Eye lens dosimetry approaches within the European EURALOC epidemiological study


http://www.euraloc.eu/
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
  \[\leftrightarrow\] 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 $\rightarrow$ 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   - From 7 papers + 3 unpublished studies, the raw data received from the authors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:
  \[ \text{frequency distribution of } \frac{H_p(3)_{\text{with}}}{H_p(3)_{\text{without}}} \]
  
  - relevant x-ray beam projections
  - relevant operator positions

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

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

- Cumulative eye lens dose DISTRIBUTION
- Number of procedures performed per year for specific exposure configuration
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

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 $\text{CC}_{\text{WB→Eye}}$
  - relevant x-ray beam projections
  - relevant operator positions

To account for the effect of lead glasses
⇒ frequency distribution of $\frac{H_p(3)_{\text{with}}}{H_p(3)_{\text{without}}}$

- 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

\[ CC_{p,x,z} \]

- \( p \): position of whole body dosimeter
- \( x \): lead glasses
- \( z \): type of x-ray system

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

Cumulative whole body dose during year \( i \), considering the position of the WB dosimeter
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

$\Rightarrow$ 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

\[
\begin{align*}
D_{\text{calc}, A_1 \_ \text{median}} \\
D_{\text{calc}, A_1 \_ \text{mean}} \\
D_{\text{calc}, A_2 \_ \text{median}} \\
D_{\text{calc}, A_2 \_ \text{mean}}
\end{align*}
\]

(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

\[ \left[ \text{CC}_{\text{WB} \rightarrow \text{Eye}} \right]_{\text{val study}} \leftrightarrow \left[ \text{CC}_{\text{WB} \rightarrow \text{Eye}} \right]_{\text{phantom study}} \]

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

Dosimetry methodology

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

Approach for calculating the cumulative eye lens dose for the entire cohort

Input for the statistical design to investigate dose-response relationship

**APPROACH 2:**
Conversion from whole body to eye lens dose

Whole body dose values above lead apron available for small part of cohort, for part of the working career

Benchmarked against approach 1 for relevant periods

*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

A

ID no. 1006, left eye

B

ID no. 1464, left eye
Individual cumulative eye lens dose calculations

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

<table>
<thead>
<tr>
<th></th>
<th>Left eye</th>
<th>Right eye</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum:</td>
<td>0.5 mSv</td>
<td>0.9 mSv</td>
</tr>
<tr>
<td>Median:</td>
<td>151 mSv</td>
<td>114 mSv</td>
</tr>
<tr>
<td>Maximum:</td>
<td>2,815 mSv</td>
<td>2,056 mSv</td>
</tr>
</tbody>
</table>

- 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.]
      \[ \rightarrow \text{Approach 2a: } D_{calc,A2a} \]
    2. The $CC_{WB\rightarrow Eye}$ obtained from the validation study [Struelens et al.]
      \[ \rightarrow \text{Approach 2b: } D_{calc,A2b} \]

- 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
  \[ \rightarrow \text{Approach 1: } D_{calc,A1} \]
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)
The research leading to these results has received funding from the European Atomic Energy Community's Seventh Framework Programme under grant agreement n° 604984.

Thank you very much for your attention!
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
mEyeDose

- 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

Protection level

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