Eye lens dosimetry approaches within the European EURALOC epidemiological study

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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

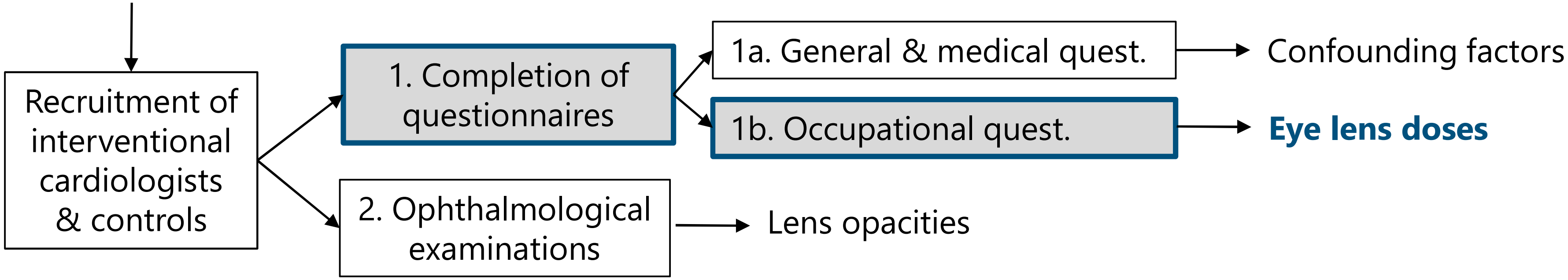
⇒ Detailed and quantitative investigation of the impact of cumulative eye lens dose on lens opacity occurrence

Cohort of 393 interventional cardiologists from
11 European countries

Mean cumulated years of exposure: 18 ± 9 years

Statistical design to investigate dose-response

Methodology



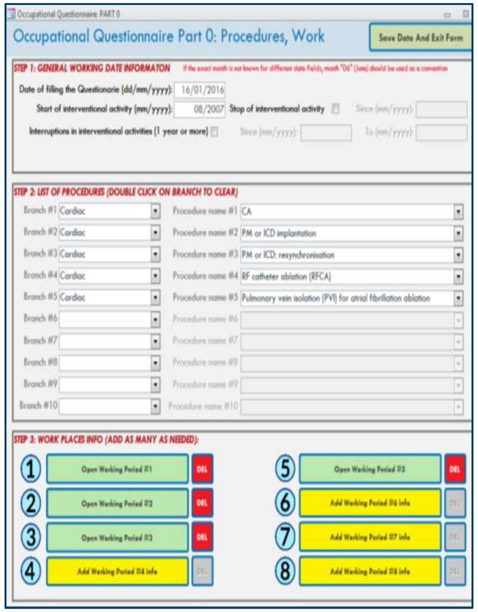
Two complementary dosimetric approaches:

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

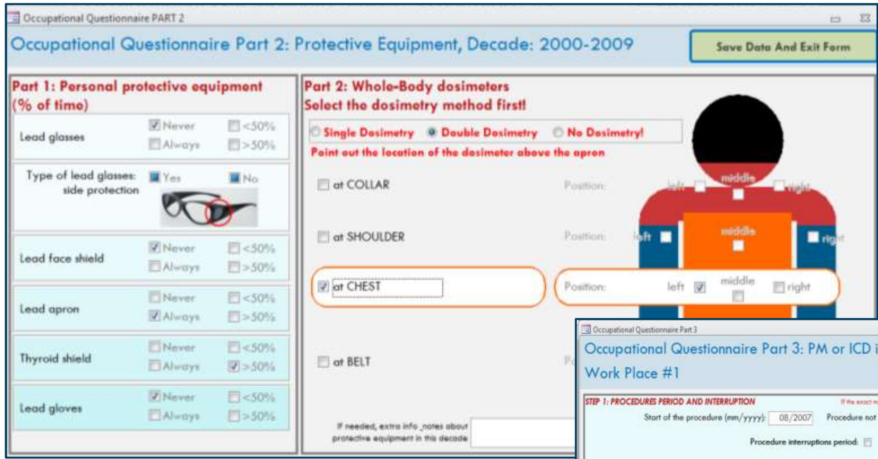
Approach 1: Information on working history

Questionnaire on occupational history (per decade)

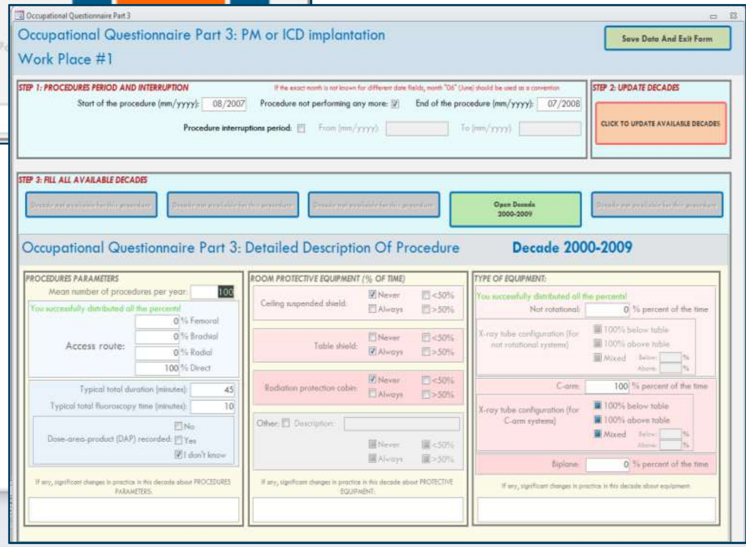
1. **Different working periods (≠ places)**



2. **Individual protective equipment and individual dosimetry**



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



Approach 1: Eye lens dose data collection

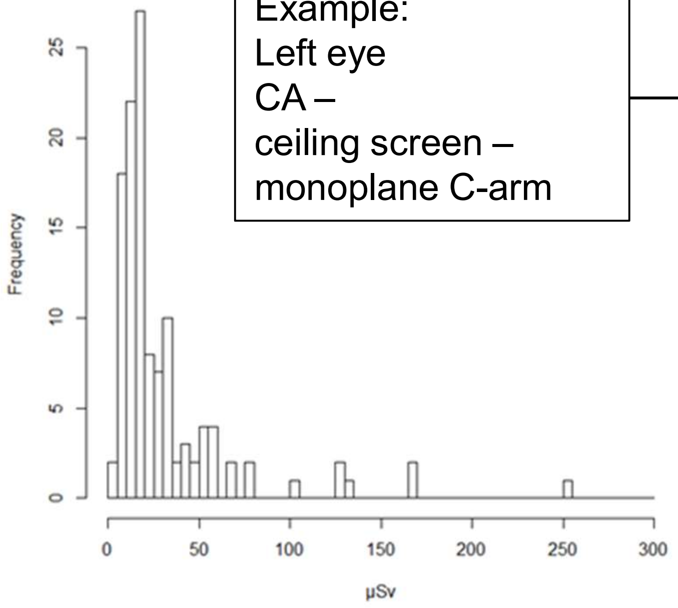
1. Literature review: only papers
   - Provided non-normalized eye lens dose data, measured in clinical practice (12/82 papers)
   - From 7 papers + 3 unpublished studies, the raw data received from the authors
2. European ORAMED project
   - 580 measurement data from clinical practice in 6 different 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

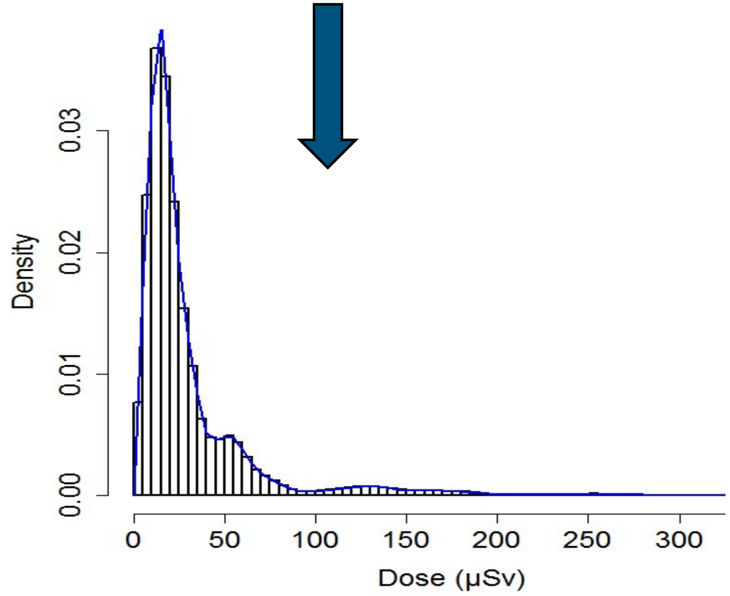
Procedure-specific eye lens doses to cumulative eye lens doses

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

Example:
Left eye
CA –
ceiling screen –
monoplane C-arm

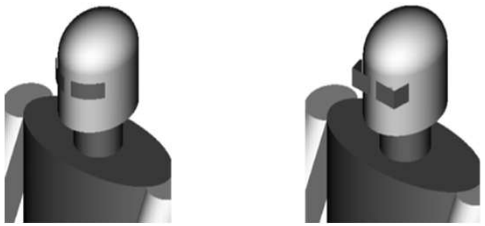


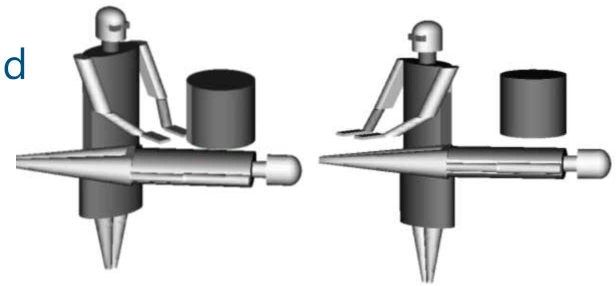
- 500,000 x sampling frequency histograms from literature data, including measurement uncertainty
- kernel density estimates

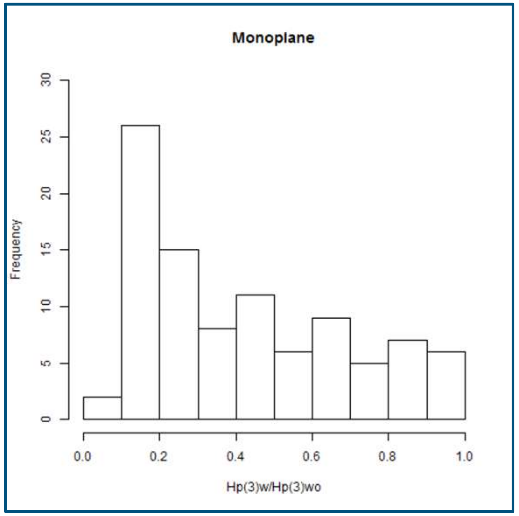


Approach 1: Eye lens dose data collection

- 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 $\frac{H_p(3)_{with}}{H_p(3)_{without}}$

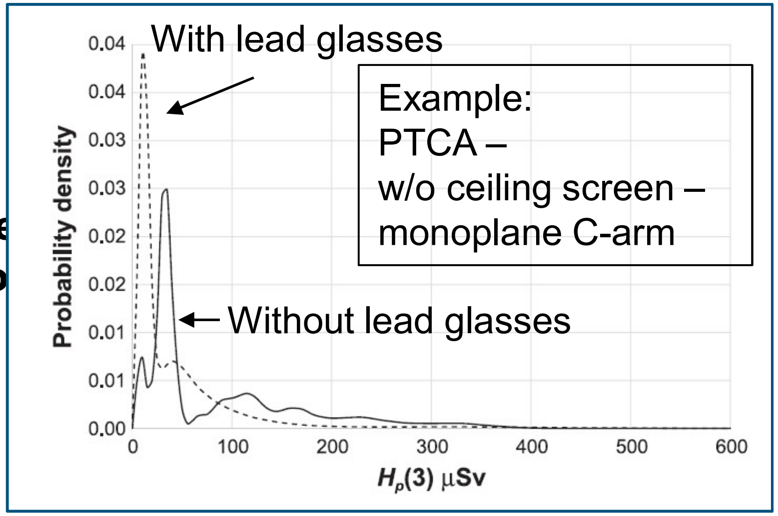






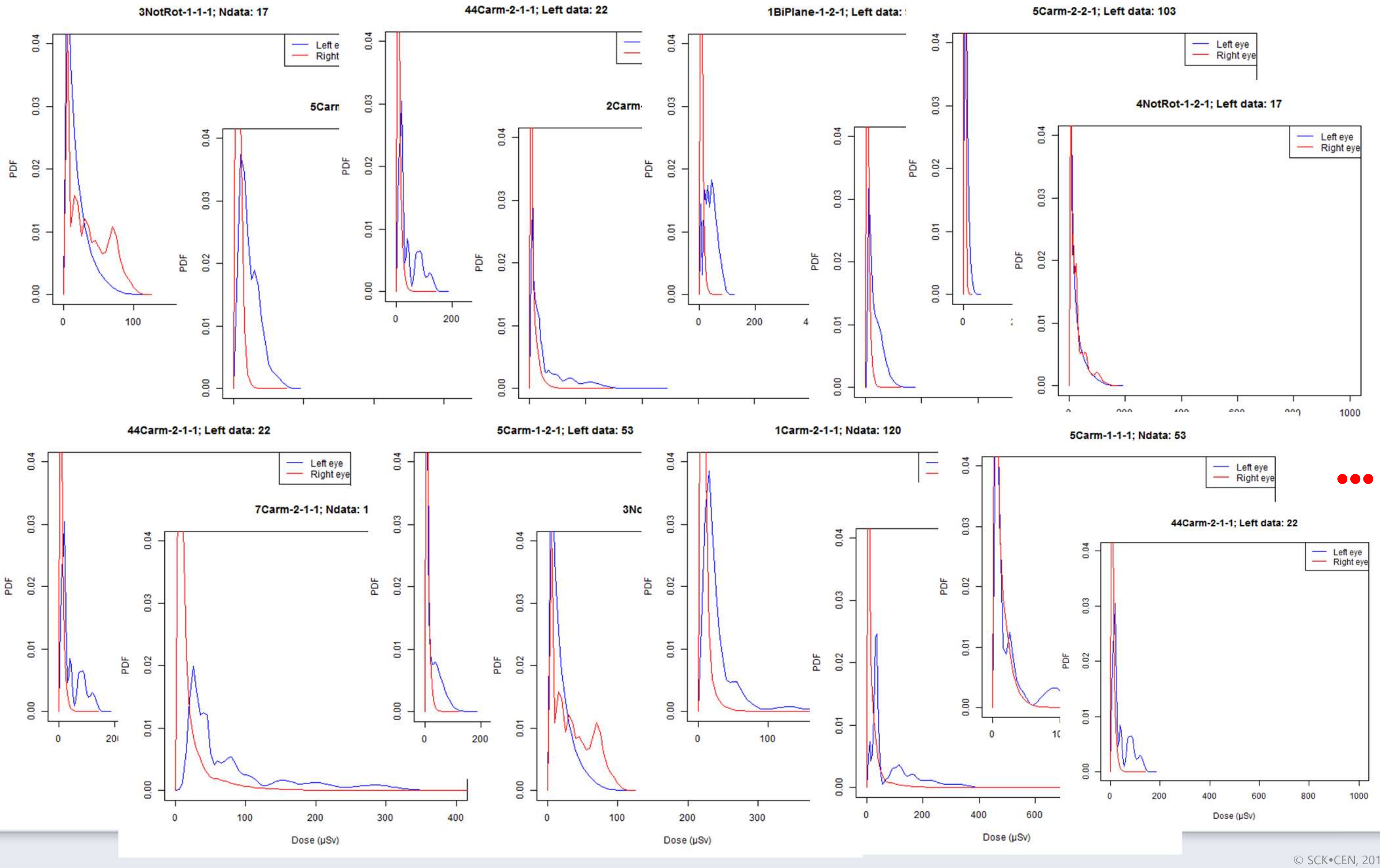
- relevant **x-ray be**
- relevant **operato**

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



* ***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

$$D_{j,x,y,z}$$

- j: type of procedure
- x: lead glasses
- y: ceiling suspended screen
- z: type of x-ray system

→ Eye lens dose **PER PROCEDURE**

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

i: year

$N_{i,j,x,y,z}$ → Number of procedures performed per year for specific exposure configuration

→ Cumulative eye lens dose **DISTRIBUTION**

Approach 2: Conversion from whole body dose

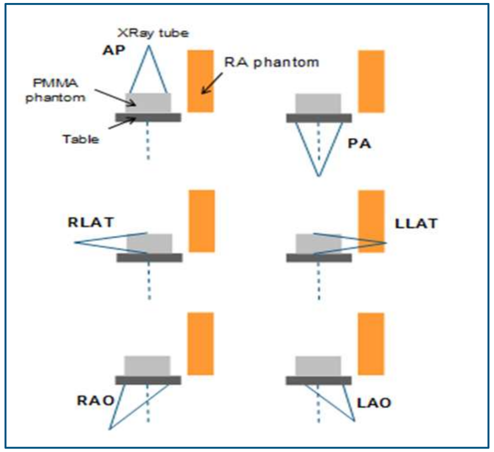
- European ELDO project (funded by DoReMi network): **"Relationship between eye lens dose and whole body dose"***

- Measurement of eye lens doses and whole body doses in clinical conditions
  - Operator: Rando-Alderson phantom
  - Patient: PMMA plates
  - Passive and active dosemeters
  - 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

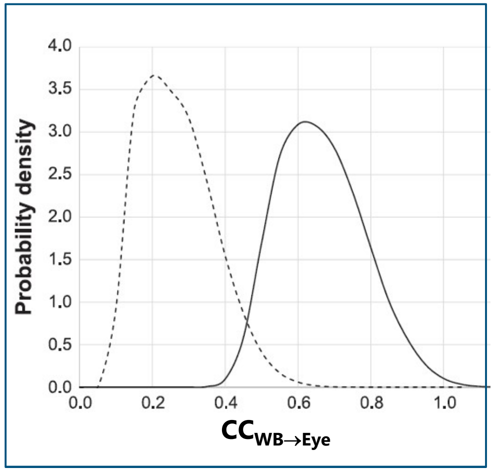
  $\Rightarrow$ frequency distribution of $\mathbf{CC_{WB \rightarrow Eye}}$

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

- To account for the effect of lead glasses

  $\Rightarrow$ frequency distribution of $\dfrac{H_p(3)_{with}}{H_p(3)_{without}}$

Probability Density Functions (PDF)



- *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

$$CC_{p,x,z}$$

- p: position of whole body dosemeter
- x: lead glasses
- z: type of x-ray system

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

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

Validation of dosimetry methodology

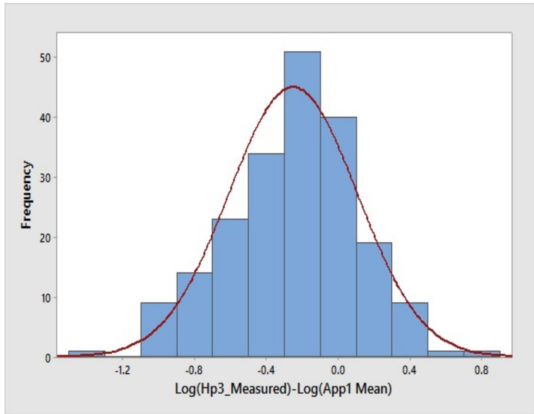
- Eye lens dose measurements in clinical practice
  - Cumulative eye lens doses during 1-2 months (left and right eye)
  - Collect occupational information for the measurement period
  - Collect corresponding $H_p(10)$ dose values above the lead apron
- 230 sets of measurements
- Cumulative eye lens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

⇒ Single eye lens dose values

Validation of dosimetry methodology

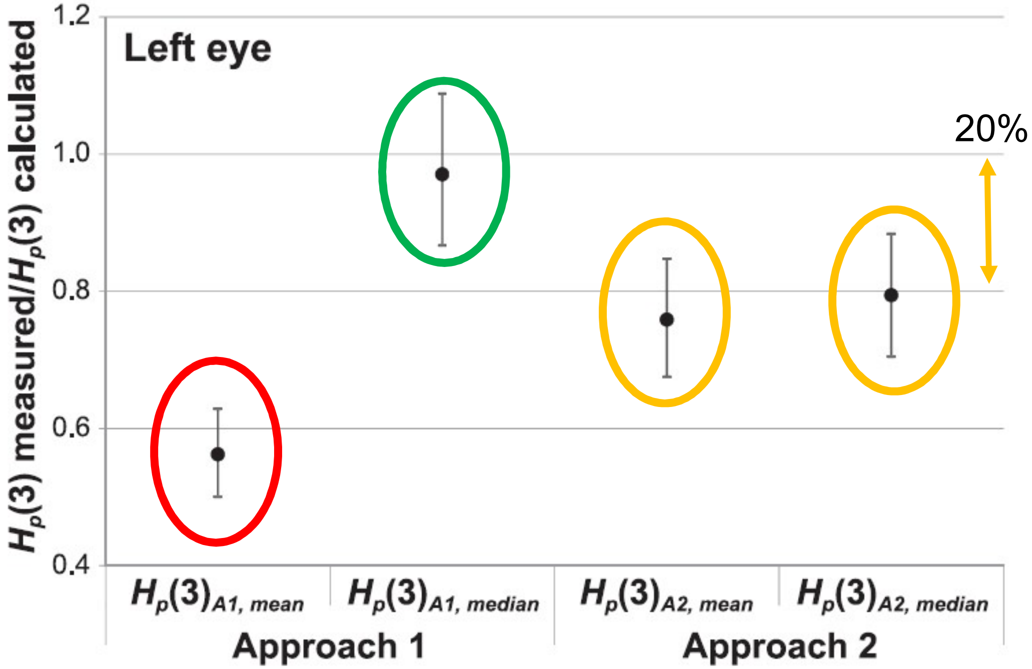
- Distributions of D_{Meas}/D_{calc} log-normal (Anderson-Darling test)

- *t*-test: significant difference between measured and calculated values



$$D_{calc,A_1\_median} \quad (p: 0.613)$$

$$\left.\begin{array}{l} D_{calc,A_1\_mean} \\ D_{calc,A_2\_median} \\ D_{calc,A_2\_mean} \end{array}\right\} (p< 0.05)$$



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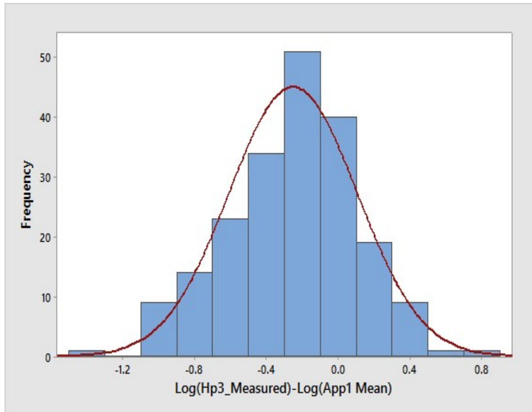

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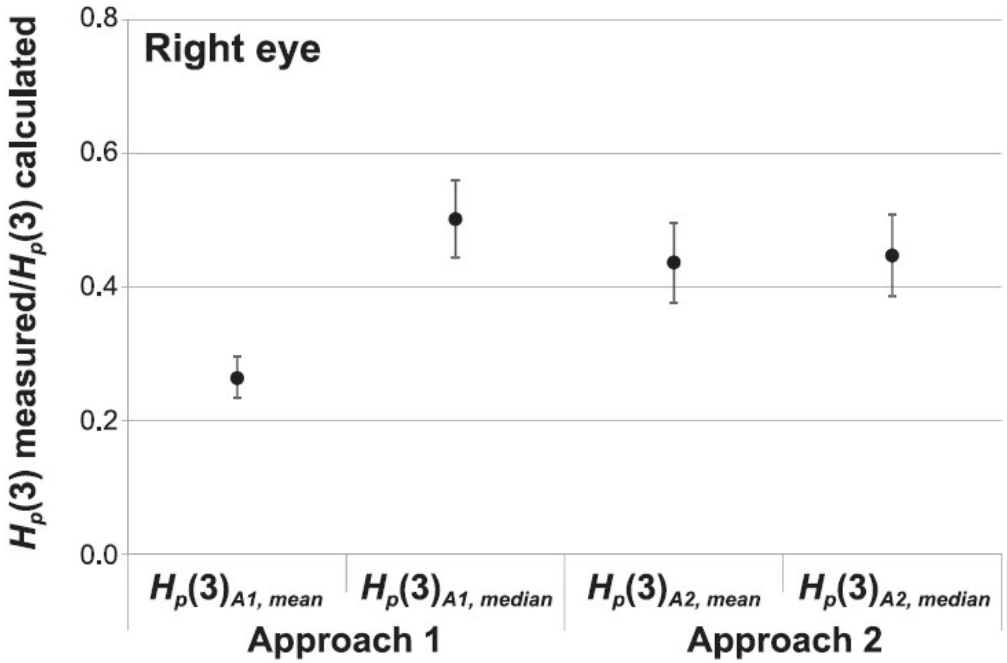
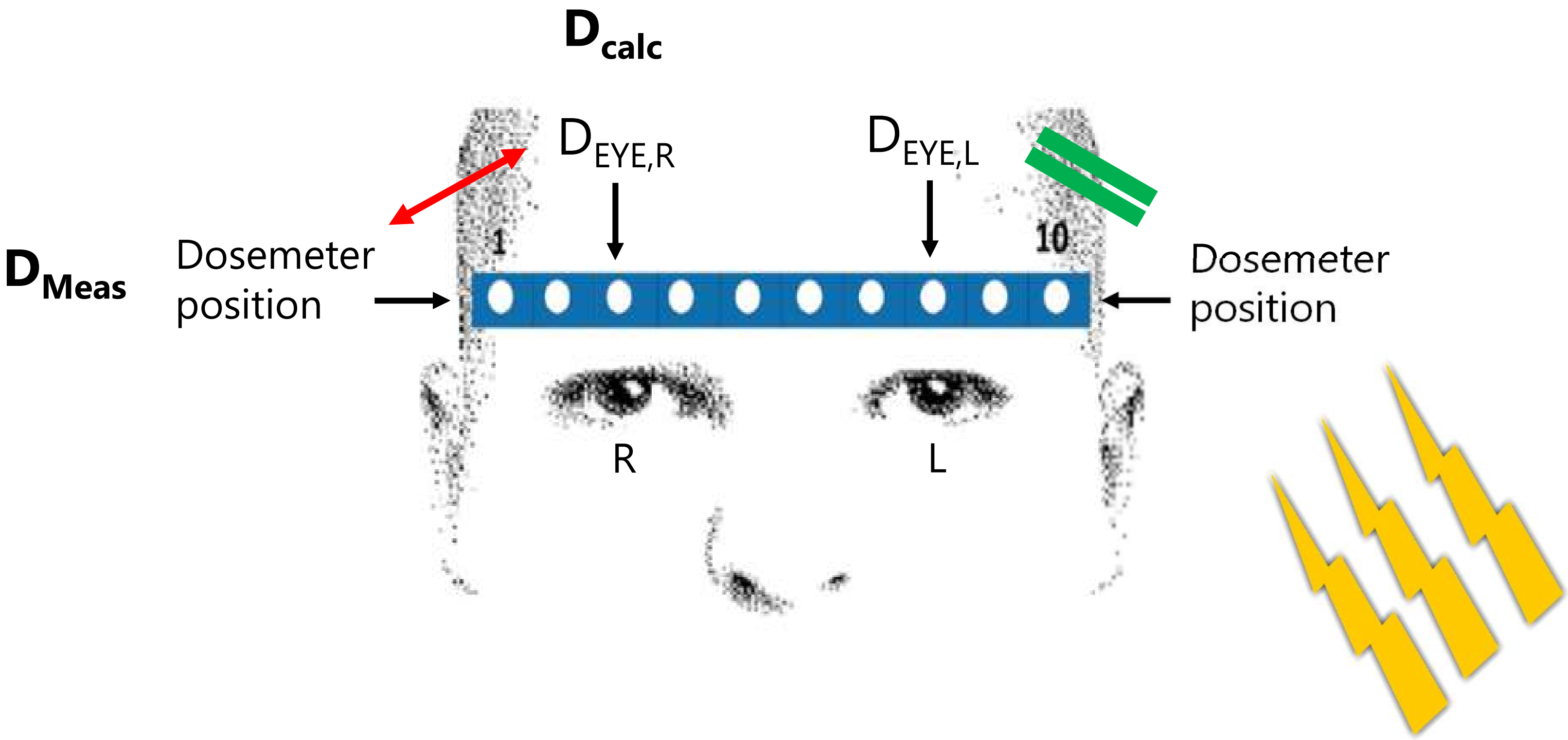


Validation of dosimetry methodology

- Right eye: less exposed

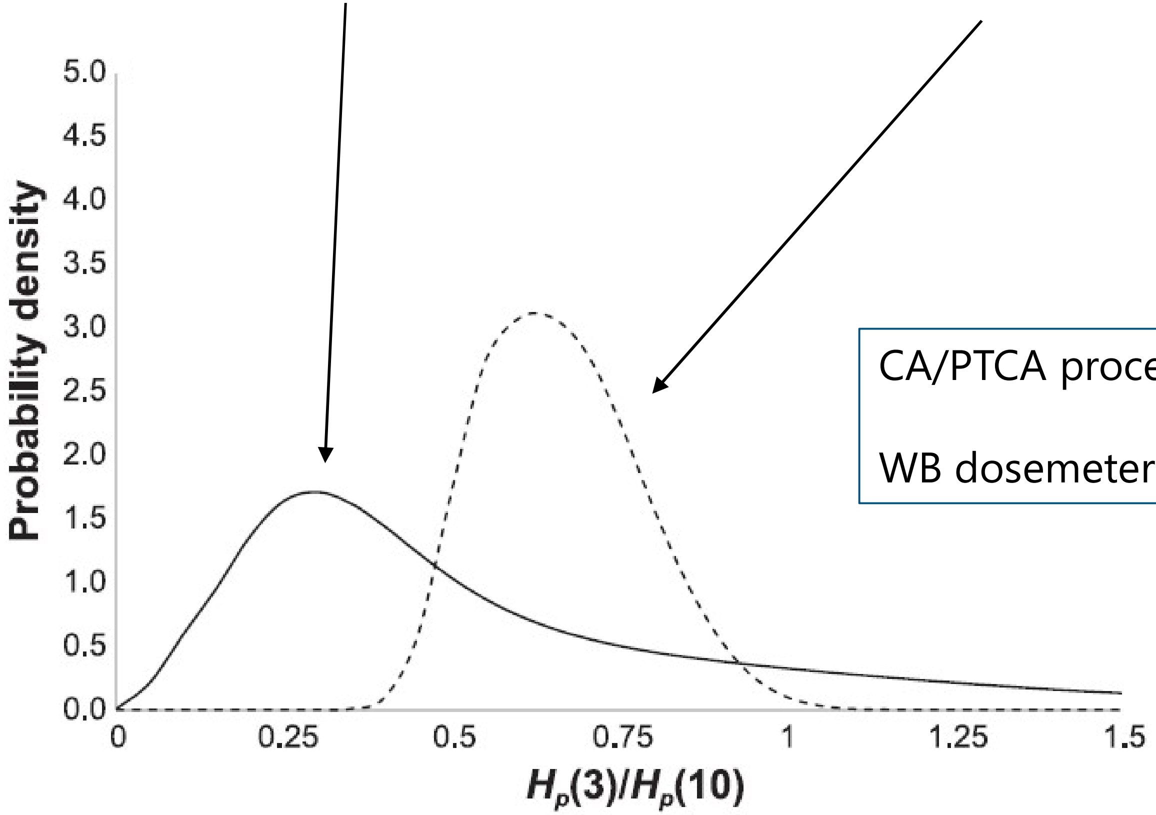


- ***Domienik J, et al. 2014*** *The impact of x-ray tube configuration on the eye lens and extremity doses received by cardiologists in electrophysiology room J Radiol Prot 34 N73-9*
- ***Domienik J, et al. 2012*** *A study of the dose distribution in the region of the eye lens and extremities for staff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

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



CA/PTCA procedures

WB dosemeter on **left side of chest**

Overview methodology

Dosimetry methodology

APPROACH 1:
Individual working history + eye lens dose data from literature

(+)
- Direct eye lens dose measurements
- Individual occupational history
- Consider the number of procedures
- Evolution over the years

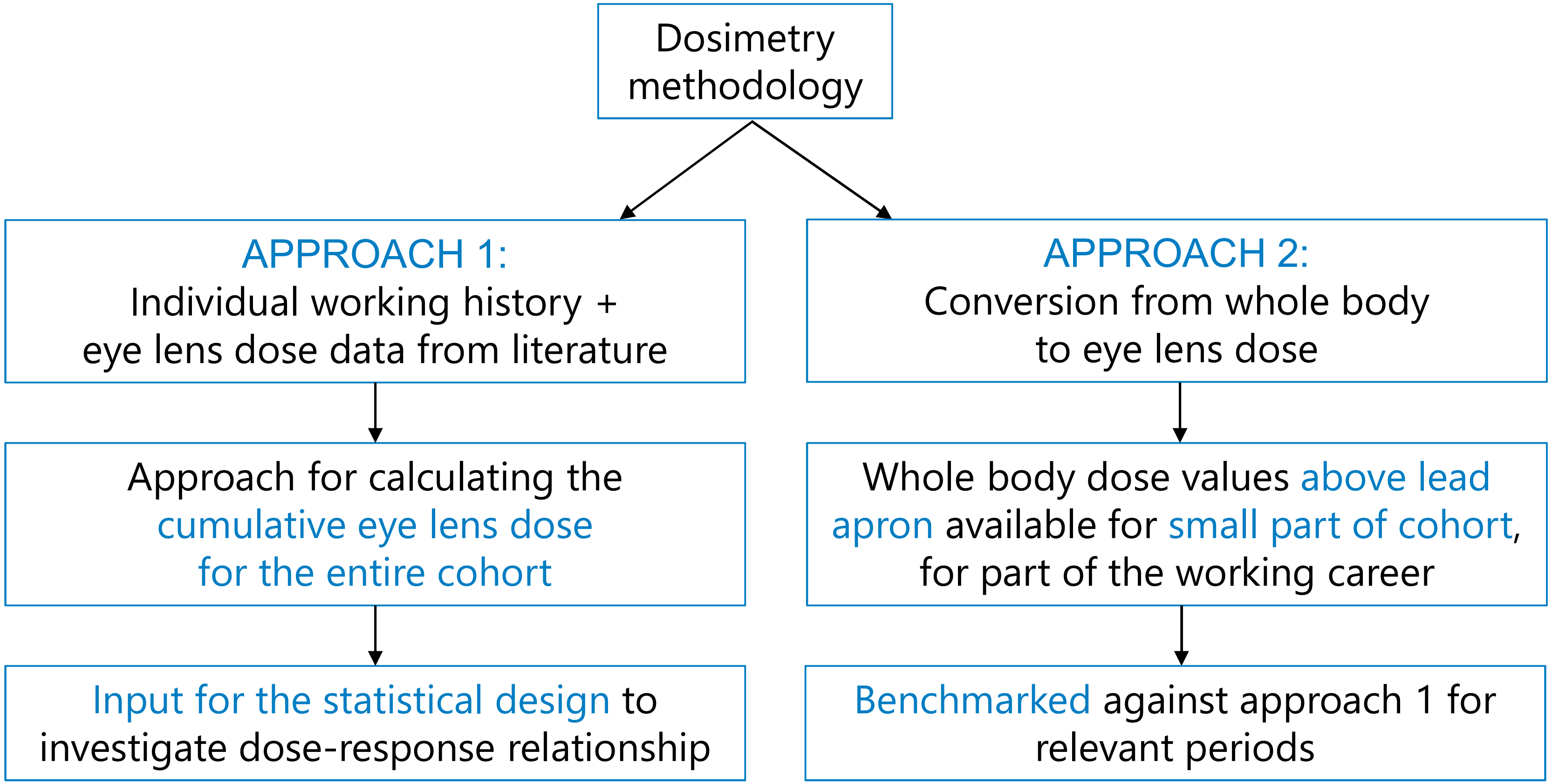
(−)
- Large spread in available eye lens dose data
    - even for similar working practices
- Confidence in self reported info from early years

APPROACH 2:
Conversion from whole body to eye lens dose

(+)
- Use of personal dose information of recruited cardiologist

(−)
- Conversion to eye lens dose
- Availability of $H_p(10)$ values above the apron
- Very low confidence in correct use of whole body dosimeter in early years!

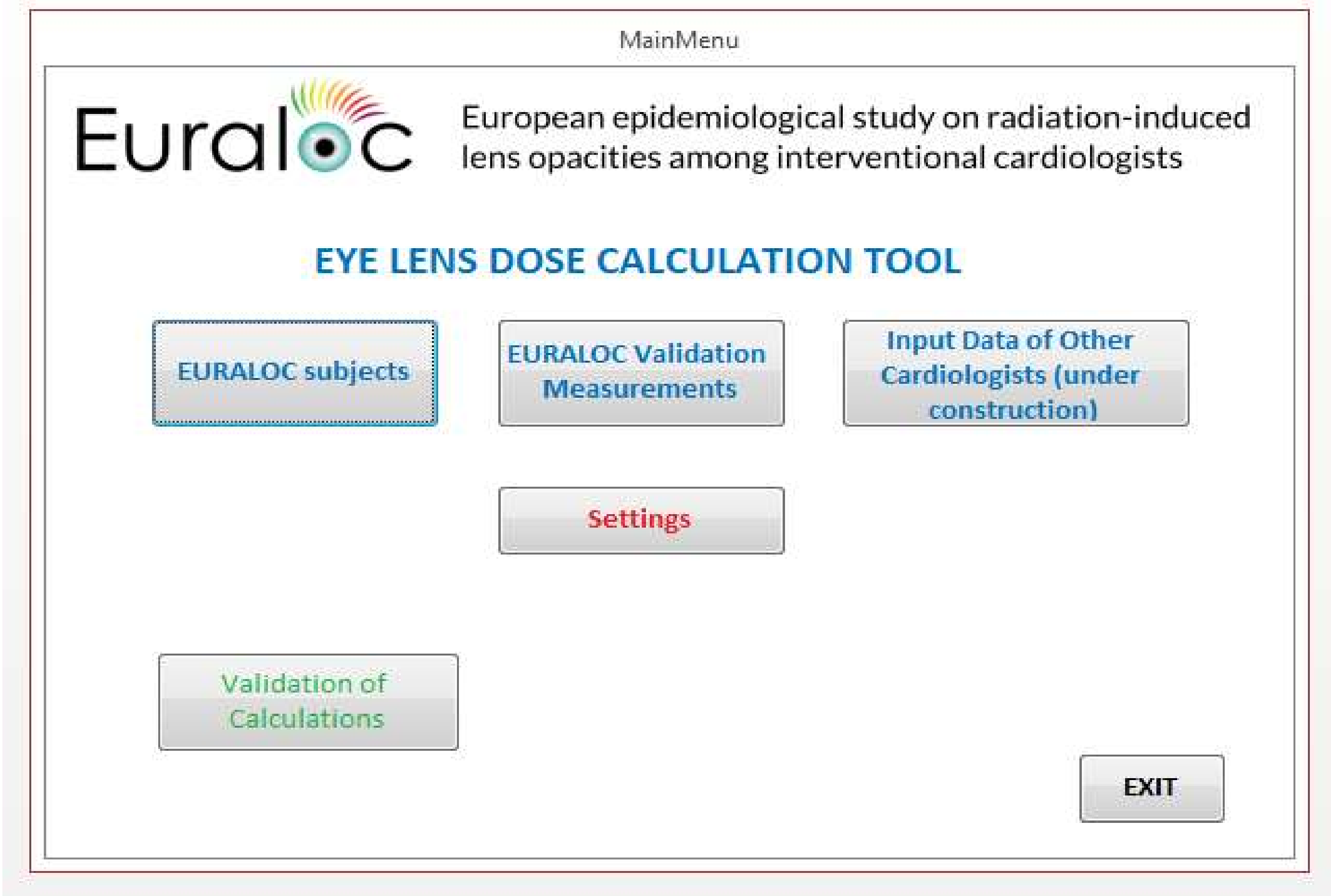
Overview methodology



***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

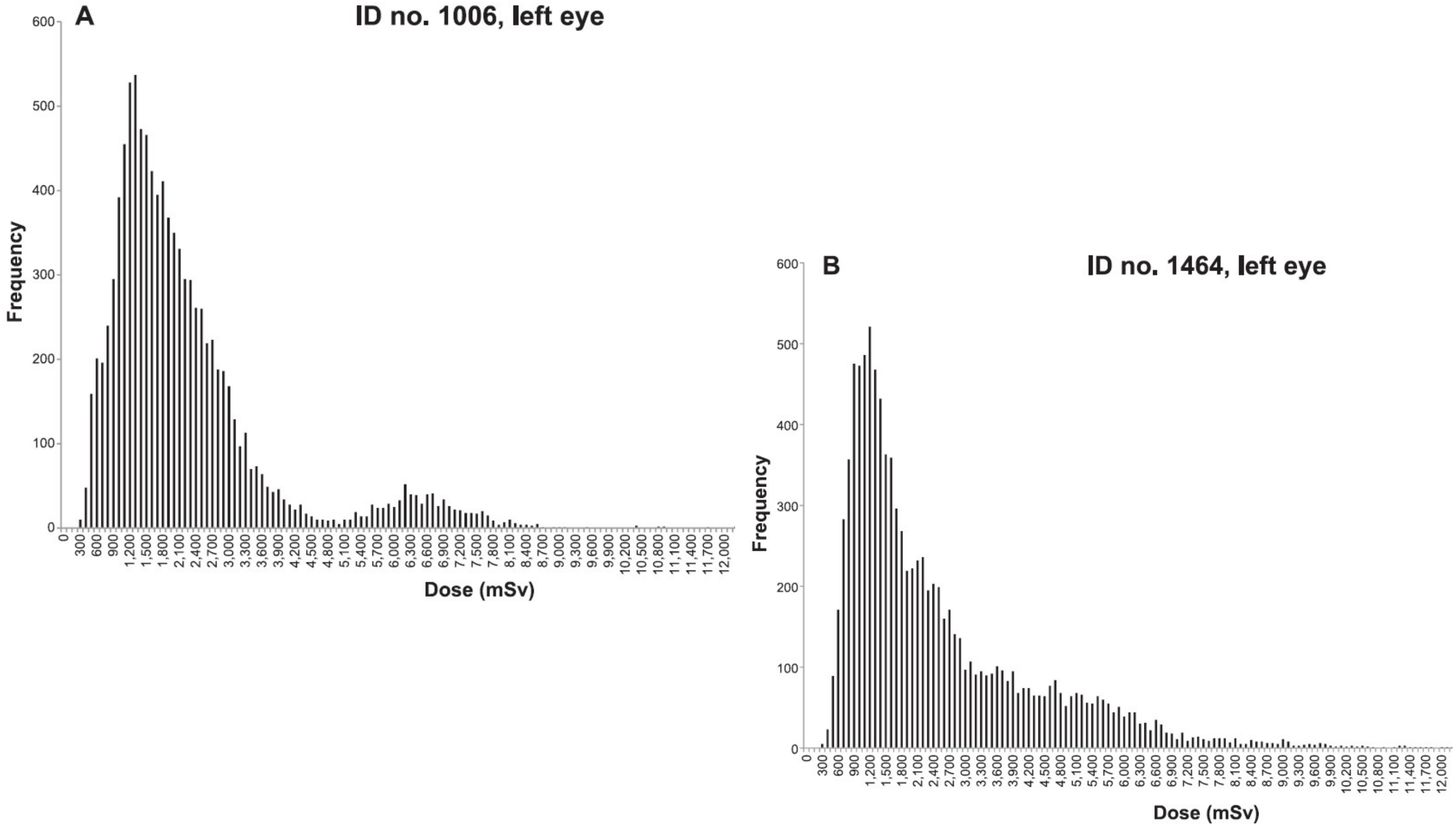
Input	Engine	Output
• Information from occupational questionnaire • Hp(10) values	• Calculated PDF for all possible combinations (192) • Combinations of: type of procedure, left/right eye, x-ray system, protection ….	• Cumulative eye lens dose values for a selected time period

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

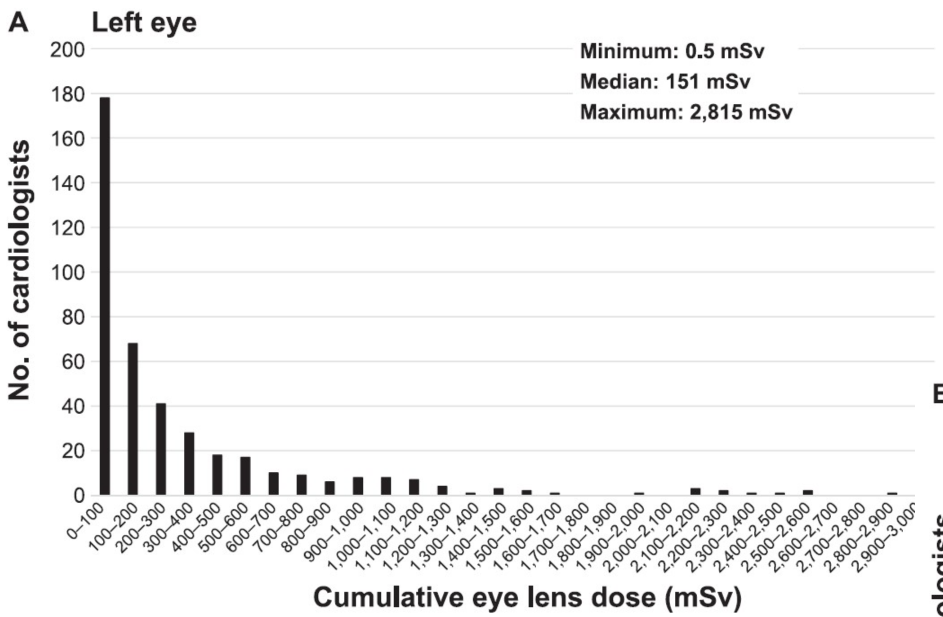
- Dose simulation design
  - Correctly accounts the uncertainties in the individual dose assessment
  - Maintains the shared errors among the cardiologists
    e.g. errors in dose estimates for a specific exposure configuration in a specific period affect all cardiologists who performed that particular procedure in that period.

Individual cumulative eye lens dose calculations

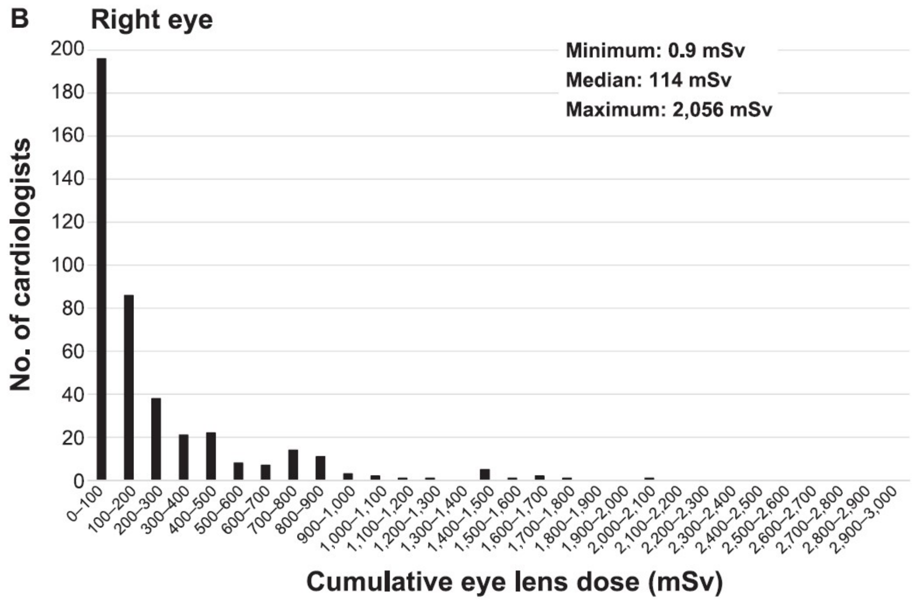


Individual cumulative eye lens dose calculations

- 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 dosemeter 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: $D_{calc,A2b}$

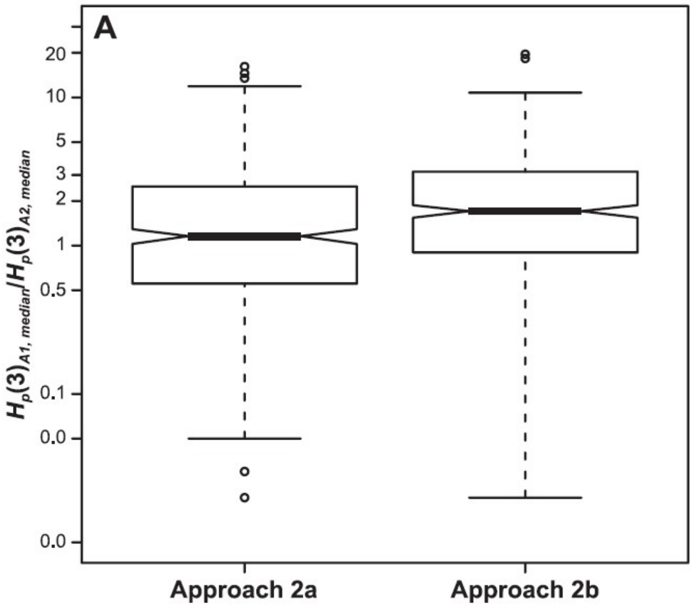
- Calculation of individual cumulative eye lens doses (APPROACH 1)
  - Calculation of eye lens dose values annually
  - Using the workload of the corresponding years, for which WB dose values are available for specific cardiologist

    → Approach 1: $D_{calc,A1}$

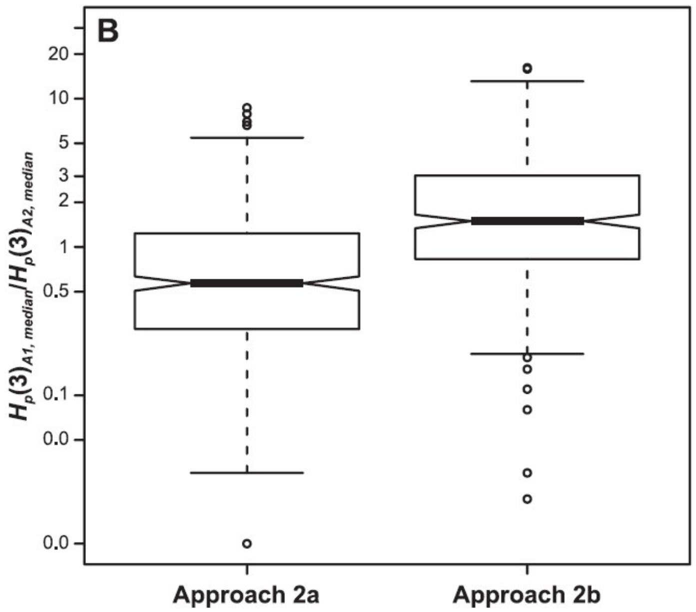
Benchmarking approach 1 and approach 2

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

LEFT EYE



RIGHT EYE



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

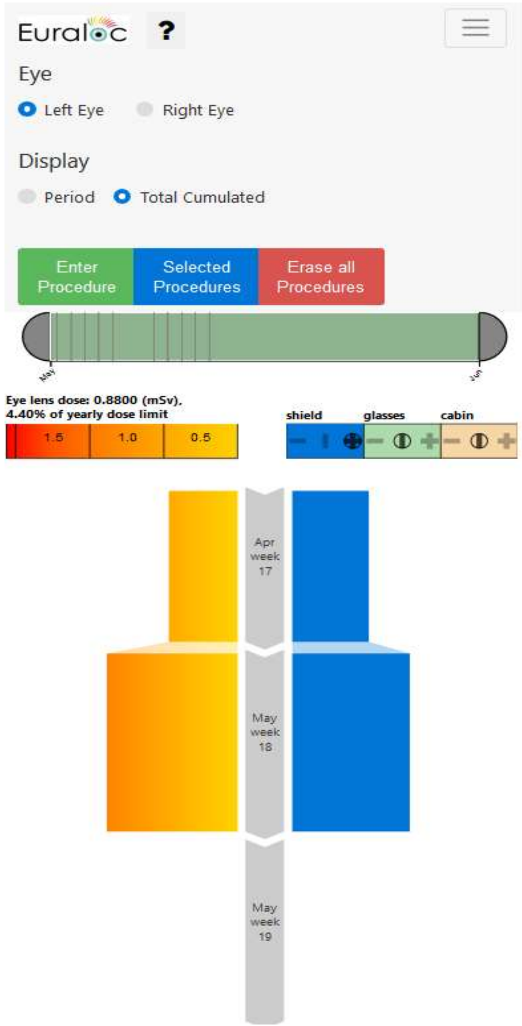
Conclusion: restrospective dose calculations

- 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**

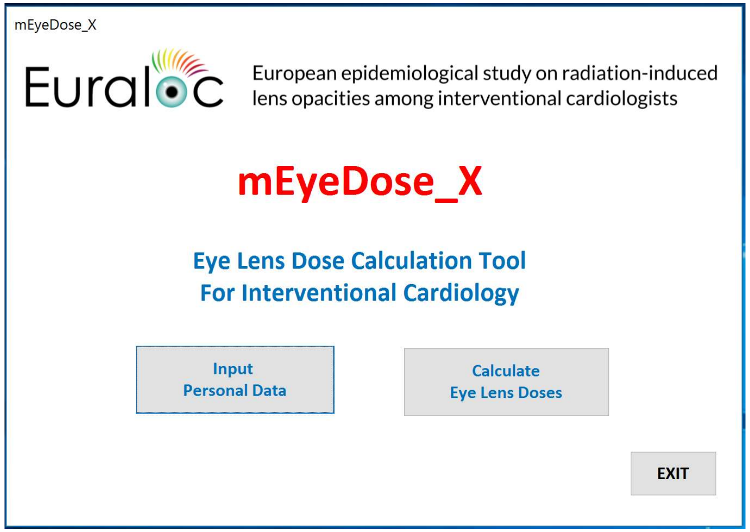
Educational tools: mEyeDose

- 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



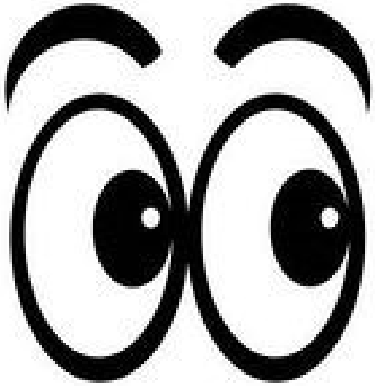
Educational tools: mEyeDose_X

- 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)*

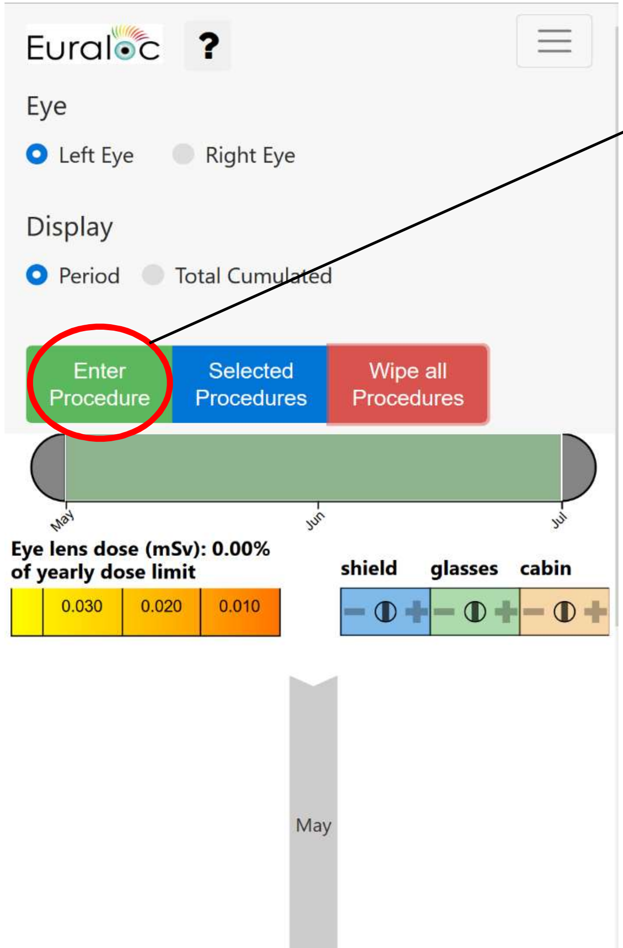


Thank you very much for your attention !

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

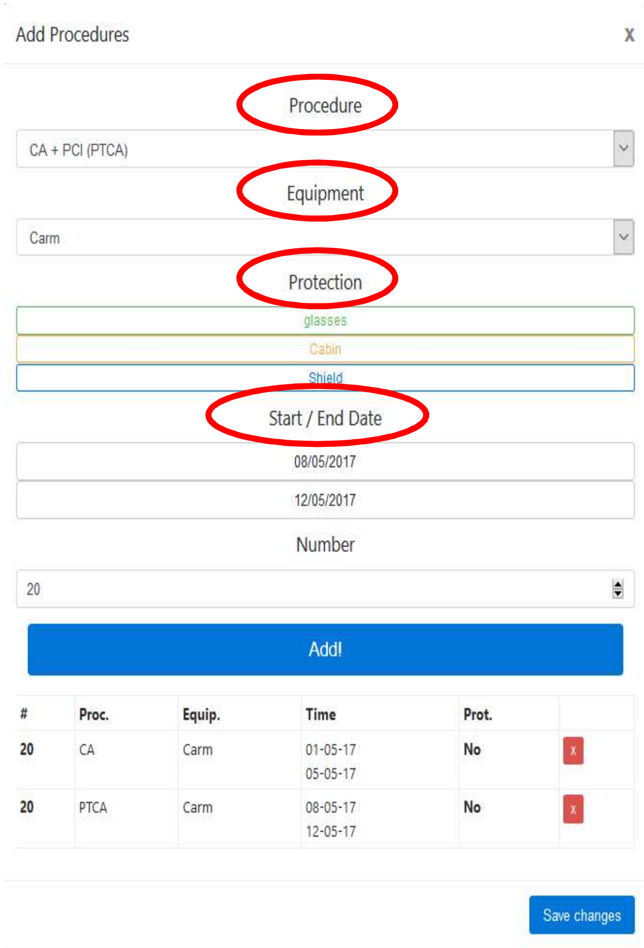
mEyeDose

- Tracking eye lens doses

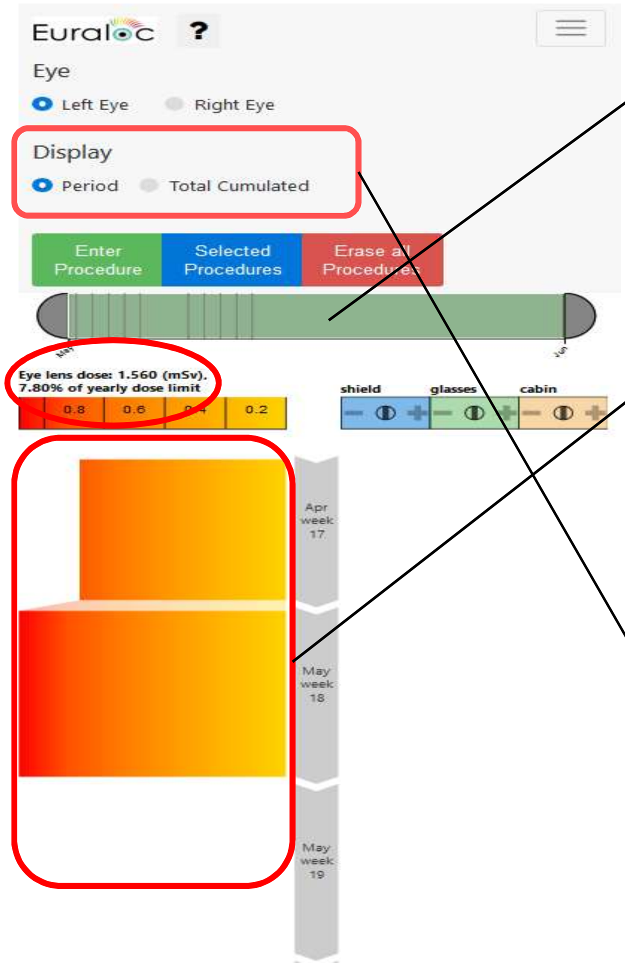


Store workload by adding
- the **#** cardiac procedures
- the **RP devices**
- The type of **x-ray system**

over a specific **date interval**



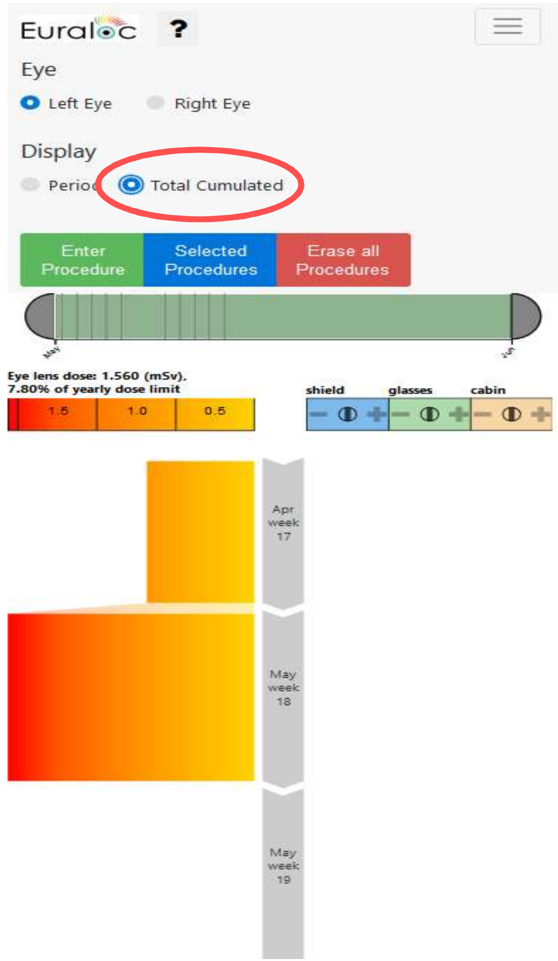
- Tracking eye lens doses



Time slider
- Procedures are added as vertical lines

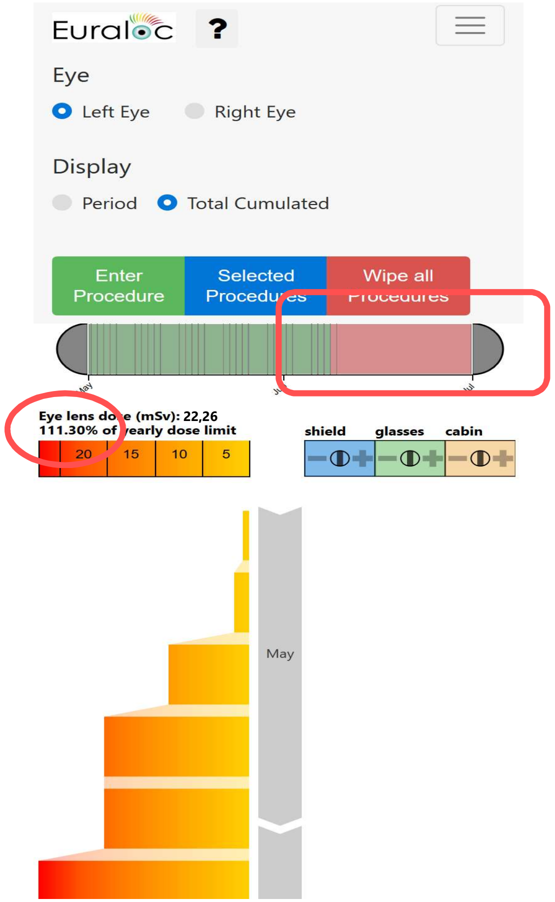
Level of eye lens dose
- Chose left or right eye
- Dose with color legend
- Dose value
- Percentage of the annual dose limit

Display
- Dose received over displayed period
- Total cumulated dose



mEyeDose

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

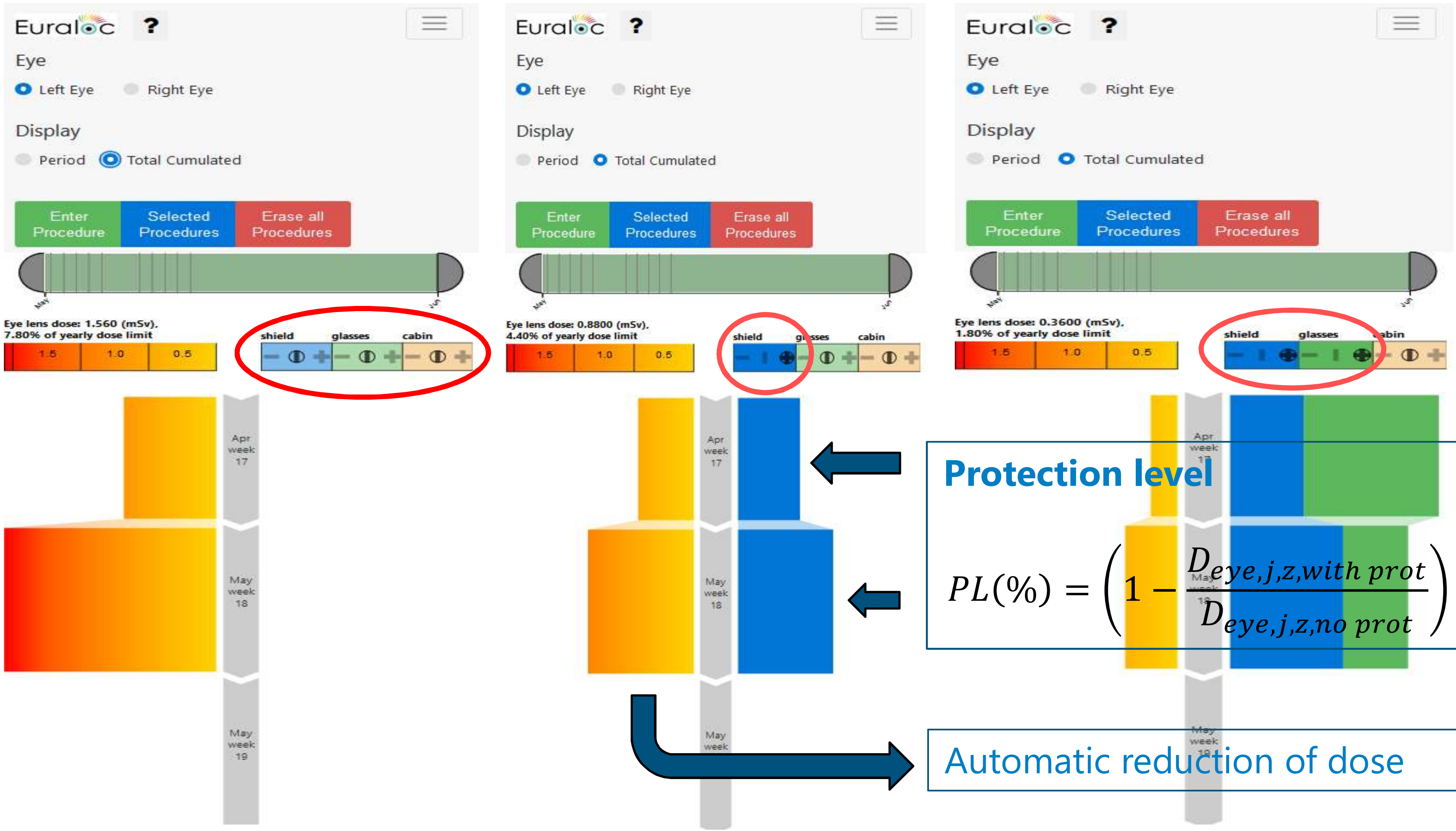


Visible in 2 ways

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

mEyeDose

- Effect of radiation protection devices



Protection level

$$PL(\%) = \left(1 - \frac{D_{eye,j,z,with\ prot}}{D_{eye,j,z,no\ prot}}\right) \times 100$$

Automatic reduction of dose

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