



Original paper

## Surgeon eye lens dose monitoring in catheterization lab: A multi-center survey

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## ABSTRACT

**Purpose:** To perform a multi-centre survey on the eye lens equivalent dose absorbed by primary interventionalist during catheterization procedures, using a personal dosimeter placed close to the eye lens.

**Methods:** 15 different cardiologists working in 3 different centers, for a total of 5 operating rooms were enrolled. All of them were provided with a single thermoluminescent dosimeter positioned on the inner side of the temples of eyeglasses. The dose monitoring, performed on a two-months basis, started in 2016 and is still running. All dose measurements were performed by a ISO 17025 standard accredited dosimetry service thus providing certified uncertainties as well. Correlation of eye lens and wrist dose with KAP was also investigated.

**Results:** A total number of 101 eye lens measurements were performed. Annual eye lens dose estimation was obtained for all 15 surgeons (mean, mode, range, standard deviation: 10.8, 8, 4.9–27.3, 5.6 mSv, respectively). Uncertainties on annual eye lens dose estimations ranged between 10% and 20%. No significant correlation was found between eye lens dose and KAP.

**Conclusions:** Cardiologists involved in catheterization procedures may receive annual eye lens doses close to the ICRP 118 dose limit and thus individual monitoring with a dedicated dosimeter should be carried out. Uncertainty assessment play a relevant role in eye lens equivalent dose estimation to ensure not to exceed dose limit.

### 1. Introduction

Interventional procedures involve high radiation doses [1].

Moreover, recent studies showed a significant increase in lens opacities associated with radiation exposure in interventional cardiologists compared to what expected [2–4].

For professional exposure, the Euratom Directive 59/2013 reduced the equivalent dose limit for the eye lens up to a factor of 7.5 compared to the previous Directive. It is noteworthy that the dose difference between non exposed and exposed workers may be reduced to only 5 mSv,

introducing a severe issue regarding the accuracy of lens equivalent dose estimations [5].

To date there are no unique indications regarding the use of protection devices and dose measurement strategies for the lens, while the IEC 62387 standard defined the methods of measurement, which must be carried out in terms of  $H_p(3)$  [6,7].

To evaluate lens dose it is possible to use direct or indirect methods. The first involves the use of passive dosimeters, placed close to the eye, both in vivo or using anthropomorphic phantom [2,8]. The seconds are based on numerical equivalent dose estimations, derived from body or

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thyroid dosimetry or from Kerma/Dose-Area Product (KAP/DAP) correlations [9,10].

Indirect estimations may be difficult due to the high number of variables and confounding factors, like operator position, operator's line of sight, shielding glasses attenuation, use of shielding screens, difference in C-arm projections and arterial access. In particular, there is no evidence of an indirect method that provides a equivalent lens dose estimation adequate in all operating contexts [11–14]. There are some suggestions for correction factors, usually defined following a conservative approach [15]. Nevertheless, conservative estimates are no longer useful when dealing with staff members expected to receive annual doses close to the limit, as in the case of primary interventionalists in catheterization procedures.

Direct measurements, however, imply the use of an additional dosimeter that should be placed close to the eye, with all related practical issues. At our knowledge there are only few studies that provide such experimental framework [2,16].

Given this background, our study aims to monitor the lens dose of surgeons involved in interventional cardiology procedures, considering different centers equipped with different angiographic systems.

The importance of such studies has also been stated by The International Atomic Energy Agency, that pointed out in the last official conference that “*a pilot individual monitoring assessment seems to be one of the best approaches to identify workers in Interventional Procedures (IP) who require eye lens monitoring and to decide on the best dosimetry system*” [17].

The final aim is to draw up a strategy for assessing the equivalent dose to the lens for all the personnel involved in the aforementioned procedures, as requested also by International Radiation Protection Association (IRPA) [18].

## 2. Materials and methods

Cardiologists working in different catheterization laboratories of several hospitals were enrolled. Only the primary interventionalist was monitored. We asked the surgeon to wear a pair of glasses equipped with dosimeter as described below. Surgeons were selected also taking into account their personal agreement with the aim of the study, otherwise the use of glasses might not be regular, as it is not mandatory. Monitoring started in November 2016, was performed routinely on a 2 months basis period, and is still running.

The surgical rooms were equipped with different angiographic systems: 3 with Artis Zee (Siemens Healthcare, Erlangen, Germany) and 2 with Allura Xper FD 20 (Philips Healthcare, Best, The Netherlands). All were provided with ceiling-suspended screens. Interventional imaging protocols were recorded and were quite different varying patient, operator and procedure. For each interventional procedure also the KAP value was recorded, as an indicator of the total dose involved in each procedure. The KAP meters accuracy is verified on an annual basis using a calibrated dosimeter. Inaccuracies were always < 25% (RP 162 suspension level is 35% [19]).

Glasses that were provided to surgeons were the same protective equipment that they use in regular routine work. The glass models were Ultralite 9941 (Protech Medical) and Front & Side (Europrotex), both providing a 0.75 mm of Pb equivalent shielding in front position. All the dosimeters were positioned on the inner side of the temples of eyeglasses, in order to measure as much as possible only shielded radiation (Fig. 1). In fact, considering the position of the TLDs, the shielding of the temples was directly taken into account. The detection surface of the TLDs was parallel to the eyeglasses temple.

The side for monitoring (left or right eye) was chosen considering the preferred position of the surgeon relating to the x-ray tube; the most exposed side was thus selected and for all the surgeons was the left side. Glasses and dosimeters were then identified with the name of the surgeon, to avoid any mistake in using them.

## 3. Dosimetry service

Dosimeters were provided by the Dosimetry Service of AOU Careggi Medical Physics Unit, Florence University Hospital. The service is accredited according to the ISO 17025 standard [19], thus providing a certified metrological chain. Moreover the dosimetric method complies the EN 62387 standard [6], and the service took part in the Eurados eye lens intercomparison in 2016. The dosimeters were Thermo Luminescent Dosimeters (TLDs, model Ext-Rad provided by Harshaw Thermo-fisher), dosimetric material was LiF100. The detection limit of the LiF TLD-100 is 60  $\mu$ Sv. Dosimeter reading was carried out with a 6600Plus automatic Nitrogen flow reader. Calibration was performed in terms of  $H_p(3)$ , traceable to a National Calibration Lab acting as Italian National Secondary Standard. TLD response variability with photon energy and angle of incidence of x-ray radiation was investigated as suggested by EN 62387 standard [6]. It is mandatory to assess the overall response deviation of the dosimeter when both photon energy and angle of incidence are changed, because these variations influence each other. The result is an overall uncertainty value of about 10% (with  $k = 1$ , corresponding to one standard deviation from the true value), mainly due to the energy dependence of the TLD response. Uncertainty could be reduced using contemporary two TLD crystals. In fact with a single TLD it is not possible to account for response variation due to the different photon energies. The service provided the enrolled surgeons with wrist and total body dosimeters, with values in  $H_p(0.07)$  and  $H_p(10)$ , respectively.

The annual eye lens dose for each surgeon was evaluated summing all the  $H_p(3)$  measured values and then rescaling to a 12 months period. Also the cumulative annual uncertainty  $\Delta d_{cum}$  was estimated

$$\Delta d_{cum} = \frac{6}{n_{reading}} \sqrt{\sum_{i=1}^{n_{reading}} \Delta d_i^2} \quad (1)$$

where  $n_{reading}$  is the number of valid readings,  $\Delta d_i$ s are the single reading uncertainties on the lens dose values provided every two months. In case of misuse of glasses (for vacation, lost dosimeters or no work in surgical room) the reading was discarded and classified as “non valid”.

Possible correlation among wrist and lens equivalent dose vs KAP was evaluated by means of Pearson correlation coefficient (significance threshold  $p < 0.05$ ). Only operators with more than 5 valid readings both for wrist and lens dose were included in this analysis.

## 4. Results

15 different cardiologists working in 3 different centers with a total of 5 angiographic rooms were enrolled. Not all the surgeons were enrolled at the same time, but for all of them a minimum of 8 months monitoring was achieved. Moreover the majority of the surgeons was monitored for more than one year.

A total number of 101 lens dose valid readings considering all the monitored surgeons was carried out, with the following average number of readings per operator: 6.7, 8 (mode), 2.5 (standard deviation), while 14 non valid readings were recorded. All the readings were considerably above the detection limit threshold of 60  $\mu$ Sv.

Table 1 shows number and type of surgical procedures that were executed during the dose monitoring: diagnostic procedures and Percutaneous Transluminal Coronary Angioplasty (PTCA) represent 85% of the total.

12-months eye lens dose estimations ( $H_p(3)$ , mSv), with the corresponding uncertainties, for the 15 monitored surgeons are shown in Fig. 2. It can be seen that a wide range of lens exposure was detected. In Table 2, the descriptive statistics of the 15 surgeons eye lens doses in terms of mean, mode, range and standard deviation are reported. Wrist equivalent doses, obtained on a two-months basis, and corresponding KAP values for each primary interventionalist are reported in Table 3.



Fig. 1. (left and right): positioning of TLD detector considering the two models of glasses used in this study.

Table 1  
Procedures details.

Total number of procedures	N. of diagnostic procedures	N. of PTCA	N. of PTCA + CTO	N. of PCI	N. of PTA
3117	1529 (49%)	1133 (36%)	30 (1%)	267 (9%)	158 (5%)

Total number of catheterization procedures with details on the procedure type: Percutaneous Transluminal Coronary Angioplasty (PTCA), Chronic Total Occlusion (CTO), Percutaneous coronary intervention (PCI), Percutaneous transluminal angioplasty (PTA).

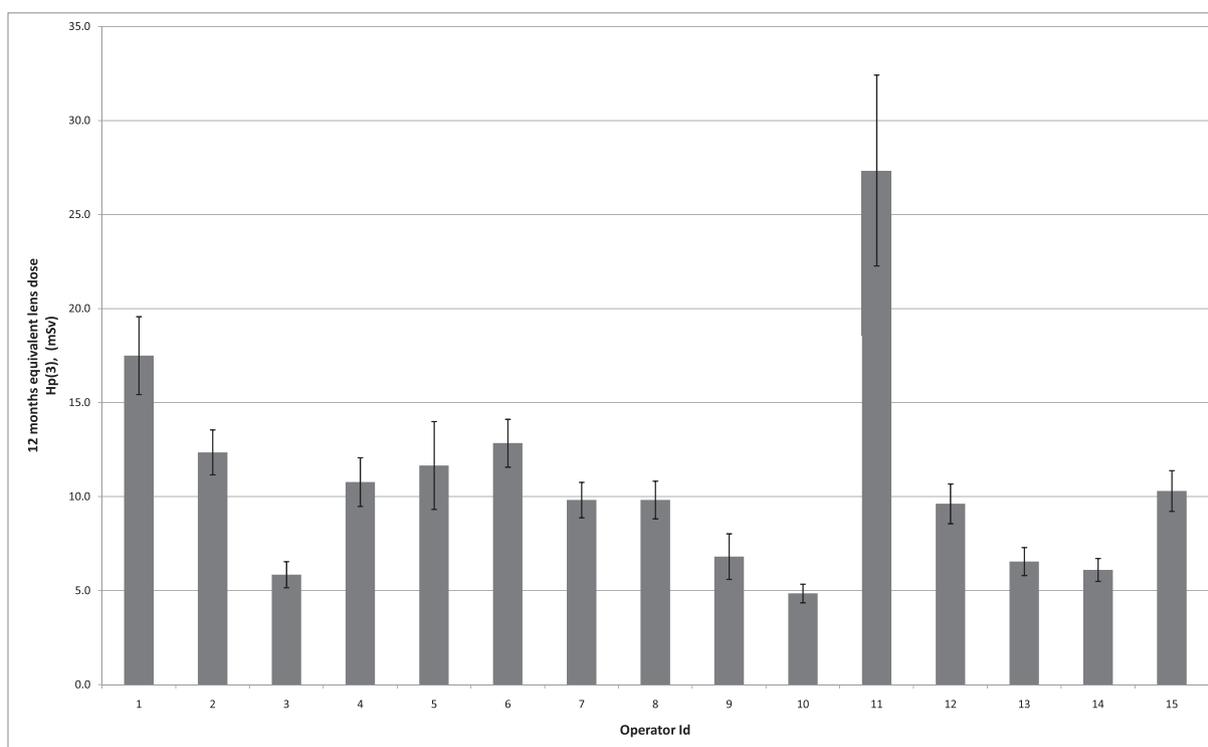


Fig. 2. 12 months cumulative effective lens dose (Hp(3), mSv) of every monitored operator with corresponding uncertainty, obtained considering a single measurement uncertainty of one standard deviation ( $k = 1$ , corresponding to  $1\sigma$ ) from the true value. “id” is the anonymous code of each primary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

Table 2  
12-months equivalent lens dose with uncertainties.

	Mean	Mode	Range	Standard deviation
12-months equivalent dose ( $H_p(3)$ , mSv)	10.8	8	4.9–27.3	5.6
12-months uncertainty (mSv)	1.4	1.1	0.5–5.1	–

Cumulative equivalent dose and cumulative uncertainty (12 months, Hp(3), mSv), obtained considering a single measurement uncertainty of one standard deviation from the true value: mean, mode, range and standard deviation calculated among all the monitored surgeons.

The individual procedure normalized dose (including the individual workload) for each cardiologist is reported in Fig. 3, where results are also compared with the procedure normalized eye lens dose of  $60 \mu\text{Sv}$  [14]. Despite the large variability, many primary interventionalists

showed median values lower than  $60 \mu\text{Sv}$ .

No significant correlation was found between lens dose and KAP for any of the surgeons.

Correlation among wrist and lens equivalent dose vs KAP was

**Table 3**  
KAP values and equivalent wrist doses.

Operator identification number	KAP (mGy × cm <sup>2</sup> , mean, range)	Wrist dose (mSv, mean, range)
1	407517, 303183–477511	3.75, 0.94–0.90
2	250247, 95892–369298	3.75, 1.70–5.40
3	395336, 238827–522959	2.23, 1.06–3.16
4	311354, 156097–627848	5.00, 2.30–10.28
5	398932, 271360–545277	2.29, 1.16–3.96
6	419869, 172998–972290	5.56, 1.16–9.84
7	426381, 166550–698019	2.91, 1.78–4.02
8	415717, 270724–606139	5.16, 2.84–8.24
9	536997, 431183–739969	2.68, 1.74–3.82
10	256123, 144104–372570	5.94, 3.22–9.70
11	275030, 184648–391313	1.32, 1.12–1.56
12	364344, 153720–598966	4.10, 1.72–6.72
13	301081, 224170–360313	7.44, 5.00–8.60
14	182845, 122613–274396	5.84, 4.32–8.88
15	273809, 167386–331901	7.58, 4.14–11.86

Two-months Kerma Air Product (KAP) values and corresponding equivalent wrist doses for each operator; mean values and range have been obtained considering all the valid readings.

evaluated for 11 surgeons out of 15; 4 did not reach the number of 5 valid readings both for wrist and lens dose. Significant positive correlation ( $p < 0.05$ ) between wrist equivalent dose and KAP was found in 7 out of 11;  $R^2$  values were (mean, range) 0.88, 0.79–0.96. For the other 4 surgeons a positive correlation was found, without statistical significance ( $p > 0.05$ ).

## 5. Discussion

The annual eye lens dose values found in this study agree with the study of Matsubara et al. [2], where different shielding glasses and different dosimeters were adopted. As expected, primary interventionalists receive annual lens equivalent dose that are close to the new European regulatory dose limit [5]. This confirms that it can be inappropriate, for these operators, to estimate eye lens dose using a correction factor to the collar or whole body dose: more accurate

strategies have to be carried out. Our results showed that there is no need to power up the sensitivity of the dosimeter (dose level are far from the sensitivity threshold of TLDs), but it is important to be aware of uncertainty. In fact, measurement uncertainties in this field are large and generally difficult to assess. So accurate and robust dose assessments are required, not to overestimate lens dose with too conservative evaluations and, on the other hand, being confident that the provided dose values are robust also from the regulatory point of view.

The robustness of the data is warranted in this study by the dosimetric service, accredited in compliance with ISO 17025 regulation [20]. Uncertainties of the dose values showed a significant range of variation, nonetheless these values are low enough to provide satisfactory accuracy.

We are aware of the large variation in eye dose values for each surgical procedure, due to duration, operator position, distance from the patient, scanning protocols [17,21–23]. For this reason our values may not be used to produce an accurate *a priori* estimation of the eye lens dose, based on the number of expected procedures.

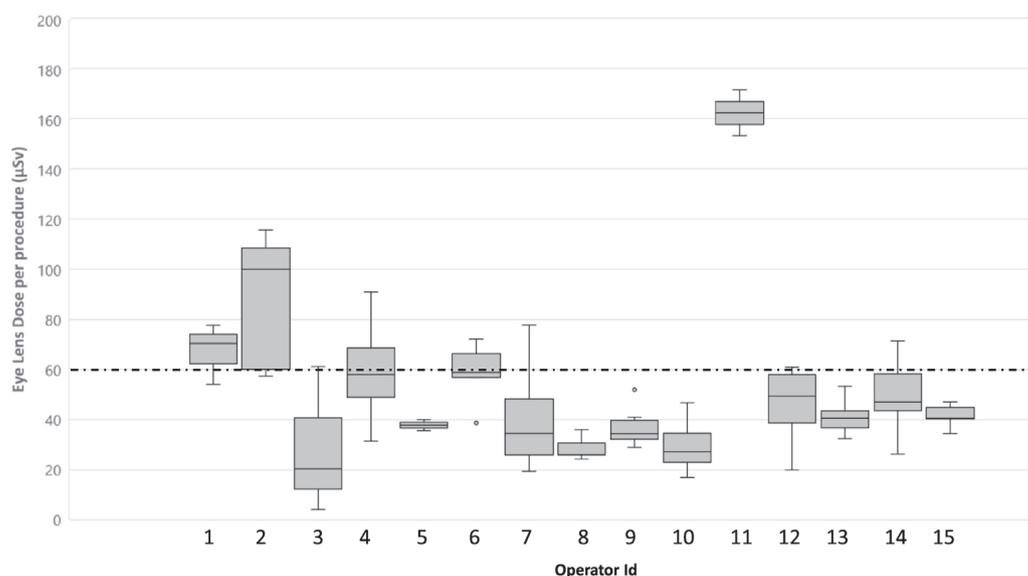
Furthermore, no correlation between lens equivalent dose values and KAP was detected. Also this observation suggests that an individual monitoring is needed, and that KAP should be used for optimization strategy only [14].

We recognize some limitations to our study.

First of all no correlation between whole body dose and KAP was investigated, because the surgeons were provided with single body dosimeter to be used under the protective apron. Then, only primary interventionalists were monitored and no analysis was carried on separating the different cardiology procedures. Moreover only catheterization procedures have been considered, while there are other fields of interventional radiology where workers are exposed to high dose levels [24–26]. Finally, for lens dose measurements a single TLD was used for reasons of ergonomics and space. This choice greatly increases the uncertainty declared by the laboratory due to the impossibility of estimating the energy of the incident radiation.

So we identify the following next steps for further investigation:

- to extend this monitoring to the whole staff, in order to determine who has to be included in a individual monitoring programme [27];



**Fig. 3.** Boxplot of individual procedure normalized eye lens dose (including the individual workload,  $H_p(3)$ ,  $\mu\text{Sv}$ ) of every monitored primary interventionalist; “Operator Id” refers to the anonymous code of each operator, as in Fig. 2. Horizontal black line in each box represents median value, grey box 25%–75% percentile, vertical black line the distribution range and grey marks the outliers. Black dot-dashed horizontal line represents the reference average eye lens dose for each cardiac procedure, as reported in [14].”

- to monitor separately different procedures, including also other fields of interventional radiology;
- to possibly find a way to reduce dosimeter uncertainty;
- to correlate lens doses also with whole body doses.

## 6. Conclusions

In conclusion, as expected surgeons involved in catheterization procedures may receive eye lens doses that are close to the dose limit. Moreover, it is difficult to derive valid eye dose estimation from the reading of other dosimeters than a dedicated one, as it may result in a false dose limit exceeding for the most exposed workers. Finally, the role of the dosimetry laboratory is quite important as it shall be very accurate in uncertainty assessment.

## Conflict of interest

None.

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