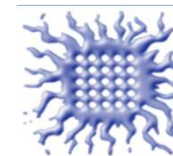


Eye lens dosimetry approaches within the European EURALOC epidemiological study

L. Struelens, J. Dabin, E. Carinou, P. Askounis, O. Ciraj-Bjelac, J. Domienik-Andrzejewska, D. Berus, R. Padovani & P. Covens



NOFER INSTITUTE OF OCCUPATIONAL MEDICINE



Vrije
Universiteit
Brussel



<http://www.euraloc.eu/>

EURADOS Winterschool January 30, 2020, Florence, Italy

EURALOC study

- Investigation of the **relationship** between the **dose** received to the **lens of the eye** and the occurrence of **lens opacities** among a population of interventional cardiologists (IC)
- Challenge

Provide a **distribution** of possible eye lens doses for each IC
↔ single dose estimate

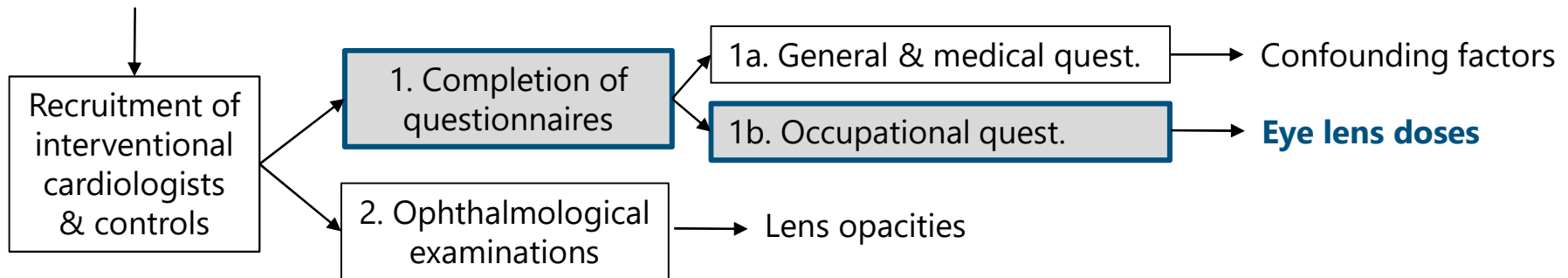
⇒ Detailed and **quantitative** investigation of the impact of cumulative eye lens dose on lens opacity occurrence



Cohort of 393 interventional cardiologists from 11 European countries

Mean cumulated years of exposure: 18 ± 9 years

Statistical design to investigate dose-response



Two complementary dosimetric approaches:

1. From **Procedure-specific eye lens doses to cumulative eye lens doses**

- Large database of eye lens doses per procedure is available
- Based on individual occupational history

2. From **annual whole-body doses to cumulative eye lens doses**

- Conversion factors from whole body dose → eye lens dose & associated uncertainty

Approach 1: Information on working history

Questionnaire on occupational history (per decade)

1. Different working periods (\neq places)

Occupational Questionnaire PART 0
Occupational Questionnaire Part 0: Procedures, Work

STEP 1: GENERAL WORKING DATE INFORMATION
Date of filling the Questionnaire (dd/mm/yyyy): 16/01/2014
Start of interventional activity (mm/yyyy): 08/2007
Stop of interventional activity (mm/yyyy):
Interruptions in interventional activities (1 year or more) (mm/yyyy) to (mm/yyyy)

STEP 2: LIST OF PROCEDURES (DOUBLE CLICK ON BRANCH TO CLEAR)

Branch	Procedure name
Branch #1 Cardiac	Procedure name #1 CA
Branch #2 Cardiac	Procedure name #2 PM or ICD implantation
Branch #3 Cardiac	Procedure name #3 PM or ICD resynchronization
Branch #4 Cardiac	Procedure name #4 RF catheter ablation (RFCA)
Branch #5 Cardiac	Procedure name #5 Pulmonary vein isolation (PVI) for atrial fibrillation ablation
Branch #6	Procedure name #6
Branch #7	Procedure name #7
Branch #8	Procedure name #8
Branch #9	Procedure name #9
Branch #10	Procedure name #10

STEP 3: WORK PLACES INFO (ADD AS MANY AS NEEDED)

1 Open Working Period 01	5 Open Working Period 05
2 Open Working Period 02	6 Add Working Period 06 info
3 Open Working Period 03	7 Add Working Period 07 info
4 Add Working Period 04 info	8 Add Working Period 08 info

2. Individual protective equipment and individual dosimetry

Occupational Questionnaire PART 2
Occupational Questionnaire Part 2: Protective Equipment, Decade: 2000-2009

Part 1: Personal protective equipment (% of time)

Lead glasses	<input checked="" type="checkbox"/> Never	<input type="checkbox"/> <50%
	<input type="checkbox"/> Always	<input type="checkbox"/> >50%
Type of lead glasses: side protection	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No
Lead face shield	<input checked="" type="checkbox"/> Never	<input type="checkbox"/> <50%
	<input type="checkbox"/> Always	<input type="checkbox"/> >50%
Lead apron	<input checked="" type="checkbox"/> Never	<input type="checkbox"/> <50%
	<input type="checkbox"/> Always	<input type="checkbox"/> >50%
Thyroid shield	<input type="checkbox"/> Never	<input type="checkbox"/> <50%
	<input type="checkbox"/> Always	<input checked="" type="checkbox"/> >50%
Lead gloves	<input checked="" type="checkbox"/> Never	<input type="checkbox"/> <50%
	<input type="checkbox"/> Always	<input type="checkbox"/> >50%

Part 2: Whole-Body dosimeters
Select the dosimetry method first!
 Single Dosimetry Double Dosimetry No Dosimetry!
Point out the location of the dosimeter above the apron

Position: at COLLAR at SHOULDER at CHEST at BELT

Position: left middle right

3. Type of interventional cardiology procedures: Workload, x-ray system, collective protective equipment

Occupational Questionnaire PART 3
Occupational Questionnaire Part 3: PM or ICD implantation
Work Place #1

STEP 1: PROCEDURE PERIOD AND INTERRUPTION
Start of the procedure (mm/yyyy): 08/2007
Procedure not performing any more:
End of the procedure (mm/yyyy): 07/2008
Procedure interruptions period: From (mm/yyyy) To (mm/yyyy)

STEP 2: UPDATE DECADES
CLICK TO UPDATE AVAILABLE DECADES

STEP 3: FILL ALL AVAILABLE DECADES
Click to update available decades for procedures
Click to update available decades for protective equipment
Open Decade 2000-2009
Click to update available decades for procedures

Occupational Questionnaire Part 3: Detailed Description Of Procedure
Decade 2000-2009

PROCEDURES PARAMETERS
Mean number of procedures per year: 100
You successfully distributed all the percent!
Access route: 0% Femoral, 0% Brachial, 0% Radial, 100% Direct
Typical total duration (minutes): 45
Typical total fluoroscopy time (minutes): 10
Dose-area-product (DAP) recorded: No, Yes, I don't know

ROOM PROTECTIVE EQUIPMENT (% OF TIME)
Ceiling suspended shield: Never, <50%, Always, >50%
Table shield: Never, <50%, Always, >50%
Radiation protection cabin: Never, <50%, Always, >50%
Other: Description: Never, <50%, Always, >50%

TYPE OF EQUIPMENT:
You successfully distributed all the percent!
Not rotational: 0% percent of the time
X-ray tube configuration (for not rotational systems): 100% below table, 100% above table, Mixed
C-arm: 100% percent of the time
X-ray tube configuration (for C-arm systems): 100% below table, 100% above table, Mixed
Biplane: 0% percent of the time

Approach 1: Eye lens dose data collection

1. Literature review: only papers

- Provided **non-normalized** eye lens dose data, measured in clinical practice (12/82 papers)
- From 7 papers + 3 unpublished studies, the **raw data** received from the authors

2. European ORAMED project

- 580 measurement data from **clinical practice** in 6 different countries

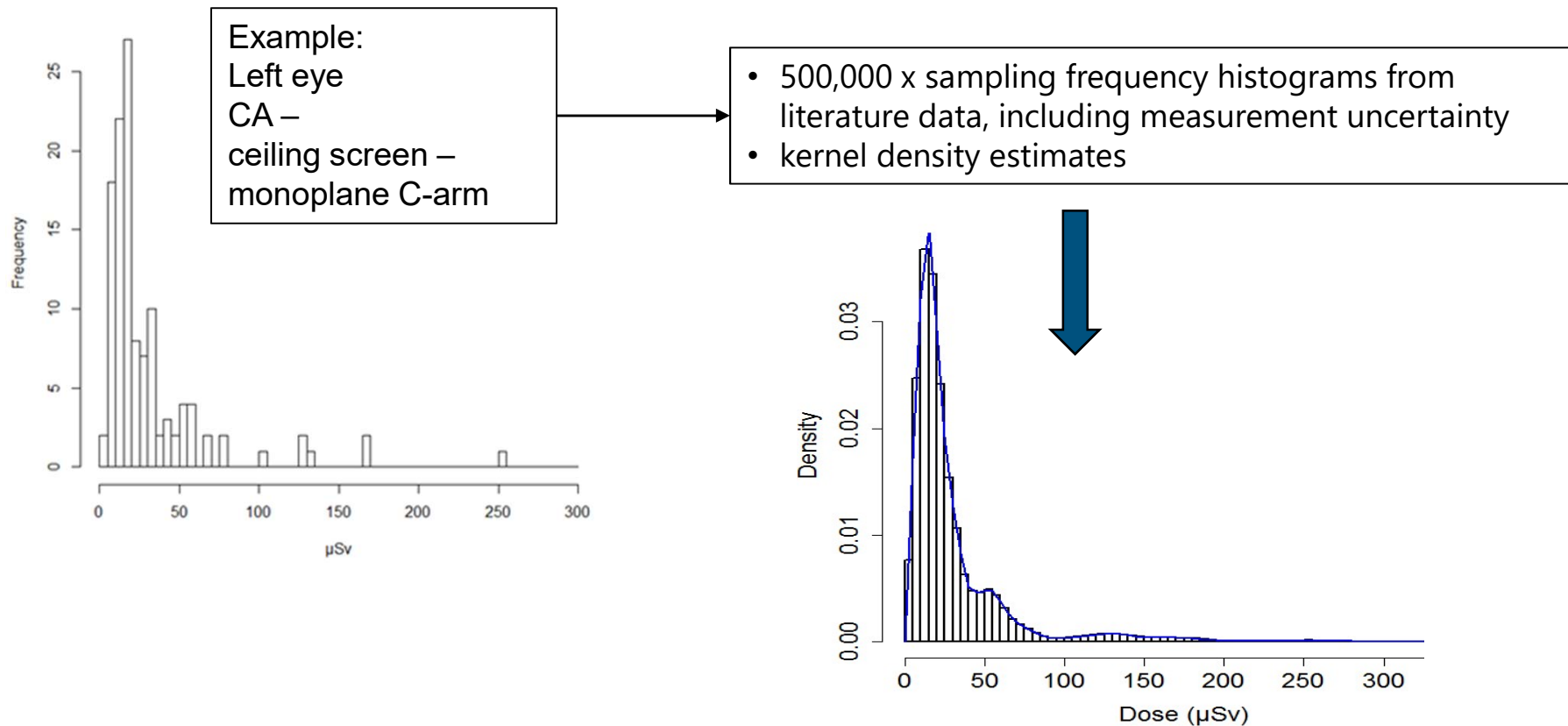
3. Data divided according to

- Type of procedure
- The use of ceiling suspended screens
- The X-ray system configuration

Separately for left and right eye

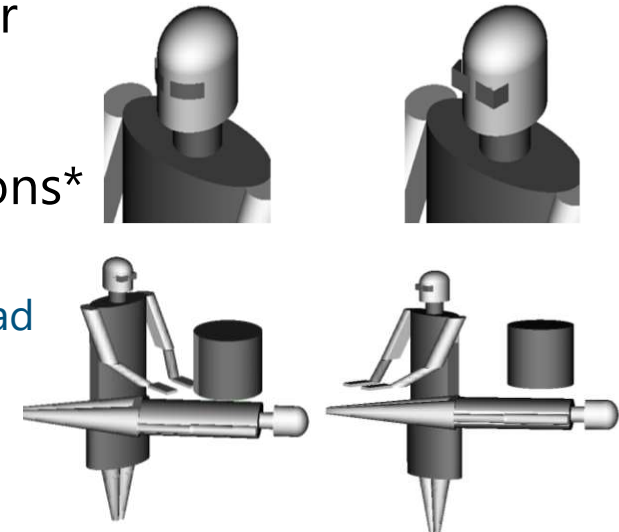
Procedure-specific eye lens doses to cumulative eye lens doses

- Based on available literature data
 - Creation of eye lens dose Probability Density Functions (PDF) for different exposure configurations

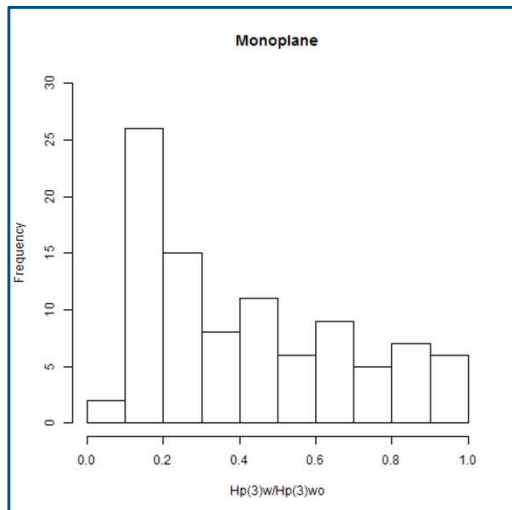


Approach 1: Eye lens dose data collection

- Published eye lens dose data do not account for the attenuation from lead glasses
- Lead glasses efficiency → Monte Carlo simulations*
 - Including the effect of **shape** of the glasses
 - Including the effect of the **rotation** of the operator's head
- For a specific procedure:

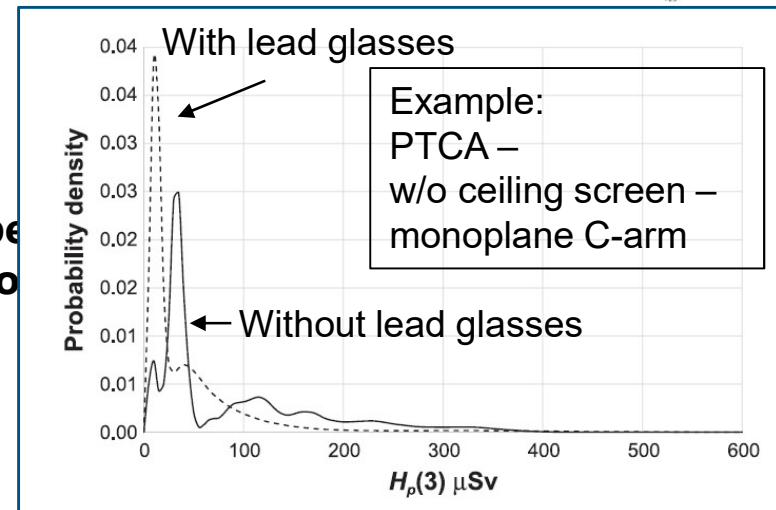


⇒ frequency distribution of $\frac{H_p(3)_{\text{with}}}{H_p(3)_{\text{without}}}$



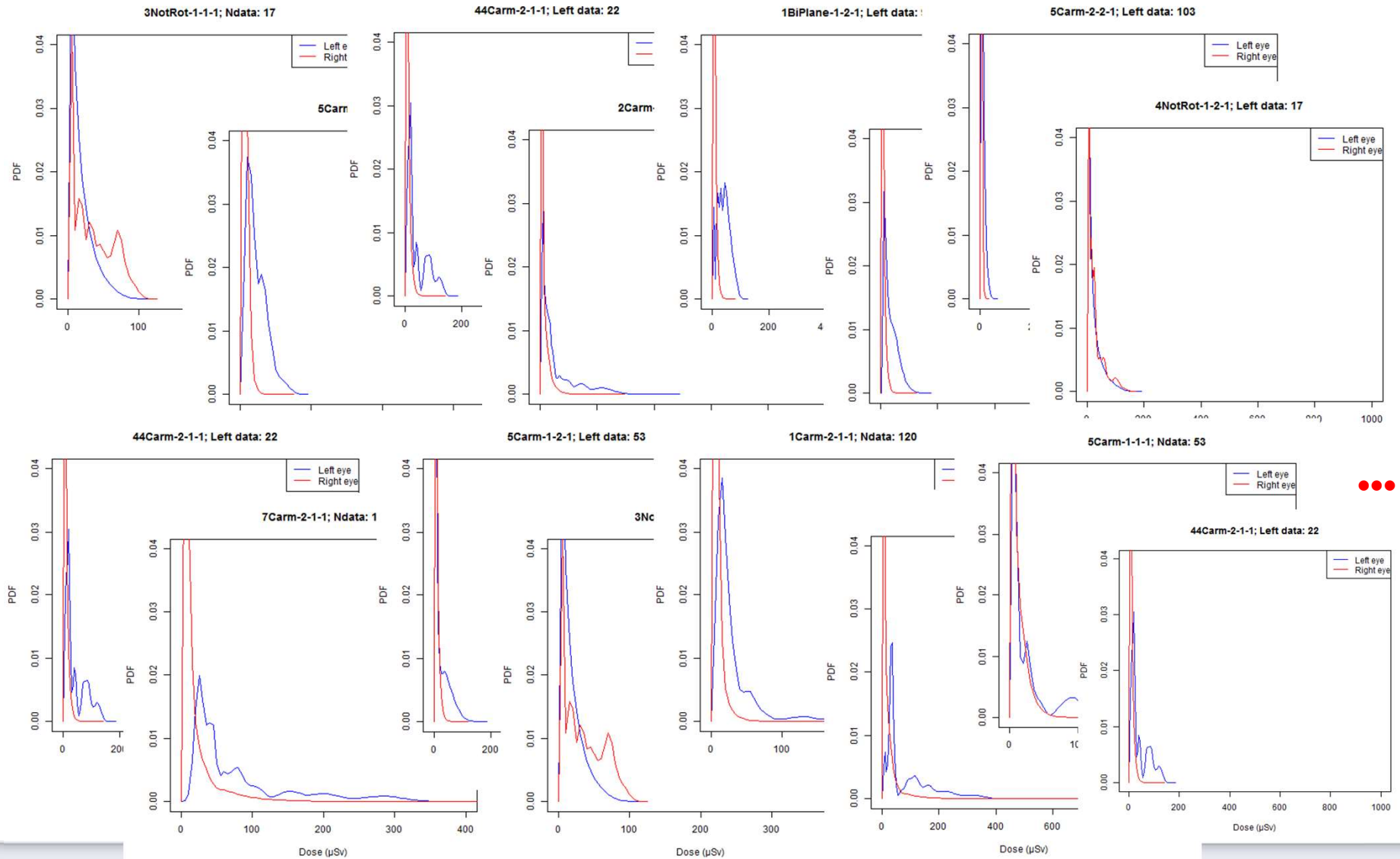
Median: 0.50
95% CI: [0.10, 0.96]

- relevant **x-ray beam**
- relevant **operator**



* Koukorava C, Farah J, Struelens L, et al. Efficiency of radiation protection equipment in interventional radiology: a systematic Monte Carlo study of eye lens and whole body doses. *J Radiol Prot* 2014; 34:509–28.

Procedure-specific eye lens doses to cumulative eye lens doses



Procedure-specific eye lens doses to cumulative eye lens doses

- Based on available literature data
 - Creation of eye lens dose Probability Density Functions (PDF) for different exposure configurations

$$D_{j,x,y,z} \left\{ \begin{array}{l} \bullet \text{ j: type of procedure} \\ \bullet \text{ x: lead glasses} \\ \bullet \text{ y: ceiling suspended screen} \\ \bullet \text{ z: type of x-ray system} \end{array} \right. \longrightarrow \text{Eye lens dose PER PROCEDURE}$$

$$D_{eye,cum} = \sum_{i,j,x,y,z} D_{j,x,y,z} \times N_{i,j,x,y,z}$$

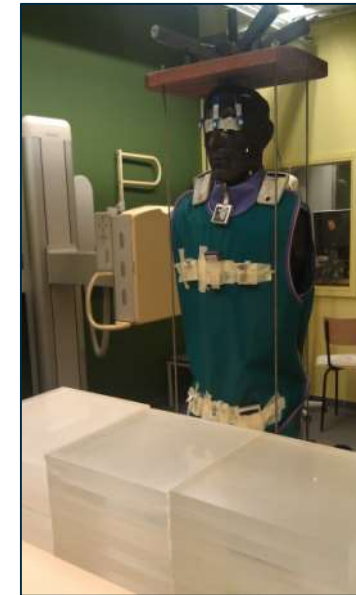
i : year

Number of procedures performed per year for specific exposure configuration

Cumulative eye lens dose **DISTRIBUTION**

Approach 2: Conversion from whole body dose

- European ELDO project (funded by DoReMi network): **“Relationship between eye lens dose and whole body dose”***
- Measurement of eye lens doses and whole body doses in clinical conditions
 - Operator: Rando-Alderson phantom
 - Patient: PMMA plates
 - Passive and active dosimeters
 - Measurements **above the lead apron**
 - Eye level
 - Collar level
 - Chest level
 - Waist level
 - Left – middle – right side

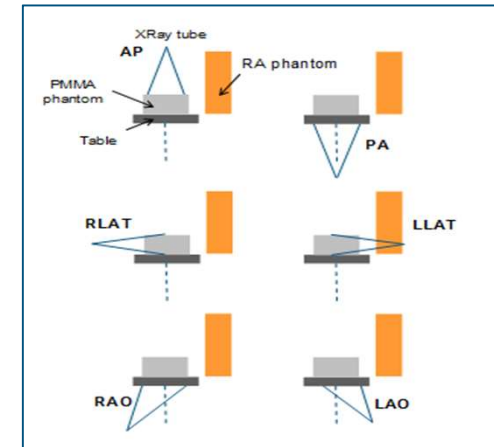


* Farah J, Struelens L, Dabin J,, et al. A correlation study of eye lens dose and personal dose equivalent for interventional cardiologists. *Radiat Prot Dosimetry* 2013; 157:561–9.

Approach 2: Conversion from whole body dose

- **Clinical conditions**

- Different x-ray beam projections
- Different operator positions
- Different x-ray beam qualities and field sizes
- Mono-plane and bi-plane x-ray systems



- For a specific procedure

⇒ frequency distribution of $CC_{WB \rightarrow Eye}$

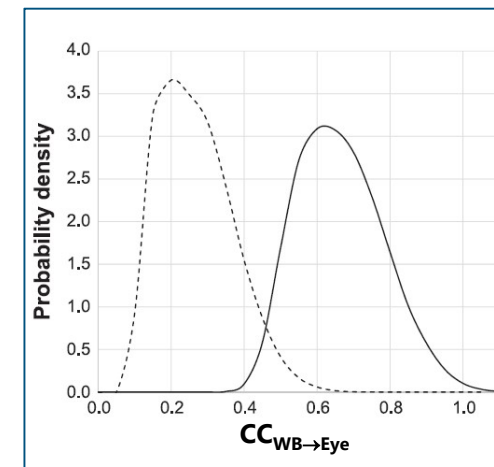
- relevant **x-ray beam projections**
- relevant **operator positions**

Probability Density Functions (PDF)



- To account for the effect of lead glasses

⇒ frequency distribution of $\frac{H_p(3)_{with}}{H_p(3)_{without}}$



- Left eye ;
- PTCA with C-arm x ray system ;
with (dotted) & without (solid) lead glasses
- WB dosemeter: left side of chest

Annual whole body doses to cumulative eye lens doses

- Based on whole body dose to eye lens dose conversion coefficients

$$CC_{p,x,z} \left\{ \begin{array}{l} \bullet p: \text{position of whole body dosemeter} \\ \bullet x: \text{lead glasses} \\ \bullet z: \text{type of x-ray system} \end{array} \right.$$

$$D_{eye,cum} = \sum_i D_{WB_{i,p}} \times CC_{p,x,z}$$

Cumulative whole body dose during year i , considering the position of the WB dosemeter

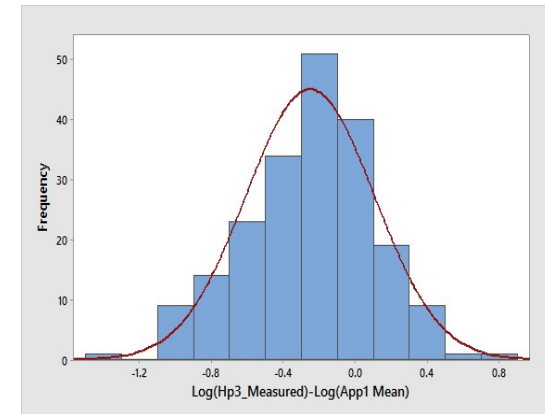
Validation of dosimetry methodology

- Eye lens dose measurements in clinical practice
 - Cumulative eye lens doses during 1-2 months (left and right eye)
 - Collect occupational information for the measurement period
 - Collect corresponding $H_p(10)$ dose values above the lead apron
 - 230 sets of measurements
 - Cumulative eye lens doses calculated
 - Approach 1 / 2: $D_{\text{calc},A1/A2}$
 - Using mean / median values of exposure configuration PDFs
- ⇒ Single eye lens dose values



Validation of dosimetry methodology

- Distributions of $D_{\text{Meas}}/D_{\text{calc}}$ log-normal (Anderson-Darling test)
- t -test: significant difference between measured and calculated values

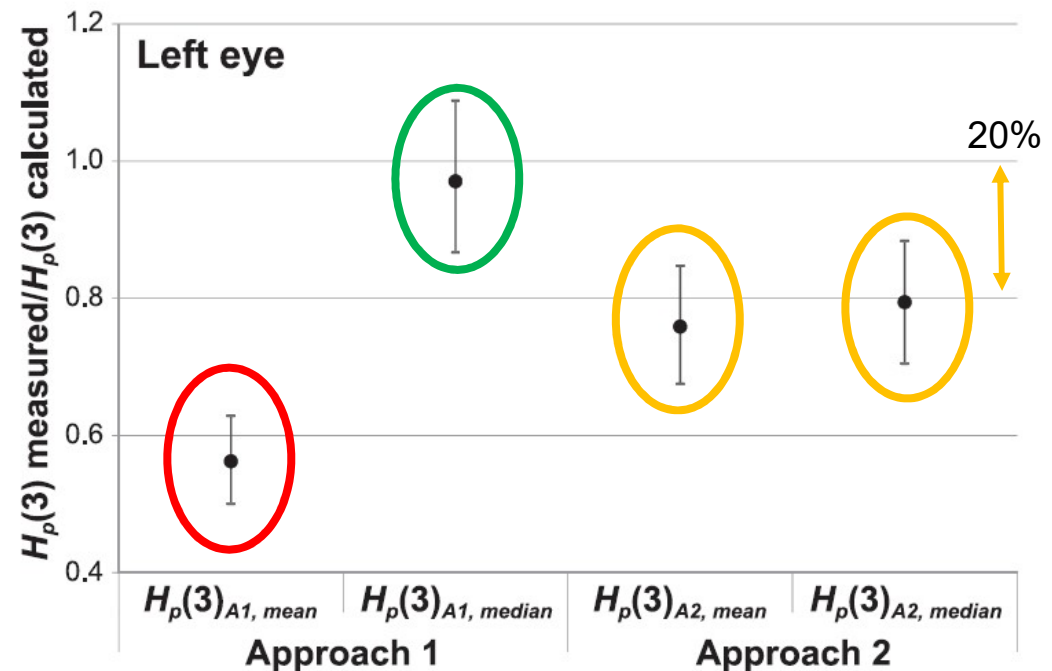


$$D_{\text{calc}, A_1_median} \quad (p: 0.613)$$

$$D_{\text{calc}, A_1_mean}$$

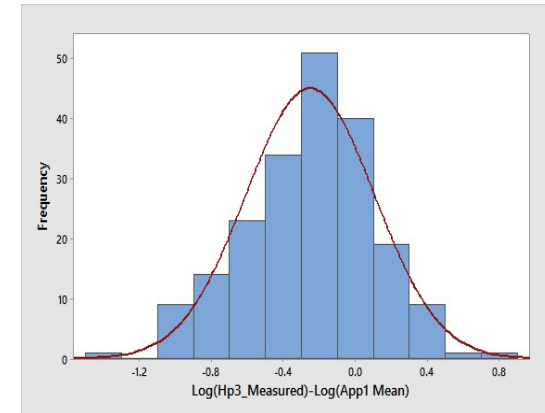
$$D_{\text{calc}, A_2_median} \quad (p < 0.05)$$

$$D_{\text{calc}, A_2_mean}$$



Validation of dosimetry methodology

- Distributions of $D_{\text{Meas}}/D_{\text{calc}}$ log-normal (Anderson-Darling test)
- T-test: significant difference between measured and calculated values



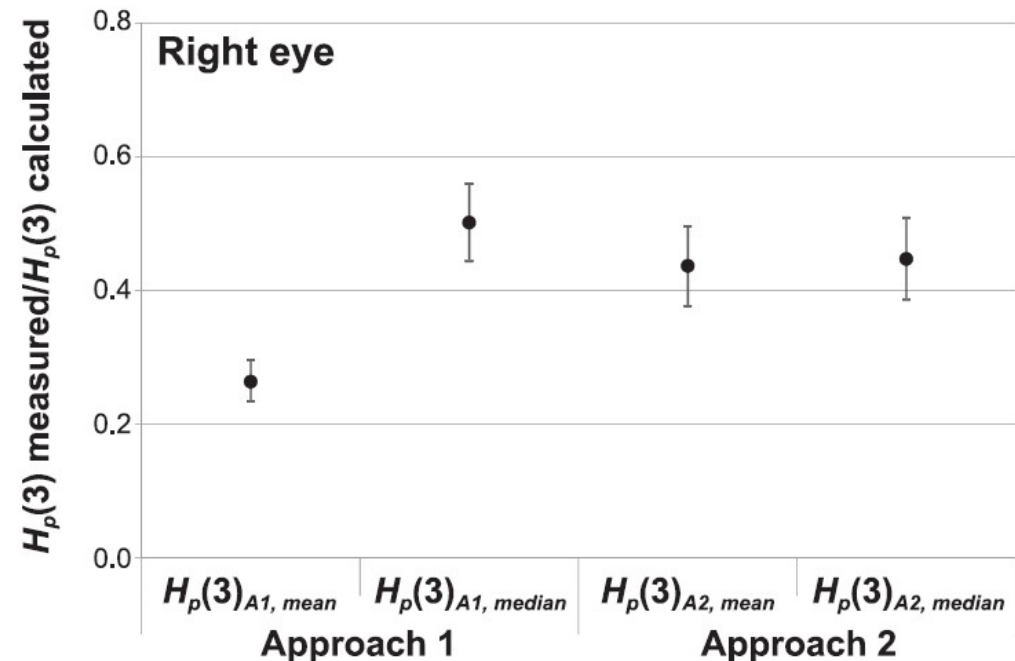
$D_{calc,A1_median}$

$D_{calc,A1_mean}$

$D_{calc,A2_median}$

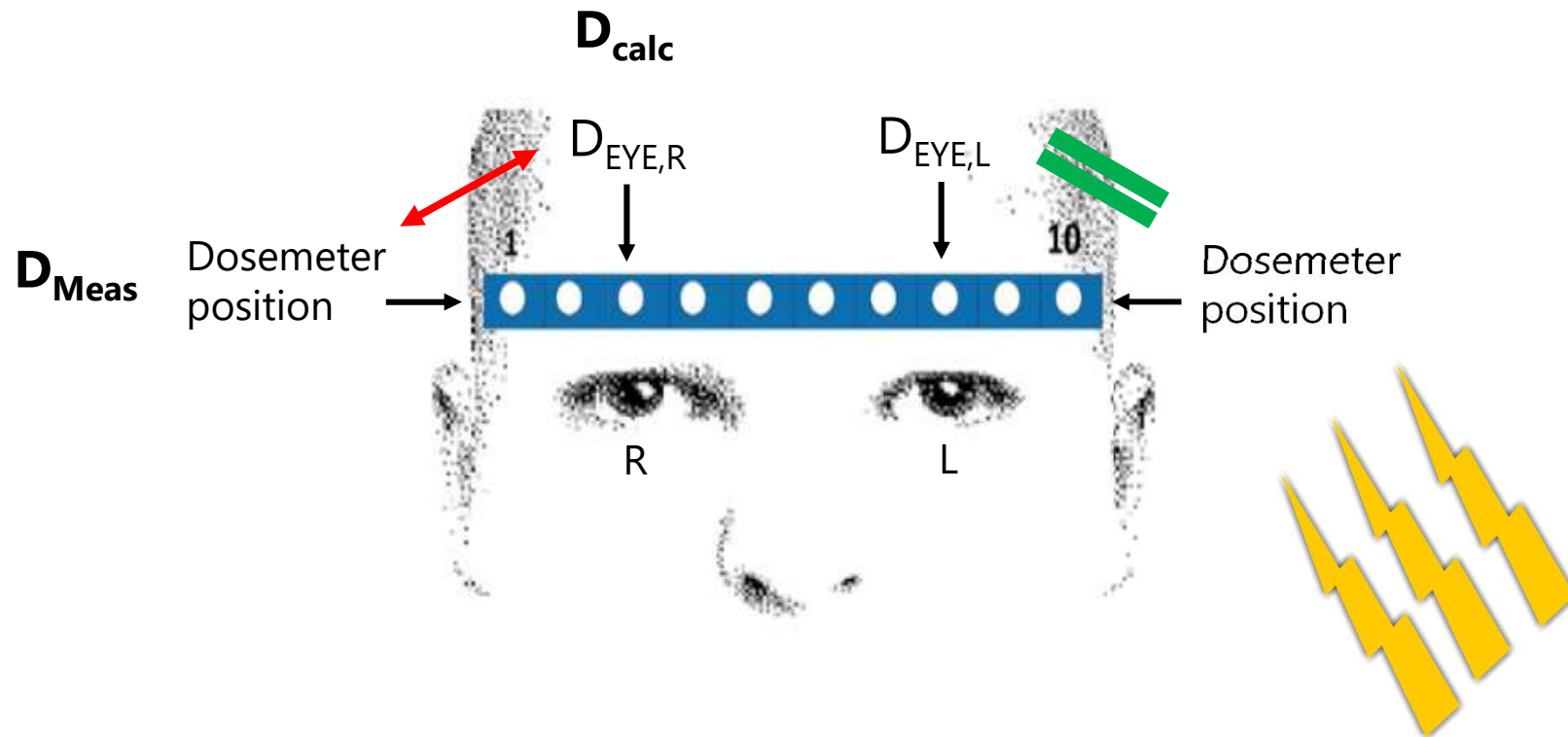
$D_{calc,A2_mean}$

(p < 0.05)



Validation of dosimetry methodology

- Right eye: less exposed

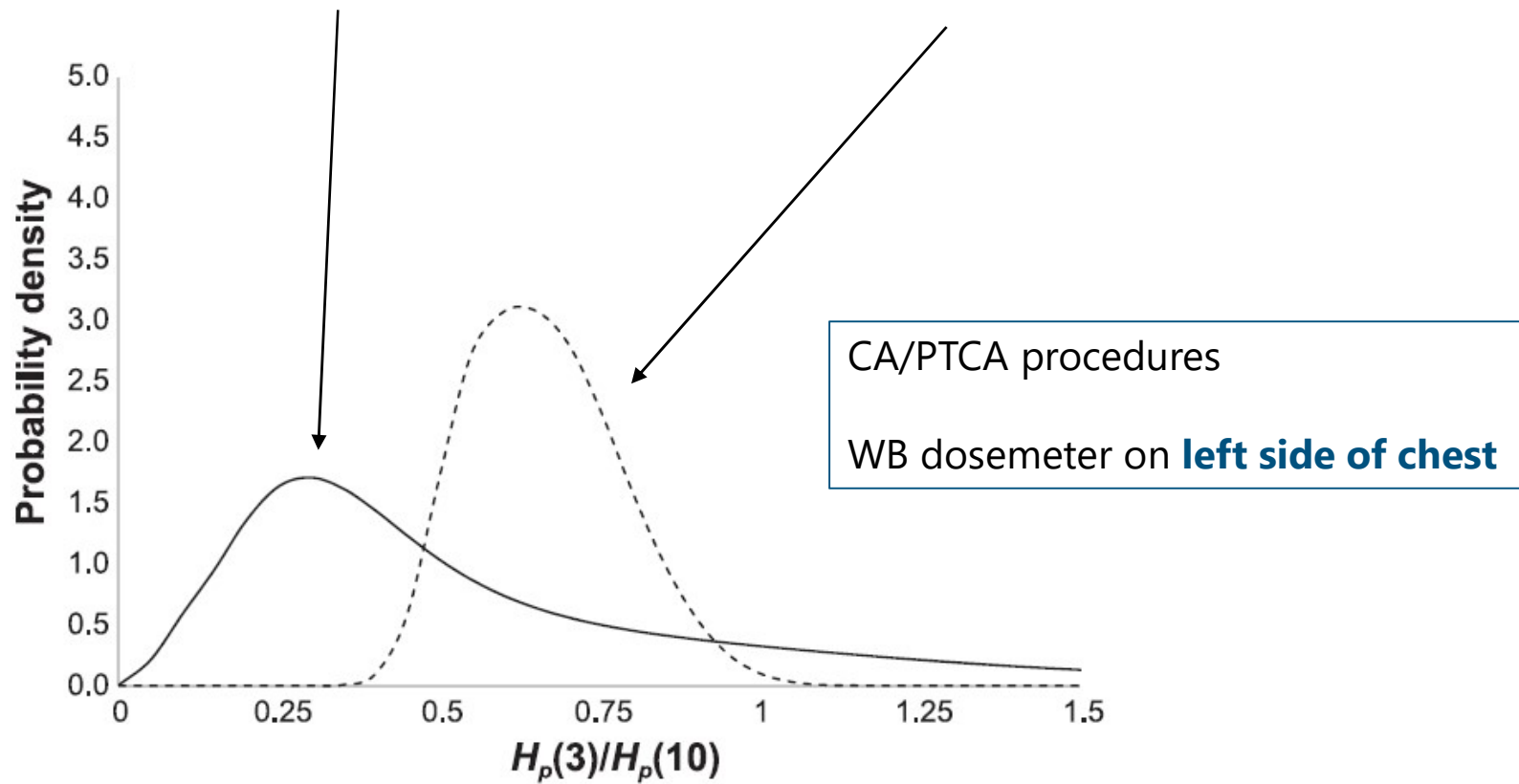


- **Domienik J, et al. 2014** The impact of x-ray tube configuration on the eye lens and extremity doses received by cardiologists in electrophysiology room J Radiol Prot 34 N73-9
- **Domienik J, et al. 2012** A study of the dose distribution in the region of the eye lens and extremities for staff working in interventional cardiology Radiation Measurements 47 130-8

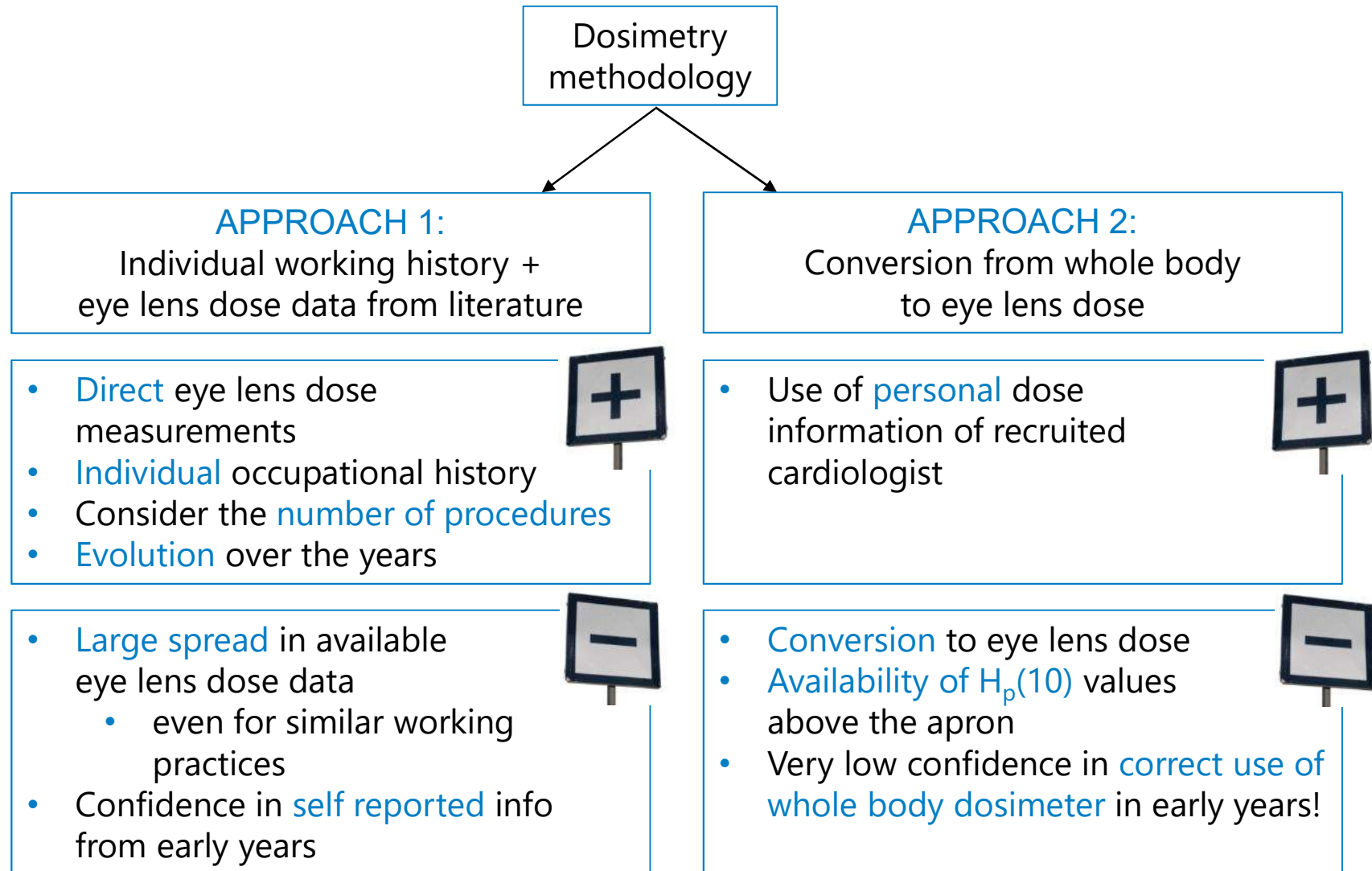
Validation of dosimetry methodology

- Whole body doses and eye lens doses are measured in clinical practice

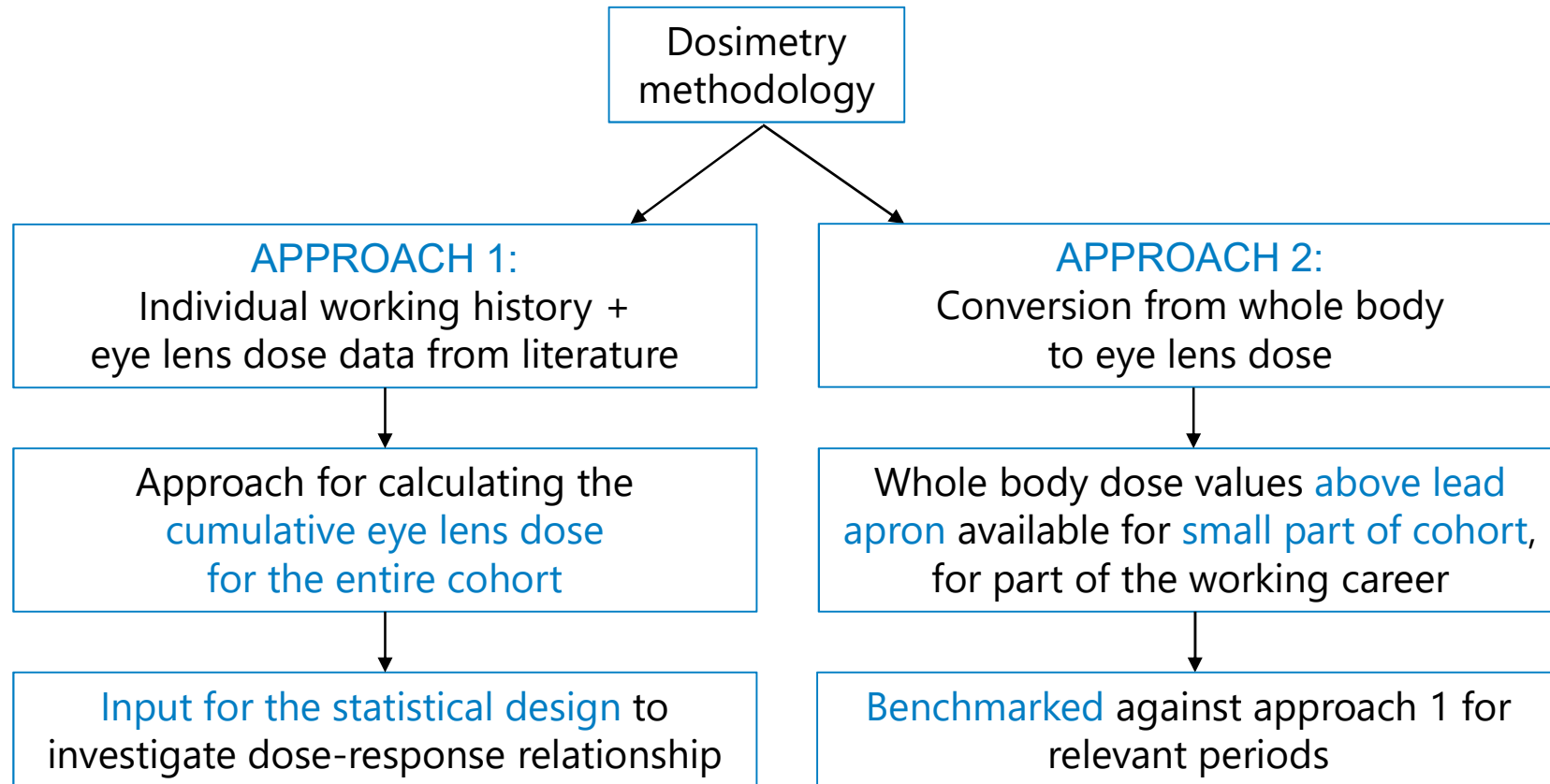
→ $[CC_{WB \rightarrow Eye}]_{val\ study}$ \Leftrightarrow $[CC_{WB \rightarrow Eye}]_{phantom\ study}$



Overview methodology



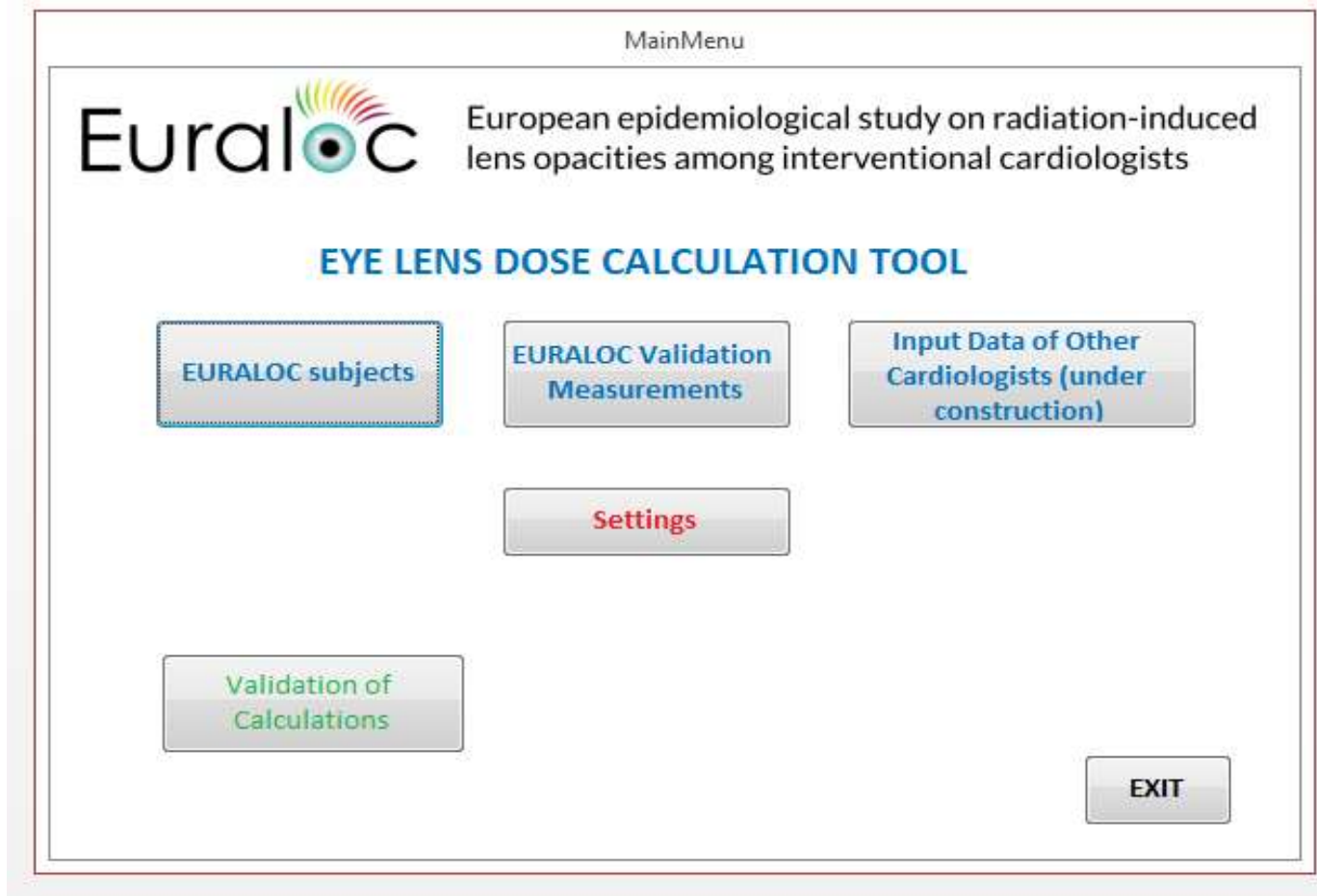
Overview methodology



Struelens L. et al., Radiation-Induced Lens Opacities among Interventional Cardiologists: Retrospective Assessment of Cumulative Eye Lens Doses. **Radiation Research**, 189, 399-408 (2018)

Retrospective dose calculation tool

- Occupational questionnaires: 420 interventional cardiologists



Retrospective dose calculation tool

- Occupational questionnaires: 420 interventional cardiologists

Input

- Information from occupational questionnaire
- Hp(10) values

Engine

- Calculated PDF for all possible combinations (192)
- Combinations of: type of procedure, left/right eye, x-ray system, protection

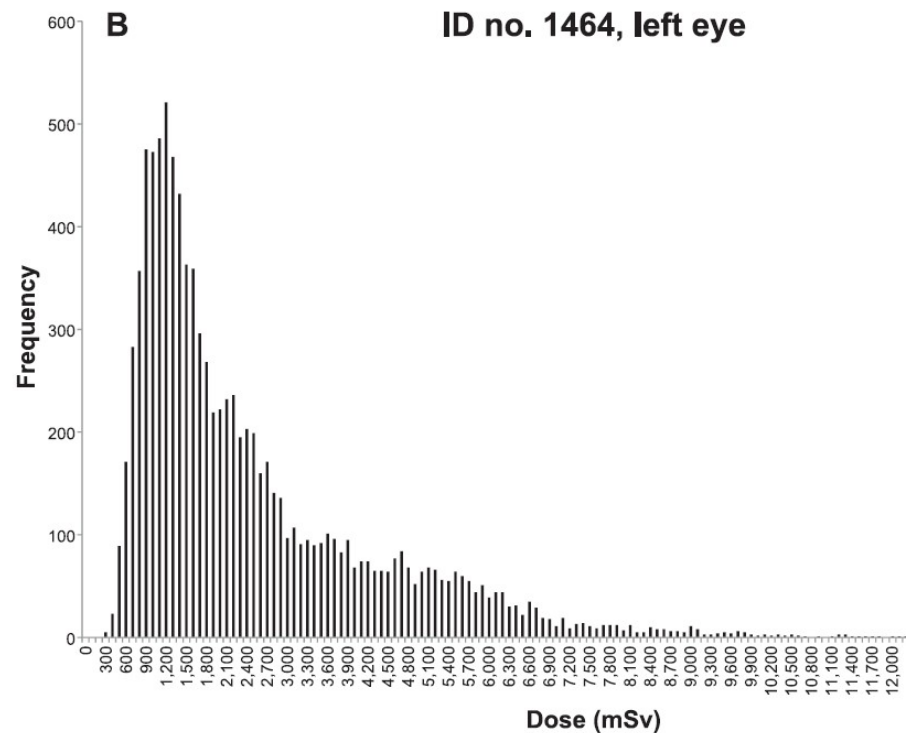
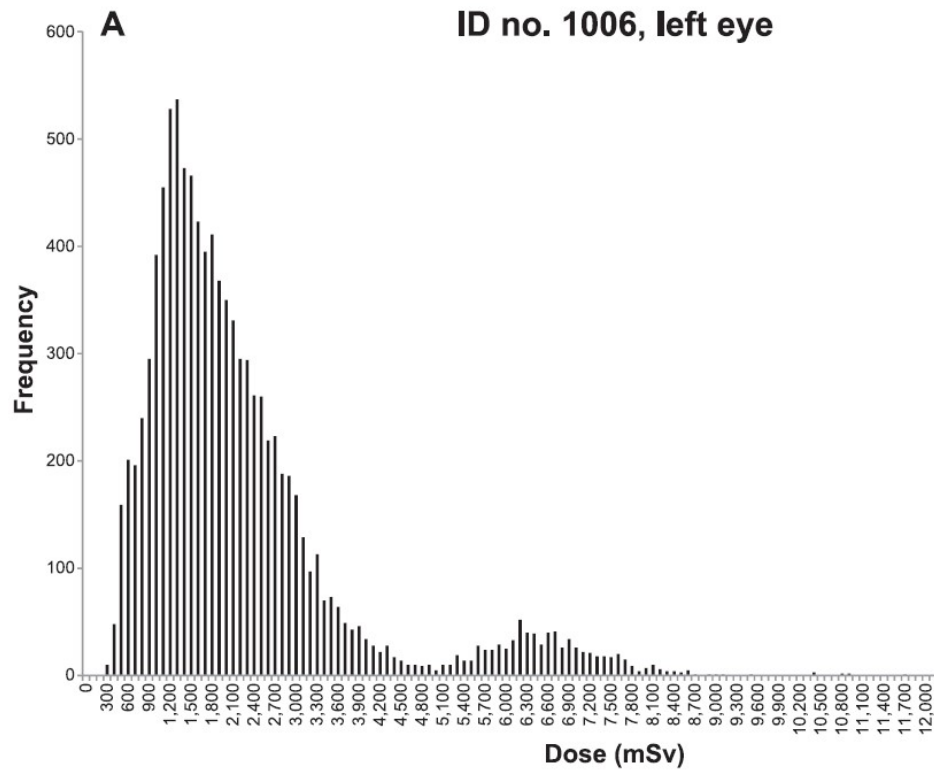
Output

- Cumulative eye lens dose values for a selected time period

Individual eye lens dose calculations

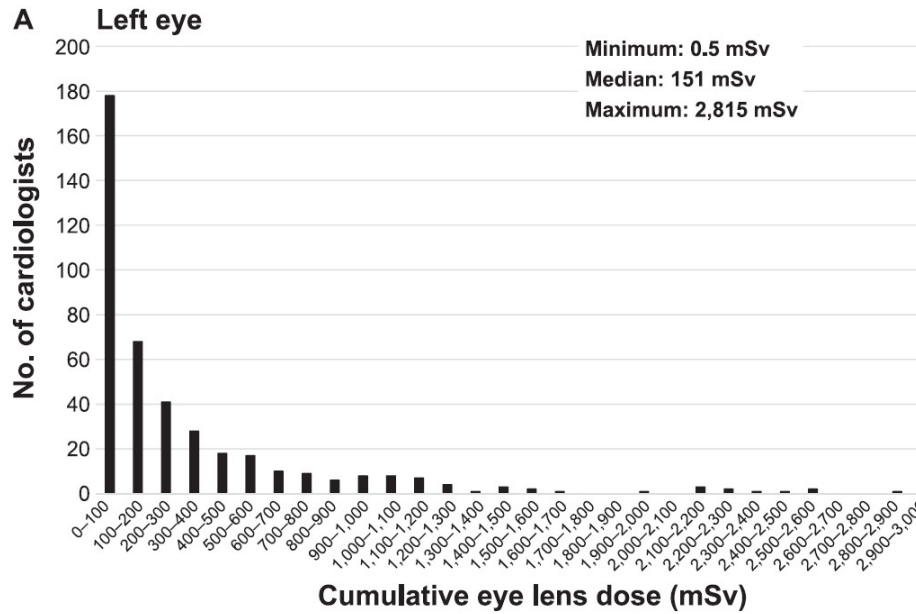
- Calculation of **individual cumulative eye lens dose distribution** (APPROACH 1)
 - The PDFs sampled **100,000 times**
 - For each realization: **one identical dose** per exposure configuration is used **for ALL cardiologists**
 - This sampled dose is multiplied by the **individual # procedures** for that exposure configuration in a specific year
 - **Cumulative dose** = sum over all exposure configurations of interest and complete working period
- Dose simulation design
 - Correctly accounts the uncertainties in the individual dose assessment
 - Maintains **the shared errors** among the cardiologists
e.g. errors in dose estimates for a specific exposure configuration in a specific period affect all cardiologists who performed that particular procedure in that period.

Individual cumulative eye lens dose calculations

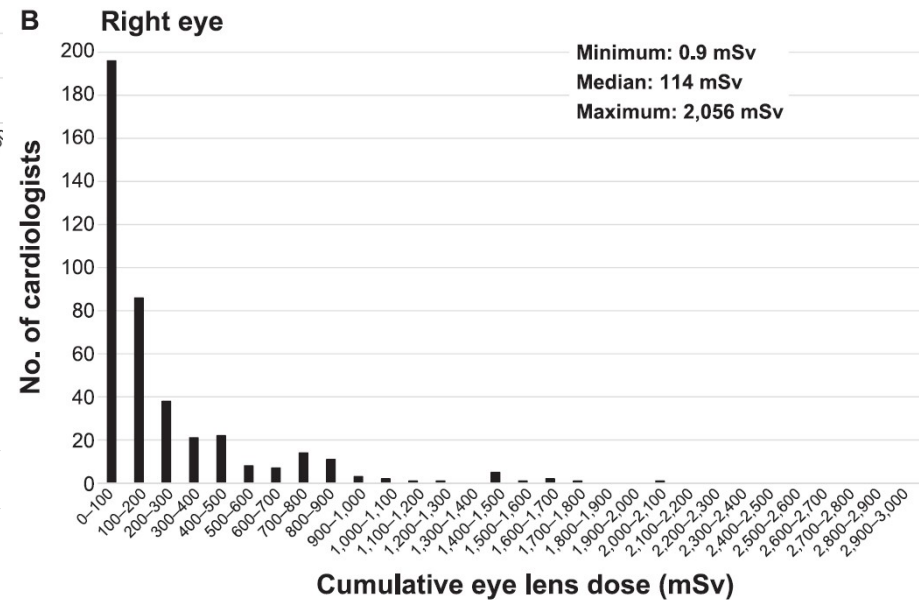


Individual cumulative eye lens dose calculations

- Calculation of cumulative eye lens doses, based on median values of the PDFs



68% < 300 mSv
42% < 100 mSv
Max = 2,8 Sv



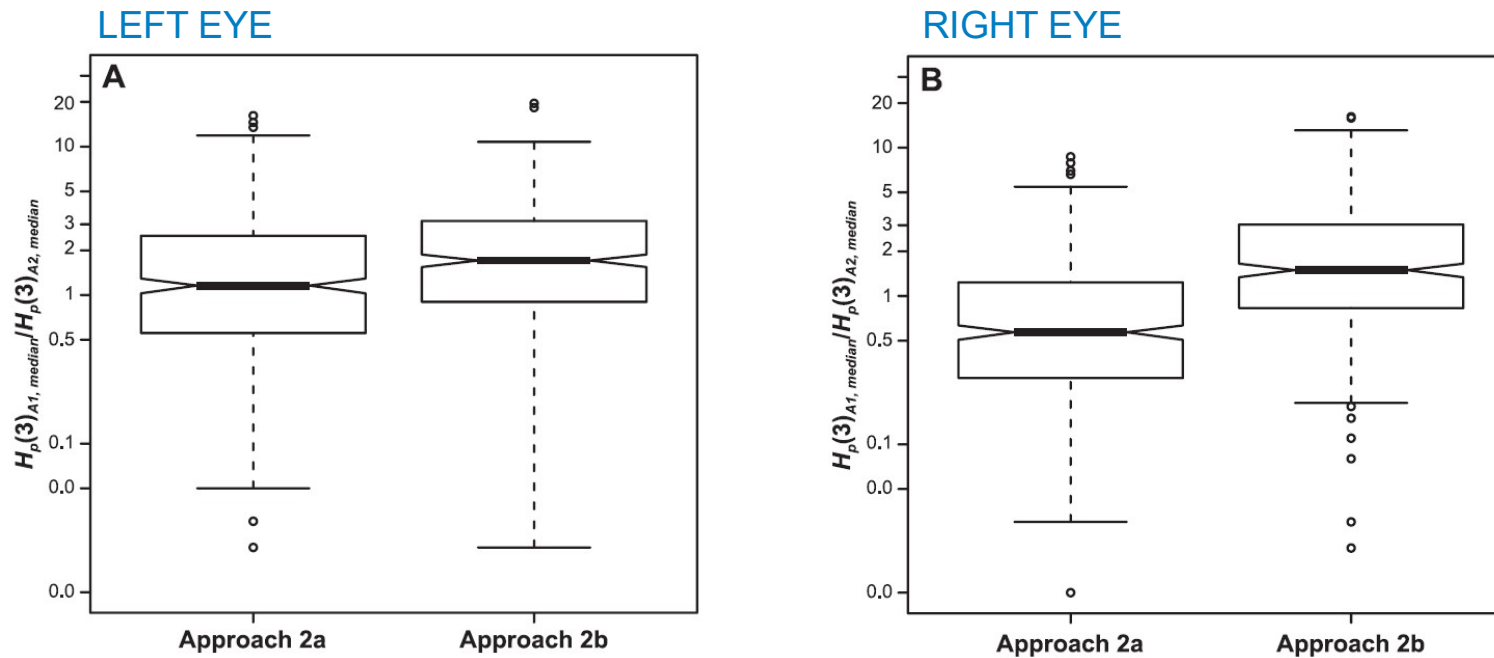
76% < 300 mSv
47% < 100 mSv
Max = 2,0 Sv

Benchmarking approach 1 and approach 2

- Calculation of **individual cumulative eye lens doses** (APPROACH 2)
 - 102 cardiologists: WB dosimeter above the lead apron for a certain period
 - Calculation of eye lens dose values, using **median values** of
 1. the $CC_{WB \rightarrow Eye}$ obtained from the extensive **phantom study** [Farah et al.]
→ Approach 2a: $D_{calc,A2a}$
 2. The $CC_{WB \rightarrow Eye}$ obtained from the **validation study** [Struelens et al.]
→ Approach 2b: $D_{calc,A2b}$
- Calculation of **individual cumulative eye lens doses** (APPROACH 1)
 - Calculation of eye lens dose values **annually**
 - Using the **workload of the corresponding years**, for which WB dose values are available for specific cardiologist
→ Approach 1: $D_{calc,A1}$

Benchmarking approach 1 and approach 2

- Paired *t*-test on log-transformed data: $P < 0.05$



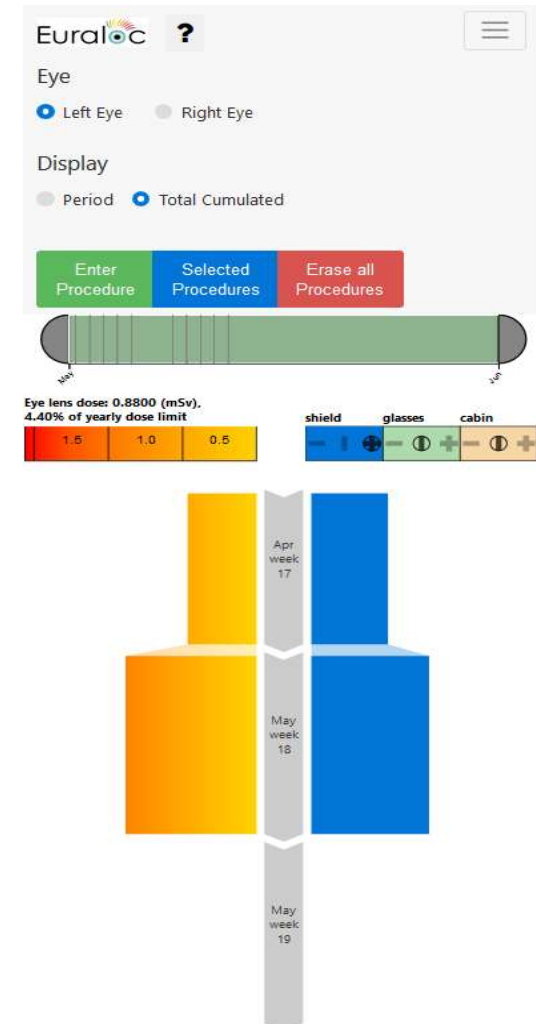
- Inaccurate self-reported data on occupational history: **overestimation of the workload**
- **Improper use** of WB dosimeters

Conclusion: retrospective dose calculations

- **Two methodologies** for retrospective calculation of cumulative eye lens doses for interventional cardiologists (IC)
 - Effort: provide a **distribution** of possible eye lens doses for each IC
 - A median cumulative eye lens dose of
 - 151 mSv (left eye)
 - 114 mSv (right eye)
 - Individual maximum eye lens doses up to 10 Sv (very small probabilities)
 - **Limitation**: methodology relies on self-reported data
 - **Validation study** (reliable information): methodology is positively benchmarked
- ⇒ methodology can be used for **prospective assessment of eye lens doses**

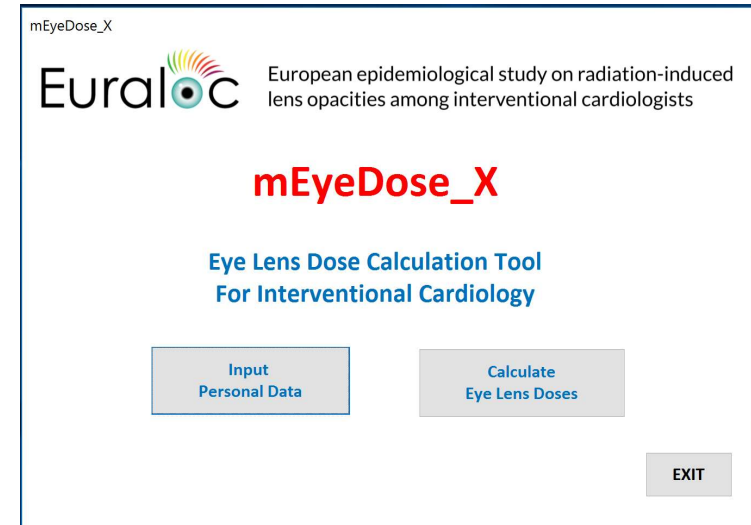
Educational tools: mEyeDose

- Development of 2 tools, with specific capabilities
- Educational App for mobile devices: **mEyeDose**
 - Target population: **Interventional cardiologists**
 - App for mobile devices: www.euraloc.eu
 - User-friendly
 - Track and learn to optimize individual eye lens doses based on workload data
 - Uses underlying median values from eye lens dose PDFs



Educational tools: mEyeDose_X

- Desktop App “mEyeDose_X”
 - Developed in Microsoft Access
 - Uses the full EURALOC dose calculation methodology
 - Can store and calculate large amount of data of multiple cardiologists (up to 2 GB)
 - Additional features:
 - Interface to export calculated data
 - Calling tutorial screens during all processes embedded
- Freely available by contacting a member of the EURALOC team:
www.euraloc.eu/en/Project_partners



Covens P. et al., Track, calculate and optimise eye lens doses of interventional cardiologists using mEyeDose and mEyeDose_X. *Journal of Radiological Protection*, 38, 678-687 (2018)



**Thank you very
much for your
attention !**

The research leading to these results has received funding from the European Atomic Energy Community's Seventh Framework Programme under grant agreement n° 604984.

● Tracking eye lens doses

The dashboard includes the following elements:

- Navigation:** "Enter Procedure" (circled in red), "Selected Procedures", and "Wipe all Procedures".
- Display Options:** "Eye" (Left Eye selected, Right Eye unselected) and "Display" (Period selected, Total Cumulated unselected).
- Dose Tracking:** A horizontal bar for May, June, and July. Below it, "Eye lens dose (mSv): 0.00% of yearly dose limit" is shown with a color-coded scale (0.030, 0.020, 0.010).
- Protection Settings:** "shield", "glasses", and "cabin" with toggle switches.

Store workload by adding

- the # cardiac procedures
- the **RP devices**
- The type of **x-ray system** over a specific **date interval**

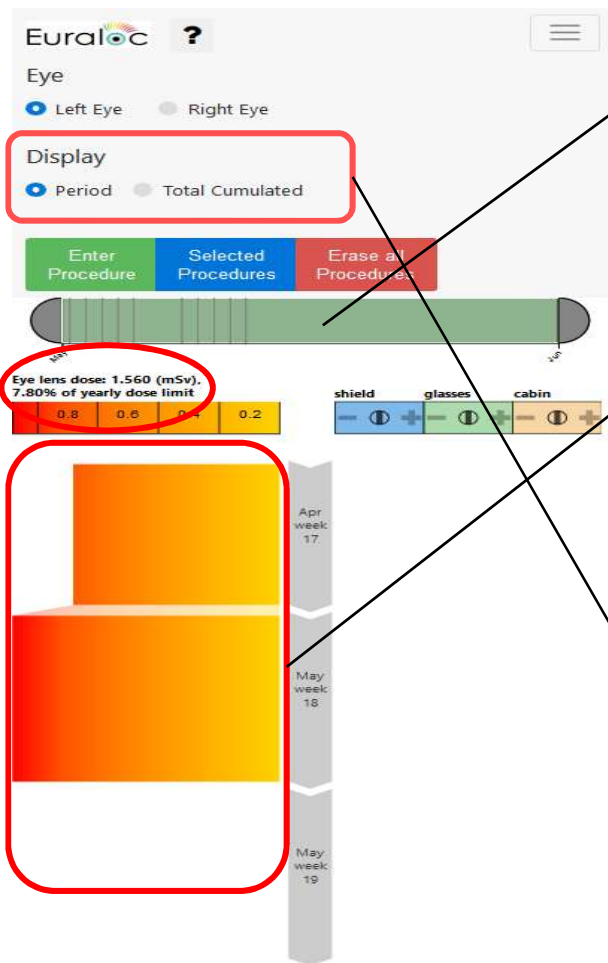
The "Add Procedures" form includes the following fields:

- Procedure:** (Circled in red)
- CA + PCI (PTCA):** (Dropdown menu)
- Equipment:** (Circled in red)
- Carm:** (Dropdown menu)
- Protection:** (Circled in red)
- Protection Options:** "glasses", "Cabin", "Shield" (radio buttons)
- Start / End Date:** (Circled in red)
- Start Date:** 08/05/2017
- End Date:** 12/05/2017
- Number:** 20
- Add:** (Blue button)

#	Proc.	Equip.	Time	Prot.	
20	CA	Carm	01-05-17 05-05-17	No	X
20	PTCA	Carm	08-05-17 12-05-17	No	X

Save changes (Blue button)

● Tracking eye lens doses



Time slider

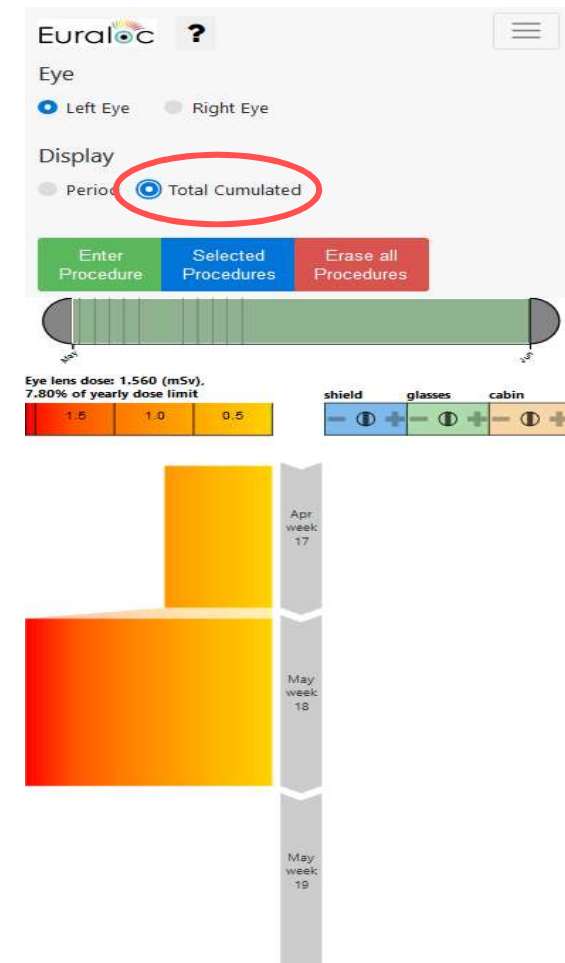
- Procedures are added as vertical lines

Level of eye lens dose

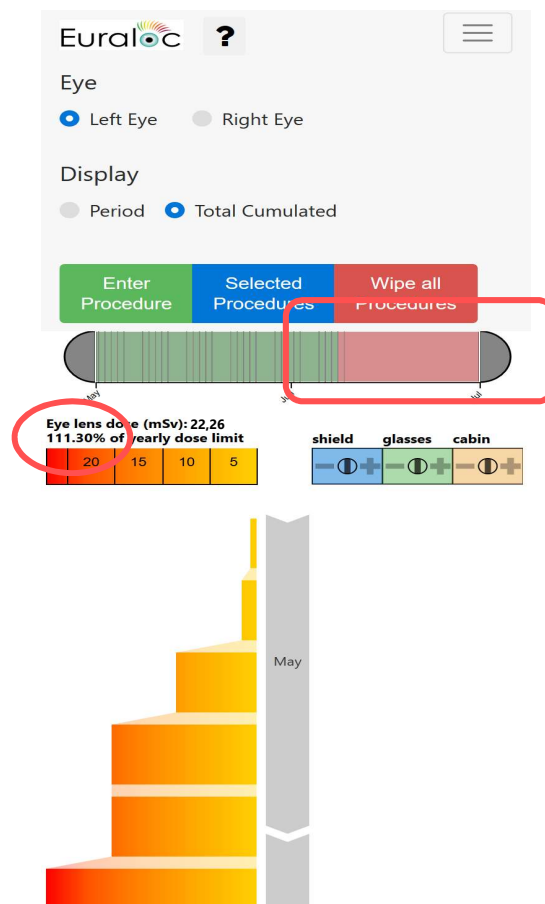
- Chose left or right eye
- Dose with color legend
- Dose value
- Percentage of the annual dose limit

Display

- Dose received over displayed period
- Total cumulated dose



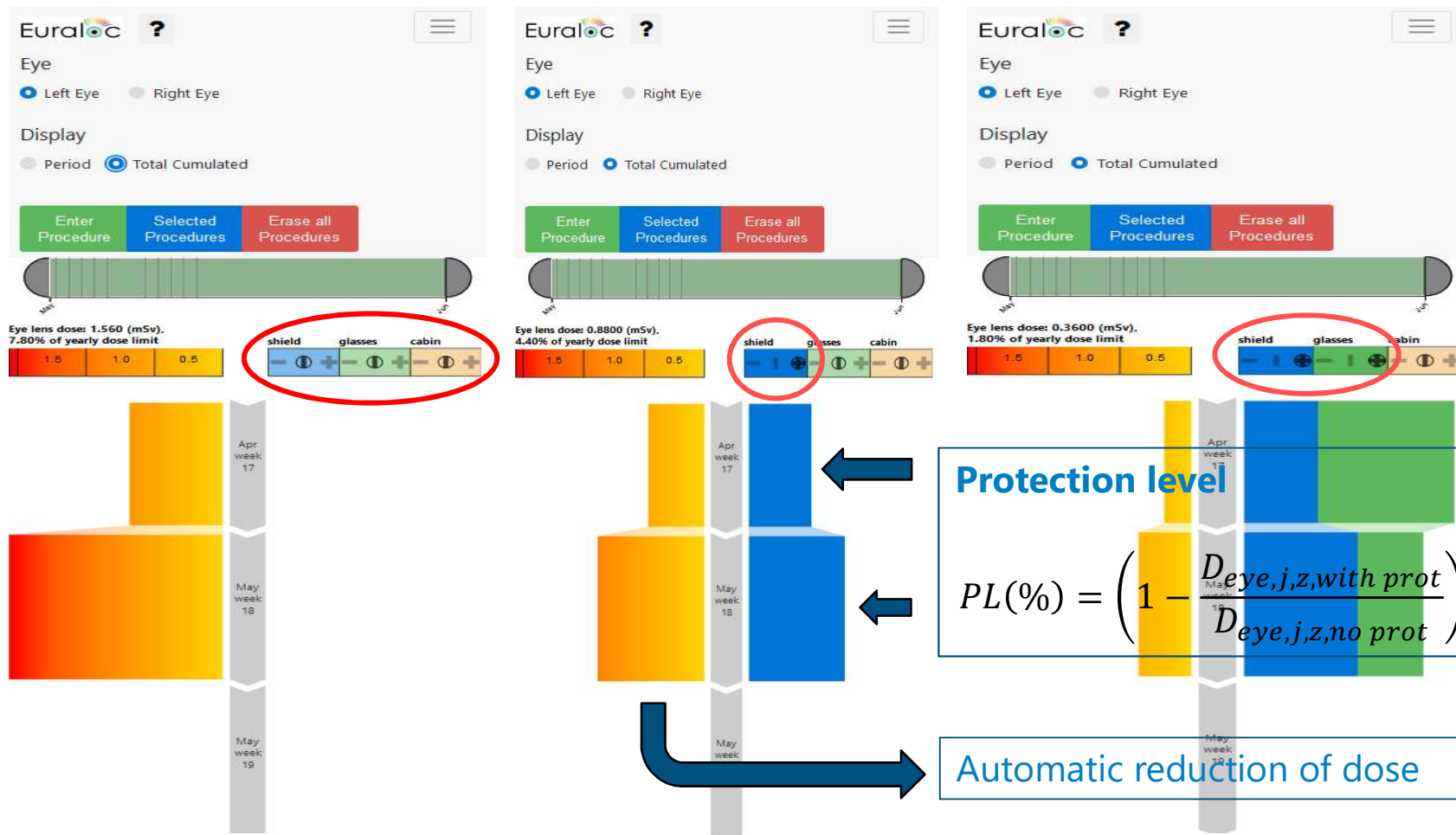
- Tracking eye lens doses: specific features
 - Exceeding the dose limit



Visible in 2 ways

- Displayed percentage exceeds 100%
- Time slider displays a red zone, indicating the moment dose limit exceeded

- Effect of radiation protection devices



Copyright © 2018 - SCK•CEN

PLEASE NOTE!

This presentation contains data, information and formats for dedicated use only and may not be communicated, copied, reproduced, distributed or cited without the explicit written permission of SCK•CEN.

If this explicit written permission has been obtained, please reference the author, followed by 'by courtesy of SCK•CEN'.

Any infringement to this rule is illegal and entitles to claim damages from the infringer, without prejudice to any other right in case of granting a patent or registration in the field of intellectual property.

SCK•CEN

Studiecentrum voor Kernenergie
Centre d'Etude de l'Energie Nucléaire
Belgian Nuclear Research Centre

Stichting van Openbaar Nut
Fondation d'Utilité Publique
Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSELS

Operational Office: Boeretang 200 – BE-2400 MOL



STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE