The eye lens dose of the interventionalist

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Technical note

The eye lens dose of the interventionalist: Measurement in practice

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ABSTRACT

Objective: Early 2018, the new eye lens dose limit of 20 mSv per year for occupational exposure to ionising radiation was implemented in the European Union. Dutch guidelines state that monitoring is compulsory above an expected eye lens dose of 15 mSv/year. In this study we propose a method to investigate whether the eye lens dose of interventionalists would exceed 15 mSv/year and to determine if the eye lens dose can be derived from the regular personal dosimeter measurements.

Methods: The eye lens dose, Hp(3), of interventional radiologists (n = 2), cardiologists (n = 2) and vascular surgeons (n = 3) in the Máxima Medical Centre, The Netherlands, was measured during six months, using thermoluminescence dosimeters on the forehead. Simultaneously, the surface dose, Hp(0,07), and whole body dose, Hp(10), were measured using regular dosimeters outside the lead skirt at chest level. The dosimeters were simultaneously refreshed every four weeks. The eye lens dose was compared to both the body-worn dosimeter values. Measurements were performed in the angiography suite, Cath lab and hybrid OR.

Results: A clear relation was observed between the two dosimeters: Hp(3) ≈ 0,25 Hp(0,07). The extrapolated year dose for the eye lens did not exceed 15 mSv for any of the interventionalists (average 3 to 10 studies/month).

Conclusions: The eye lens dose can be monitored indirectly through the regular dosimeter at chest level. Additionally, based on the measurements we conclude that all monitored interventionalists remain below the dose limit and compulsory monitoring limit for the eye lens dose.

Introduction

The increase in fluoroscopy guided interventions with respect to open procedures [1–3], has resulted in significant benefits for patients, including faster recovery, shorter hospital stay and smaller scars [1]. A drawback of the use of fluoroscopy is the ionizing radiation risks for both patient and intervention staff [2,3]. The occupational ionizing radiation risks in interventional fluoroscopy are generally higher when compared to other radiological modalities [2,4–6], which is the result of the short distance between staff and the radiation source, i.e. the radiation scatter from the patient, and the sometimes lengthy procedures [2,4–6].

As a result of various studies into tissue effects of ionizing radiation, reported by the International Commission on Radiation Protection (ICRP) [7], the equivalent dose limit for the eye lens was lowered from 150 mSv/year down to 20 mSv/year in the European law, 2013/59/Euratom Basic Safety Standards. This dose limit was subsequently implemented in Dutch law[8,9] in the beginning of 2018, which also states that staff surpassing a boundary of 15 mSv/year on the eye lens dose must be classified as a type-A radiation worker [8,9]. The law requires that the whole body dose as well as the eye lens dose be monitored in type-A radiation workers [8–11].

The eye lens dose is typically monitored through a dosimeter on a band worn on the head [12]. However this is a cumbersome device, which is sometimes displaced during or thrown away together with disposable hairnet after the intervention. The eye lens dose can also be monitored indirectly through the whole body thermoluminescence dosimeter, if a good estimate can be established of the correlation between the eye lens dose and the whole body dose [9]. For estimation of the eye lens dose the measurable parameter Hp(3) is recommended, in literature as well as by the Dutch radiation society (NCS).[10,13,14] For measuring the correlation with the whole body dose, the Hp(0,07) is seen as the optimal measurable parameter [9,15]. Various studies have

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already investigated this correlation in the past [11–13,16,17]. They however show varying results, which is likely due to variation in staff positioning in the scanning room, orientation and usage of the C-arm as well as orientation, angle dependence and energy dependence of the dosimeters used [11–13,16,17]. Because of these variations, hospitals should preferably establish a correlation between eye lens dose and whole body dose which is representative for their own setting in which the interventional fluoroscopy procedures are performed [9].

In the Máxima Medical Centre, location Veldhoven, the Netherlands, the interventional A-workers are the interventional radiologists, cardiologists and the vascular surgeons, operating in respectively the angiography suite, the Cath Lab and the hybrid OR.

In this study we investigated the correlation between the eye lens dose and the whole body dose for this group of interventionalists, by monitoring both values with dedicated dosimeters for the period of 6 months.

Methods

Subjects

The participants in this study are employees of the Máxima Medical Centre, who perform interventions using fluoroscopy. The population is divided into three groups: the interventional radiologists who operate in the angiosuite and the hybrid OR (N = 2), the cardiologists who operate in the Catheterization Lab (N = 2) and the vascular surgeons who operate in the hybrid OR and the angiosuite (N = 3). All participating interventionalists have considerable experience in performing the interventions using fluoroscopy. All participants signed an informed consent. The supporting personnel, e.g. operating assistants, who were present during the interventions were not included in the study, as they are not in de A-category for radiation workers and were not expected to exceed the 15 mSv/year boundary value.

The C-arms used were the Toshiba Infinix-I (Tokyo, Japan) in the angiography suite, the Philips Allura Xper FD10 (Best, The Netherlands) in the Cath Lab and the Siemens Artis Pheno (Erlangen, Germany) in the hybrid OR.

Dosimeters

In the study two types of dosimeters were used: one for monitoring the whole body dose and one for monitoring the eye lens dose. The whole body dosimeters consisted of Thermoluminescence material (LiF: Mg,Ti), had dimensions of 3.2 × 3.2 × 0.9 mm and was worn at chest height at the left breast pocket or at the thyroid collar. The whole body dosimeters consisted of two detectors: one for the surface dose at a depth of 0.07 mm: $H_p(0,07)$, and one for the depth dose at 10 mm: $H_p(10)$. The eye lens dosimeters were attached to a band and were worn on the forehead. They consisted of the same thermoluminescence material. The eye lens dosimeter measures a depth dose at 3 mm: $H_p(3)$. Both types of dosimeters were provided by Mirion Technologies[14] and the readout was also performed by Mirion technologies in the Netherlands. The determined values were expressed in mSv.

Data collection

From December 2018 until end of May 2019 data was acquired. The eye lens dose and surface dose values were worn for four weeks and then changed for a new dosimeter, conform our clinical practice. Special care was taken to ensure that the two types of dosimeters were always worn simultaneously and were collected together for readout. During this period the following information was additionally collected by the assisting teams in each of the three intervention rooms: the performing physician, date of the procedure, performed procedure, positioning of the interventionalist during the procedure and the position of the eye that was closest to the intervention, the imaging time, the Dose Area Product (DAP), the use of personal radiation protection equipment, and whether the eye lens dosimeter was worn or not. The specific dose information of the interventions was collected from the dose reports that are routinely sent to the PACS. Additionally, in each intervention room an independent observer monitored the interventions during one week to independently asses positioning and usage of radiation protection equipment.

Statistical analysis

Statistical analysis is performed using SPSS (IBM SPSS Statistics, version 22) and Excel (Microsoft, Washington, VS). The eye lens dose estimated through Hp(3) is cumulatively assessed against the cumulative estimation for the surface dose Hp(0,07). If a four-weekly measurement is missing from the dataset for either dose measures, this is taken into account by omitting the measured data for those four weeks from the cumulative value of the other dosimeter as well. The correlation strength between the two parameters is assessed using linear regression, where $p < 0,05$ is considered significant.

Results

The results in Fig. 1 show that the measured cumulative Hp(3) values are found to correlate rather well with the measured cumulative Hp (0,07) values. Strikingly, the observed correlation is quite similar for the cardiologists and the interventional radiologists, despite the fact that they perform different procedures in different intervention rooms. We find a correlation between the two types of dosimeter measures that can be described as: Hp(3) ≈0,25Hp(0,07), with an R^2 of 0,98. Linear regression analysis gives a p-value < 0,001. The dose values measured for the vascular surgeons was so low that it was difficult to estimate a trend from that. In the dose measurements from one of the cardiologists we observed an outlier with relatively high Hp(3), compared to the rest. The readout procedure for this dosimeter was checked, but was performed normally according to Mirion, and additionally there was no recollection of having left the dosimeter in the Cath Lab.

Similarly, also the correlation of the measured cumulative Hp(3) values correlate rather well with the measured cumulative Hp(10) values. The results are shown in Fig. 2. The correlation found here can be described as Hp(3) ≈0,36 Hp(10), with an R^2 of 0,98. Linear regression analysis gives a p-value < 0,001.

The individual monthly measurements can also be plotted against

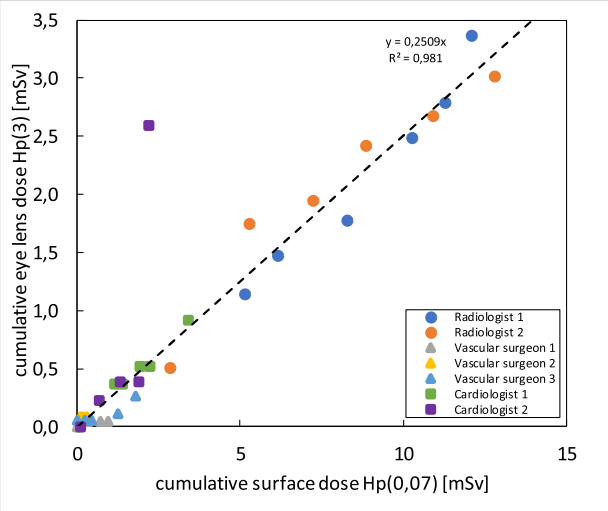

Fig. 1. Cumulative eye lens dose, estimated through Hp(3) for the interventionalists as a function of the cumulative surface dose, estimated through Hp(0,07).

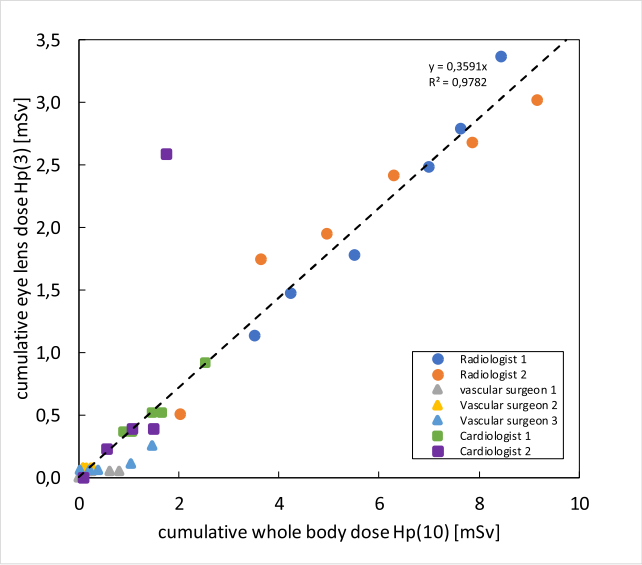

Fig. 2. Cumulative eye lens dose, estimated through Hp(3) for the interventionalists as a function of the cumulative whole body dose, estimated through Hp(10).

each other, but result in a poorer correlation, with an R^2 of 0,71, due to the relatively low dose levels that are involved (see Fig. 3). Linear regression analysis gives a p-value < 0,001.

Fig. 4 shows the measured cumulative Hp(3) as a function of the applied cumulative Dose Area Product for the different interventionalists. It is clear from this data that the relation between the eye lens dose and DAP is not the same between different types of procedures and that even within a specific group of interventionalists uneven distribution of procedure types can be observed.

Based on the record keeping of the assisting staff during the interventions in the investigated period (see Table 1), we found that, on average, the left eye of the interventionalist is closest to the scattering radiation source (see Fig. 5). Not for all procedures it is possible to use the lead screen effectively, as can be seen in Table 1. The cardiologists did not have access to lead glasses during the time this study was performed.

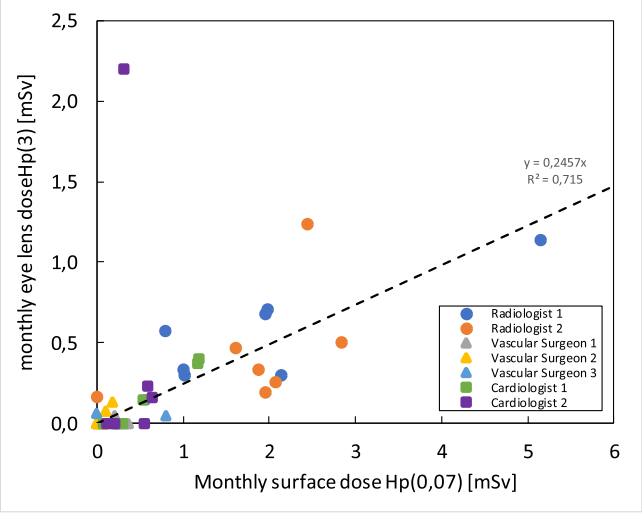

Fig. 3. Monthly eye lens dose, estimated through Hp(3) for the interventionalists as a function of the monthly surface dose, estimated through Hp(0,07).

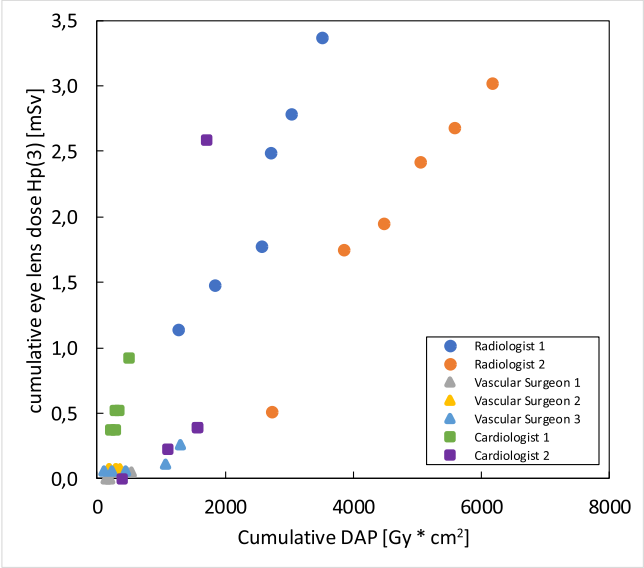

Fig. 4. Cumulative eye lens dose, estimated through Hp(3) for the interventionalists as a function of the cumulative Dose Area Product.

Discussion

In this study we show that a clear correlation is observed between the cumulative eye lens dose worn on the forehead and the cumulative surface dose measured on the chest-worn dosimeter. This means that derivation of an estimated eye lens dose from an always worn personal dosimeter is possible. We measured both eye lens and whole body dose and using extrapolation, we show that for the present workload all the interventionalists are expected to stay below the doselimit of 20 mSv/year [7,9] for both eye lens and body dose. Additionally, for the present workload the interventionalists are expected not to exceed the boundary of 15 mSv/year, above which additional compulsory monitoring is required according to the Dutch radiation society NCS [9]. Based on the badge results the vascular surgeons would not exceed the 6 mSv/year.

The factor of correlation between cumulative eye lens dose and cumulative surface dose on the body dosimeter is 0,25 (the equation is Hp (3) = 0,25*Hp(0,07)) [18,19]. However, this result is based on only 6 measurements per interventionalist. In earlier studies a larger variation of correlation factors was found, ranging between 0,33 and 1,68 [12,26,30–33]. There is however also a large variation in the manner these studies were performed. Carinou et al. [12] en Bjelac et al. [31] analyzed relatively old reports in literature and Liu et al. [13] performed a phantom study in contrast to the work reported here. The investigations of Alejo et al. [15] en Nowak et al. [33] are comparable to the present study in terms of approach and they observed correlation factors between 0,33 en 0,40 [15,33]. Various reports state that the diversity in observed correlation factors is due to the positioning on the body of the dosimeters as well as the properties of the dosimeters and additionally the positioning of the interventionalists themselves during the procedures [9,13,14]. The difference in correlation factor we observed in this study compared to literature can also be in part attributed to the fact that we chose to position the eye lens dosimeter in the middle of the forehead of the interventionalist instead of closer to the left eye, which was found to be the dominantly exposed eye during most of the interventions. Domienik et al investigated the variation along the forehead of the interventionalist using multiple TLD's [34]. They found that the eye closest to the radiation source can receive an eye lens dose of a factor 1,3 to 2,3 higher than the measurement on the forehead, whereas the eye furthest away from the radiation source only receives a factor 0,5–0,6 of the forehead dose on the eye lens.

Compared to the vascular surgeons and the cardiologists, the

Table 1
Positioning and usage of personal radiation protection equipment for the various interventionalists. If the lead glasses are worn, the eye lens dosimeter was worn above the leadglass.

specialist	# procedures	median exposure time [min] (IQR)	median dose area product [Gycm^2] (IQR)	compliancy wearing eye lens dosimeter [%]	usage of lead ceiling screen [%]	usage of lead glasses [%]	estimated distance to tube [min - max]	position of the whole body dosimeter	Procedures (%)
Interventional Radiologist 1	80	5,1 (10,2)	10,1 (30,5)	96,25%	86,25%	6,25%	45 [25–85]	thyroid collar	PTA* (61,7%), embolisation (14,8%), nefrostomy (8,2%), rest (14,7%)
Interventional Radiologist 2	116	6 (13,1)	12,8 (22,8)	100,00%	96,55%	88,79%	45 [25–85]	left breastpocket lead vest	PTA (54,3%), embolisation (4,3%), nefrostomy (10,9%), rest (30,5%)
Vascular Surgeon 1	25	7,4 (15,2)	15 (32)	96,00%	84,00%	24,00%	45 [25–85]	thyroid collar	PTA (50%), EVAR** (33,3%), rest (16,7%)
Vascular Surgeon 2	18	10,75 (13,5)	17,8 (43,2)	100,00%	94,44%	100,00%	45 [45–60]	left breastpocket lead vest	PTA (53,8%), EVAR (38,5%), rest (7,7 %)
Vascular Surgeon 3	55	5,9 (11,4)	12,2 (35,8)	96,08%	92,16%	76,47%	45 [45–85]	left breastpocket lead vest	PTA (63,3%), EVAR (23,3%), rest (13,4%)
Cardiologist 1	18	3,3 (3,7)	29,1 (28,9)	100,00%	77,78%	0,00%	45 [25–45]	left breastpocket lead vest	CAG*** (88,9%), pacemaker implant. (11,1 %)
Cardiologist 2	36	4,9 (4,2)	66,9 (35,8)	91,67%	100,00%	0,00%	45 [45–45]	left breastpocket lead vest	CAG (100%)

* PTA = Percutaneous Transluminal Angioplasty.
** EVAR = Endovascular Aortic Repair.
*** CAG = Coronary Angiogram.

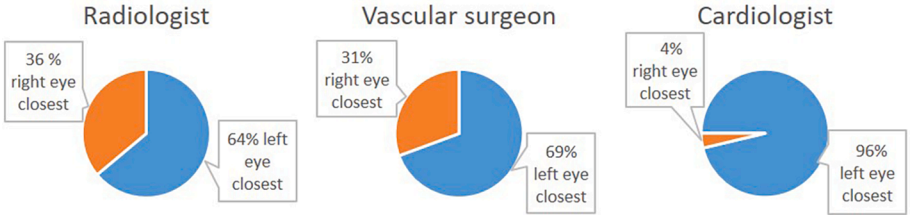

Fig. 5. Pie charts showing the estimated percentage of the time each of the two eyes is closed to the scattering radiation source during the intervention. This data was derived from the average positioning information that was gathered during the interventions.

interventional radiologists performed the most procedures in the investigated period, because of which, logically, the eye lens dose for the radiologist turned out higher as well. Comparing the two interventional radiologists however, we observe that radiologist 1 has a significantly higher eye lens dose as a function of the dose area product (see in Fig. 4) compared to radiologist 2, which is likely due to the different set of interventions performed in the studied period as is shown in Table 1. Also, a difference in eye lens dose value between the various interventionalists can be explained by different usage of radiation protection equipment. High eye lens doses reported in earlier studies were mainly explained by the lack of usage of radiation protection equipment [26–29].

Various studies have shown that a significant dose reduction can be achieved by using the ceiling mounted leadscreen [20–25]. If the lead screen is used optimally, an eye lens dose reduction of up to 50–60% may occur [20,23]. Optimal usage here reflects the positioning of the lead screen close to the skin of het patient, preferably positioned over the patient [9,20,22,24,25]. In this study the cardiologists used the lead screen in this way most often, because they have a limited set of interventions they perform in the Cath lab that allow effective usage of the lead screen most of the time. The larger variation in interventions and thus positioning of the interventionalist in the operating room, sometimes does not allow for an optimal positioning of the lead screen, although the screen is used always when possible.

Limitations

One of the main limitations of our study is that the pool of interventionalists is low, as in our hospital interventions are only performed by a limited number of interventionalists as they need to comply with requirements on a minimum number of interventions performed per year. In addition, during the study two interventionalists lost their monthly eye lens dosimeter once, which limited the amount of data that was collected during those two months. The eye lens dosimeter is easily discarded together with the skull cap after an intervention. Another limitation was the choice to position the dosimeter on the forehead rather than towards the left eye, which is the dominantly exposed eye in most interventions. Based on the current results we cannot discriminate between the two eyes of the interventionalists.

Conclusion

A strong positive correlation is found between the eye lens dose and the whole body dose for both the interventional radiologists and the

cardiologists. This allows the monitoring of the eye lens dose by estimating its value based on the whole body dosimeter value, if the radiation protection equipment is used appropriately. The vascular surgeons are expected to stay below the limit of 6 mSv/year, thus not requiring a separate eye lens dose monitoring approach based on the new regulations [8,9].

Author contributions

EJM: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Visualization, Validation, Writing - original draft, Writing - review & editing. **DWHvZ:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing - original draft. **MJAL:** Investigation, Resources, Writing - review & editing. **CMESNT:** Investigation, Resources, Writing - review & editing. **CvP:** Conceptualization, Methodology, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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