moth regular monitoring is required
- Recommendation of dose monitoring (*IAEA, 2011; IRPA, 2017*):
  - **If annual equivalent dose to the lens is likely to exceed a dose of the order of (5-6) mSv**

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When is monitoring needed?

- Recommendation of dose monitoring *(Martin, 2011)*:
- Recommendation of dose monitoring *(IAEA, 2011)*:

Table 6. Indicators for deriving dose estimates for use in risk assessments

Organ	Dose/DAP ($\mu Gy\ Gy^{-1}\ cm^{-2}$)	DAP per month[a] ($Gy\ cm^2$)	Dose per cardiology procedure (μGy)	No. of cardiology procedures per month[a]
Eye	1	2000	80	25
Thyroid[b]	1.5 (0.2)		100	
Hand (percutaneous procedures)	40	120		
Hand (femoral access)	5	1000	300	16
Leg[b]	10 (2)		(40)	(100)

DAP, dose–area product.
[a]Workload for which dose monitoring should be considered. It is likely to be required for an individual with a workload double this value.
[b]Doses in brackets relate to where protection is being used.

Martin, BJR, 2011

Fluoroscopy guided procedures

- **Interventional cardiology**

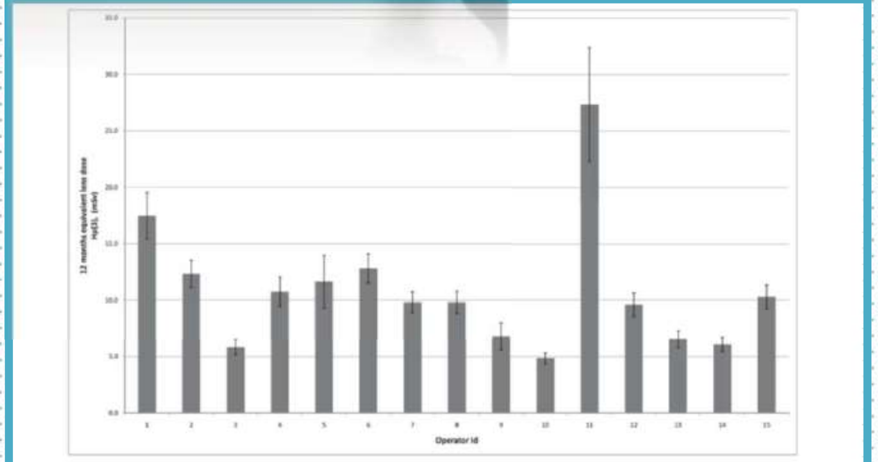

Fig. 2. 12 months cumulative effective lens dose (Hp(3), mSv) of every monitored operator with corresponding uncertainty, obtained considering a single measurement uncertainty of one standard deviation (k = 1, corresponding to 1σ) from the true value. "id" is the anonymous code of each primary interventionalist.

Betti, EJMP, 2019

- **Interventional neuroradiology**
  - Eye dose per procedure: **248/18 μSv**, with and without glasses
  - Number of procedures for 20 mSv/y: **119/602**, with and without glasses
- **Fluoroscopy** (gastro, gyneacology, urology..)
  - **(0.1-0.5) mSv/procedure**
  - Average: 13 mSv/y

Tavares, Int Neurorad, 2016
Bahruddin, jJP, 2016

Routine eye lens monitoring

- May be necessary in:
  - Interventional radiology and cardiology
  - For use of fluoroscopy used outside the imaging departments
- Take into account:
  - Energy and angle of incident radiation
  - Geometry of the radiation field
  - Use of personal protective equipment

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How to use of a dedicated eye lens dosimeter ?

- The position should be as close as possible to the eye (preferably in contact with the skin)
- Detector should face the radiation source
- In interventional procedures:
  - On the side closest to the x-ray tube
  - Behind the glasses (not very convenient)
  - Above the glasses (correction factor)

If use of a dedicated eye lens dosimeter is impractical?

- Dosimeter at trunk or thyroid level above the protective tools
  - **Correction factor of 0.75 (!)**
- Large uncertainty
- Caution, if the measured dose levels are close to the dose limits

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In the absence of any dose measurement

- Eye lens dose could be estimated from patient dose, using the conversion from P_{KA} to eye lens dose of:
  - **1 µSv/Gy cm² (protective tools are used)**
  - **10 µSv/Gy cm² (without protection)**
- Even larger uncertainty and variability

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Conclusions

- **Accurate dose measurements** are a prerequisite for investigation of low dose effects to the lens of the eye
- **Dedicated and calibrated dosimeters**
- Question of **what dose monitoring is appropriate** for an interventional facility is not straightforward
- Possible options: active, passive dosimetry and link to patient dose indices (with larger uncertainty)

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Conclusions

- Optimistic situation with eye protection
  - If radiation protection devices (most importantly protective screens or lead glass barriers) are not used, the risk for eye injuries is elevated

If radiation protection devices and techniques are properly used, **one can keep the radiation dose to eye lens at optimal level**

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Future?

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