Radiation Measurements 46 (2011) 1203–1209

Contents lists available at ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

Staff eye lens and extremity exposure in interventional cardiology: Results of the ORAMED project

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ARTICLE INFO

Article history:
Received 6 March 2011
Received in revised form
23 April 2011
Accepted 13 June 2011

Keywords:
Interventional cardiology
Extremity
Eye lens
Dose
Occupational

ABSTRACT

Within the ORAMED project a coordinated measurement program for occupationally exposed medical staff was performed in different hospitals in Europe. The main objectives of ORAMED were to obtain a set of standardized data on doses for staff in interventional cardiology and radiology and to optimize staff protection. Doses were measured with thermoluminescent dosemeters on the ring finger and wrist of both hands, on legs and at the level of the eyes of the main operator performing interventional procedures. In this paper an overview of the doses per procedure measured during 646 interventional cardiology procedures is given for cardiac angiographies and angioplasties (CA/PTCA), radiofrequency ablations (RFA) and pacemaker and defibrillator implantations (PM/ICD). 31% of the monitored procedures were associated with no collective protective equipment, whereas 44% involved a ceiling screen and a table curtain. Although associated with the smallest air kerma – area product (KAP), PM/ICD procedures led to the highest doses. As expected, KAP and doses values exhibited a very large variability. The left side of the operator, most frequently the closest to the X-ray scattering region, was more exposed than his right side. An analysis of the effect of parameters influencing the doses, namely collective protective equipment, X-ray tube configuration and catheter access route, was performed on the doses normalized to KAP. Ceiling screen and table curtain were observed to reduce normalized doses by atmost a factor 4, much smaller than theoretical attenuation factors typical for such protections, i.e. from 10 to 100. This observation was understood as their inappropriate use by the operators and their non-optimized design. Configurations with tube above the patient led to higher normalized doses to the operator than tube below, but the effect of using a biplane X-ray suite was more complex to analyze. For CA/PTCA procedures, the upper part of the operator's body received higher normalized doses for radial than for femoral catheter access, by atmost a factor 5. This could be seen for cases with no collective protection. The eyes were observed to receive the maximum fraction of the annual dose limit almost as frequently as legs and hands, and clearly the most frequently, if the former 150 mSv and new 20 mSv recommended limits for the lens of the eye are considered, respectively.

1. Introduction

Cardiac diseases are still one of the most often causes of mortality in the human population. Interventional cardiology (IC) is a diagnostic or therapeutic technique in which cardiac chambers or coronary vessels are accessed by inserting catheters through blood vessels. Visualization and guidance of the devices inserted into the patient plus acquisition of additional high-quality images are done using X-ray imaging (fluoroscopy and radiography). Due to its advantages over surgery (low invasiveness, risk, cost etc.) the frequency of this technique has increased (Thom et al., 2006; Togni et al., 2004), so has the workload per physician (Vañó et al., 1998). The specific character of IC procedures results in inevitable

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[1] Deceased: this paper is dedicated to his memory.

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doi:10.1016/j.radmeas.2011.06.034

occupational exposure of the medical staff to ionizing radiation scattered from the patient. Significant radiation doses are received especially by unshielded body parts, primarily legs, arms, hands and eyes of the staff (Kim et al., 2008; Kim and Miller, 2009; Martin, 2009; Vanhavere et al., 2008).

These facts as well as the new technical developments, differences in the individual practices of the applied procedures and lack of systematic large-scale studies, have revealed the need to assess the actual doses received by the medical personnel, within the ORAMED (Optimization of radiation protection of the medical staff) project (see Koukorava et al., 2009 and Domienik et al., 2011 for preliminary results). Coordinated measurements were organized in 6 European countries in order to obtain a set of standardized data on extremity and eye lens doses for staff in IC. The main aim of the measurement campaign was to collect data on extremities and eye lenses doses received by the main operator. The results for IC are presented in this paper together with an analysis of the effect of parameters that influence the doses. Recommendations that could be formulated in order to optimize radiation protection measures are published elsewhere (Carinou et al., 2011).

2. Material and methods

2.1. Selected procedures

The following IC procedures were selected for the study: cardiac angiography (CA) and angioplasty (PTCA; percutaneous transluminal coronary angioplasty), radiofrequency ablation (RFA), and pacemaker (PM) and defibrillator implantations (ICD). A total of 646 procedures were measured in 56 hospitals from 6 European countries: Belgium, France, Greece, Poland, Slovakia and Switzerland. The detailed numbers per type of procedure are given in Table 1. In the following of the text CA/PTCA stands for either CA or PTCA procedure, i.e. both categories are considered together, and similarly for PM/ICD.

2.2. Measurement protocol

A unified measurement protocol was defined and used by all partners in order to have a common framework for collecting and measuring data for the different procedures. For each monitored procedure the following information was collected: operator and hospital identification, procedure type, access of the catheter, position of the operator with respect to the X-ray tube, personal (lead apron, thyroid collar, glasses, gloves) and collective (table lead curtain, ceiling suspended screen, mobile radiation protection cabin and wall) protective equipment, air kerma – area product (KAP) values and X-ray beam projection. KAP values were registered as indicated by the X-ray system, i.e. no additional calibration or correction factor was applied.

The doses were measured in terms of the dose equivalent $H_p(0.07)$, operational quantity recommended for dose measurements to eye lens, skin and extremities (ICRP, 1996; ICRU, 1998; ISO, 1999; EC, 2009). Eight thermoluminescent dosemeter (TLD) chips were attached to the main operator for a single procedure (see Fig. 1): four dosemeters were used to record the dose to the left (L) and right (R) hands, on the ring finger and wrist of both hands (L and R Finger, L and R Wrist positions, respectively) on palmar or dorsal sides depending on whether the tube was located below or above the patient couch, respectively; two dosemeters were placed on the legs (L and R Leg), few centimetres below the lead apron; finally two dosemeters were placed close to the eyes, one between them (on the forehead, M Eye), the other one next to the left or right eye (on the temple, L/R Eye) depending on whether the X-ray tube was on the left (the large majority of cases) or right side of the operator, respectively. If the operator wore lead glasses the TLDs were placed in such a way that they were not shielded by the glasses. The doses to the eyes were then assessed in absence of leaded glasses, thus overestimating the doses when leaded glasses were worn. Obviously, an additional suspended ceiling screen was or wasn't used, depending on the case. For some procedures, e.g. PM/ICD, because of sterility requirements it was not possible to monitor the hands; these cases corresponded to a small fraction of the overall collected data.

2.3. Dosemeters

The TLDs used were made of LiF:Mg,Cu,P and were calibrated against $H_p(0.07)$ in reference fields according to ISO standard (ISO, 1999). Because every partner used its own set of TLDs and calibration procedure, to assure that coherent results would be obtained an intercomparison exercise was organized before starting the measurements. Samples of TLDs were irradiated to ^{137}Cs beams and a more realistic X-ray field (70 kV, with a 4.5 mm Al and 0.2 mm Cu filtration) on an ISO slab phantom. They were read blindly by every partner using its own calibration procedure, and their response was checked against the conventionally true $H_p(0.07)$ value of the corresponding irradiation. Reference $H_p(0.07)$ values were equal to 8.0 and 6.6 mSv for ^{137}Cs and the 70 kV X-ray field, respectively. In the latter case the reference was calculated with Monte Carlo simulations. The range of the relative deviations of dosemeters' responses was within ±15% and it was considered acceptable. For every measurement in hospital the dosemeters worn by the monitored operator were accompanied by unused ones for subsequent background subtraction. The lower detection limit (LDL) of each partner was evaluated as twice the standard deviation calculated from the set of background dosemeters. LDLs ranged from 4 to 32 μSv, depending on the partner. Any dosemeter reading below the LDL was set equal to the LDL. Finally, for single measurements relative uncertainties were estimated in the range 13–20%, depending on the partner, taking into account the following components: calibration, repeatability, homogeneity, and dose, energy and angular responses.

Table 1
Numbers of procedures measured and associated descriptive statistics of the KAP distributions (minimum, 1st quartile, median, mean, 3rd quartile, maximum and standard deviation SD) for the IC procedures monitored in this work, and reviewed ranges of mean KAP and weighted mean KAP values (Kim et al., 2008 and references therein).

	N	KAP [Gy cm^2]								
		This work							Kim et al., 2008	
		Minimum	1st quartile	Median	3rd quartile	Maximum	Mean	SD	Range of mean KAP	Weighted mean[a]
CA/PTCA	261	4.3	21.4	44.4	75.0	419.7	63.3	67.0		
CA	80	4.3	12.4	18.9	34.3	198.8	32.2	38.3	13–130	41
PTCA	181	4.7	31.6	53.5	90.6	419.7	77.1	72.2	46–180	85
RFA	188	0.9	11.1	28.1	67.4	415.0	52.8	64.3	11–120	58
PM/ICD	197	0.1	4.2	12.2	39.2	509.8	36.8	69.9	5–15	12

[a] Mean of the mean KAPs of the reviewed studies, each one weighted by the number of monitored procedures.

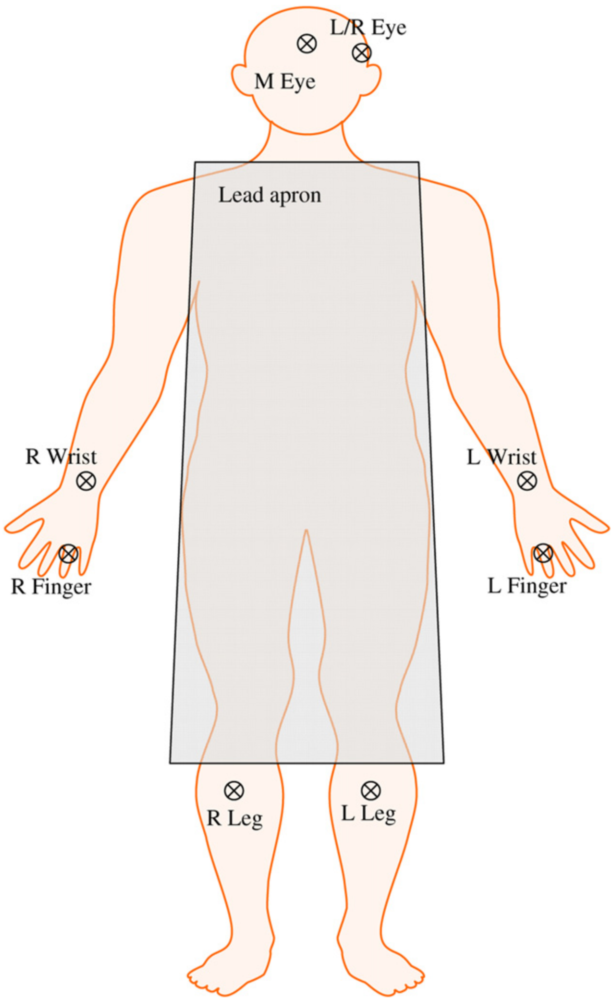

Fig. 1. Location of the eight dosemeters used per measured procedure and placed on the left (L) and right (R) sides of the operator; in the large majority of cases the L/R Eye position was on the left side.

2.4. Analysis of parameters influencing the doses

For each type of IC procedures parameters influencing the doses were analyzed. Investigated parameters were: use of collective protective equipments, X-ray tube configuration and catheter access route (for CA/PTCA only). The analysis was applied on the median values of the normalized doses, $H_p(0.07)$/KAP, in comparable conditions whenever possible: when the effect of the ceiling suspended screen was studied, comparisons concerned the same type of procedure (CA/PTCA, RFA, PM/ICD), tube configuration (tube below, biplane, tube above) and catheter access route (radial or femoral, for CA/PTCA); conversely, for studying the effect of the tube configuration the shielding condition should be similar (with or without ceiling screen, table screen). In all cases and configurations the statistical significance of observed differences was assessed using a multi-parameter analysis of variance (ANOVA).

2.5. Study limitations

Our study has some limitations. One may wonder whether presenting the study to the operators and taping 8 dosemeters on their body might *de facto* increase their awareness to radiation protection and then modify their behaviour during the procedure in such a way their exposure was reduced. This bias can hardly be completely avoided but we insisted on the fact that we were interested in a status of present dose levels associated with current working practices, so no modification of the latter should be introduced. However, the opposite idea may hold as well, as the taped dosemeters might introduce a discomfort, thus slowing down the procedures and increasing the doses. This effect was null for the leg and wrist dosemeters; the eye ones were taped in such a way that the vision was not obstructed; the finger dosemeters, placed at the base of the ring fingers, were almost not felt by operators. Any significant inconvenience wouldn't have been tolerated by the operators anyway.

The main limitation lies in the fact that since real procedures were monitored the different parameters influencing the doses, i.e. time, distance, shielding and intensity and characteristics of the radiation field, varied simultaneously during any single procedure and also between procedures of the same type; this lead to strong interactions in the data analysis, attenuating the effect of some parameters. This was particularly expected for the collective equipment because they were frequently not appropriately positioned, or efficiently used only a fraction of the time, or even almost not used at all though available. In the data these equipment were marked as either 'used' or 'not used', 'partial use' or 'inappropriate use' having been counted as 'used'.

3. Results and discussion

3.1. Generalities

In Fig. 2 the frequency of observed use of personal and collective protective equipments during the procedures is shown. In all cases at least a lead apron was worn, plus a thyroid collar for 91% of the cases, plus lead glasses for 37% with additional lead gloves for 2%. For 31% of the cases no collective equipment was used. Moreover, table shielding only and ceiling screen only were used in 19% and 4% of the monitored procedures, respectively. In only 46% of cases a level of shielding compatible with good radiation protection (RP) practice was reached, i.e. use of either both table and ceiling screens (44%) or mobile radiation protection cabin (referred as RP cabin in the following) or mobile wall screen (2%). Patient shield, used during 10 procedures (1.6%), was analysed as a ceiling screen. Furthermore, RP cabin and mobile wall screens were encountered during RFA procedures only.

As far as X-ray tube configuration is concerned the tube was located in most cases (90%) below the patient (referred as tube below configuration in the following, i.e. PA projection), 8% of the procedures were performed with biplane suites and 2% with the tube located above the patient (tube above configuration, i.e. AP projection).

In Table 1 and Fig. 3 statistics of the KAP distributions for the different IC procedures are shown. For CA/PTCA additional distinction is made between diagnostic (CA) and therapeutic (PTCA) cases. In total 261 procedures were collected for CA/PTCA, divided in 80 CA and 181 PTCA, 188 RFA and 197 PM/ICD. As expected a large variation in KAP values is observed, varying between minimum and maximum values by orders of magnitude: almost 2 for CA/PTCA, more than 2 for RFA and more than 3 for PM/ICD. Mean and median KAP values for PTCA are more than twice as high as for CA procedures, and the range is almost twice as big. The highest mean and median KAP values were encountered for CA/PTCA, the lowest for PM/ICD by a ratio 3.6 for the medians. Comparing these results with already published ones and recently reviewed by Kim et al. (2008) it can be seen that for CA, PTCA and RFA procedures the mean KAP is well located in the respective range of reviewed mean KAP and consistent (within 22%) with the weighted mean KAP (see Table 1). However, a significant discrepancy is observed for PM/ICD procedures. The review by Kim et al.

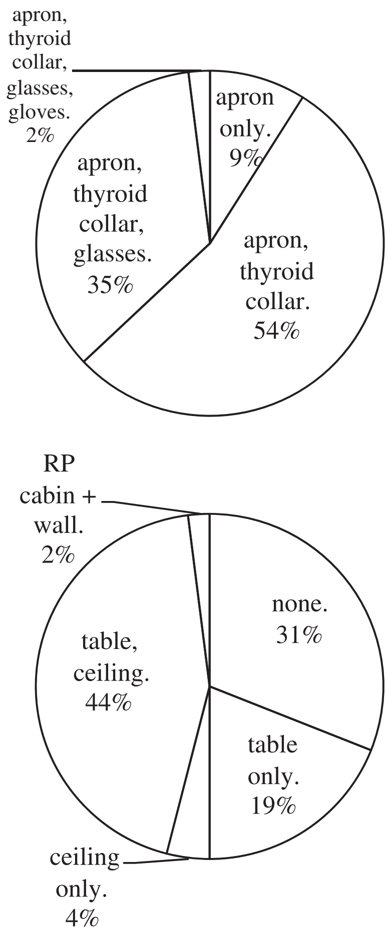

Fig. 2. Frequency of used personal (top) and collective (bottom) protective equipment.

covers two studies in this case, for a total of 109 PM/ICD procedures, to be compared with 197 in the present study. Obviously, since they were determined per procedure the observed minimum and maximum KAP values fully cover the range of mean KAP from Kim et al.

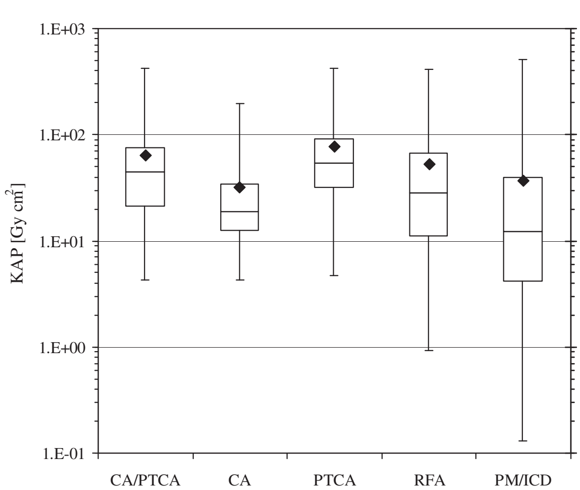

Fig. 3. Descriptive statistics of the KAP distributions (bars: minimum and maximum, box: 1st and 3rd quartiles, horizontal line: median, diamond: mean) for the IC procedures monitored in this work.

3.2. Doses and normalized doses

In Table 2 and Fig. 4 the mean $H_p(0.07)$ values and mean $H_p(0.07)$ values normalized by the respective KAP values, $H_p(0.07)$/KAP, are shown at the different measurement positions for CA/PTCA, RFA and PM/ICD procedures. Using the ratio $H_p(0.07)$/KAP (referred as normalized dose in the following) rather than the simple $H_p(0.07)$ is more useful because this allows comparing procedures of different complexities. However, for a given procedure type normalized dose distributions still exhibit large relative standard deviations since it is well known that staff doses and KAP hardly correlate, particularly for CA/PTCA procedures which involve notably several different angulations (see, e.g., Trianni et al., 2005 and Krim et al., 2011). It can be seen on Fig. 4 that for all positions the left side part of the operator received higher doses and normalized doses than his right side. This is due to the fact that in the very large majority of cases the X-ray tube and consequently the scattering centre of ionizing radiation were located at his left side. The location of the maximum mean dose is mostly observed at the L Finger for CA/PTCA, with close values for L Wrist and L Leg, at the L Leg for RFA and at the L Finger for PM/ICD. The different positions occupied by the operators, mostly defined by the access route (femoral or radial artery for CA/PTCA, femoral for RFA and direct, at the level of the patient's shoulder, for PM/ICD), plus the effect of the used shields can explain these differences. The eyes are associated with the lowest doses in all cases. PM/ICD procedures lead to the highest doses and normalized doses, although mean KAP values for these procedures are on average smaller, as seen on Fig. 1. During these procedures the operator stands closer to the scattering centre than during the others which means that received doses per KAP unit are higher, explaining the stronger difference on the figure showing the normalized doses. It is also worth noting that maximum doses, i.e. 6.6, 4.9, 5.0 and 1.1 mSv at the L Finger, L Wrist, L Leg and L/R Eye positions, respectively (see Table 2), were all registered for the same PM/ICD procedure with a high KAP value of 371 Gy cm^2 and no room protective equipment used, with the exception of the L Wrist dose which corresponded to a KAP equal to 92 Gy cm^2 and only a table shield used but for PM/ICD also.

In Table 2 are also shown the data extracted from the review made by Kim et al. (2008), summarized here as the range of mean or median doses, as appropriate, from which dose estimations from dose rate measurements, phantom simulations and Monte Carlo (MC) calculations were not considered. Taking into account the different measurement positions involved in this work for comparison, the variations of doses can be considered similar, except for the case of CA/PTCA procedures for which the reported mean doses to the hand and eye, published by Vañó et al. (1998) are significantly higher than those observed here.

3.3. Parameters influencing the doses

3.3.1. Effect of the collective protective equipment used

For CA/PTCA statistically significant effect of the ceiling suspended shield on median normalized doses to fingers, wrists and eyes was observed for radial access and tube below the patient: for fingers (wrists) normalized doses are reduced by a factor 1.3 (1.7) and 1.6 (1.3) for the left and right positions, respectively; when the ceiling shield is used the median eye normalized doses are reduced by a factor 1.6 and 2.3 at the left and middle positions, respectively (see Vanhavere et al., 2011 for more information). For legs a significant effect of the use of the table shield was observed for femoral access and tube below, with a reduction factor of 3.5 and 1.3 for left and right, respectively.

For RFA procedures and tube below configuration no statistically significant effect of the ceiling suspended screen on normalized

Table 2
Descriptive statistics of the dose distributions, $H_p(0.07)$ (minimum, 1st quartile, median, mean, 3rd quartile, maximum and standard deviation SD) and mean normalized dose values, $H_p(0.07)$/KAP, for the IC procedures monitored in this work, and reviewed ranges of mean or median, as appropriate, hand and eye doses (Kim et al., 2008 and references therein).

			This work								Kim et al., 2008	
			L Finger	R Finger	L Wrist	R Wrist	L Leg	R Leg	L/R Eye	M Eye	Hand[a]	Eye[a]
CA/PTCA	μSv	Minimum	8	8	8	8	6	4	4	4	CA: 5-787,	CA: 5-1120,
		1st quartile	29	18	32	22	16	13	17	13	PTCA: 33-470,	PTCA: 9-170,
		Median	66	32	83	47	37	29	32	23	CA/PTCA:	CA/PTCA:
		3rd quartile	154	63	192	82	191	59	54	42	235-514	170-439
		Maximum	5000	503	1775	579	1567	1232	820	644		
		Mean	176	57	163	70	163	62	52	42		
		SD	406	73	239	83	288	115	77	68		
	$\mu Sv\ Gy^{-1}\ cm^{-2}$	Mean	3.3	1.3	3.4	1.6	3.0	1.2	1.0	0.8		
RFA	μSv	Minimum	5	4	4	4	5	4	4	4	40–993	47–281
		1st quartile	10	8	23	11	13	8	8	8		
		Median	28	17	51	28	32	30	18	16		
		3rd quartile	57	32	137	57	151	57	39	32		
		Maximum	896	446	1838	880	1819	780	880	633		
		Mean	59	34	123	55	156	55	43	30		
		SD	115	54	211	93	300	93	82	57		
	$\mu Sv\ Gy^{-1}\ cm^{-2}$	Mean	2.3	1.7	3.8	2.5	3.8	2.1	1.7	1.8		
PM/ICD	μSv	Minimum	5	8	4	4	4	4	4	4	255–1050	39–?
		1st quartile	53	34	32	32	20	20	8	8		
		Median	164	104	98	81	67	64	28	21		
		3rd quartile	395	273	233	218	231	258	60	59		
		Maximum	6564	4328	4852	3825	4996	4046	1083	810		
		Mean	412	277	304	233	247	239	59	50		
		SD	910	528	690	465	568	494	122	93		
	$\mu Sv\ Gy^{-1}\ cm^{-2}$	Mean	22.9	17.4	15.3	14.8	12.9	13.0	5.5	5.5		

[a] Mean or median dose, as appropriate, per procedure; dose rate measurements, phantom simulations and MC calculations were not considered.

doses to fingers, wrists and eyes was seen. However, a significant effect of the table shield on leg normalized doses was shown, with a reduction factor of 4 and 1.9 for left and right sides, respectively.

For PM/ICD and tube below configurations the table shield reduces normalized doses to legs by a factor 1.4 and 1.6 for left and right sides, respectively. However, no significant effects of ceiling suspended shields were observed for the normalized doses to fingers, wrists and eyes.

As compared with expected attenuation factors reported in previous studies (Christodoulou et al., 2003; Maeder et al., 2006) or which can be theoretically estimated thanks to well-established calculation tools (see, e.g., Nowotny and Höfer, 1985), the values reported here are surprisingly low. Indeed, a shield of a typical 0.5 mm lead-equivalent thickness leads to attenuation factors in 100–10 for 70–100 kV medical X-ray fields, respectively. This result can be discussed in light of the study limitations previously described. In the present study a status of present dose levels was established, associated with current working practices, and the information on the use of collective protective equipment was mainly based on the knowledge of their presence or not at workplace. This is somehow different from the method employed by authors specifically assessing the effect of protective equipment, e.g., Maeder et al. (2006) for the ceiling shield who introduced a modification of working habits for this purpose, or Thornton et al. (2010) who used a phantom operator, thus considering static configurations. Maeder et al. obtained a reduction factor 19 of the normalized dose to the eyes associated with the use of a ceiling shield. However, a weak effect (factor 1.1) was seen for the normalized dose to the hands, in agreement with present results. Furthermore, as already mentioned interactions between the different parameters influencing the doses led to a possible apparent attenuation of their effect, although in the analysis care was taken to minimize this. These parameters were analyzed separately with Monte Carlo calculations (see Koukorava et al., 2011) and, as far as collective protective equipment are concerned, it was shown that attenuation factors close to the theoretical ones can be achieved provided these equipment are correctly positioned with respect to the main operator. Thus, the measurement results strongly indicate that the available collective

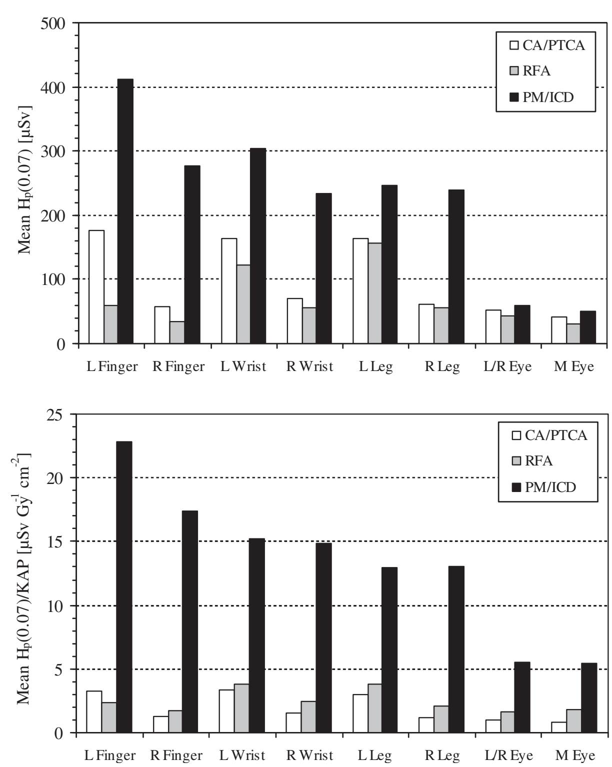

Fig. 4. Mean doses, $H_p(0.07)$ (top) and mean normalized doses, $H_p(0.07)$/KAP (bottom), at the different measurement positions for CA/PTCA, RFA and PM/ICD procedures.

protective equipments are not appropriately used, their design being an important criterion as well.

3.3.2. Effect of the X-ray tube configuration

For CA/PTCA procedures the effect of tube configuration was studied for cases with femoral access and when ceiling shields (for the eyes, wrists and fingers) or table shields (for the legs) were used. There were only two cases to compare: tube below the table and biplane systems. For the fingers, wrists and legs normalized doses are statistically similar between biplane systems and tube below configurations. In the biplane cases the eye normalized doses are lower than in tube below cases, by a factor 0.5 and 0.3 for left and middle positions, respectively. In these cases the eyes were either very well protected by the ceiling or lateral suspended shield or protected by the image intensifier of one of the X-ray tubes of the biplane system.

For RFA and shielded cases finger, wrist and leg normalized doses were observed 1.9 and 1.7 times higher and 2.6 times smaller in biplane than in tube below configurations, respectively. The situation was reverted for the eyes, and the observations were explained by an improper use of the ceiling shields.

It has to be noticed that although biplane systems resulted in lower normalized doses to the eyes, this wasn't the case for the doses because KAP values associated with biplane configurations were higher than those with below configurations: mean KAP was 118 against 57 Gy cm^2 for CA/PTCA and 55 against 52 Gy cm^2 for RFA, respectively.

For PM/ICD comparisons between tube below and above configurations, with no collective protective equipment present, could be performed. As expected normalized doses are increased by a factor 2.3–2.4 for the eyes and reduced by a factor 5.5–5.9 for the legs between below and above configurations, respectively.

3.3.3. Effect of the access route

Effect of the access route could be analyzed for CA/PTCA only, comparing radial and femoral accesses. When no ceiling shield was used and tube was below the table, as expected higher normalized doses to fingers, wrists and eyes were seen for the radial access, by factors ranging in 1.1–4.8 as, in this case, the operator was closer to the X-ray beam compared to the femoral access. However, if a ceiling shield was used, the differences were smaller and even adverse effects could be observed. A possible explanation is that the ceiling shield was better positioned for procedures with radial access than for those with femoral access. Indeed, when the operator is closer to the X-ray beam (radial access), it is easier to correctly use the shield. For legs only cases with table shield could be analyzed and it was observed that higher normalized doses were received for femoral access than for radial access, by a factor 1.7. This is probably due to the fact that although the operator is further away from the X-tube for femoral access the table shield, if improperly positioned and oriented, does not protect the legs anymore.

3.4. Position of the maximum dose

On Fig. 5(top) is shown the frequency of the position where the maximum dose was recorded. It can be seen that most frequently the maximum dose was recorded at L Finger, L Wrist and L Leg positions. Clear preeminence of L Finger was seen for PM/ICD because with a direct access the left hand is very close to, and even sometimes inside, the direct X-ray beam. However, since the annual limit for hands and legs (500 mSv) is different to that for the lens of the eye (150 mSv), it has to be taken into account (ICRP, 2007). This is done on Fig. 5 (middle) which shows the frequency of the position where the maximum fraction of the annual limit for the corresponding position was seen. It was observed that the eyes

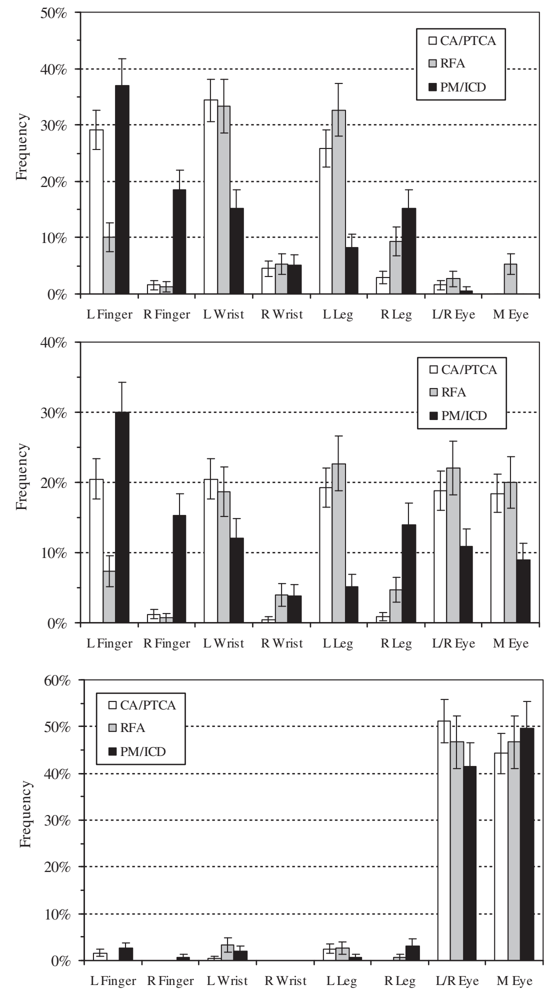

Fig. 5. Frequency of the monitored position where the maximum dose is observed among all positions (top) and where the maximum fraction of the annual limit for the corresponding position is seen, using the 150 mSv annual limit for the lens of the eye (middle) and the recently recommended 20 mSv (bottom), for CA/PTCA, RFA and PM/ICD procedures. Error bars correspond to the statistical uncertainty associated with the population of each bin.

become more important, with a frequency level similar to that of the other positions. Finally, if the new 20 mSv annual limit for the lens of the eye recently recommended by the ICRP (2011) is considered (see Fig. 5, bottom), this part of the body becomes clearly the most important.

4. Conclusion

A large dose data set was collected for interventional cardiology procedures (CA/PTCA, RFA and PM/ICD) at the level of the hands, legs and eye of the main operator. The measurements were done using TLDs calibrated in terms of $H_p(0.07)$. The largest doses were observed for PM/ICD procedures, due to the close proximity of the operator to the scattering centre in this case. For all procedures the left side of the operator was on average more exposed than his right side.

The effect of parameters liable to influence the doses was investigated. Main studied parameters were: collective protective equipment, tube configuration and catheter access route. From the measurements the ceiling shield was observed to reduce normalized doses by a factor of around 1.5 to the fingers and wrists, and around 2 to the eyes for CA/PTCA procedures. A normalized dose reduction by a factor ranging from 1.3 to 4 of the table shield could be shown for legs, with a better protection for the left leg in general. These reduction factors are much smaller than those expected for such equipment, typically from 10 to 100. Thanks to a Monte Carlo calculations (Koukorava et al., 2011), in which the effect of collective protective equipment could be analyzed separately, this observation was mostly understood as their inappropriate positioning with respect to the main operator and their non-optimized design; their partial use along interventional procedures is also likely to be part of the explanation. For PM/ICD procedures tube above configurations were associated with normalized doses almost 2.5 folds higher and 6 folds smaller than tube below ones, for eyes and legs, respectively. The effect of biplane configurations was more complex to analyze because self-shielding may occur and ceiling shields, if present, are more difficult to properly use. In CA/PTCA procedures as expected normalized doses were observed higher (by 1 to 5) for radial than for femoral access when no shielding was used. However, observation of a reverse effect when shielded cases were considered indicated inappropriate use of shields.

It was observed that when annual limits are taken into account the eyes correspond almost as frequently as the other monitored positions to the position where the maximum dose is registered, and even become the most frequent positions if the new limit of 20 mSv recommended by the ICRP (2011) is applied. This raises the issue of the importance of adequate dose monitoring and personal protection, such as lead glasses (see Vanhavere et al., 2011).

Finally, from the set of data collected for interventional procedures during the ORAMED project recommendations could be formulated to optimize the radiation protection of medical staff; they are given elsewhere in this issue (Carinou et al., 2011).

Acknowledgement

The authors would like to warmly thank all the people from the 56 hospitals for their help in collecting these data.

This study has received funding from the European Atomic Energy Community's 7th Framework Program (FP7/2007-2011 – grant agreement no. 211361).

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