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Measurements of eye lens doses in interventional radiology and cardiology: Final results of the ORAMED project

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A B S T R A C T

Within the ORAMED project (Optimization of Radiation Protection of Medical Staff) a coordinated measurement program for occupationally exposed medical staff was performed in different hospitals in Europe (www.oramed-fp7.eu). The main objective was to obtain a set of standardized data on extremity and eye lens doses for staff involved in interventional radiology and cardiology and to optimize radiation protection. Special attention was given to the measurement of the doses to the eye lenses. In this paper an overview will be given of the measured eye lens doses and the main influence factors for these doses. The measured eye lens doses are extrapolated to annual doses. The extrapolations showed that monitoring of the eye lens should be performed on routine basis.

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1. Introduction

Cataract is the loss of transparency of the lens of the eye. The cataracts progress slowly to cause vision loss and may eventually lead to blindness. Luckily, it is quite easy to treat. Cataract is typically associated with old age and metabolic conditions like diabetes. It is known that cataract can also be radiation induced (ICRP, 2000). In the present ICRP approach, cataract induction is a tissue reaction with a definite threshold (ICRP, 2007). This threshold is between 0.5 and 2 Gy for acute exposures, and 5–6 Gy for prolonged exposures. There is a latency period that can last for many years.

The present annual dose limit for the eye lens for occupationally exposed workers is set to 150 mSv per year (European Commission, 1996). The operational quantity to be used to monitor the dose to the lens of the eye is $H_p(3)$ (ICRU, 1993). Eye lens doses have received a lot of attention in the last years because of some epidemiological studies on Chernobyl clean-up workers, interventionalists and survivors of the A-bomb (Worgul et al., 2007, Junk et al., 2008; Vano et al., 2010; Ciraj-Belac et al., 2010). These studies show clearly that the threshold dose for cataract induction is lower than presently assumed, even lower than 0.8 Gy. It is not even sure that there is a threshold at all.

In this paper an overview will be given of the eye lens measurement results from the ORAMED project (Optimization of Radiation Protection of Medical Staff). Both the measured eye lens doses and the main influence factors for these eye lens doses in interventional radiology will be presented and discussed. The measured eye lens doses will be extrapolated to yearly doses, and this shows that monitoring of the eye lenses can become important.

2. Materials and methods

The procedures that were chosen to be monitored are cardiac angiographies (CA) and angioplasties (PTCA), pacemaker and defibrillator implantations (PM/ICD), radiofrequency ablations (RFA), angiographies and angioplasties of lower limbs (DSA PTA LL), carotids, brain (DSA PTA C&C) and reins (DSA PTA R), embolisations and endoscopic retrograde cholangio-pancreatography procedures (ERCP). All measurements were normalized to the KAP values

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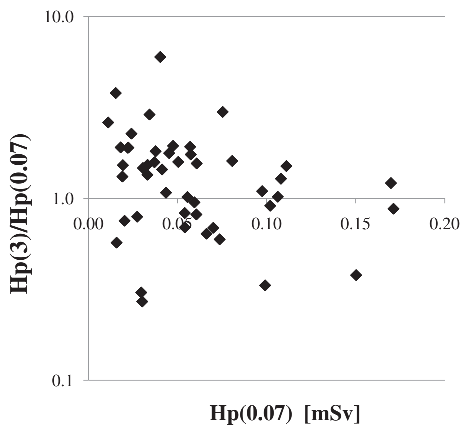

Fig. 1. Ratio of $H_p(3)$ measurements with the EYE-D dosemeter, compared to the $H_p(0.07)$ measurements in a series of hospital interventional procedures.

(Kerma Air Product). These KAP values were registered in the protocol. Also radiation protection measures, like the use of lead glasses by the physician, were noted down in the protocol.

$H_p(3)$ is defined as the operational quantity to control the dose limits for the eye lens doses. However, at the beginning of the project there was no suitable dosemeter or proper calibration procedure for eye lens dosimetry. In addition, ICRP 103 (2007) states that, in practice, $H_p(0.07)$ can be used for monitoring eye lens doses, when $H_p(3)$ is not measured. So, initially, the doses were measured in terms of $H_p(0.07)$ using thermoluminescent (TL) dosemeters of LiF:Mg,Cu,P type in plastic bags. One dosemeter was put in the region between the eyes of the physician and another one near the left or right eye depending on whether the X-ray tube is on the left or right side with respect to the operator. The plastic bags were taped on the physician at the beginning of the procedure, and removed at the end. The dosemeters were calibrated using N-60 and N-80 X-ray beams (ISO, 1996).

Within the ORAMED project an eye lens dosemeter was developed: the EYE-D (Bilski et al., 2011). To compare the eye lens dosemeters in bags with the new eye lens dosemeter, we performed a series of measurements in hospitals. During about 100 routine interventional procedures both the $H_p(0.07)$ bags and the EYE-D dosemeter were worn simultaneously (detection limit of the order of 10 μSv). Also the EYE-D dosemeters were calibrated using N-60 and N-80 X-ray beams (ISO, 1996). The EYE-D dosemeter was worn near the left or right eye, attached to a support around the head, as close as possible to the $H_p(0.07)$ bag. In Fig. 1, the ratios of the $H_p(3)/H_p(0.07)$ can be seen for these hospital measurements. As expected, there is a large spread, because the doses were very low, and the two dosemeters were not exactly on the same location. However, when considering only the values above 50 μSv, the median ratio is 1.12. In laboratory tests we also compared the calibration coefficients of both the $H_p(0.07)$ bag dosemeters (on slab phantom) and the $H_p(3)$ EYE-D dosemeter (on cylindrical head phantom). We used both N-60 and N-80 radiation qualities, and the difference was never more than 5%. From these tests, we can conclude that for the purposes of the present study the $H_p(0.07)$ measurements from the ORAMED measurement campaign can be used as a good approximation of the $H_p(3)$ eye lens doses.

There is a large number of influence factors that can give a big variability for the eye lens doses: different geometries of the various X-ray systems, protective equipment, complexity of the medical procedures (fluoroscopy time, number of acquired images), work technique (X-ray tube configuration, projections used, etc.) and physician's experience. A statistical analysis (two-way analyses of the variance, ANOVA test) was performed to see which parameters have a statistically important effect on the eye lens doses. The significance levels that were used for testing the null hypotheses were 0.05. The statistical packages used for this purpose were the SPSS and STATISTICA. The parameters which were found to be significant are listed in the discussion part. Using the measurements database, the magnitude of these influence parameters on the eye lens doses was determined.

To check if the annual limits might be exceeded, we tried to extrapolate the measured eye lens values per procedure to annual doses. In the European Directives (European Commission, 1996) it is written that monitoring is required if there is a possibility of reaching the 3/10th of the annual limits. For the present eye lens dose limit this means an annual value higher than 45 mSv.

To extrapolate the doses, we needed to know how many procedures a certain operator performs per year. This was estimated from the logbook of the hospital/room or from personal contacts. It was of course assumed that the measured procedures were representative of all the procedures that this person performs per year. Still, the calculated doses are likely to underestimate the real ones. First, because in general operators tend to be more careful

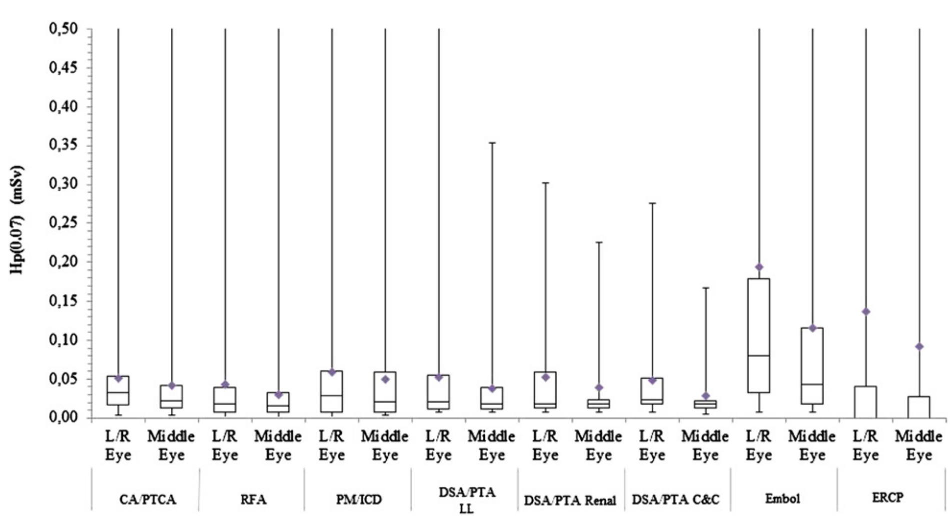

Fig. 2. Zoomed graph of the measured $H_p(0.07)$ values at the eyes during the different procedures. Shown are the minimum, 1st quartile, median, 3rd quartile, mean (diamond) and maximum values.

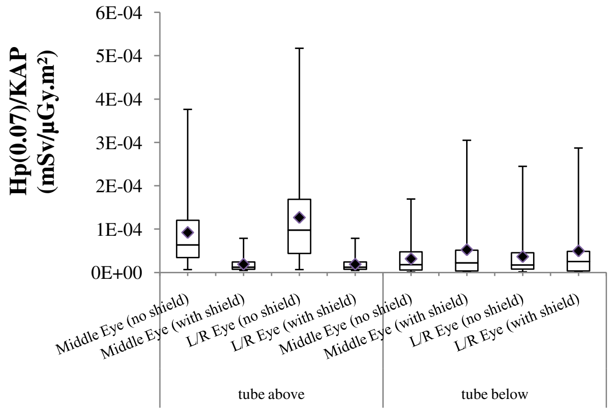

Fig. 3. Box plot showing the influence of the ceiling shield on the eye lens doses for ERCP, when the tube is below and above the operating table. Shown are the minimum, 1st quartile, median, 3rd quartile, mean (diamond) and maximum values.

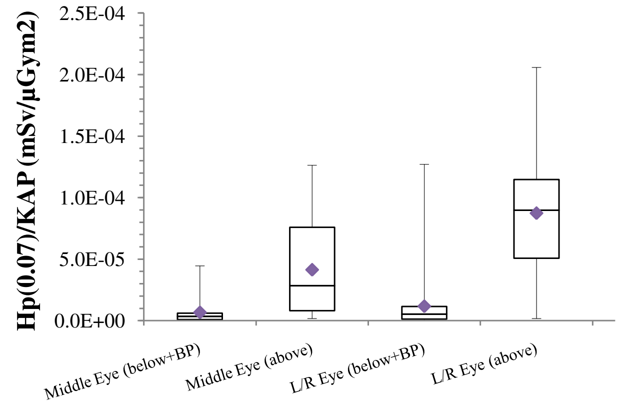

Fig. 5. Box plot showing the influence of the tube configuration (above versus below and biplane) on the eye doses for the embolizations procedures. Shown are the minimum, 1st quartile, median, 3rd quartile, mean (diamond) and maximum values.

in their procedures when dose measurements are performed and secondly, most of the operators perform different types of procedures. We only took into account the types of procedures for which measurements had been performed. All these extrapolation data are a mixture of persons using lead glasses, ceiling shields, or no protection at all. Optimization is certainly possible, but here the intention was to give an idea of the present realistic status of the eye lens doses.

3. Results

The data have been collected from 34 European hospitals and cover almost 1300 procedures (Carinou et al., 2011; Domienik et al., 2010). In general, the doses to eye lens are low, but with great variability. An overview of all the measured eye lens doses can be seen in Fig. 2. The major influence factors are shown in Figs. 3–5. The highest doses are found in embolizations, with a mean value of about 60 µSv per procedure. The values for the other procedures are on average lower. However, one can see that the range of measured values is large, and that much larger values can be found. In most of the procedures monitored, values up to 1 mSv per procedure were measured in a few cases. For ERCP a maximum eye lens dose of 4 mSv was measured, and for embolizations 2.5 mSv.

All the measured values can also be normalized to the respective Kerma Area Product (KAP) values. These can be found in Table 1. Again there is a large spread in values, because many factors affect

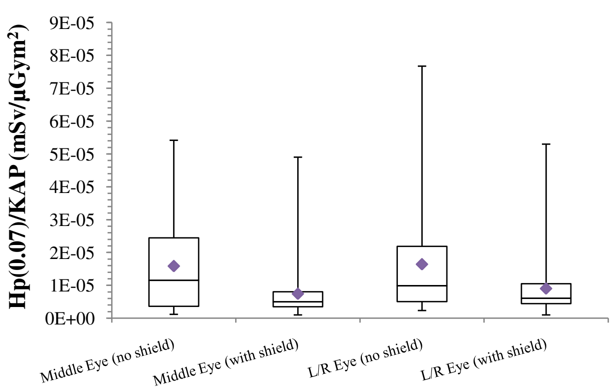

Fig. 4. Box plot showing the influence of the ceiling suspended shield to the eye doses (middle eye versus left/right eye) for radial access and tube below configuration for CA/PTCA procedures. Shown are the minimum, 1st quartile, median, 3rd quartile, mean (diamond) and maximum values.

the eye lens doses. The highest doses per KAP are found for PM/ICD, with an average of 2×10^{-5} mSv/µGym^2. We used the KAP meters that were present in the respective hospitals. Not all of them were calibrated, which is a limitation of the study. During the SENTINEL study, 25 different KAP meters in cardiac and interventional units hospitals were calibrated, and this yielded calibration factors between 0.4 and 0.8 (Jankowski et al., 2008). Another study showed better results, with calibration factors for 12 KAP meters between 0.9 and 1.2 (Hetland et al., 2009).

In case the operator wears lead glasses, the TLDs were placed in such a way that they are not shielded by the glasses. So, the measured values are overestimating the real eye lens doses when lead glasses are used. From all the monitored cardiology procedures, 36% of the operators wore lead glasses. For the interventional procedures only 25% wore lead glasses. From the simulations that were performed within the ORAMED project (Koukorava et al., 2011) we learned that a lead glass (if properly worn) can reduce the doses to the eye lens by a factor 3 to 7.

In Tables 2 and 3 the extrapolated doses can be seen. For ERCP we were able to extrapolate the respective eye lens doses for 17 physicians. Mostly the operators perform only these kind of procedures. It can be seen that the doses are low, and no monitoring is needed. The 15 physicians for CA/PTCA clearly have higher doses. None surpasses the present dose limit, but 3/10th of the limit can clearly be reached. The data for PM/ICD and RF ablations separately are relatively low, but often operators perform both kinds of procedures. When the combinations are taken into account (for those where we have both types of measurements), the doses are much higher; one person even surpassed the present limit. For embolizations and angiographic procedures it is also difficult to estimate the annual doses. Most operators perform many different

Table 1
Results of the measurements for the eyes (left/right) for the different procedures per KAP values.

$H_p(0.07)$/KAP [mSv/µGym^2]	1st quartile	Median	3rd quartile	Maximum	Mean
CA/PTCA	4.2E-6	7.3E-6	1.3E-5	7.7E-5	1.0E-5
RF Ablations	3.3E-6	8.2E-6	2.0E-5	1.6E-4	1.7E-5
PM/ICD	9.1E-6	1.9E-5	5.0E-5	8.8E-4	5.4E-5
DSA/PTA Lower limbs	1.6E-6	4.1E-6	1.3E-5	5.8E-3	4.7E-5
DSA/PTA Renal	1.0E-6	2.0E-6	4.2E-6	1.1E-5	3.0E-6
DSA/PTA C&C	1.9E-6	2.8E-6	6.8E-6	4.4E-5	5.8E-6
Embolizations	2.1E-6	5.2E-6	1.9E-5	2.1E-4	2.3E-5
ERCP	9.2E-6	2.7E-5	7.8E-5	5.2E-4	6.3E-5

Table 2
Extrapolated annual doses for different operators.

Operator ERCP	# Procedures	Annual dose [mSv]	Operator CA/PTCA	# Procedures	Annual dose [mSv]	Operator embolizations + angiography	Annual dose [mSv]
1	100	50	1	260	10	1	27
2	107	3.9	2	230	28	2	23
3	30	0.3	3	750	47	3	6
4	70	0.6	4	1200	69	4	4
5	110	2	5	1000	46	5	15
6	100	0.2	6	710	10	6	4
7	300	0.4	7	900	26	7	11
8	1281	17	8	600	11	8	31
9	689	6	9	630	11	9	14
10	70	0.7	10	630	12	10	10
11	107	5	11	500	5	11	7
12	250	2	12	1000	27	12	14
13	125	1.2	13	500	30	13	20
14	150	1.4	14	600	9	14	49
15	230	2	15	1100	9	15	85
16	36	3.4				16	9
17	150	9					

types of procedures, and the doses can be quite different for renal, lower limbs and cerebral procedures. We did not always have measurement data for all the procedures that they perform, so especially here, the doses can be an underestimation. The resulting overview in Table 2 shows that the doses can be high enough to need monitoring.

4. Discussion

The major influence factor is clearly the presence of a ceiling shield. For ERCP, the doses to the eyes are reduced by a factor of 5–8 when a ceiling suspended shield is used and the tube is above the operating table (Fig. 3). When the tube is below the table, no statistically significant influence is shown. For embolizations a similar reduction by a factor 3–7 is observed, and in these cases most tubes were below the table. In case of CA/PTCA, the reduction is less and only statistically significant for radial access: a factor of 1.6–2.3 (Fig. 4). The same order of reduction is found for RF ablations. More surprisingly, no significant effect was found for RF ablations and lower limb angiographies. The reason for these differences is probably the incorrect positioning of the ceiling shield. For the ERCP procedures there is a clearly lower dose to the eyes when the tube is below the table (factor 1.8). The effect is much larger when no shield is used. Also for embolizations there is a statistically significant reduction in the eye lens doses (Fig. 5) for tube below the table cases (factor 8–20).

About the effect of the access, when the ceiling shield is absent, the doses to the eyes for CA/PTCA are lower (1.2–4.8) for the femoral access compared to the radial access. When the ceiling shield is present, the influence of the access is not statistically significant.

Another parameter which clearly helps in reducing the doses is when the operator uses the automatic contrast injector and goes outside of the room during the image acquisition mode. This reduces not only the eye lens doses but all the doses, especially the hand ones.

Concerning the eye lens equivalent dose limit, for occupational exposure in planned exposure situations, a recent ICRP statement on tissue reaction recommends to reduce the limit to 20 mSv/year, averaged over a period of 5 years, with no single year exceeding 50 mSv (ICRP, 2011). With this new lower proposed limit, the requirements for eye lens dose monitoring and radiation protection measures will be even higher. Only for ERCP procedures, monitoring is still not generally needed. For the other procedures the 3/10th of the limit can be surpassed easily without the proper protection measures. As an example, in Table 2 it can be seen that for CA/PTCA half of the monitored persons would exceed this new proposed limit.

Table 3
Extrapolated annual doses for different operators doing PM/ICD and RFA.

Operator	Procedure	#	Annual dose [mSv]
1	PM/ICD	44	1.1
2	PM/ICD	400	31
3	PM/ICD	100	6.1
4	PM/ICD	100	1.6
5	PM/ICD	110	0.1
6	PM/ICD	100	0.2
7	PM/ICD	144	1.2
1	PM/ICD + RFA	150 + 60	88 + 63
2	PM/ICD + RFA	190 + 190	24 + 13
3	PM/ICD + RFA	90 + 190	25 + 7
4	PM/ICD + RFA	110 + 50	0.8 + 1.5
5	PM/ICD + RFA	40 + 20	4 + 0.1
6	PM/ICD + RFA	40 + 20	7 + 0
7	PM/ICD + RFA	80 + 350	1 + 5
1	RFA	180	1.7
2	RFA	60	1.1
3	RFA	100	1.8
4	RFA	70	0.6
5	RFA	100	6.3
6	RFA	65	0.2
7	RFA	160	2.0
8	RFA	210	8
9	RFA	60	4

5. Conclusion

An extensive data set has been collected with measured eye lens doses to medical staff in different interventional procedures. The measurements have been obtained using TLDs in plastic bags, calibrated in $H_p(0.07)$. The highest doses to the eye lens were measured during embolisations, around 60 μSv per procedure. The major influence factor to reduce the eye lens doses is a well-positioned ceiling shield and the use of lead glasses. For ERCP and embolizations this can be a factor from 3 to 8, while for CA/PTCA and ablations this reduction factor varies from 1.5 to 2.5.

The annual eye lens doses depend largely on the workload and the protection measures used. The present dose limit of 150 mSv per year for $H_p(3)$ is generally not reached, but doses can be sufficiently high so that monitoring is recommended for all the procedures that were studied, except for ERCP. If the dose limit is reduced to 20 mSv, many physicians could surpass this limit, and therefore monitoring and the proper use of radiation protection equipment will even be more important.

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