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Original paper

Eye lens monitoring programme for medical staff involved in fluoroscopy guided interventional procedures in Switzerland

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ABSTRACT

Epidemiological studies indicate that radiation damages to the eye lens occurs at lower dose values than previously considered (Worgul et al., 2007; Chodick et al., 2008; Ciraj-Bjelac et al., 2010; Rehani et al., 2011; Vano et al., 2010) [1–5]. The International Commission on Radiological Protection lowered the equivalent dose limit value for the eye lens to 20 mSv/year (ICRP, n.d.) [6]. This new limit has been incorporated into the revised Swiss legislation [7]. Prior this change, it was agreed that if the effective dose limit was respected it would implicitly imply the respect of the limit to the eye lens, for penetrating radiation. The concept had to be reviewed in the light of necessary application of the new eye lens dose limit. The new Swiss legislation proposes to use the value of $H_p(0.07)$ measured over the protective apron to estimate the eye lens dose.

This study aims to investigate the validity of this approach for medical staff during fluoroscopy guided procedures. The results show that the ratio between thorax and eye lens doses varies greatly from one medical speciality to another, but also between surgeons within the same speciality. Moreover, for a given physician, the ratio varied over the periods of surveillance. Those variations confirmed the crucial influence of external parameters related to experience, practice and workload. The surveillance method is appropriate for most of the procedures performed in the department included in this study. Nevertheless, for the particular configuration in urology, the respect of the effective dose limit measured by the routine dosimetry does not allow direct compliance with the dose limit to the eye lens, unless appropriate protective eye wear gear are worn.

1. Introduction

The sensitivity of the eye lens to ionising radiation has been clearly demonstrated with numerous studies based on large epidemiological datasets [2–5]. The follow up of the Hiroshima and Nagasaki cohort highlighted a significant increase in the rate of diagnosed cases of partial or total opacity of the eye lens [8]. The International Commission on Radiological Protection (ICRP) introduced the annual dose equivalent to the eye lens at 300 mSv in 1977 [9]. The epidemiological study of the liquidators who intervened immediately on the scene of the Chernobyl accident helped to better understand the mechanisms behind the progressive opacity of the eye lens [1]. These observations were corroborated with studies on astronauts, that suggest low-dose-induced effects, challenging the initial hypothesis that the occurrence of induced radio-cataract is only valid for high doses [10,11]. This was also confirmed by studies on physicians working in interventional radiology [12,13].

Based on the growing epidemiological evidence, the occupational dose limit value for the eye lens was adapted accordingly. The limit originally set to 300 mSv was reduced to 150 mSv in 1991 [14]. With former recommendations, the eye lens dose limit was well above the whole-body dose limit, for penetrating radiation only. It was thus generally agreed that the whole-body dosimetry guaranteed compliance with the eye lens dose limit [15], and a general consensus appears amongst authorities regarding the absence of a dedicated surveillance programme for the eye lens dosimetry. The latest exposure limit value was lowered in 2011 to 20 mSv on a five-year average [6,16], equal to the limit for the whole body and thus imposing the development of a dedicated surveillance programme [7]. The design and application of a suitable dosimetry monitoring method is a matter of importance and is the subject of numerous studies in Europe [17,18].

This major change in dose limit is of high interest and concern in hospitals. The medical personnel using fluoroscopy equipment can be particularly close to the patient, having their eyes lens exposed to an inhomogeneous scattered radiation field. In these conditions, the location of the dosimeter is critical to obtain a representative estimate of the eye lens dose [19]. There is no national or international consensus yet on where the dosimeter should be worn. The analysis carried out by

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a working group of the European EURADOS network indicates though that the best position for eye lens routine dosimetry is as close as possible to the eye, and, if possible, in contact with the skin, oriented towards the radiation source [17]. If eye protection gears are used, the dosimeter should be placed under them. If this is not feasible, the dosimeter should be placed on the protection; an additional reduction factor should then be determined. Another methodology to evaluate the eye lens dose is to place an additional dosimeter above the protective apron as proposed by the IAEA [19]. This methodology would be acceptable only for homogeneous fields [7], though this is not the case for a large majority of the personnel in the medical sector. In the case of inhomogeneous exposure, the ratio between the eye lens dose and the dose measured on the apron is extremely hard to determine and depends on many parameters that are difficult to quantify: type of procedure, personal habits, exact location of dosimeters, protective measures taken, etc. However, a range of values for the ratio between the dose to the eye lens and the dose measured by the dosimeter on the apron is available in the literature for interventional radiology, interventional cardiology and some nuclear medicine procedures [20–33].

The eye lens dose monitoring also presents a significant metrological challenge. The International Commission on Radiological Units and Measurements (ICRU) recommends the use of a specific quantity by introducing the quantity $H_p(3)$ [13,33]. In practice in Switzerland, almost no dosimetry service is able to assess the eye lens dose in terms of $H_p(3)$ and alternative methods based on $H_p(0.07)$ are proposed [17,19].

The aim of this study is to evaluate the concept of the routine eye lens dose monitoring that is proposed in the recently revised Swiss Radiological Protection Ordinance and in the corresponding Dosimetry Ordinance that has come in force on January 1st, 2018 [7]. The new Swiss Dosimetry Ordinance stipulates that the dosimetry of the eye lens should be monitored using a suitable dosimeter [7]. The text describes a practical and pragmatic solution for a homogeneous exposure, easily applied by companies and dosimetry services, while ensuring an effective monitoring.

The second chapter of the ordinance stipulates that the equivalent dose to the eye lens is assumed to be equal to the individual dose on the surface, $H_p(0.07)$, measured by the whole body dosimeter. In the case of inhomogeneous radiation fields for which the whole body dose is not representative of the eye lens dose, the surveillance authority may require specific eye lens dosimeters to be worn on a case-by-case basis. Within this legal context, our study helps the local radiation protection team to identify the sectors concerned by an extra dosimeter, specific for eye lens dosimetry, at the Lausanne University Hospital (CHUV).

This study is based on the measurement of the operational quantity $H_p(0.07)$, measured with the whole body dosimeter. A first series of measurements was done with phantoms, under controlled geometrical conditions, (*i.e.* specific X-Ray tube position, and define radiation protection gears) choosing the best representative conditions for each given medical speciality. These measurements are important to estimate the correction factors to be applied between dosimeters worn at several positions in static conditions. A second set of measurements was done with dosimeters placed on medical staff using fluoroscopy equipment in services of diagnostic and interventional radiology, angioplasty, surgery, urology and pain treatment centre. Surgeons were equipped with whole body dosimeters placed on the thorax under and over the lead apron and, with a dedicated dosimeter taped on their protective glasses, closest as possible to the eye lens. The study provides the basis to define a specific eye lens dose measurement method for the different categories of persons at-risk for which their professional activity could lead to exceed the annual limit.

2. Materials and Methods

2.1. Individual dosimetry monitoring

2.1.1. Badge

The Swiss Dosimetry Ordinance stipulates that the supervisory authority may require that two dosimeters should be worn, on the chest, for work involving high doses carried out with a protective apron [7], one over and the other under the protective apron. All the staff participating in this study was introduced with double dosimetry in case this modality was not yet available.

The Swiss Dosimetry Ordinance define the $H_p(10)$ and $H_p(0.07)$ calculation of follow [34]:

$$H_p(10) = H_{p_{under}}(10) + a \cdot H_{p_{above}}(10) \quad (1)$$

$$H_p(0.07) = H_{p_{under}}(0.07) + H_{p_{above}}(0.07) \quad (2)$$

where$H_{p_{under}}$ represents the dose indicated by the dosimeter placed under the apron and $H_{p_{above}}$ the dose of the dosimeter placed on the apron; a = 0.1 when no thyroid protective collar is worn and a = 0.05 if it is worn. The use of dosimeters under the lead apron, take into account the possibility for the medical staff to received dose during procedure where the lead apron is not mandatory.

The dosimeters used for this study were the whole body routine dosimeters provided by the dosimetry service of the Institute of Radiation Physics (IRA) (Fig. 1). Whole body dosimeters provide data for the operational quantities $H_p(10)$ and $H_p(0.07)$. The first chip was used to measure the deep dose equivalent with a filter of 1.8 mm Al and 0.4 mm PE, while the second was used to measure the shallow dose equivalent with a filter of 0.07 mm PETD-Al. The IRA's dosimeters use Thermo Luminescence Detector (TLD) LiF-100 type: Mg, Cu, P. The results of interest for this study were provided in terms of $H_p(0.07)$ calibrated using a Cs-137 reference source. In addition to those dosimeters, single TLD (LiF: MCP-N, Mg, Cu, P) pellets were used for measurements on phantoms either in individual tight plastic bags or strips as shown in Fig. 2. The $H_p(10)$ value measured with the dosimeters is not taken into account.

The values presented in this study correspond to the routine $H_p(0.07)$ values as transmitted to the national dose register. No specific correction regarding angular or energy response of the dosimeter was done on raw data in order to evaluate the method under realistic routine conditions.

2.1.2. Eye lens dosimetry

When using $H_p(0.07)$, measured with the dosimeter worn on the chest over the apron to estimate the eye lens dose, the local radiation protection expert must determine an individual correction factor if protective glasses are worn. This correction factor needs the consent of the supervisory authority and is then communicated to the individual dosimetry service in order to calculate the dose to the eye lens from the formula below:

Fig. 1. Routine badge dosimeter used for this study, based on two TLD pellets.

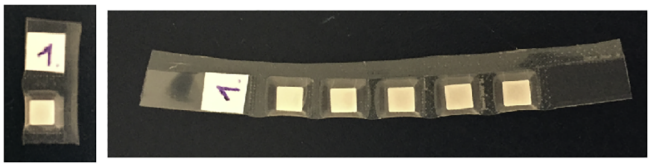

Fig. 2. Single TLD pellet in individual bag (left), TLD pellets in a plastic strip (right).

$$H_{eyelens}(0.07) = f_c * H_p(0.07) \quad (3)$$

where f_c is the attenuation factor of the protection. The determination of the protection effectiveness of glasses used in the hospital is at this stage beyond the scope of the study and is thus not considered in this article.

The purpose of this study is to investigate a possible correlation between the $H_p(0.07)$ routine measurement and the eye lens dose. For this purpose, in addition to the whole body dosimeters previously described, we used the eye lens routine dosimeters (Dosiris) of the Institute of Radiation protection and Nuclear Safety (IRSN) in France. The eye lens dosimeter, placed as closed as possible to the eye lens, provide data for the operational quantity $H_p(3)$. Dosiris dosimeter use TLD 7LiF: Mg, Ti. IRSN provided results in terms of $H_p(3)$ calibrated for an energy of 118 keV (beam quality N150) [35].

In order to evaluate the method under realistic routine conditions, this study was based on routine measurement results that do not require any specific correction on the dosimeter read-out signal.

2.1.3. Measurements under controlled conditions

Measurements were first performed in controlled conditions, with phantoms, in a radiological room to determine geometric correction factors for a given configuration (see Fig. 3). The position of the phantoms and the X-ray tube were set to mimic as close as possible the characteristic position during a standard procedure for identified cases.

An Alderson RANDO anthropomorphic phantom (model 200, RSD, USA) was used to represent medical personnel during irradiations in controlled conditions. A container filled with water together with Vinyl Polychoride cylinders and a skull phantom were used to simulate the patient, generating the scattered radiation field.

Measures under controlled conditions were performed with a fluoroscopic imaging system from Siemens (Artis zee), used with the parameters recommended by the local medical staff. The settings were the following: a tube tension of 70 kV_p, a current intensity of 199.3 mA, a square field of 30 cm × 30 cm and 7.5 images per second.

The same irradiation was repeated several times to reach a dose in the mSv level, in order to reduce uncertainties. An active dosimeter (mirion DMC 3000) was placed on the chest phantom to monitor the exposure range.

The RANDO phantom representing the physician was equipped with several dosimeters (Table 1) on the thorax, the thyroid, the forehead, the temples and the eyes as illustrated on Figs. 4 and 5. A strip of 11 TLD pellets, interspaced every 2 cm and labelled numbered from left to right from 0 to 20, was placed on the forehead.

The measurements done at different positions on the head were performed to check that the measurements on the forehead are indeed representative of the eye lens dose and to evaluate the dose distribution on the forehead to check where the highest dose is expected.

In order to do dose measurements close to the reality, different radioprotection gears were used, and are summarized in Table 2. The choice to use these protections was done by following the practices observed at the hospital.

Table 1
Reference position and identification of the dosimeters. Dosiris dosimeter worn on the left side, to be closer to the X-Ray tube [18].

Type of dosimeter	Position on the phantom			Reference name
Badges	Chest	Left	Under apron	B. 4
			Above apron	B. 3
		Right	Above apron	B. 2
	Thyroid	Centre	Above apron	B. 1
TLD	Eye	Right		A.2
		Left		A.3
	Temple	Right		A.1
		Left		A.4
TLD (strip of 3 chips)	Chest	Left	Under the left badge above apron	C
TLD (strip of 11 chips)	Forehead	Left to right		TLD Frontal strip
Dosiris	Close to the eye	Left		Dosiris

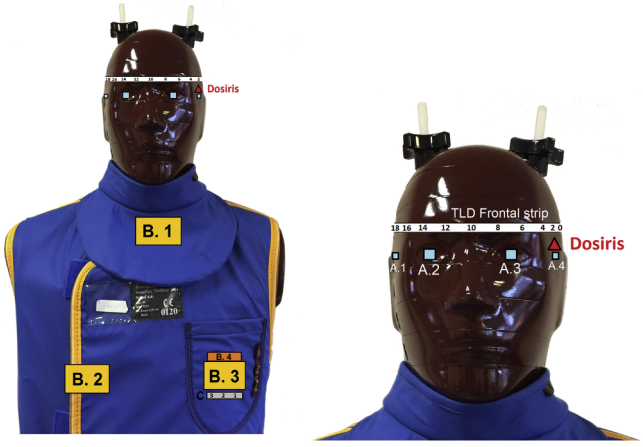

Fig. 4. Reference position of dosimeters.

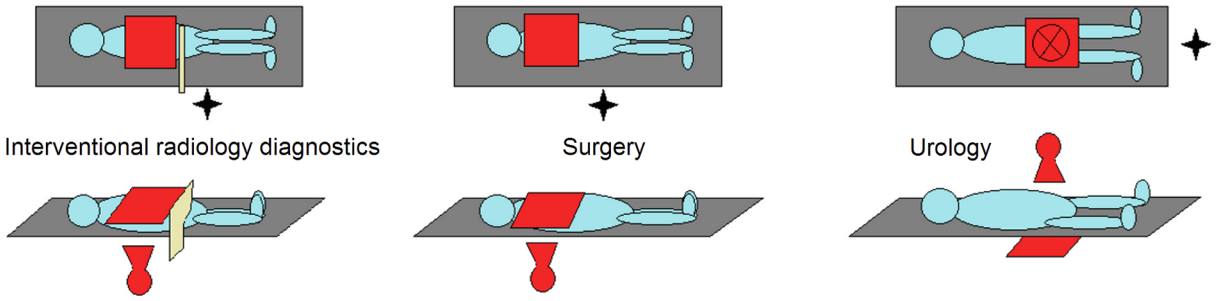

Fig. 3. Configurations used under controlled conditions. The cross represents the position of the physician; the red shapes around the patient represent the X-ray tube and the detector. The yellow frame represents a mobile protective gear. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

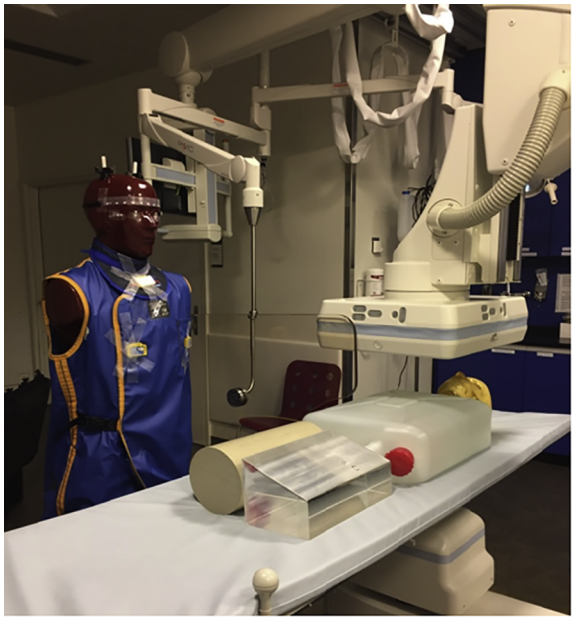

Fig. 5. Position of the phantoms and dosimeters during the measurements in the radiological room.

Table 2
Radiation protection gear used for the different speciality. "+" represent the use of the protection and "−" the unused. All thickness in this table are lead equivalent between 50 and 110 kV_p.

	Screen	Lead Apron	X-Ray tube position
Diagnostic and Interventional radiology	+ 0.5 mm	+ 0.25 mm	Under the table
Surgery	− −	+ 0.25 mm	Under the table
Urology	− −	+ 0.25 mm	Above the table

2.1.4. Measurements in clinical procedures

Twenty-one physicians from five services at CHUV participated in this study over a four-months period that took place between beginning of August until the end of November 2016. The number of physicians in each sector is given in Table 3. Each physician had a set of two badge dosimeters placed on the left chest, one under and one over the apron, to ensure the routine surveillance by double dosimetry and a Dosiris dosimeter. The eye lens dosimeter was taped on the external side of the left arm of the protective eyewear (Fig. 6) or worn with a solid headband provided by IRSN. Routine measurements were done according the habit of each practitioner, and with radiation protection gear present in each room (screen or skirt leaded). The kit was collected and exchanged each month.

2.2. Calculation of the correction factor

The purpose of this part of the study is to determine a correction factor to assess the eye lens dose based on the $H_p(0.07)$ value measured at the thorax. In order to comply with standard conditions of use, we assumed that $H_p(3)$ measured on the temple was the eye lens dose, while $H_p(0.07)$ was the dose on the thorax. The correction factor k is defined as the ratio of the dose received to the eye lens $H_p(3)_{Dosiris}$ and the dose measured in terms of $H_p(0.07)$ at the thorax level over the apron:

$$k = \frac{H_p(3)_{Dosiris}}{H_p(0.07)} \quad (4)$$

The relative uncertainty on the measurement of the absorbed dose by the TLD pellets is calculated according to the internal procedure [36] and following the Guide to the expression of uncertainty in measurement (GUM) [37] and does not exceed 10% at $k = 2$.

The relative uncertainty for measurements by Dosiris dosimeters is indicated on the IRSN measurement certificate, maximum 50% for energies below 118 keV.

Table 3
Number of physicians by service equipped with dosimeters for the study.

Service	Number of physicians
Diagnostic and Interventional radiology	8
Angioplasty	6
Surgery	3
Pain treatment centre	2
Urology	2

Fig. 6. Typical position of the Dosiris dosimeter taped on protective glasses.

3. Results

3.1. Measurements under controlled conditions

A colour-coded schematic representation of the distribution of the dose on the forehead is shown on Fig. 7 for the three given services, *i.e.* diagnostic and interventional radiology, surgery and urology. The ratio of the $H_p(0.07)$ dose measured on the chest and the $H_p(3)$ close to the eye is summarised in Table 4. Selected ratios were highlighted to better understand the dose difference between dosimeters or localisations.

The doses measured with the TLD pellet on the strips placed on the forehead, which is closest to the eye are consistent with the doses measured with the single TLD pellet directly taped on the eye. The best agreement is found for urology between the TLD on position 8 on the strip and the eye, with a difference of 3.4%. The largest difference, 17%, is observed for the surgery between the TLD on position 8 on the strip and the eye. The largest difference is less than 20%.

Moreover, a strip of 3 TLDs was placed under the chest dosimeter to study the dose distribution, and to see if the position of the passive dosimeter has a significant influence on the k ratio. However, with dose uncertainties in the measurements, it could not be demonstrated that such a small change in position significantly modified the dose on the chest badge.

3.2. Measurements during clinical procedures

The kit of dosimeters supplied to the physicians at CHUV provided data for an estimation under routine conditions with a representative clinical workload during the four-month period of this study. The values of the correction factors k (Eq. (4)) obtained for each physician in a service are compiled and presented Fig. 8. It can be seen that for the departments of diagnostic and interventional radiology, angioplasty, surgery and the pain treatment centre the set of values k is less than 1, however there is one value higher than 1, which was later explained by

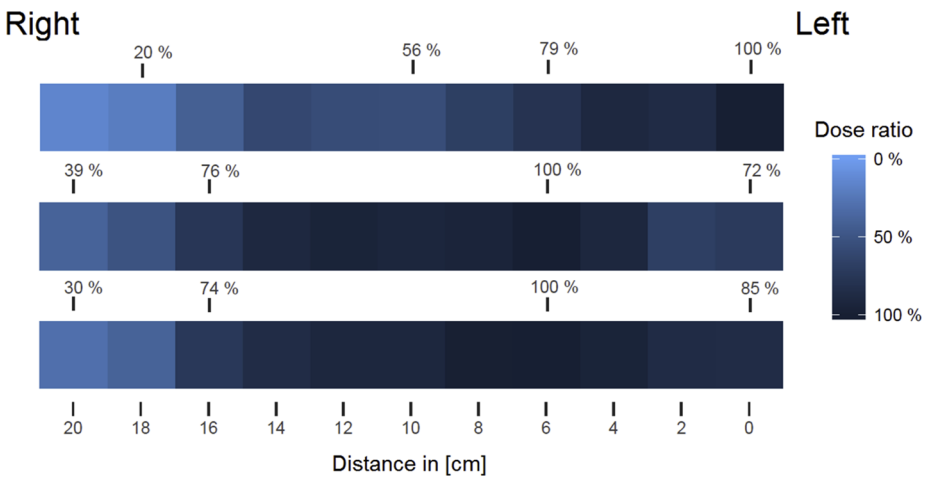

Fig. 7. Dose gradient measured by the TLD band placed on the forehead for (from top to bottom) diagnostic and interventional radiology, surgery, urology. For each medical speciality, the highest dose was used as reference for normalisation.

Table 4
Ratio between the most important dosimeter for different departments. k (Eq. (1)) is the ratio between $H_p(3)$ Dosiris and $H_p(0.07)$ which correspond to the dose calculation (Eq. (2)) with the badge under and above the lead apron. A. 2 and A. 3 correspond to the right and left eye dose, respectively, while A. 4 is the left temple dose. B.1 is $H_p(0.07)$ on the collar badge.

Ratio	Diagnostic and interventional radiology	Surgery	Urology
k= Dosiris/$H_p(0.07)$	0.39	0.28	0.72
A. 3/Dosiris	1.20	1.48	0.87
A. 4/Dosiris	1.37	1.24	0.82
B.1/Dosiris	3.14	0.91	0.89
A.2/A. 3	0.79	0.91	0.92
TLD Frontal strip8/$H_p(0.07)$	0.42	0.36	0.6
A.3/$H_p(0.07)$	0.47	0.42	0.62

a malpractice to a practitioner. The lowest end of the span can be explained by the workload of the person involving activities outside theatre (i.e. without protective glasses thus without the Dosiris dosimeter). The factor k shows a large span of variation for the urology department with values greater than 1.

All data from physicians in the same service are represented in a boxplot format on Fig. 9. The lower limit of the rectangle corresponds to the 25th percentile, while the upper limit corresponds to the 75th percentile. The horizontal line indicates the median value. The segments at the ends of the rectangle indicate the extreme values. In these

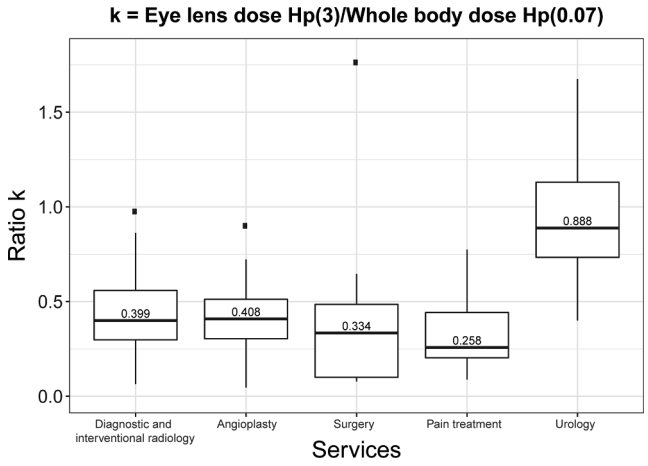

Fig. 9. k-ratio by services.

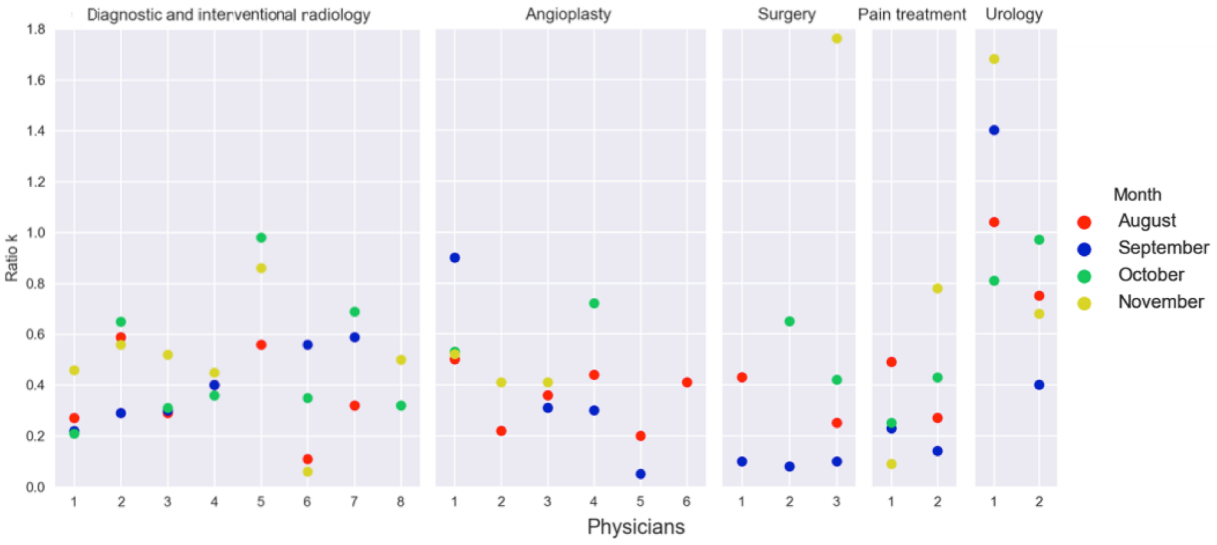

Fig 8. k-ratio for each physician, by service.

figures, points represent the atypical values (values greater than 1.5 times the height of the box).

For departments of diagnostic and interventional radiology, angioplasty, surgery and pain treatment centre, the median values of k are under the unity which indicates that the dosimeter placed on the chest over the lead apron receives a higher dose than the one situated near the eye lens. The urology department presents a maximal value above one, whereas the median value is close to one, while remaining lower.

4. Discussion

Results obtained with the strips positioned on the forehead of the phantom clearly indicate an asymmetric dose gradient with a maximum on the left side of the skull for diagnostic and interventional radiology, and a maximum dose above the left eye for surgery and urology. The dose distribution can be explained for each service by the position of the phantom towards the X-ray tube and the orientation towards the patient. This support the work of S. Principi et al. [38]. As shown Table 4, measurements under controlled conditions indicate that Dosiris dosimeter underestimated the dose received by the eye lens by a factor 1.48 in the worst case for surgery.

The doses measured with the TLD pellet show a good correlation between the dose obtained on the eye, A.2 and A. 3, and the one above the eye TLD 12 and TLD 8 respectively, on the forehead. This indicates that a dosimeter worn on the forehead, above the eye, would be appropriate for a measurement of the eye lens dose. This approach however faces the reluctance of physicians to wear an additional dosimeter on their forehead on a routine basis. Physicians are yet willing to join occasionally dedicated specific studies.

The Swiss approach requires no modification of the existing personal dosimetry system. An alternative option based on the possible use of an active personal dosimeters requires an adequate training of the staff and more complex data acquisition systems and data analysis treatment tools [39,40]. This approach is though an interesting alternative and could be used in the future.

The difference of the k value measured on the phantom and the median k value obtained with the medical staff during clinical procedures is below 20% for both diagnostic and interventional radiology and surgery services. The difference is less than 23% for the urology service. This indicates that the local radiation protection team may estimate the eye lens dose when new procedures are introduced as well as the efficiency of protective gears with phantom-based measurements.

The ICRP recommended wearing an additional dosimeter at collar level and above the thyroid protective collar [41]. The recommendation was also made by the Eurados working group [17]. Our results in controlled conditions support this recommendation and indicate that the dose values measured on the thyroid level are closer in absolute value to those measured by the Dosiris dosimeter than the dose values measured with the badge placed on the thorax. However, results summarised in Table 4 show a large variation of the ratio collar dose on eye lens dose. Doses measured at the thyroid may be lower than the eye lens dose measured by the Dosiris dosimeter. Indeed, a ratio of 3.14 is observed for the diagnostic and interventional radiology. This difference could be explained by the choice of the different radioprotection gears in the theatre. This indicates that the measurement on the thyroid cannot be used on its own to ensure the respect of the dose limit on the eye lens and requires the determination of a correction factor to correctly assess the eye lens dose [17,42]. An article of Tom Jupp et al. [43] goes in this direction, they found a ratio between eye lens dose and collar dose above one for nurse and radiographer in cardiology. A limit not to exceed on the collar could be set to ensure compliance with the dose limit to the eye lens. However, with the Swiss approach, even though we can't provide a very accurate value for the eye lens dose, we make sure that the limit is not exceeded. Doses measured by the standard routine procedure, *i.e.* with an additional dosimeter on the chest level and above the protective apron, may also, albeit seldom, be lower than the eye lens dose measured by the Dosiris dosimeter. Besides, this approach gets the slight advantage that it does not require any change from the user, as s/he can continue to wear the dosimeter on the chest as s/he is used to do for the double dosimetry that is now in practice for many years in CHUV.

The k ratio remains below unity for services of diagnostic and interventional radiology, angioplasty, surgery and the pain treatment centre, and indicates that a dosimetric surveillance based on the routine dosimetry can ensure the respect of the eye lens dose limit as long as the cumulative $H_p(0.07)$ is below 20 mSv per year. This observation is consistent with the Yoshihiro Haga et al. conclusion's [44], but also with the results of Alejo et al. [45] who found a factor of 0.33 and 0.40 in paediatric interventional cardiology. Only one practitioner in the surgery service had a ratio above unity, and this was explained by the fact that s/he informed that s/he forgot to wear the routine dosimeter. This shows that in practice the constant wearing of two dosimeters is problematic and cannot be guaranteed. Moreover, the last ratio Table 4 (left eye/$H_p(0.07)$) always below one, although impossible to test in clinical condition, support the fact that the routine chest badge would be an appropriate dosimetry to verify the respect of the eye lens dose limit.

A large variation of the k factor can be observed between staff members within a given service. For instance, a ratio of 0.06 is found for a given surgeon in the diagnostic and interventional radiology service, while a ratio fourteen times larger, 0.86, is found for another surgeon over the same period. This variation can also be seen with the wide spread of the box plot for some physicians on Fig. 9.

Furthermore, a large variation of the k factor can be observed for a given physician over the time (Fig. 8). For instance, the k factor calculated for physician number 6 of the diagnostic and interventional radiology service spans from 0.06 to 0.56 for the four months period of this study.

The median value of the k factor for the urology service is close to unity (0.89) while it is below 0.5 for the four other services. This value is consistent with the dose ratio of 0.9 ± 0.4 reported by Medici et al. [46], and higher than the dose ratio of 0.5 ± 1.2 reported by Vano et al. [33]. The higher value of the k factor in urology can be explained by the specific configuration of the procedures with the position of the x-ray tube above the patient, witch is also clearly specify for Medici et al.

The use of lead glasses would help, despite a factor k sometimes greater than 1 in urology, compliance with the eye lens dose limit. Indeed, their effectiveness makes it possible to reduce the dose received to the eye lens by a factor 3 to 7, depending on the model [47,42]. Moreover, Principi et al. [38] showed that depending on the position of the practitioner, the dose to the eye lens could be reduced. In the same way, the use of lead screen as ceiling suspended, according to the ORAMED project [42], can reduce the eye lens dose up to 90% for a wearer of lead glasses.

Although conducted conscientiously, this study presents some limitations. Firstly, measures were carried out only in a single hospital, and did not include all the trades working with ionising radiation. Secondly, the data were only collected on 21 workers and over a period of 4 months. Finally, as the scope of the study was to collected data during routine intervention, the effect of the radiation protection gears was not measured separately.

5. Conclusion

These measurements under routine conditions with a typical clinical workload indicate that the determination of an average correction factor to correctly assess the eye lens dose from a dosimeter worn on the chest is complex. High variations on the correction factors are obtained coming from the high dependency of these factors on the type of procedures, personal habits, the precise position of the routine dosimeters and the use of addition radiation protection gears. It is thus not possible

to accurately estimate the received dose to the eye lens from the routine dosemeter placed at the chest level over the apron measuring the quantity $H_p(0.07)$. However, the study showed that for services with a standard configuration, (*i.e.* the X-ray tube placed under the patient) it is possible to use this routine dosemeter to verify the respect of the eye lens dose limit. In other words, the respect of the routine dose limit $H_p(0.07)$ measured with double dosimetry ensures the respect of the annual eye lens dose limit. Contrariwise, in some fields of activity, such as urology, more in-depth studies will have to be carried out in order to find a way to ensure compliance with the lens dose limit without protective eye wear gears.

Our study confirms the validity of the Swiss approach for eye lens dosimetry. Nonetheless, if the annual dose limit on the badge were to be exceeded, there is as yet no reliable means of calculating the dose received by the eye lens. In fact, in the absence of a dedicated dosimeter, close to the eye lens, Switzerland will face the same challenges as its European partners for a precise measurement of the dose to the eye lens. Our study also confirms that eye lens dosimetry poses a major challenge for the years to come both in metrology and operational radiation protection, as also shown by Zagorska et al. [48]. It must be noticed that the new dosimetry ordinance accommodates these limitations by giving the supervisory authority the possibility to demand a dedicated eye lens dosimeter when measurements with the routine dosimeter aren't suitable to monitor the dose limit.

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