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Evaluation of equivalent dose to eye lens through dose equivalent Hp(3)

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ABSTRACT

Purpose: Individual dosimetry allows to quantify doses from ionizing radiation of exposed workers. Scientific and epidemiological evidences highlight the need for adequate measures for a greater protection of the eye and a reduction in annual doses. ICRP Publication 103, illustrating the operational dose quantity Hp(d) for the individual monitoring, proposes a depth d = 3 mm for eye lens monitoring, indicating that even the Hp(0.07) can be used. In this study, it was investigated if there are differences in the evaluation of the equivalent dose to eye lens (H_{lens}) using Hp(3) or Hp(0.07).

Materials and methods: A slab phantom calibration was performed by an Accredited Calibration Laboratory in terms of Hp(3) and Hp(0.07) using ext-rad TLD-100 (LiF:Mg,Ti) dosimeters. Hp(0.07) and Hp(3) were measured for 26 exposed workers to assess H_{lens}. The measuring took place monthly in 2017 to obtain both semestral and annual doses.

Results: $H_{lens}(0.07)$ was always smaller than $H_{lens}(3)$. However, the differences were not statistically significant (Mann-Whitney test, $p > 0.05$) for both semestral and annual doses. The percentage differences were 7 ± 3%, 6 ± 3% and 7 ± 2% for I semester, II semester and whole year, respectively. The mean underestimation index < 10%, intra-class correlation coefficient > 0.99, coefficient of variation < 3% and the excellent correlation ($R^2 \approx 0.999$) for both semestral and annual doses highlighted that Hp(0.07) can be used to evaluate H_{lens} instead of Hp(3).

Conclusions: No statistical evidence was found that the use of Hp(0.07) underestimates the equivalent dose to eye lens obtained through Hp(3).

1. Introduction

Individual dosimetry provides the tools for measuring doses from ionizing radiation of exposed workers. Recent scientific and epidemiological evidences, with regard to the effects on exposed workers, highlight the need for adequate measures for a greater protection of the eye and a reduction in annual doses. In particular, the eye lens is one of the most radiosensitive tissues in the body [1,2] and the cataract is the principal effects due to radiation exposure of the eye lens [3]. The International Commission on Radiological Protection (ICRP) has updated, in the Publication 118 [4], the threshold absorbed dose for the radio-induced cataract to ≈0.5 Gy for both acute and fractional exposures.

The medical staff performing interventional cardiology and radiology (IC/IR) procedures has to stand close to the patients and thus to the primary radiation beam. Although they wear a lead apron and thyroid collar, their hands, legs and eyes are not protected. Therefore, these parts could receive significantly high doses. There is evidence that eye lens doses can be high in IR/IC, and cases of cataract have been reported in recent years [5]. In Directive 2013/59/EURATOM (European Atomic Energy Community), the need for a strong reduction in current exposure levels is indicated [6]. In particular, referring to ICRP Publication 103, new recommendations on the equivalent dose limit for eye lens in occupational exposure are reported [7]. For occupational exposure in planned situations ICRP now recommends an equivalent dose limit for the eye lens of the eye of 20 mSv/year, averaged over defined periods of 5 years, with no single year exceeding 50 mSv. So far, the limit of annual equivalent dose for lens of the eye was 150 mSv/year.

ICRP Publication 103, illustrating the operational dose quantity "personal dose equivalent Hp(d)" for the individual monitoring, proposes a depth d = 3 mm for eye lens monitoring, Hp(3), indicating that even the Hp(0.07) can be used. Recently, in the Individual Monitoring

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Table 1
Dosimetry service specifications related to the operational dose quantity Hp(d) for x and gamma radiation.

Material	LiF:Mg,Ti
Response interval in energy	20 keV–1.25 MeV
Detection limit	0.05 mSv
Total uncertainty of the dosimetry system	≤ 20% (range: 0.05 ÷ 0.5 mSv)
(95% confidence level)	≤ 20% (> 0.5 mSv)
Fading	< 0.1%

Table 2
Hp(3) and Hp(0.07) irradiation parameters at the Accredited Calibration Laboratory.

	Beam code[a]	Average calibration energy (keV)	Irradiation distance (cm)	Air KERMA[b] (mGy)	$Hp(d)_{cal}$ (mSv)
Hp(3)	N-40	33	250	7.40E − 01	9.60E − 01
	N-60	48	250	5.90E − 01	9.70E − 01
	N-100	83	250	5.30E − 01	9.70E − 01
	N-120	100	250	5.70E − 01	9.90E − 01
	N-150	118	250	6.03E − 01	1.00E − 01
Hp(0.07)	H-30	19.7	250	5.05	5.11
	H-60	37.3	250	3.88	5.01
	W-60	45	250	3.46	5.16
	W-110	79	250	2.99	5.12
	W-200	137	250	3.28	5.09
	W-300	208	250	3.49	4.97

[a] The beam code refers to International Standard ISO 4037 [9].
[b] Air KERMA is at reference environmental conditions: T_0 = 293.15 °K, P_0 = 101.3 kPa. $Hp(d)_{cal}$ = dose equivalent for calibration.

Service (IMS) of Perugia General Hospital, operational dose quantity Hp (3) was introduced. In this study, it was investigated whether there are differences in the evaluation of the equivalent dose for the eye lens of exposed workers using Hp(3) or Hp(0.07).

2. Material and methods

The IMS of Perugia General Hospital performs the individual monitoring of employees exposed to ionizing radiation of the Perugia General Hospital and other public or private hospitals in Umbria region (Italy).

Ext-rad with single element Thermo Scientific™ TLD-100 thermoluminescent material are used as dosimeter for the monitoring of equivalent dose to eye lens (H_{lens}). It consists of lithium fluoride (Li natural) LiF:Mg,Ti. The reading is performed with the Thermo Scientific™ Harshaw TLD™ Model 6600 Plus Automated Reader Instrument. Table 1 shows the dosimetry service specifications for x and gamma radiation.

To adopt the operational dose quantity Hp(3), a calibration was performed by an Accredited Calibration Laboratory (ACL) in terms of the personal dose equivalent Hp(3). 15 dosimeters were irradiated with narrow photon beams (N) at five different energies (3 dosimeters for each energy) using a phantom slab, as suggested by ISO 12,794 (ISO, 2000) [8]. The irradiation parameters (beam code, average calibration energy, irradiation distance, air KERMA, dose equivalent for calibration $Hp(d)_{cal}$) are listed in Table 2. In addition, a calibration in terms of the personal dose equivalent Hp(0.07) was performed using H (High)-type and W (Wide)-type photon beam (Table 2). Hp(3) and Hp(0.07) irradiation parameters have different beam code, because the ACL had only N-type photon beam available for Hp(3) at the time of the calibration procedure.

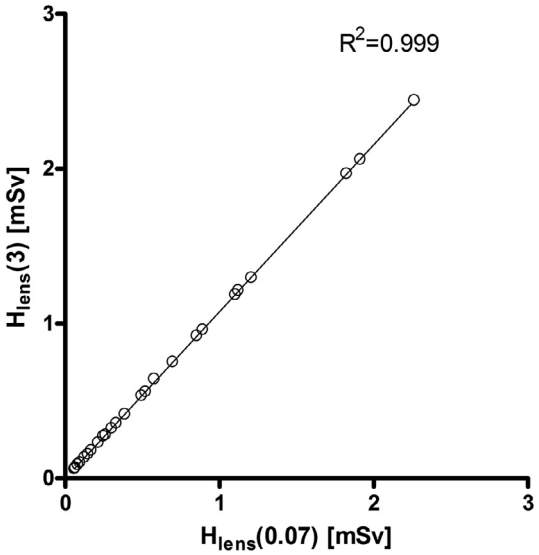

Fig. 1. Scatter plot between annual $H_{lens}(0.07)$ and annual $H_{lens}(3)$ for each exposed worker.

Personal dose equivalent Hp(3) and personal dose equivalent Hp (0.07) were measured for 26 exposed workers of Perugia General Hospital. 20 exposed workers were from the Cardiology Department – Haemodynamic Unit, 3 from Neuroradiology Department – Angiography Unit and 3 from Radiology Department – Angiography Unit. They performed diagnostic tests through x-ray medical equipment with voltage range from 90 kV to 110 kV. Each exposed worker wore protective lead glasses (front lens: 0.70 mm lead glass; side shields: 0.50 mm lead glass) in order to reduce the scattered radiation by at least 90% and an elastic band on his forehead, where the dosimeter is attached. In this way the dosimeter was placed right above one of the front lens, to obtain both Hp(3) and Hp(0.07).

The personal dose equivalent Hp(d) was calculated for each exposed worker through a customized algorithm as:

$$Hp(d) = q \times ECC \times C(d, E) \quad (1)$$

where q is the measured charge (nC) of the worn dosimeter from which

Table 3
Semestral and annual comparison between $H_{lens}(0.07)$ and $H_{lens}(3)$ for 26 exposed workers. Dose data are expressed in mSv.

	I Semester		II Semester		Year	
	$H_{lens}(0.07)$	$H_{lens}(3)$	$H_{lens}(0.07)$	$H_{lens}(3)$	$H_{lens}(0.07)$	$H_{lens}(3)$
Mean value	0.35	0.38	0.26	0.28	0.61	0.66
SD	0.39	0.43	0.28	0.3	0.62	0.67
Minimum	0.03	0.03	0.03	0.03	0.06	0.06
Maximum	1.51	1.63	1.11	1.19	2.27	2.44
Mean difference ± SD (%)	7 ± 3		6 ± 3		7 ± 2	
ICC	0.997		0.997		0.997	
CV (%)	2.1		1.7		1.6	
MW p-value	0.700		0.762		0.741	

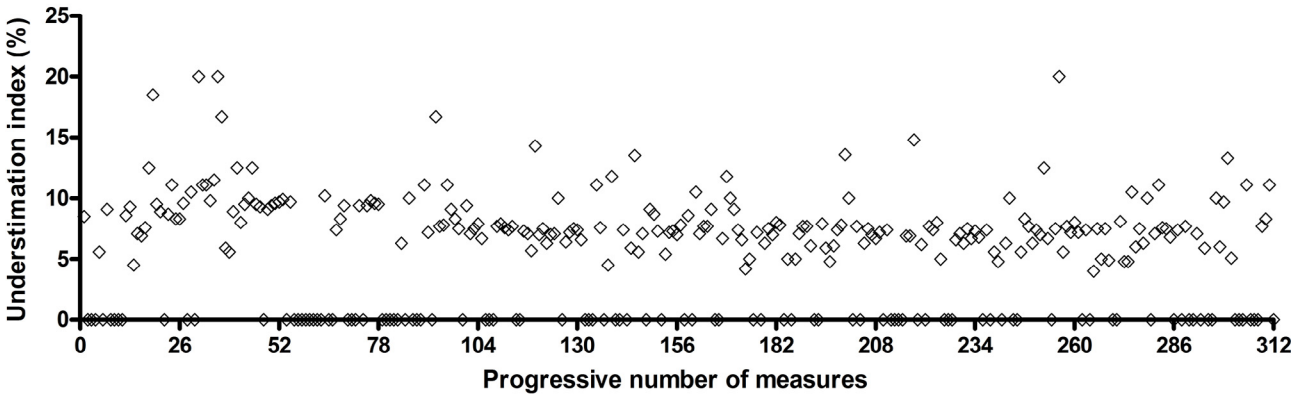

Fig. 2. Percentage Underestimation Index (UI) of $H_{lens}(0.07)$ with respect to $H_{lens}(3)$ for all monthly doses.

background was subtracted, ECC is the element correction coefficient of the dosimeter and C(d,E) is the calibration factor at the depth d and average calibration energy E (Table 2) chosen in relation to the diagnostic tests performed by the worker. The calibration factors were calculated as the ratio of $Hp(d)_{cal}$ and mean value of the measured charge, where the background was subtracted, of the 3 dosimeters irradiated at the ACL for each calibration energy.

Finally, the equivalent dose to eye lens (H_{lens}) was obtained by:

$$H_{lens}(d) = f \times Hp(d) \quad (2)$$

where Hp(d) is in turn Hp(3) or Hp(0.07) and f is the transmission factor. The transmission factor takes into account the use of radiation safety glasses. In particular, in case of constant use of high-protection lead glasses f = 0.1 [10].

The measuring took place monthly in 2017. For each exposed worker the sum of monthly $H_{lens}(3)$ and $H_{lens}(0.07)$ was considered in order to obtain both semestral (I: January-June, II: July-December) and annual doses.

Agreement was quantified by calculating the mean difference (MD) between $H_{lens}(0.07)$ and $H_{lens}(3)$ and standard deviation (SD) of this differences, the coefficient of variation (CV), which is the ratio between SD and MD expressed as percentage, the coefficient of determination R^2, which indicates the proportion of variance of a variable that is explained from another variable, and the intra–class correlation coefficient (ICC), which is defined as the ratio between SD and the total variance [11]. In order to analyze the difference between $H_{lens}(0.07)$ and $H_{lens}(3)$, the percentage underestimation index (UI) of $H_{lens}(0.07)$ with respect to $H_{lens}(3)$ was calculated for each exposed worker. Differences between measures were also checked by using the Mann-Whitney test [12]. All the statistical analyses were performed using IBM-SPSS® version 25.0 (IBM Corp., Armonk, NY, USA, 2017) and two-sided probability values < 0.05 were considered to be statistically significant.

3. Results

Table 3 shows the semestral and annual comparison between $H_{lens}(0.07)$ and $H_{lens}(3)$. As it can be seen, the maximum $H_{lens}(0.07)$ and $H_{lens}(3)$ annual values were smaller than 3 mSv. Mean $H_{lens}(0.07)$ was always smaller than mean $H_{lens}(3)$, however, the differences were not statistically significant ($p > 0.05$) for both semestral and annual doses. The percentage differences were 7 ± 3%, 6 ± 3% and 7 ± 2% for I semester, II semester and whole year, respectively. ICC values were greater than 0.8, while CV values were smaller than 2.5%. Fig. 1 provides the scatter plot between annual $H_{lens}(0.07)$ and $H_{lens}(3)$ for each exposed worker, showing an excellent correlation ($R^2 \approx 0.999$). Fig. 2 shows the UI for all monthly doses. The mean UI was 6 ± 4% (range 0–20%). $H_{lens}(3)$ was greater than $H_{lens}(0.07)$ for 68% of the measures. In the remaining 32% the values were considered equal, being the measures below the detection limit (0.005 mSv for H_{lens} applying a transmission factor f = 0.1).

4. Discussion

IC/IR procedures are known to be associated with a high level of radiation exposure of medical staff. The recently suggested decrease of the annual dose limit for the eye lens, from 150 to 20 mSv, caused the need to reconsider the evaluation method of H_{lens} in exposed workers. In this paper it was investigated, to the best of our knowledge for the first time, whether there are differences in the evaluation of H_{lens} using Hp(3) or Hp(0.07).

The statistical analysis performed with the Mann-Whitney test showed that the use of Hp(0.07) doesn't underestimate the equivalent dose to eye lens obtained through Hp(3). Moreover, the mean UI smaller than 10% for both semestral and annual doses, ICC greater than 0.99 indicating an almost perfect agreement, CV smaller than 3% and the excellent correlation ($R^2 \approx 0.999$) highlighted that, in our setup for the evaluations of H_{lens} in exposed workers, Hp(0.07) can be used instead of Hp(3).

A limit of this study is the use of different radiation qualities for the calibration procedure of Hp(0.07) and Hp(3), due to the unavailability at the ACL of the same beams. Future studies should consider this aspect using, if possible, the same radiation qualities.

5. Conclusions

There was no statistical evidence that the use of Hp(0.07) underestimates the equivalent dose to eye lens obtained through Hp(3).

Declaration of Competing Interest

None.

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