Session 6

Radiation protection of patients and staff in interventional procedures

EVALUATION OF PATIENT RADIATION DOSE DURING PERCUTANEOUS CORONARY INTERVENTION IN SUDAN

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Abstract

Cardiac catheterization is an interventional procedure used for the diagnosis and treatment of coronary arteries diseases. Patients are exposed to prolonged radiation exposure during the procedure. Tissue reaction (erythema) effects are now well documented as one of the serious complications of extended radiation exposure procedures. The objectives of this work are to measure patient radiation dose and effective doses during Percutaneous Coronary Intervention (PCI). A total of 118 PCI were evaluated. Calibrated X-ray machines were used to perform all the procedures. Patient dose measurements were performed using kerma Area Product (KAP) meter. The mean and range exposure parameters were 81.5(53-125) kVp, 444.2 (61.6-898) mA and 4.3 (0.016-8) s for tube potential, tube current and time, respectively. The mean cumulative average dose (CAD) was 36.94 (0.1225-479.88) Gy.cm2. The mean effective (mSv) dose was 5.8 (0.02-76.6) Patients exposed to different dose values based on their clinical indications. Although, no patients developed tissue reaction effect, optimization of patient doses in important especially for young patients

1. INTRODUCTION

Cardiac catheterizations have contributed greatly to the treatment of heart diseases in its development be fore five decades [1]. Cardiac catheterization under fluoroscopic guidance has become an essential technique to the practice of cardiology. However, the radiation exposure to the patient is significantly higher compared with other radiological examinations [2]. Dose monitoring during catheterization procedures and re-evaluation of equipment and techniques used, if necessary, are mandatory to keep patients radiation risk as law as reasonable achievable [3]. Patient dose measurement from cardiac catheterization procedures has been used frequently for the evaluation of patient risk from radiation exposure. Although the health benefits from appropriate use fluoroscopy during these procedures cannot be disputed, patient and staff may exposed to significant during the intervention. Typical patient doses have been reported in the literature [2-6]. Medical workers are responsible for measuring the radiation dose and assessing the risks and benefits to determine if an X-ray procedure is justified. Some of contributing factors in the observed variations of patients' exposure can be attributed to the use of suboptimal imaging equipment, and poor choice of technical factors due to the lack of experience. Recently, tissue reactions effect due to cardiac catheterization were reported in developed countries due to the complex procedures [3,4]. Few studies were performed in Sudan regarding patient doses and its related risks [5,7-9]. Therefore, the objectives of this work are to measure patient radiation dose and effective doses during Percutaneous Coronary Intervention (PCI).

2. MATERIAL AND METHODS

2.1 STUDY AREA AND PATIENT POPULATION

All cardiac catheterization procedures were performed in three cardiac catheterization centers: Wad Madani Heart Center (WMHC), Sudan Heart Center (SHC), and Al-Faisal Specialized Hospital (FSH), in Sudan. The data of patient demographic, technical parameters, and mean and range of patient's doses used in cath lab catheterization was collected during the period from September 2015 to October 2016. All machines had passed quality control tests performed by Sudan Atomic Energy Commission (SAEC).In the present study, the patient

dose measurements during cardiac catheterization were made by using some dosimetric quantities, namely dose area product (DAP-Gy.cm^2), total dose area product (DAP) or cumulative dose area product (CDAP-mGy.c m^2), cumulative dose (CD-rad.cm^2), entrance dose (ED-mGy), and cumulative air kerma (CAK-mGy) were measured during data collecting. The data collected also including patient's sex, age, height, weight, number of frames , number of films, and total fluoroscopic time (FT). Exposure factors as kVp and mA also collected as well as procedure type.

2.2 X RAY MACHINE

All procedures were performed at three fluoroscopic x ray units with total filtration 3.5 mm Al (Table 1). The machines had already passed the routine quality control tests performed by Sudan Atomic Energy Commission.

2.3 SAMPLE SIZE:

A total of 118 (84 (71.1%) males and 34 (28.9%) females) percutaneous intervention (PCI) were performed at three hospitals: Wad Madani Heart Center (WMHC) (59 patients (50%)), Sudan Heart Center (SHC) (42 patients (35.6 %)) and Al-Faisal Specialized Hospital (FSH) (17 patients (14.4%))

TABLE 1. X ray machine characteristics

Hospital	X-ray machine(Model)	Filtration	kV max	Pulsed fluoroscopy	Date of installation
SHC	PHILIPS Integris V5000	3.5 mm Cu	125	YES	1998
FSH	GE 9800PLUS	NA	120	YES	NA
WMHC	Philips (Allura X per FD 10)	2.5 mm Al	150	YES	2011

3. RESULTS AND DISCUSSION

Cardiac catheterizations are the highest patient radiation dose among the radiological X-ray procedures. Some of the factors that affect the patient's radiation dose depend on the X-ray system, but many others depend on how the operator uses the x-ray system. During the procedure, the cardiologist should be kept aware of the fluoroscopy time, the number of cine series and cine frames, and the total patient dose. As patient radiation dose increases, the operator should consider the radiation dose already delivered to the patient and the additional radiation necessary to complete the procedure [10].

Table 2 presents the mean and range of demographic data for adult patients undergoing percutaneous intervention (PCI) procedures, which show that 58.2% of the procedures were performed in Sudan Heart Center (SHC) which within high range of BMI, but Madani Heart Center (WMHC) within normal range of BMI. Body mass index had the most significant association with the radiation dose during the procedure. Despite having similar procedure times and contrast doses, patients with increased BMI received much higher radiation dose during CAG. Obese patients require more than double the radiation dose in comparison to those with normal BMI. The operator should be aware of the increased dose of radiation required when performing CAG in patients with a high BMI, and especially in LAO cranial and caudal views. [2].

Table 3 presents the mean and range of technique parameters for adult patients undergoing percutaneous intervention (PCI) procedures, which show that the high (kVp, No. of films, and fluoroscopic time) were found in Al-Faisal Specialized Hospital (FSH), while that the high (mA & No. of frames) were found in Wad Madani Heart Center (WMHC). Table 4.12 presents the mean and range of technique parameters for pediatric patients undergoing percutaneous intervention (PCI) procedures, which show that the high (kVp, No. of films, and fluoroscopic time) were found in Sudan Heart Center (SHC), while that the high mA were found in Wad Madani Heart Center (WMHC).

Table 3 illustrates the mean and range of technique parameters for adult patients undergoing percutaneous intervention (PCI) procedures.

Hospital	Tube potential (kVp)	Tube current (mA)	No of Films	Fluoro Time (min)	No of Frames
FSH	116 (110-120)	120 (83-318)	16 (1-35)	12.4 (10.1-33.8)	738.1 (110-1838)
SHC	85.7 (70.47-105.8)	350 (160-554.3)	7.8 (4-22)	4.48 (0.9-22.4)	525.5 (257-1234)
WMHC	80.9 (67-106.5)	730.9 (448.6-851.7)	15.8 (1-47)	7.47 (1.25-20.13)	771 (26-2434)

Patient doses in this study showed wide variation due to the variation in clinical indication and patient morphological characteristics. Therefore, in complex procedure patient may receive a higher doses. Although, the patient doses and effective dose within the range of previous studies. A radiation dose monitoring for patient received a dose above 1.0 Gy.

4. CONCLUSIONS

Considerable variations were observed among patient populations in terms of radiation dose, and fluoroscopic time. These variations are due to the different indications, patient characteristics and pathological findings. Also, a remarkable difference between the therapeutic and the diagnostic doses was observed. This can be attributed to the prolonged exposure times in therapeutic procedures. Furthermore, the practitioners should optimize the radiation dose for further dose reduction without compromising the diagnostic and therapeutic findings. The monitoring of radiation workers is not established properly.

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RADIATION DOSE INCURRED TO PATIENTS AND ENDOSCOPIST ARISING FROM ERCP PROCEDURES

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Abstract

Endoscopic retrograde choloangiopancreatography (ERCP) is now widely used in diagnosis and treatment of gastrointestinal tract disorders. Internationally there are not many data available on radiation dose of patients and physicians from ERCP. Till now we have not traced any relevant data for Iran. In the study, both patient and physician organ doses were measured and patient effective doses were estimated. TLDs were used to measure organs dose of 30 patients. DAP values were utilized to compute effective dose of patients. To assess the effectiveness of an extra lead shield in reducing physician's dose, a leaded cover was wrapped around the X-ray tube. Organs dose of the phantom were measured with and without the wrap around shield. The results show that, as is expected, therapeutic ERCP deliver on average higher doses to patients than diagnostic ERCPs. In the study the DAP values and fluoroscopy time is significantly lower than the corresponding values reported by other researchers elsewhere. Thus ERCP imposes the risk of harmful effects of radiation exposure both to the patients and members of staff. However, the dose to the patient and the physician himself is highly depending on endoscopist experience, technical skills and knowledge in radiation protection.

1. INTRODUCTION

Endoscopic retrograde choloangiopancreatography (ERCP) is now widely used in diagnosis and treatment of gastrointestinal tract disorders (1). While an ERCP is performed patient and physician are exposed to primary and scattered X-ray for a relatively long time. Thus ERCP is considered a medium dose technique compared to CT scan in one hand and conventional radiographies on the other hand (2). However the incurred dose from ERCP procedures is highly depended on endoscopist experience and technical skill (3).

Exposure to ionizing radiation imposes harmful effects to our health, which may come into sight very early or after long time; the severity of the biological outcome also is subject to several physical and biological factors, but mainly to the dose (4).

Thus the knowledge of the absorbed radiation dose to the organs of a patient undergoing a diagnostic or therapeutic procedure involving ionizing radiation is essential in order to assess the detriment of the procedure; which in turn is needed to estimate the net benefit from the procedure (5).

Despite the fact that ERCP procedures, in general, may impose relatively high risk to patients and staffs, not many researchers have investigated the incurred dose and the associated potential harmful effects. Fewer studies have been carried out in developing countries, till now we have not traced any relevant report from Iran.

ERCP is a highly technical and a good quality procedure with minimum complications demands skilled, experienced and knowledgeable physicians and technicians (6). In addition, staff awareness of dose levels and associated risks of harmful effects might persuade them to be more cautious.

The purpose of the present study was to measure organ dose and estimate effective dose of both patient and physician arising from diagnostic and therapeutic ERCP procedures in a teaching hospital in Mashhad-Iran.

2. MATERIALS AND METHODS

In the present study, both patient and physician organs doses were measured and patient effective dose was estimated. Measurements were carried out for 30 patients who under-went ERCP by APELEM X-ray unit (APX HF III model), with thermoluminescent dosimeters (TLD-100H, LiF: Mg, Cu, P) and a dose area product meter (DAP) in a teaching hospital in Mashad-Iran.

Before irradiation, TLDs were calibrated. In order to calibrate these dosimeters, TLDs were annealed at 240°C for 10 min, and then were irradiated by irradiator 2210 manufactured by Thermo Electron Corporation

(The average ^{137}Cs equivalent dose was 6.4 mSv per 100 revolutions of the carrier disk) with defined dose. The exposed TLDs were read by a Harshaw 3500 manual TLD reader. TLD chips were placed inside thin plastic sachets to protect them from physical and chemical damages. Each set of dosimeters were accompanied by four blanks, these were treated exactly as the dosimeters used for patients and physicians; but were not exposed. Mean dose of blanks was taken as background for irradiated TLDs. Also, a DAP meter (Gammex-RMI) was attached to the X-ray unit and was used while ERCP examinations were conducted. DAP values and fluoroscopy times were recorded for individual patient.

It is internationally common to measure entrance surface dose as a good approximation of organs which are not located too deep from body surface. Similarly in this work to measure dose incurred by patients organ's of interest (thyroid, lens of the eyes) TLDs were placed on patient skin at five different locations. The estimated risk associated with exposure to ionizing radiation of individual is based on the effective dose (E). To estimate effective dose, DAP value and effective dose to DAP ratio are required. The first quantity was recorded for individual patient, the latter was determined for a Rando phantom. To obtain effective dose and DAP for the phantom, 60 TLDs were inserted in organs and tissues defined by ICRP-60 (7) and ERCP was performed with the Rando phantom. Then effective dose (E) was determined from equation (1):

$$E_{eff} = \sum_T W_T D_T \quad (1)$$

Where W_T is tissue T weighing factor and D_T is absorbed dose to organ T of phantom. To obtain mean organ doses of the phantom, it is necessary to combine the cross-sectional anatomical data with experimentally determined dose distributions within the phantom. For a measured dose distribution, the organ dose D_T can be derived from: $D_T=\sum_i f_i(\text{organ}) \times D_i$, where fi(organ) slice i and D_i the average radiation does to the part of this organ within slice i. Finally, the effective dose of the patient was calculated from the following equation:

$$E_{eff}(mSv) = DAP_{patient}(mGycm^2) \times \left(\frac{E_{eff}(mSv)}{DAP(mGycm^2)}\right)_{phantom} \quad (2)$$

Also for the physician, entrance surface doses to the lens of eyes, thyroid, gonads and hands were measured by TLDs. Since the physician use protective lead apron, TLDs were placed under the leaded thyroid shield and apron.

In order to assess the leaded cloth shield effect which was wrapped around the X-ray tube, ERCP was carried out while a Rando phantom was placed beside the patient's bed at nearly the same position where the physician normally stands. Then phantom organs doses were measured by TLDs with and without the lead shield. The organs of interest were lens of the eyes, thyroid and gonads.

3. RESULTS

Dose measurements were collected for 30 patients, 20 from diagnostic and 10 from therapeutic procedures. Estimated mean effective dose of patients were 1.15 mSv and 2.14 mSv from diagnostic and therapeutic procedures respectively. Details of organs doses of physicians and patients are presented in Table 1 and Table 2.

TABLE 1. MEAN VALUES OF THE ORGAN DOSE FOR ENDOSCOPIST IN DIAGNOSTIC AND THERAPEUTIC ERCPS.

TLD position	number of patients	Average dose (mGy)	Dose range (mGy)
Diagnostic ERCP			
Right hand	20	0.024	0.019-0.031
Left hand	20	0.027	0.020-0.038
Thyroid	20	0.024	0.017-0.036
Lens of the eye	20	0.024	0.020-0.029
Gonad	20	0.025	0.021-0.031
Therapeutic ERCP			
Right hand	10	0.039	0.027-0.054
Left hand	10	0.037	0.018-0.075
Thyroid	10	0.032	0.020-0.052
Lens of the eye	10	0.031	0.020-0.040
Gonad	10	0.035	0.020-0.059

TABLE 2. Mean values of the organ dose for patients in diagnostic and therapeutic ERCPs.

TLD position	number of patients	Average dose (mGy)	Dose range (mGy)
Diagnostic ERCP			
Thyroid	20	0.031	0.026-0.036
Lens of the eye	20	0.028	0.022-0.033
Gonad	20	0.065	0.031-0.095
Therapeutic ERCP			
Thyroid	10	0.039	0.020-0.058
Lens of the eye	10	0.035	0.016-0.049
Gonad	10	0.051	0.023-0.086

The acquired DAP values varied widely, 0.88-7.00 with the average of 4.09 and 2.22-17.53 with the average of 7.60 $Gy.cm^2$ for diagnostic and therapeutic respectively.

The results of dose measurements with the Rando phantom for effective dose are showed in Table 3. In the study, fluoroscopy time was 2.8 minutes and DAP values was 705 $Gy.cm^2$. Organ dose of the physician with wrap around shield cover of X-ray tube and without it are presented in Table 4.

TABLE 3. Measured dose with the Rando phantom for the effective dose in organs and tissues defined by ICRP-103 (8) and ERCP.

Organ	Dose (mGy)	Organ	Dose (mGy)
Gonads	0.034	Liver	1.428
Bone marrow	0.322	Esophagus	0.393
Colon	0.093	Thyroid	0.048
Lung	0.208	Skin	1.064
Stomach	0.298	The remaining organs	0.076
Bladder	0.046		

TABLE 4. Physician organ dose with and without leaded shield wrapped around the X-ray tube.

TLD position	Dose with a lead shield around the X-ray tube (mGy)	Dose without a lead shield around the X-ray tube (mGy)
Thyroid	0.022	0.071
Lens of the eye	0.033	0.047
Gonad	0.056	0.022

4. DISCUSSION

Based on our results presented in Table 1, from diagnostic procedures maximum organ dose of the physician is attributed to his left hand (0.027 mGy) while from therapeutic procedures, his right hand received the highest dose (0.024 mGy). General speaking and as would be expected therapeutic procedures delivered higher dose to all studied organs.

From Table 2 it is evident that patient gonads received relatively higher dose (both from diagnostic & therapeutic).

This is due to the fact that patient's gonads, females in particular, are closer to radiation field and (in the present study) were not shielded. Thus more efficient protection is essential. Although patient's thyroid and the lens of eyes different dose from different procedures nevertheless the difference are not noticeable (max difference in order of 0.010 mGy).

The dose ranges for patient's gonads from both procedures are much wider than comparable figures for thyroid and the lens of eyes. This is implying that higher dose may arise from a more complicated procedure or less skilled or experienced physician or both, which in either case, calls for enforcement of more efficient radiation protection measures.

The data showed in table 4 are evident that covering the X-ray tube with a leaded cloth shield reduces the leakage radiation and hence the physician organ dose, however this conclusion is not true for gonads.

In Table 5, DAP values, fluoroscopy times and mean effective dose of patients obtained in this work and corresponding results reported by other researchers are presented. Generally technical parameters including DAP values and fluoroscopy time were used by the physician in the present study, consequently effective doses

of patients who took part in this survey are similarly smaller, may he our co-worker physician was more concerned to the safety of his patients.

Table 6 compares the doses received by physician radiosensitive organs during therapeutic ERCP from other studies published in the literature. In this study organ doses incurred by our co-worker physician are smaller nearly by one order of magnitude.

TABLE 5. Comparison of DAP values, fluoroscopy times and mean effective dose of patients from endoscopic retrograde cholangiopancreatography (ERCP) reported by other researchers in the literature.

Study	Diagnostic ERCP			Therapeutic ERCP		
	DAP ($Gy.cm^2$)	Fluoroscopy time (min)	E_{eff} (msv)	DAP ($Gy.cm^2$)	Fluoroscopy time (min)	E_{eff} (msv)
Larkinet et.al. (9)	13.5	2.3	3.1	66.8	10.5	12
Tsalafoutas et.al. (10)	13.7	3.1	2.9	41.8	6	8.7
Buls et.al. (11)	-	-	-	49.9	6	9.9
This study	4.09	0.54	1.15	7.60	1.27	2.14

TABLE 6. Organ dose values reported by other studies and the values obtained in the present study.

Study	Hand (mGy)	Thyroid (mGy)	Lens of the eye (mGy)
Buls et.al. (11)	0.44	0.30	0.34
Germanaud et.al. (12)	-	0.10	0.13
Cohen RV (13)	-	2.05	1.67
This study	0.04	0.03	0.03

5. CONCLUSION

Organ doses of patients resulting from diagnostic procedures are smaller than similar quantities from therapeutic actions. Patients gonad dose are unexpectedly high, which call for (or) stipulate better protection of gonads patients. If ERCP parameters are reduced patient's effective dose would be reduced too.

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OPTIMIZING FLUORO-GUIDED INTERVENTIONS BY PATIENT AND STAFF EXPOSURE TRACKING IN CONTEXT

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Abstract

In a research collaboration between the radiology department of Maastricht University Medical Center and Philips Healthcare, the effect of providing personalized contextual feedback enabled by automated patient and staff exposure tracking was evaluated.

The study consisted of a reference phase in which patient and staff exposure was tracked for a range of Fluoroscopic Guided Intervention (FGI) procedures and a feedback phase in which personalized feedback was provided. After that an anonymous evaluation was carried out? for the various interventional staff roles (operators, technologists, nurses)

Results showed that personalized feedback was scored valuable by 76% of the staff and in 52% lead to changed behavior. In particular, for the technologists a significant lower ratio of scatter dose vs interventional system output was observed: 0.12 (0.04–0.50) µSv/Gy·cm^2 versus (phase 2) 0.08 (0.02–0.24) µSv/Gy·cm^2, p = 0.002.

It can be concluded that personalized feedback increases radiation awareness and safety and is useful to provide to staff involved in FGI.

1. INTRODUCTION

Optimizing radiation dose in Fluoroscopic Guided Interventions (FGI) is a challenging task because of the wide variation of occurring dose values, and the large number of effects that contribute to the observed dose values [1]. Thanks to the introduction of DICOM RDSR [6], most newly installed angiographic equipment will have the possibility to export extended system radiation output data, up to the individual irradiation event level (i.e. foot pedal press). For collection and analysis of this radiation output data there is a variety of commercial and open source solutions available [5]. A remaining challenge is to derive meaningful conclusions from these created large data sets.

In FGI the occupational exposure of staff members is of interest as well. Most countries require interventional staff to wear dosimeters to determine legal occupational dose, however there are still challenges with respect to the accuracy of reported data [2]. Another issue is that the legal staff exposure data is received mostly long after the procedure took place, and therefore difficult to close the feedback loop by correlating high personal exposure values with specific events. Since 2010 there is also the possibility to receive real time feedback on individual exposure [3]. This real time feedback is helpful as an educational tool, but creating sustained improvements over a longer time remains a challenge.

By combining the detailed radiation output data (RDSR) from the fluoroscopic system with the personal staff exposure values (derived from DoseAware) and placing them in the context of a specific procedure, it is possible to create meaningful personalized feedback. For example, from the procedural Dose Area Product (DAP)

a minimum threshold value for staff exposure can be estimated, which can be used to determine whether a dosimeter actually has been worn by the staff. Another possibility is mounting a reference dosimeter on the C-arm itself [4] that can be compared with the dosimeter readout from an individual staff member. If the ratio staff/reference is above 10%, it can be concluded that no additional shielding has been used [4]. The average scatter ratio during a procedure can be determined on the base of this ratio, which can be used to benchmark operators, as the effects of patient size and case complexity are dividing mostly out from the staff and reference dosimeter.

In the paper the effect of providing personalized feedback to hospital staff of the Maastricht University Medical Center IR department has been studied.

2. METHODS

The study was approved by the institutional ethical committee. Employees enrolled in this study gave their written informed consent. Written informed consent of the patients involved in the procedures was waived.

2.1. Data collection setup

In figure 1 the various systems used for the data collection are shown. The personal dosimeters (Personal Dose Meter) are communicating to a Xhub via an 868.3 MHz radiofrequency signal, mounted in the examination room. The Xhub itself can communicate via the hospital network to the angio system, exchanging the accession number of the exam, and receiving the "start exam" signal when a new patient is selected for acquisition. After receiving the "close exam" signal from the fluoroscopic system, the staff exposure data is automatically exported to the dose management system.

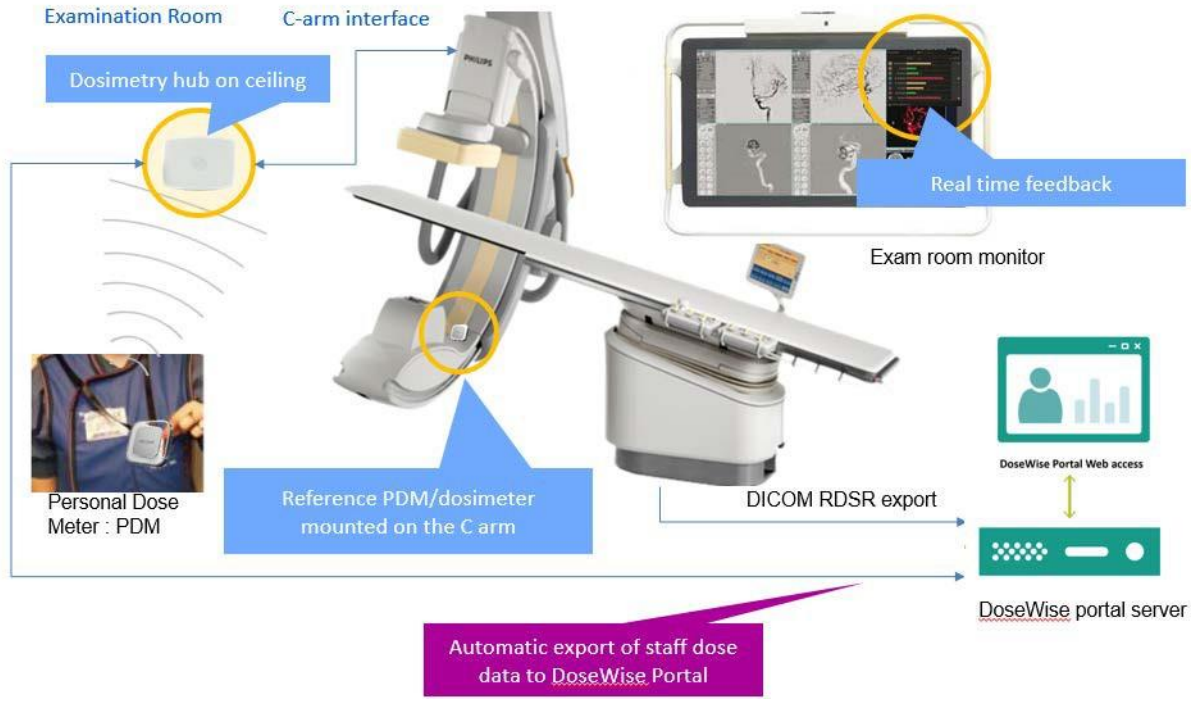

*Figure 1 : connect*ions

At the same time also the system output radiation data is exported in the form of DICOM RDSR. In DoseWise Portal the corresponding patient and staff exposure values are matched on base of the exam accession number. DoseWise captures, tracks alerts and reports on patient and staff radiation output to support users in performing statistical analysis of medical imaging radiation output and staff dose. This allows quantitative trends and

statistics that users may use as input in planning and tracking dose optimization activities. During the study, the optimal way to present combined data to the end user for this was investigated. For that, in the hospital also rapid prototyping environment (based on Mathematica) was used in combination with DoseWise portal.

2.2. Study design

The feedback study ran between Nov 2015 and Sept 2016. During this period the real time feedback display (DoseAware) which was introduced in the hospital in 2013 has been kept in use during all procedures. The study consisted of two phases: (1) months 1–5: staff not receiving personalized dose feedback (n = 701) and dose data for each procedure were prospectively collected and (2) month 6–8: staff receiving weekly individual personalized dose feedback (n = 381). After eight months, the dose feedback was evaluated anonymously through a standardized questionnaire.

2.3. Feedback

In figures 2-4 some examples of feedback that is provided by the portal, either in overview format (for the Medical Physics Expert) or personalized for the interventional staff member. In figure 2 a comparison overview is shown for the staff dose per case for the preceding week. Next to the median per procedure type (either individual exam descriptions coming from the RIS or reference names grouped together for similar radiation usage characteristics) also comparison to the peer group (e.g. doctors, RT's, nurses etc) is shown. In the last 2 columns the accumulated dose year to date (YTD) and a prediction based on previous 6 months of data for the annual dose. This enables a timely prediction when there is still opportunity to take actions to prevent exceeding the annual limit, in contrast to legal dosimetry where it can only be determined after the exceed has occurred.

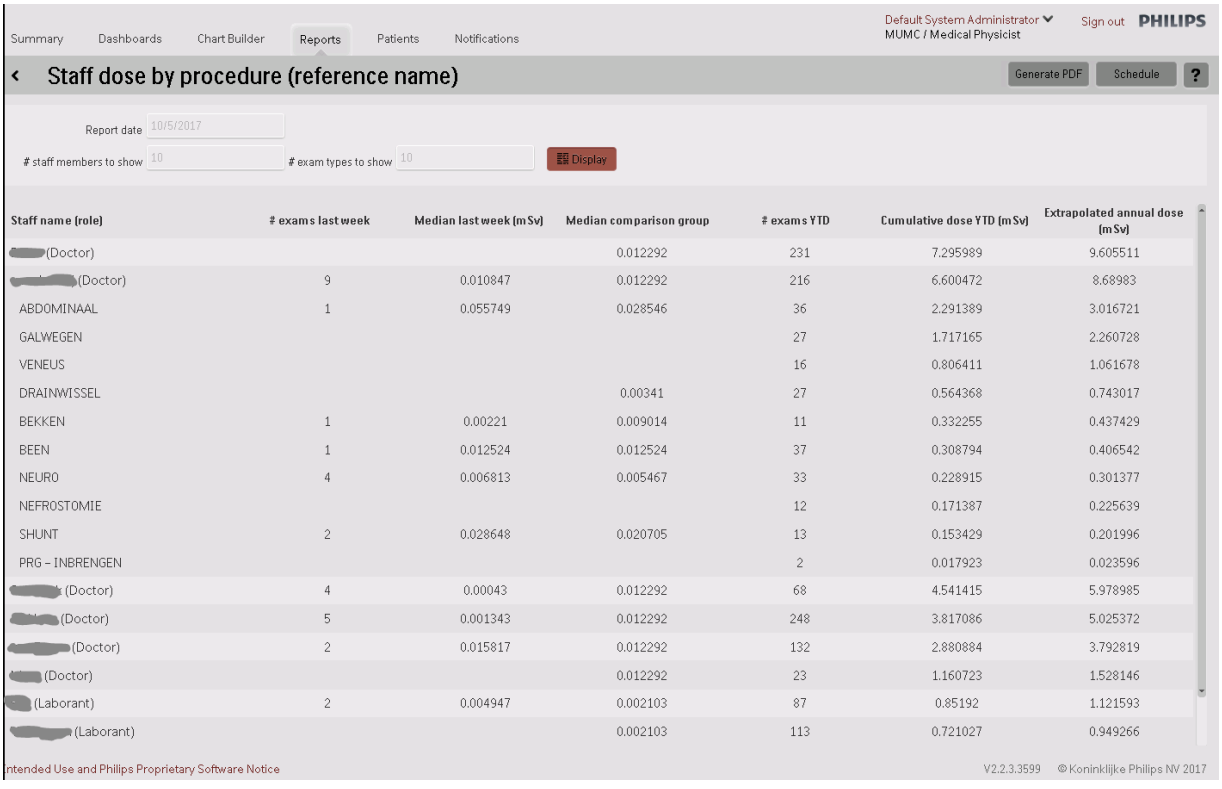

Figure 2 : Example of staff dose reports visible for the Medical Physics Expert

In figure 3 the scatter ratio (personal dosimeter/reference dosimeter in %) is depicted, both in relation to the cases in the preceding week as well as averaged over the year. The scatter ratio is similar as for the staff dose value itself compared with peer groups, and it can be seen that there are significant differences per procedure and differences between staff members depending on workflow such as operator position in relation to irradiated area on the patient.

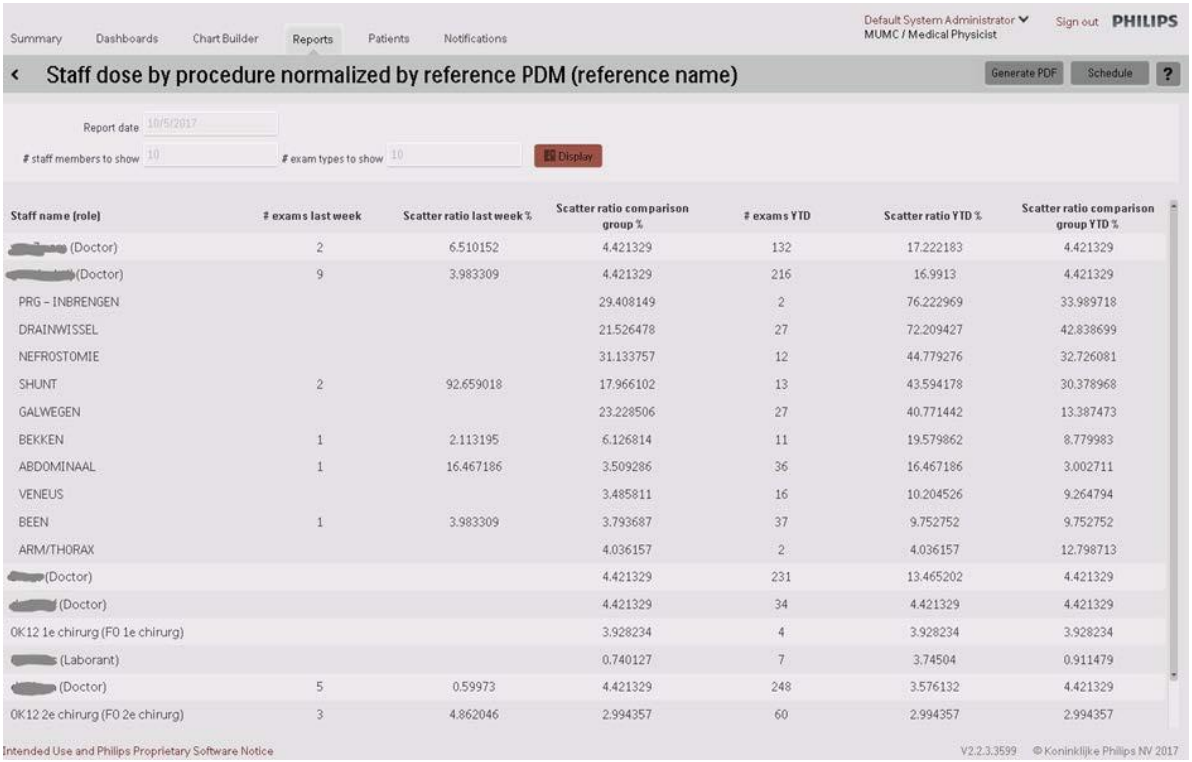

Figure 3 : scatter ratio report for Medical Physics Expert

Depending on local workflow and focus area it is possible to design dashboards that provide insight in targeted improvement areas. In figure 4 to the left the fraction of staff dose obtained during fluoroscopy compared to obtained during acquisition/exposure runs is visualized per staff member. To the right the mean staff dose per case is shown, which shows large difference per staff dosimeter, that can be attributed to workflow or patient/procedure type differences.

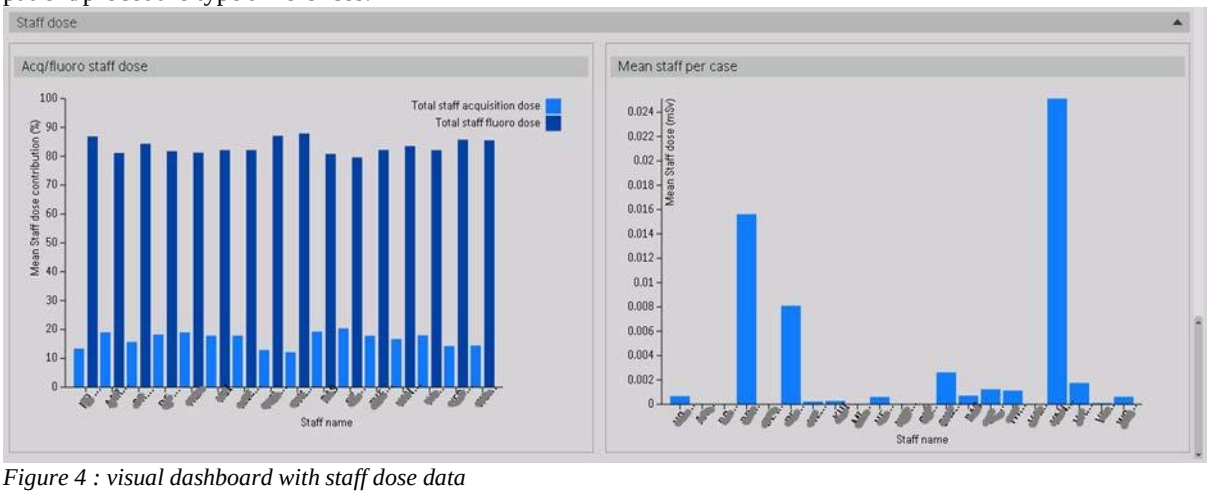

Figure 4 : visual dashboard with staff dose data

3. RESULTS

After introducing the personalized feedback, the wearing of PDM dosimeters by physicians and technicians increased by 13%, from 75 to 88% compared to phase 1 (before feedback). For the first technician (FT), the normalized dose was significantly lower in the feedback phase 2 compared to phase 1 (median (IQR) relative normalized FT dose: 0.12 (0.04–0.50) versus 0.08 (0.02–0.24) µSv/Gy·cm^2, p = 0.002). The normalized first operator (physician) doses showed no significant difference before and during the feedback; median (IQR) normalized FO dose: 0.52 (0.17–1.45) µSv/Gy·cm^2 (phase 1) versus 0.40 (0.15–1.27) µSv/Gy·cm^2 (phase 2), p=

0.24. The use of the radiation protection tools; table drape, table shield and ceiling shield were increased by 2, 15 and 28% during the feedback phase, respectively which was scored in a separate database.

3.4. Evaluation of Questionnaires

After completion of phase 2 a questionnaire to the staff was submitted. Details on the questionnaire can be found in the bibliography [1]. The response rate on the feedback questionnaire was 78% (21/27 returned questionnaires, 8 physicians and 13 technicians). The individual dose feedback was scored as valuable by 76% of the respondents; there was no difference in average scoring between physicians and technicians ($p < 0.05$). 71% of the team members reported that the feedback increased their personal radiation dose awareness, and 57% answered that the feedback increased their feeling of occupational safety or even had changed their behaviour (52%).

4. DISCUSSIONS

Personalized feedback is a next step in radiation dose optimization in FGI and aims to enhance knowledge and stimulate intrinsic motivation of medical staff to optimize procedure and personal doses. Implementation of individual exposure monitoring and weekly personalized exposure feedback proved technically feasible by means of an automated combined patient and medical staff exposure monitoring system with automated feedback generation. In general, the staff wore a lead apron, thyroid collar and sometimes leaded glasses, so the over-lead exposure measurements are an overestimation of the actually received effective staff dose. Nevertheless, unshielded body parts such as the extremities and (often) the lens of the eye are not protected when directly exposed to the scattered radiation [7]. As the Dutch legal dosimetry is reported back to the staff as over-lead Hp(10) values, the same measure was presented in the feedback forms as the staff is familiar in interpreting these values. To increase awareness and to maximize the educational effect, the feedback was presented within a short time span after performing the procedures. The medical staff indeed indicated that awareness for radiation exposure was increased and a positive behavioural change with respect to radiation safety was experienced. Moreover, the results show that personal over-lead exposures decreased significantly for technicians during the feedback phase, whereas the median absolute and normalized primary operator exposure displayed a non-significant trend toward dose reduction. This difference might be due to the fact that technicians have more options to seek distance during X-ray exposure than physicians. Although the absolute and normalized technician exposures were low compared to the physician exposures, the personalized feedback resulted in significant dose reduction. To set the primary operator exposure in perspective, the median over-lead exposure of roughly 12 µSv per procedure (pre- and postfeedback) are about 2000 times lower than the annual legal dose limit of 20 mSv for interventional radiologists in Europe [8]. However, the large range and maximum exposures of > 600 µSv indicate that awareness by interventional radiologists of such occasional ‘high personal dose procedures’ is necessary. As the nature of our questionnaire was anonymous, no correlations could be deduced between positive/negative answers in the questionnaire and an individual decrease/ increase in personal dose. Further research has to be performed to evaluate long-term effects of feedback on medical staff dose with regard to individual responsiveness to personalized dose feedback. Such an evaluation could provide further insights into improvement in personalized feedback and, in general, how to promote radiation safety.

Real-time, in-room dose feedback to medical staff may also raise awareness of high exposure [4]. Previous studies have shown positive effects on occupational doses of monitors that provided real-time feedback on radiation exposure, either visually [9-14] or auditory [15]. From our experience, a disadvantage of the visual monitor is that in particular the primary operator cannot constantly keep track of the screen as his/her attention needs to be focused on the procedure. Furthermore, real-time feedback provides momentary dose rate information during an individual procedure only. However, retrospective procedure dose information in particular in comparison with similar procedures allows for more reflection. Our results indeed demonstrated that the personalized feedback is an effective radiation awareness tool in addition to live monitoring, which was already used in clinical practice in our hospital setting. In this sense, personalized feedback can be regarded as a staff dose optimization tool induced by a behavioural change resulting from increased awareness, rather than optimizing protocols or introducing new dose reduction techniques.

5. CONCLUSIONS

Patient dose and medical staff effective doses from personal dose meters can be monitored simultaneously by an automated real-time dose tracking system and can be used to create personalized feedback on occupational and patient radiation dose. Personalized dose feedback is able to increase health-care professionals' radiation awareness as well as to improve radiation safety and individual protection in the clinical setting. Personalized dose feedback can be used as a dose optimization tool and for benchmarking of patient and staff doses, while educating staff and initiating a change in behaviour.

5.5. Outlook

With the availability of DICOM RDSR on angiographic equipment in clinical use becoming more widespread (DICOM RDSR export is a mandatory feature for new equipment produced since 2013 and upgrades need to be available for systems produced after 2008) the possibility to enhance the understanding of dose management optimization during FGI has significantly increased. Nevertheless, compared to optimization initiatives in diagnostic CT there is still a lag that has to do with the difficulty of standardization in FGI. In future the hope is that data registries that currently exist such as ACR TRIAD [16] can be extended to FGI [17] and expanded internationally. An interesting possibility enabled by automated staff dose tracking would to improve data collection for occupational dose registry initiatives such as the IAEA ISEMIR-IC database [18].

With respect to classification of procedures more effort will be necessary to expand the RADLEX Playbook concept with FGI, also outside the radiology domain, and facilitate towards international implementations. Key will be the interface between dose management systems and other information systems in the hospital, such as the order entry/scheduling systems in Hospital IS, Radiology IS and Cardiology IS domains. The standardized procedure descriptions will then need to be expanded with a complexity index that is specific, measurable and agreed upon by clinical domain experts [19]

As parameters such as Dose Area Product and staff exposure are typically lagging indicators, thanks to the extended data stored thanks to DICOM RDSR it is also possible to start investigating leading indicators for dose performance. Examples of such leading indicators could be: the usage of projection angles, choosing of table height, frequency of using fluoro store functionality replacing an exposure run, selection of acquisition/fluoro protocols etc. Future study is necessary to determine if there can be a solid correlation between leading and lagging indicators determined per operator, which can give input to further dose optimization activities.

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PRELIMINARY SURVEY OF PATIENT EXPOSURE DURING INTERVENTIONAL CARDIOLOGY PROCEDURES IN MOROCCO

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Abstract

Interventional cardiology is practice capable of delivering important amount of radiation to patients and practitioners.In some cases; the dose patients may reach high levels causing appearance of deterministic effects. For this it is necessary to optimize the doses delivered to patients. The aim of this study was to estimate the DAP and effective doses received by patients in diagnostic and therapeutic interventional in Moroccan hospitals.

The survey concerns 537 interventional cardiology (IC) procedures (340 Coronarography (CA), 149 Percutaneus transluminal coronary angioplasty (PTCA), Mitral dilatation (MD), Implantation of pacemaker and Ablation performed by 7 cardiologists on different installations. The data collected for each procedure were: patient characteristics, dosimeter indicators (Dose Area Product (DAP), fluoroscopy time (FT) and number of frames) and parameters of the primary beam: kV, mAs.

The mean of DAP in CA and PTCA were 33.12 and 85.83 Gy.cm2 respectively, and 3.98 min and 17.63 min for fluoroscopy time and 470 and 866 for frames.

Implementation of radiation safety culture in the various healthcare centers in our country requires establishment of radiation protection and surveillance programs and patient dose registration. Our perspective is investigation local DRLs.

Keywords: Patient dose, interventional cardiology, DAP. Effective dose.

1. INTRODUCTION

A special attention should be taken to interventional cardiology because of large doses that could receive patients, which can cause radiation cancerous effects.

In these kinds of procedures, it is necessary to be vigilant concerning the regulation application to insure the radiation protection of patients and medical staff.

The variability of doses delivered is very high depending on the complexity of diagnostic and interventional procedures performed, the equipment used and the practitioner experience and skilfulness. In some cases, the dose received by patients can reach levels causing the emergence of deterministic effects [1] [2].

The purpose of this study was to estimate the DAP received by patients in interventional cardiology for diagnostic and therapeutic in Moroccan interventional cardiology centres.

2. METHODS

The present work was conducted to investigate doses in selected interventional cardiac procedures:

(1) Coronary angiography (CA);
(2) Percutaneous transluminal coronary angioplasty (PTCA) and mitral dilatation (MD);
(3) Pacemaker implantation, and radiofrequency cardiac ablation (RFCA).

The survey was carried out in four centres of catheterization and involved data of 537 patients (table 1). Data gathered for each procedure were: patient characteristics, dosimetry indicators kV, mA, fluoroscopy time (FT), Dose area product (DAP), and the cumulative dose (CD), and number of frames (F).

TABLE 1. Cardiac interventional procedures in the sample of patient dose survey.

Procedure	No. of patients
Coronarography (CA)	340
Percutaneus transluminal coronary angioplasty (PTCA)	149
Mitral dilatation (MD)	9
Pacemaker implantation	22
Radiofrequency cardiac ablation (RFCA)	17

3. RESULTS&DISCUSSIONS

Radiation dose measurements in terms of DAP, fluoroscopy time (FT) and number of frames (F) are given in Table 2.
We examined the dose of patient representing DAP in Fig 1 and 2, mean and median values of DAP reported for CA and PTCA procedures.
Fig 1 and Fig 2 summarize DAP evolution according to different centers, for CA and PTCA procedures. It is noted that the mean dose is surestimated relatively to the median. This shows the important fluctuation of values. Fig 3 and 4 show the percentages of DAP for different ranges. The results obtained are compared with those of previous studies in table 3.

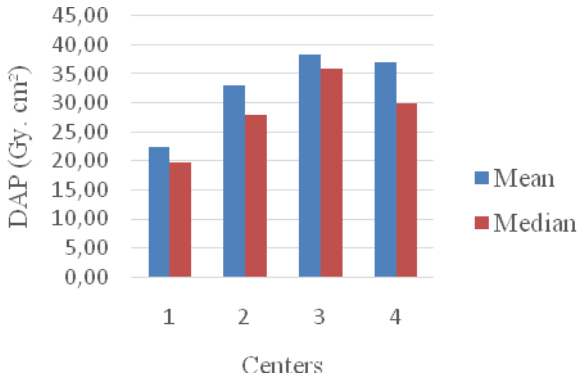

FIG. 1. Mean and median DAP during CA in the centers.

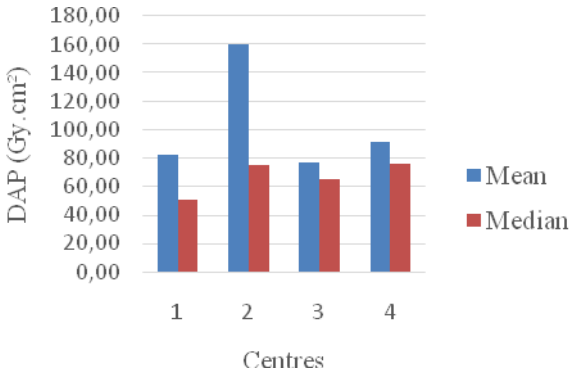

FIG. 2. Mean and median DAP during PTCA in the centers.

TABLE 2. Patient doses in accordance with fluoroscopy time and number of frames for CA and PTCA procedures.

	CA					PTCA				
Parameter	Range (Min-Max)	Mean	Median	SD	Third quartile	Range (Min-Max)	Mean	Median	SD	Third quartile
DAP(Gy.cm²)	0.49-175.67	33.12	27.98	23.16	42.83	1.16-752	85.83	69.98	85.23	99.66
FT(min)	0.2-18.48	3.98	3.08	2.95	5.13	2.02-37.38	17.63	10.33	58.22	16.23
F	29-1629	470	423	233	591	236-4458	866	763	596	1044
CD(mGy)	0.96-3274	505.27	455.04	322.61	619	32-6021	1324	957	1124, 97	1828
ED (mSv)	0.09-32.15	6.06	5.12	4.23	7.84	0.21-137.6	15.67	12.81	15.5	18.10

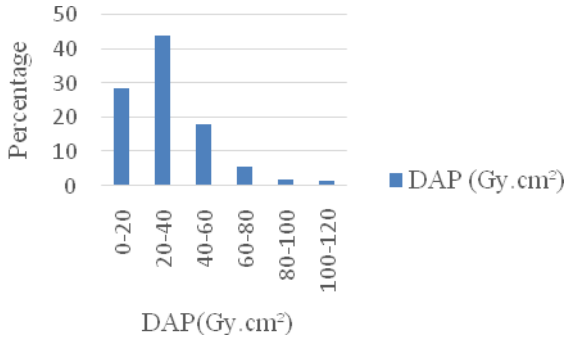

FIG. 3. DAP of CA procedures in different centers.

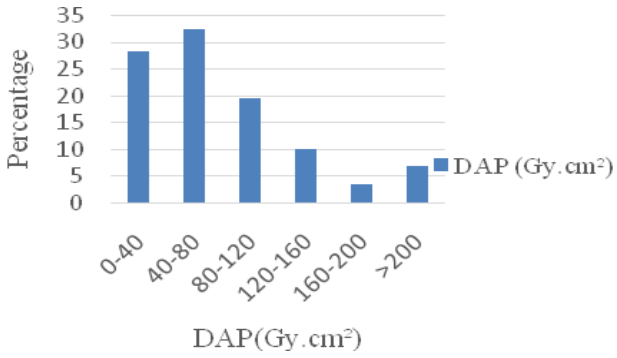

FIG. 4. DAP of PTCA procedures in different centers.

The DAP permits to determine the effective dose ED (mSv) using the conversion factors defined for different impacts associated with the procedures. We used the mean value of 0.183 mSv / Gy.cm² [3]. The mean of ED for CA and PTCA were 6.06 and 15.67mSv respectively.

For Pacemaker implantation, RFCA and MD, the mean values are:

- 45.31, 101.37 and 12.09 Gy.cm2 for DAP;
- 8.29, 18.55 and 2.21mSv, for ED;
- 312.64, 601.82 and 104.69 mGy, for cumulative dose;
- 12.81, 20.91 and 6.24 min, for fluoroscopy time.

Previous studies have evaluated DAP and FT and F values. Results are grouped in table 3.
The comparison showed that during CA, the DAP and FT mean values are lower than the others and almost similar with results obtained by Padovani et al [6]. For PTCA procedures, values are comparable to those of the previous works and close to those obtained by Padovani et al [6].

TABLE 3. Comparison of our results and published study evaluated DAP, FT and F in CA and PTCA

	CA							PTCA						
	DAP (Gy.cm²)					FT (min)	F	DAP (Gy.cm²)					FT (min)	F
	Patient	Mean	Median	SD	Third quartile	Mean	Mean	Patient	Mean	Median	SD	Third quartile	Mean	Mean
Tsapaki [4]	195	47.3	39.1	27.9	60.4	6.5	1779	97	68	58.3	48.7	80.7	12.2	1914
Vano [5]	288	66.5	45.7		69.3			45	87.5	66.7		122.3		
Padovani [6]	13	39.3		18		3.6	878	54	101.9		84.9		18.5	1434
Broadhead [7]	2174	57.8	45.5		69.9	5.7	689	214	77.9	61.1		100.6	12.4	504
Zorzetto [8]	79	55.9	52.5		65.6	4.9	1350	31	91.8	82.6		104.6	12.2	1500
Our study	340	33.1	27.9	23.1	42.8	3.9	470	149	85.8	69.9	85.2	99.6	17.6	866

4. CONCLUSIONS

Given the relatively high dose received in interventional radiology, and in order to take into account the optimization of the procedures involved, it is necessary to establish a radiation protection system in our country. It may be necessary to start with the registration of the patient dosimetry that can guide staff in improving more the radiological practices.
Our Future work will to expand the investigation to several centres by accessing more interventional radiology procedures to evaluate effective doses and to investigate local DRLs [9] [10].

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RETROSPECTIVE ANALYSIS OF RADIATION PROTECTION IN INTERVENTIONAL CARDIOLOGY FOR PROPOSING EYE LENS DOSIMETRY

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Abstract

Accurate assessment of eye lens dose to staff performing the procedure is a challenge in interventional cardiology. The aim of present study is to propose appropriate operating and calibration energy range for eye lens dosimeter in interventional cardiology. In practice the typical operating range of the tube voltage is 70–100 kV_p in interventional cardiology. In the present study to know the direction of scattered photon reaching to the eye the solid angles were measured from centre of optical crosswire projected on couch top to each interventional cardiologist eye level. Further the Compton scattering energy distribution plots have been studied and analyzed. In present study it was found that the cardiologists having extreme heights it was observed that solid angle of about 30˚ to 50˚ for standard projections. On further analysis of Compton plots suggests that the most probable average energy reaching to eye of cardiologists is 20 to 35 keV range in interventional cardiology. In this

presentation the energy range provided for better radiation protection and dosimetry of eye, devised in a theoretical manner validated by physics.

1. INTRODUCTION

The recent revisions in ICRP for the dose limit for lens of eye of occupational worker has drawn attention of researchers to develop eye lens dosimeter for accurate measurement. The potential exposure of ionizing radiation in cathlab medical interventions may result in several deterministic and stochastic effects.[1-3] The objective of this study is to propose the ideal operating and calibration energy range for eye lens dosimeter in interventional cardiology.

2. MATERIALS & METHODS

The present study was carried out on Siemens Axiom Artis Zee units (Siemens, Erlangen, Germany) interventional cardiology unit which has monoplane digital flat panel systems with the undercouch X-ray tube geometry and Automatic Brightness Control (ABC) features. Most common operating range of the tube voltage was in the range of 70–100 kV_p. In the present study relevant cardiologist related information as name; sex, age, and height of 10 cardiologists was recorded. The solid angles were measured from centre of optical crosswire projected on couch top to each interventional cardiologist eye level to know the direction of scattered photon reaching to the eye. These solid angles have been measured for undercouch tube geometry with two standard projections RAO 15˚as well as at LAO 45˚oblique tube angle respectively. The Compton scattering energy distribution plots have been studied and analyzed.

3. RESULTS & DISSUSSION

In the present study it was observed that the eye lens was not exposed to primary radiation unless radiological principles / radiation protection (ceiling suspended screens, leaded glasses) not practiced well. Further the leakage radiation is not much of serious concern if the machine complies with equipment safety standards as specified by National Atomic Regulatory Agency.

The main problem of radiation protection in cardiology is due to Compton scattered radiation. The present study analyzed the Compton spectra of maximum kVp used for the procedure. We have observed that 100 kVp incident

photons produce about Compton electron maximum energy of 25 keV at the level of eye angle with respect to isocenter. This Compton electron energy produced is very less at maximum operating parameters of machine. In addition, these low energy Compton electrons are generated for very less fraction of time and the intensity of it is also very minimal because the use factor of 100 kVp in machine is very low, primarily used at rare standard projections at oblique X-Ray tube angles. The Compton electron produced were not much of concern as the maximum energy of Compton electron produced in interventional cardiology is 25 keV, which will be stopped within the air, not reaching to eye of cardiologist.

Cardiologists having extreme heights in the department were observed solid angle of about 30˚ to 50˚ for two standard projections 15˚as well as at 45˚ tube angle respectively. The Compton photon reaching to eye at 30˚ to 50˚ angle was found of about 92 to 88 keV maximum energy range for 100 kVp incident photons respectively. The Compton photon reaching to eye at 30˚ to 50˚ angle was found of about 68 to 64 keV maximum energy range for 70 kVp incident photons respectively. However, it is known that the interaction of X-Ray having energy specific kVp with tissue result in a Compton photon spectrum of energy between 0 to E_{max} (depending on the tube kVp). The average energy of a photon spectrum is $E_{avg} = 1/3\ E_{max}$, where E_{max} is the maximum energy of the photon. Hence, the analysis of Compton plots for average energies suggested that the most probable energy reaching to eye of cardiologists would be 20 to 35 keV energy range in interventional cardiology.

It discusses that the Compton electrons are not of much concern for eye lens dosimetry and protection as compared to Compton photons. The Compton photon energy reaching to eye is ranging 20 to 90 keV. However, the most probable energy range of Compton photon is in the range of 20 to 35 keV. The average energy of tube voltage 80 kVp lies in this range. The X-ray tube is highly stabilized at the 80 kVp. The present study suggested that the tube voltage 80 kVp appropriate to use for eye lens dosimeters calibration. The findings of the study provided the data for better radiation protection and dosimetry of eye, describing good practices in a theoretical manner validated by physics.

4. CONCLUSIONS

This study provides the basic information about ideal operating energy range for eye lens dosimeter in interventional cardiology to researchers. The findings of this retrospective study used to develop ideal

eye lens dosimeters. The eye lens dosimeter should be fabricated and calibrated to measure the radiation spectrum of 20 to 35 keV energy range ideally. This energy range should be used for better protection approach and dosimetry of eye in interventional cardiology.

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EYE LENS MONITORING IN INTERVENTIONAL CARDIOLOGY AND RADIOLOGY PROCEDURES
Our experience

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Abstract

International Commission on Radiological Protection has recently re-evaluated dose limit to the lens of the eye, owing that protracted exposure to the relatively small doses and dose rates may lead to the cataract at dose levels much lower than previously considered. Occupational exposure from interventional x-ray procedures is an area in which increased eye lens exposure may occur. Appropriate dosimetry is an important element to investigate the correlation of observed radiation effects with radiation dose, to verify the compliance with regulatory dose limits and to optimize radiation protection practice. The paper presents the overview of practical methods for eye lens doses assessment in interventional procedures in in the context of potential monitoring needs. In addition, a practical methodology to assist decision making about need for specific eye lens individual monitoring using a dedicated passive dosimeters calibrated in terms of Hp(3) is presented in this work.

1. INTRODUCTION

Based on the results of a number of studies on radiation cataractogenesis, the International Commission on Radiological Protection (ICRP) re-evaluated the dose limit for the eye lens, based on the new findings that, at relatively high exposures (>1 Gy), lens opacities may occur within a few years. Nevertheless, at lower doses and dose rates, similar to those that might be encountered in interventional procedures, cataracts may occur over many years. Consequently, ICRP has set the threshold dose for radiation-induced eye cataracts to be around 0.5 Gy for both acute and fractionated exposures [1] and recommended a reduction of the dose limit for the eye lens for workers from 150 mSv to 20 mSv per year, averaged over defined periods of 5 years, with no single year exceeding 50 mSv [1,2]. As new evidence on eye lens injuries associated with exposure to ionizing radiation have become available, eye lens dosimetry has also become a very active research area [3-11].

The objective of this work is to provide summary of potential methods for eye lens doses assessment and to present a practical methodology to assist decision making about need for specific eye lens individual monitoring.

2. EYE LENS DOSE ASSESSMENT OPTIONS

Contrary to the whole body dosimetry, eye lens dosimetry is not currently well established and numerous studies were carried out to investigate various aspects of eye dosimetry, such as the development of new dedicated eye dosemeters and calibration procedures [5,9,10]. Furthermore, studies have been conducted to investigate methods of the assessment of the eye lens dose levels and monitoring arrangements, to study correlations of eye lens dose with other personal dose equivalents used in other types of monitoring or with patient dose indices and to perform retrospective eye lens dose assessment [3-6,8,11].

The best option is to use a dedicated eye lens dosimeter. The position of a dedicated eye lens dosemeter should be as close as possible to the eye and the detector should face the radiation source. In particular, in interventional procedures, the dosemeter should be on the side closest to the x-ray tube and when protective lead glasses or face masks are used, the dosemeter should be worn behind these tools, which is not very convenient in most cases. Alternatively, dosemeter could be worn above the protection and appropriate correction must be applied. When the use of a dedicated eye lens dosemeter is impractical, the eye lens dose can be alternatively evaluated using a dosemeter at trunk or thyroid level above the protective tools [5].This method for the estimation of the eye lens doses is associated with large uncertainty and great caution is needed if the measured dose levels are close to the dose limits. In the absence of any dose measurement, the eye lens dose could be estimated from patient dose, for example using the conversion from air kerma area product to eye lens dose of 1μSv/Gycm^2, when protective tools are used, and 10 Sv/Gycm^2 for situations without protection. However, in this case the uncertainty and variability is even larger [6].

3. PRACTICAL METHOD FOR EYE LENS DOSE ASSESSMENT IN THE CONTEXT OF NEED FOR SPECIFIC MONITORING

Routine monitoring of the eye lens dose should be undertaken if the provisional estimation indicates that the annual equivalent dose to the eye lens is likely to exceed a certain dose level, such as 5-6 mSv (i.e. 3/10 of the dose limit) [3,6,12]. To undertake a pilot individual monitoring assessment is one of the best approaches to identify workers that require eye lens monitoring and to decide on the best dosimetry system.

The ambient dose equivalent, H*(10), is an operational dosimetric quantity used for dosimetric characterisation in the radiation fields. It is widely measured as a part of workplace monitoring in industry and medicine. Using results of such workplace monitoring, it is possible to obtain rough estimation of the occupational and public exposure levels. Testing of ambient dose equivalent level is a part of regulatory requirement in Republic of Serbia. It provides information about dose levels at positron of all staff members in interventional procedures, including level of the head. Procedure for measurement of ambient dose equivalent rate is based on use of a use of calibrated dosimeter and suitable phantom (water, PMMA) as a scattering medium. Ambient dose equivalent rate is measured at head, chest, pelvic and extremity levels for all operators and all acquisition modes. The information about dose levels at head position can be used to assess order of magnitude of eye lens dose, if combined with workload for a particular operator, e.g. number of procedures, typical duration, contribution of different projections and conversion from H*(10) to Hp(3). Later conversion is assumed to be one for relevant x-ray beam qualities and in the context needed accuracy. With respect to the uncertainty of certain parameters, differences in working habits of operators and individual patient characteristic, a conservative approach is preferably used. As an example, ambient dose equivalent rate values in the vicinity of an interventional cardiology unit Axiom Artis (Siemens, Erlangen, Germany), measured using a calibrated pressurised ionisation chamber 451 P (Fluke Biomedical) are presented in Table 1.

If 1200 procedures are performed every year using this particular x-ray unit, including 600 coronary angiographies (CA) and 600 percutaneous coronary interventions (PCI), which last 10 min and 45 min, respectively, estimated eye lens dose is approximately 220 mSv, per year, excluding use of protective glasses. Similarly, estimated eye lens dose per procedures is 70 μSv and 315 μSv for CA and PCI, respectively, or average 180 μSv per procedure. If a interventional cardiologist performs 30 CA and 20 PCI procedures on monthly basis, eye lens dose would be 5 mSv or (50-60) mSv per year. Use of protective glasses would reduce this level for a factor 5-10 [5].

TABLE 1. EXAMPLE OF MEASURED AMBIENT DOSE EQUIVALENT H*(10) RATES AT THE POSITION OF INTERVENATIONAL CARDIOLOGIST

Projection	PA (with ceiling screen and portable shield)		PA (with portable shiled)		PA cranial (with ceiling screen and portable shield)		LAO (with ceiling screen and portable shield)		Caudal (with ceiling screen and portable shield)		RAO cranial (with ceiling screen and portable shield)		SPIDER (with ceiling screen and portable shield)	
Aquisition mode	Fluoro (70 kV, 137 mA, 15 f/s)	Akvizicija (78 kV, 473 mA, 15 fps)	Fluoro (70 kV, 137 mA, 15 f/s)	Akvizicija (78 kV, 473 mA, 15 fps)	Fluoro (66 kV, 143 mA, 15 f/s)	Akvizicija (68 kV, 439 mA, 15 fps)	Fluoro (65 kV, 143 mA, 15 f/s)	Akvizicija (72 kV, 496 mA, 15 fps)	Fluoro (66 kV, 148 mA, 15 f/s)	Akvizicija (74 kV, 498 mA, 15 fps)	Fluoro (67 kV, 169 mA, 15 f/s)	Akvizicija (72 kV, 495 mA, 15 fps)	Fluoro (70 kV, 144 mA, 15 f/s)	Akvizicija (74 kV, 787 mA, 15 fps)
Head of the first operator, H*(10) (µSv/h)	600	500	1100	5000	42	300	50	190	41	140	35	250	80	480

This estimation implies a need for specific individual monitoring. A pilot two-month monitoring was therefore performed using a calibrated Hp(3) dosimeters for both left and right eye. In parallel, a whole body Hp(10) dosimeter worn above the apron at chest level. For eye lens dose measurement, thermoluminescent dosimeters LiF:Mg,Cu,P (DXT-100) were used. These dosimeters are otherwise used for extremity monitoring, however, if suitably calibrated in terms of Hp(3), they can be used for eye lens dose measurement. Due to small size, they can be easily affixed close to the eyes. These dosimeters were calibrated in ISO N-80 standard beam quality using a homogenous head phantom. Whole body dose was measured using routinely used LiF:Mg,Ti (TLD-100TM) dosimeters, calibrated in terms of Hp(10). All dosimeters were read using Harshaw 6600 Plus Automated TLD Reader (Thermofisher Scientific, USA). Results are presented in Table 2.

TABLE 2. EXAMPLE OF MEASURED AMBIENT DOSE EQUIVALENT H*(10) RATES AT THE POSITION OF INTERVENATIONAL CARDIOLOGIST

Cardiologist ID	Hp(3) [mSv]		Hp(10) [mSv]	Hp(3)/Hp(10)		Number of procedures		Hp(3) [µSv]/procedure	
	Right eye	Left eye	Whole body	Right eye	Left eye	PCI	CA	Right eye	Left eye
1	0.67	1.8	1.01	0.663	1.782	54	76	5	14
2	0.67	1.64	0.97	0.691	1.691	23	47	10	23
3	0.63	1.89	2.81	0.224	0.673	55	79	5	14
4	1.5	6.7	2.18	0.688	3.073	33	68	15	66
5	0.8	1.27	2.03	0.394	0.626	46	79	6	10
6	1.05	3.01	1.5	0.700	2.007	45	70	9	26
7	1.45	7.36	4.04	0.359	1.822	59	98	9	47

Based on the results presented in Table 1 and Table 2, one can conclude the following:

- Eye lens dose, based on the assessment using workplace monitoring results is overestimated by a factor 2-3, owing that realistic number of procedures per operator is 400-1000 (Table 2); Variations in operators' working habits are not taken into account; Still, this information provides order of magnitude of eye lens dose levels in the context of decision making for specific monitoring needs;
- Dose to the left eye is higher than dose to the right eye, which is to be expected in hemodynamic procedures in which source of radiation is on the left side;
- Variations in dose level among the operators could be explained by differences in types and number of procedures performed by individual cardiologists, as well as by different working techniques;
- Dose levels presented in Table 2 are not corrected for use of protective glasses, owing the position of dosemeters during the measurements; With respect to the fact that protective glasses are not used or not regularly used by the operators, this information is considered to be representative;
- Pilot monitoring results revealed that that left eye dose levels are in the range (10-66) µSv/procedure, e.eg. that 20 mSv eye lens dose limit could be exceeded if 300 or more procedures are performed annually;
- In such circumstances a specific eye lens monitoring is needed; if use of dedicated eye dosimeters is not practical, eye lens doses can be assessed using Hp(3)/Hp(10) ratio obtained during pilot monitoring for a particular operator, as presented in Table 2;

- Record keeping and establishment of eye lens individual monitoring is a particular challenge in this sense.

4. CONCLUSION

Available dosimetry date indicate that variation in eye lens dose levels, due to multiple influencing factors, are significant and that in certain cases eye lend dose can easily exceed newly established dose limits. The overview of available dosimetry method for eye lens dose assessment in interventional procedures is presented in this work. In particular, practical dosimetry methods that can be potentially applied in interventional procedures in radiology and cardiology are described. If a monitoring based on dedicated eye lens dosimeters is not available or practical, alternative methods based on other personal dose indices can be used, with higher uncertainty.

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Quantification of scattered radiation exposure to medical staff in the Cath lab within pelvic vascular interventions

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1. INTRODUCTION

In course of the usage of fluoroscopy during endovascular interventions, the interventionist but also other involved medical personnel (radiology technicians, anaesthesiologist) are receiving a certain dose of scattered radiation. To decrease the radiation exposure for the medical staff a great number of protection devices (hardware as well as software) are provided by the industry.

To quantify the efficiency of these protection devices (lead apron, lower- and upper table protection - such as ceiling mounted protective screen), interventions have to be simulated by means of an anthropomorphic phantom. Since the scattered radiation depends on several parameters (field of view [FOV], irradiated cross section) various interventional scenarios have to be simulated by changing above-named parameters.

To train of the behaviour of the medical staff in interventional suites, online-dosimetry systems are increasingly used. Thus, it is necessary to verify the received dose values by the usage of well-known standard dosimetry systems, such as ionization chamber, thermoluminescent dosimeter (TLD) and semiconductor dosimeter. Furthermore, the relationship between distance and incident angle has to be evaluated.

The short distance to the irradiated volume and also the large penetrated cross section within percutaneous vascular interventions can cause high exposures with ionizing radiation to medical personnel in the angiography suite. Prostate artery embolization, a new treatment of benign prostatic hyperplasia is described as a safe and effective treatment but also results in high radiation exposure for patient and medical staff caused by its complexity and the resultant increase of fluoroscopy time (Laborda et al., 2015).

2. METHODS

In our angiography suite a floor-mounted Siemens Artis zee angiography system (Siemens Healthcare, Erlangen, Germany) is in use. Accumulated dose values were quantified using a real-time dosimetry system RaySafe i3

(Unfors RaySafe AB, Uggledalsvägen 29 S-427 40 Billdal, Sweden). The PDMs are semiconductor dosimeters using four silicon diode sensors per device, with different amounts of filtration to enable beam quality calculation. The dosimeters are calibrated for a Personal Dose Equivalent Hp(10).
The aim of this study was to quantify the angular response of three (Blue, Grey, Red) personnel dosimeters (PDMs) in the horizontal and vertical plane.

Experimental setup:
A water phantom (25cm x 25cm x 15cm) was irradiated under constant conditions (63.8 kV,394.4 mA, 0.3 mm Cu-filter, 114 mGy/min) by applying digital subtraction angiography (DSA) runs with an frame rate of 7.5 images per second over ten seconds. Arising scatter radiation was detected by PDMs on the same level of the water phantom (109 cm) and distance of 60 cm. Part of the experiment was a change of the PDMs alignment in steps of 15° in the horizontal plane (first) and in the vertical plane (second).

In a second session, the issue was focused on accumulated dose values in the area of gonads and eye lens for medical staff in the angiography suite (interventionist, assistant and anaesthesiologist).
To obtain reliable and also comparable conditions, a Rando Alderson Phantom served to simulate an irradiated human body. Interventionist, assistant and anaesthesiologist were replaced by lead aprons fitted at a telescopic infusion stand. The red PDM was placed in the area of gonads (measuring height: 78 cm) and the blue PDM was affixed to a phantom head in eye area (eye level 176 cm).
Following distances were measured:
Rando Alderson Phantom – Interventionist: 78 cm
Rando Alderson Phantom – Assistant: 120 cm
Rando Alderson Phantom – Anaesthesiologist: 155cm

To determine the connection between irradiated volume and arising scatter radiation DSA runs (frame rate 7.5 fps, 10 s) were performed with a field of view (FOV) of 48 cm (70 kV, 338.7 mA, 490 mGy/min) and 11 cm (83.1 kV, 616.8 mA, 1845 mGy/min) diagonal length.
Additionally radio-protective quality of under-table shielding and upper body protection devices (Gap: shielding - phantom: 4 and 8 cm) was analysed.

3. RESULTS

Regarding the angular response of PDMs in vertical and also in horizontal plane obtained measuring results for all three PDMs (Grey, Blue, Red) exhibit almost homogenous dose values for a range between -60° and 60° in horizontal aberrance with respect to the water phantom. Beyond and also below this area a symmetrically sharp drop-off of determined dose values could be observed.
In terms of vertical tilting of PDMs, the resulting change of measured data appears in a consistently high plateau in the range of elevation angles of ± 60°. Distally to this area, similar to the horizontal angulation of PDMs, a strong decrease of detected measuring data can be seen. Especially scattered radiation vertically from above the PDMs detected less sensitive then scattered radiation from below.

In the matter of individual lens doses, results of the experiment show that under-table shielding doesn't ensure a considerable protective effect for the "Interventionist" and also for the "Assistant". The opposite trend appears for eye lens dose of the "Anaesthesiologist". The use of under-table shielding results in a dose reduction from 29.17µSv to 10.03 µSv, a resultant change of 66 percent. Regarding the application of upper-body protection devices for the "Interventionist" and also for the "Anaesthesiologist", a significant reduction of determined dose values is quantified. For the assisting staff the usage of upper-body protection devices doesn't have a strong impact on the lens dose (from 31.5µSv to 29.2 µSv).
In contrast to the protection devices, we observed, that the reduction of the FOV from 48 cm to 11 cm has a significant impact on the lens dose for all three "trail participants". Without any further protective procedures the dose exposure is lowered by an average of about 80 percent.

In terms of gonad doses of the different professional groups, we found that the reduction of FOV effects an average dose reduction amounts to 73 percent. But also the sole application of an under-table shielding ensures a mean reduction of the gonad dose of about 98 percent.

4. DISCUSSION

Radiation protection is an important issue not only for patients but also for medical personnel in the cath lab. Therefore, the consequent but also correct application of protection devices is crucial. Since individual positions in the angiography suite also result in different dose exposures, the protective effect of protection systems cannot be consistently quantified for the whole staff.
An efficient alternative to passive protection devices (lead apron, under-table shielding, upper body protection…) is the active reduction of the FOV by means of electronic magnification. Especially in situations where common protection devices can hardly be applied in a correct manner, an increased use of electronic magnification can contribute to lower the dose exposure of the staff in the intervention room.
Online dosimetry systems can have a positive effect on the behaviour of medical personnel in the range of x-rays (Khosravinia, 2013). In consideration of possible inaccuracies of displayed dose values real-time occupational dosimetry systems like RaySafe i3 can be a useful tool conditioning the staff in a dose-reducing behaviour in the cath lab.

OCCUPATIONAL DOSIMETRY IN MEDICAL IMAGING: *Overview of the activities within EURADOS WG12*

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Abstract

EURADOS is a non-profit scientific association for the promotion and co-ordination of research and development activities in the various fields of dosimetry of ionizing radiation. Sub-group 1 of EURADOS Working Group 12 "Dosimetry in medical imaging" (WG12) is specialized in the field of staff dosimetry in medical imaging. This paper presents an overview of the current activities of the group mainly focused on two topics: the eye lens dosimetry and the use of active personal dosimeters (APDs) in hospitals.

Regarding the topic of eye lens dosimetry, the actions currently in progress are: a) the collection of a large quantity of measured eye lens doses for various interventional procedures,; b) the preparation of guidelines on double dosimetry and c) organization of an intercomparison of eye lens dosimeters within European individual dosimetry services.

The topics on the use of APDs in hospitals include: a) a survey on the use of APDs in European hospitals, b) testing various APDs in various conditions (continuous and pulsed reference fields in laboratories and realistic fields in hospitals) and c) a study of the influence of the lead apron on the calibration of the dosimeters.

1. INTRODUCTION

The aim of European Radiation Dosimetry Group, EURADOS (wwww.eurados.org), is to promote research and development and European cooperation in the different fields of dosimetry of ionizing radiation. Due to the increasing use of ionizing radiation in the medical sector that has also an impact on occupational exposures and the decrease in the eye lens dose limit for the occupationally exposed personnel, a specific subgroup (SG1 Staff dosimetry) of EURADOS WG12 (Dosimetry in medical imaging) has been formed in order to study the eye lens dosimetry for medical workers as well as the use of active personal dosimeters (APDs) in hospitals. This paper presents the main work undertaken by the subgroup in the last two years.

2. TOPICS AND TASKS OF THE SUBGROUP

In the context of the decrease of the eye lens dose limit for occupational exposure to 20 mSv per year stated by the recent revision of the European Basic Safety Standards Directive 2013/59/EURATOM [1], eye lens monitoring is of great concern, especially regarding the radiation protection of workers in interventional radiology and interventional cardiology (IR/IC).

The topic of eye lens dosimetry is divided in the following tasks:

- evaluating the exposure of the eye lens of the medical staff working with fluoroscopy systems with main aim to formulate basic guidelines on eye lens monitoring,

- investigating the present situation and preparing guidelines on matters of individual monitoring related to the use of algorithms for the estimation of the effective dose and the eye lens dose when radiation protection garments are used,
- organizing an intercomparisons of eye lens dosimeters among European individual dosimetry services to check their performance in routine work for occupational monitoring for photon and beta radiations and completing the previous intercomparison (IC2014eye) [2] limited only to photon radiations.

A second topic is focused on the use of active personal dosimeters (APDs) in hospitals. Considering that occupational exposure in medicine is a matter of growing concern, APDs are increasingly used. For the staff in medical applications, they can be very useful in the context of operational radiation protection taking advantage of an immediate dose reading and an alarm at a pre-set dose and/or dose rate level. Still, when used in hospitals, and especially in the pulsed fields of interventional radiology and cardiology applications, extra care has to be taken that the APDs have the appropriate characteristics for the specific fields encountered. The energy and angular dependence, the response to betas, and the response to pulsed fields can give problems for several types of APDs.

Some years ago, the ORAMED project looked at some aspects of the APDs' use in hospitals [3]. However, at that time, the possibilities to irradiate with pulsed standardized fields were limited, and no standard was available to guide the tests. In the meantime this has been changed, and also some new devices have been placed in the market that are supposed to respond better to pulsed fields.

The topic of the use of APDs in hospitals is divided in the following tasks:

- a survey via a questionnaire on the use of APDs in European hospitals,
- testing of various APDs in different conditions (continuous and pulsed reference fields in laboratory, realistic fields in hospitals with phantoms and worn by staff in hospitals)
- a study of the influence of the lead apron on the calibration of the dosimeters.

3. CURRENT RESULTS

3.1. Eye lens dosimetry

3.1.1. Collection of a large quantity of measured eye lens doses in interventional radiology in order to prepare guidelines on eye lens monitoring

In the literature some data concerning eye lens doses already exist, especially in cardiology, but data are missing in many other specialties such as urology, pain management, gastroenterology, etc. Moreover, the methodologies used for the measurements are not always well described or even the reported eye lens doses are estimated from other quantities, among others patient doses and whole body doses.

Therefore, a measurement campaign has been launched among different European hospitals in order to collect as much data as possible to achieve a large database consisting of data obtained by using a common measurement protocol. The data gathered in the database will allow us to evaluate the exposure of the eye lens and together with the literature review, WG12 will try to formulate some basic guidelines on eye lens monitoring. Fifteen participants from 10 different countries sent data. In total 1072 data sets have been collected from 8 different medical specialties. Unfortunately, the data available per specialty was not enough to do any reliable analysis. Therefore, this database was completed with specific procedures like urology and vascular surgery where high eye lens doses are expected and some measurements can be performed from some of the collaborating groups.

3.1.2. Literature review for the preparation of guidelines on double dosimetry and eye lens monitoring

A thorough literature review was performed which included scientific papers and consolidated documents issued by different international organizations. The main conclusions are:

— The use of the algorithms strongly depends on the position of the dosimeters, the radiation protection devices; apron and thyroid collar. There is a significant influence on the X-ray setup.
— Most algorithms have been derived using the ICRP-60 coefficients instead of ICRP-103.
— The readings of dosimeters worn outside the radioprotective apron can be used to assess the eye lens exposure. Further investigation is needed on the specific algorithms.
— Special attention needs to be drawn on the calibration of dosimeters (active or passive) when they are used outside the radioprotective apron.

In order to continue the study the group agreed on a roadmap which includes the preparation of two questionnaires, one addressed to regulators and the other one to individual monitoring services in order to find out the state of the art and the common practices in Europe.

3.1.3. Organization of an intercomparison of eye lens dosimeters between European individual dosimetry services

A total of 22 European individual monitoring services from 12 different countries participated in the $IC2016_{eye}$ intercomparison. The dosimeters provided by the participants were all composed of thermoluminescent detectors, of various types and designs.

The irradiations were carried out with several photon fields (S-Cs and N-100 series defined in ISO 4037-1 standard[4], RQR6 diagnostic fields defined in IEC 61267 standard [5]) and beta radiation field series (Kr-85, Sr-90/Y-90 and Ru-106/Rh-106) defined in ISO 6980-1 standard [6]). The irradiations were performed on a cylindrical head phantom developed during the ORAMED European project [3]. Conversion coefficients to relate air kerma to $H_p(3)$ were taken from Behrens[7] for ISO 4037 qualities, from Principi et al. [8] for IEC 61267 qualities and from Behrens et al. [9], [10] for beta radiation qualities.

The irradiations were carried out at PTB (Germany) and NIOM (Poland) calibration laboratories.

Participants were asked to report the doses in terms of $H_p(3)$ using their routine protocol. The results provided by each participant were compared to the reference delivered doses. All the results were anonymously analyzed.

Regarding photon qualities (Figure 1), the results of this intercomparaison ($IC2016_{eye}$) are very similar to those obtained during the previous intercomparison ($IC2014_{eye}$), a majority of participants provides a response in accordance to the ISO 14146 standard requirements [11]. Some difficulties are noticed for setups with large angles. Regarding beta qualities (Figure 1), results show that only dosimeters designed for $H_p(3)$ are able to perform properly eye lens dose monitoring. Indeed, dosimeters designed for $H_p(0.07)$ are not suitable to monitor the dose to the lens of the eye in case of betas because they are too thin.

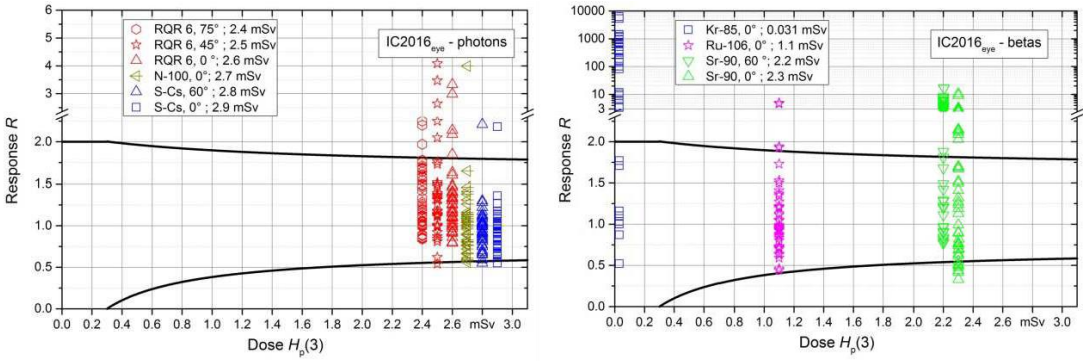

Figure 1. Summary of all reported response values as a function of reference dose for all the participants ($IC2016_{eye}$)

3.2. Use of APDs in hospitals

3.2.1. Survey via a questionnaire on the use of APDs in European hospitals

First, a questionnaire was drafted and circulated to find out the present use of APDs in hospitals. The survey confirmed that there is extensive use of APDs in European hospitals. It was also concluded that in majority of cases the calibration of APDs is not adequately addressed, as radiation beam qualities in which dosimeters are calibrated differ from those in which dosimeters are used.

3.2.2. Tests of APDs in various conditions (continuous and pulsed reference fields, realistic fields in hospitals and worn by staff in hospitals)

A systematic testing of a series of selected APDs in standardized pulsed fields is performed, together with tests in continuous fields for comparison reasons. Tests are also being performed in hospital set-ups, where realistic fields are generated using patient phantoms. The APDs are exposed in pulsed fields, to investigate if there are differences with varying pulse parameters.

Finally, 3 types of APDs were also selected to be tested in field. A large number of medical staff in several hospitals all over Europe are wearing both an APD and a reference passive dosimeter,

simultaneously for several weeks. Within this experimental campaign, differences between both types of personal dosimeters will be analysed.

3.2.3. Study of the influence of the lead apron on the calibration of the dosimeters

The influence of the lead apron on the response of both active and passive dosimeters is being tested both by experiments and MC simulations. It is clear that wearing the dosimeter above the lead apron affects its response because of the backscatter difference. Results highlight that calibration procedures in these cases might need revision.

4. CONCLUSIONS

The up to now results from SG1 tasks highlighted the need on guidance on occupational dosimetry in medical applications with emphasis on pulsed fields and the related eye lens dosimetry. The guidance can be provided by the regulatory authorities and professional organizations. SG1 of WG12 of EURADOS is currently elaborating the results of the various tasks and is planning to draft recommendations aiming at ensuring a harmonized occupational monitoring in medical imaging and at improving radiation protection of workers within Europe.

Acknowledgment: The authors acknowledge the support of EURADOS for the presented work.

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OPTIMITATION OF THE PATIENT DOSE IN PROSTATIC ARTERY EMBOLIZATION

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Abstract

The aim of the paper is to quantify the reduction of radiation doses received by the patient during prostatic artery embolization (PAE) procedures before and after implementation of Low-dose examination protocols, available on Siemens systems, based on image noise reduction algorithms combined with optimized system settings. During the procedures the following parameters were evaluated: exposure parameters (kV, mAs), number of acquired images, reference air kerma value (Ka,r) and air kerma-area product (PKA), spatial distribution of the dose to the patient's skin and of the peak skin dose (PSD). The results showed a reduction around 83% in the P_{KA} values and 86% in the value of PSD (Peak Skin Dose)

INTRODUCTION

Prostatic artery embolization (PAE) is a recent interventional procedure that is used for treating patients with lower urinary tract symptoms (LUTS) due to benign prostatic hyperplasia (BPH). The first intentional treatment of BPH with PAE in humans was published in 2010, by Carnevale et al [1]. It is a technically challenging procedure that uses a micro catheter, guided through the internal iliac and vesical arteries, to inject small particles into the arteries that nourish the prostate, to block the vessels that feed the prostate gland [2]. PAE requires a well-trained interventional radiologist because of the complex prostatic vascular anatomy and the potential for complications in elderly patients with atherosclerosis and very thin prostatic arteries. There are little data published regarding radiation dose in PAE procedures.

Our research group are evaluating the patient and staff dose in different types of interventional procedures, and recently, we evaluate the dose distribution on patient´s skin and estimate the occupational doses to the medical staff from the first cases of PAE conducted in Recife, Brazil [3]. The results showed that the mean patient's peak skin dose per procedure was 2674.2 mGy and the total P_{KA} values per procedure ranging between 322.6 –748 Gy · cm^2, with the mean value of 523.9 Gy · cm^2 [3]. These results are similar of that reported by Bagla *et al* [4].

To reduce the patient dose and optimize this procedure a new examination protocol, based on image noise reduction algorithms combined with optimized system settings, was implemented and the results of patient doses underwent to PAE procedures are presented in this paper.

MATERIALS AND METHODS

The present study was undertaken at an Interventional Department of the largest public hospital in Recife-Brazil, in cooperation with the medical team and the clinical specialist of Siemens Healthcare. The study was approved by the Brazilian National Research Ethics System (SISNEP) under the certified number 42561014.3.00005209 (CAAE). The equipment used at the institution is a Siemens Artis zee angiographic system, equipped with a flat panel image detector receptor. In the present study a group of 26 PAE procedures were evaluated. The first procedures (15 patients) were performed using the conventional protocol and 9 patients undertaken the PAE procedure after the implementation of the optimization protocol, called RECiFE (Radiation Exposure Curtailment For Embolization) protocol. This protocol is based on the use of Low-dose examination protocols, within Artis systems' CARE (Combined Applications to Reduce Exposure) and CLEAR package, which uses intelligent algorithms for noise reduction and signal boost methods, resulting in a balanced visualization of fine vessels in low-dose imaging in fluoroscopy and DSA imaging.

In order to estimate the distribution of the patient skin dose and the PSD- Peak Skin Dose, sheets (dimensions: 35.6 cm x 43.2 cm) of Radiochromic film (Gafchromic XR-RV3 - ISP-International Specialty Products, Wayne, NJ, USA) were used. The films were placed under the patient around the hip region with the orange side facing up as recommended by the manufacturer. The reflective density of the films used in the procedures was also measured after 24 h post exposure, using a reflective densitometer X-Rite Series 500. The reflective densities of the films were measured after 24 h post exposure, which is the period of time assumed to be necessary for the film darkening to stabilize. The radiochromic film was calibrate as described previously by Garzón et al 2016 [3]. The accumulated and partial P_{KA} and $K_{a,r}$ values as well as the following acquisition parameters: the number of images, the *C*-arm projections, the electronic magnifications (FOV) and the irradiation parameters (kV, mA and pulse width) for fluoroscopy, DSA and CBCT modes were extracted from Digital Imaging and Communications in Medicine (DICOM) headers at the end of each PAE procedure.

RESULTS AND DISCUSSION

Table 1 presents the mean and minimum–maximum values of the irradiation parameters used for PAE procedures performed in the both, usual and optimized protocol. The table also presents the characteristics of the patients evaluated. The results show that in the optimized protocol the value of the kV was reduced and the width pulse used to acquire DSA images to visualize the anatomy of the prostatic arteries was also reduced.

Table 1- Patient age and weight and irradiation parameters used during the PAE procedures in the usual and optimized procedure.

Parameter		Usual Protocol	Optimized Protocol
PATIENT Average – (Min-max)	Age (years)	67.3 (54-85)	71.9 (51-85)
	Weight (kg)	69.7 (60-88)	74.9 (59-96)
FLUOROSCOPY Average – (Min-max)	Time (min)	32,1 (15.8- 48.3)	26.7 (18.8-41,2)
	kV	70,0 (65-77)	66.5 (64 -71)
	mA	143.45 (114-180)	176.8 (121-233)
	pulse width (ms)	14.9 (12.7-25.3)	13,6 (11-14,7)
DSA	Acquire Time (s)	213.3 (140-291)	188.2 (143-230)
	kV	78.9 (71.0-91.0)	70.4 (68.0-77.0)
	mA	651.1 (443-776)	779.1(114-784)
	pulse width (ms)	97.6 (86.6- 111.2)	44.1 (37-50.4)
CBCT	Time (ms)	4.5 (4.4-4.6)	4.5(4.4-4.6)
	kV	108 (107- 109)	109.5 (108-111)
	mA	381.5 (367-396)	367,3 (355-379)

Figure 1 shows the distribution of the total P_{KA} values per PAE procedure, in terms of box-and-whiskers diagram. This diagram shows the quartiles of the data from each procedure, and its maximum and minimum values. The line in the box represents the median value. The results show that the distribution of P_{KA} obtained with the PAE procedures performed with the optimized protocol are lower than that obtained with the usual PAE protocol. The average value per procedure of the P_{KA} obtained with the optimized protocol is around 83% lower than the value obtained in the usual protocol. This is a consequence of the optimization of the irradiation parameters with the reduction of the kV and the width pulse to acquire the DSA images, and to use the Artis systems CARE and CLEAR package for noise reduction, obtaining an image adequate for the examination.

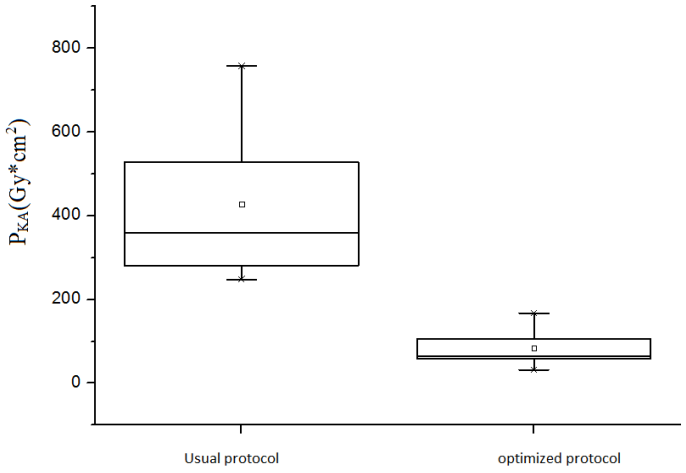

Figure 1- Distribution of P_{KA} for the PAE procedures performed with usual and optimized protocols

The patient skin dose distribution was evaluated using the radiochromic films. Figure 2 shows the images of two films, one for the patient underwent a PAE examination with the usual protocol and the other one for the patient with the optimized procedure. It was observed that with the optimized protocol the PSD (peak Skin dose) presented a reduction from 3.45 Gy to 0.487 Gy. Figure 3 shows the distribution of the PSD values obtained in terms of box-and-whiskersdiagram.

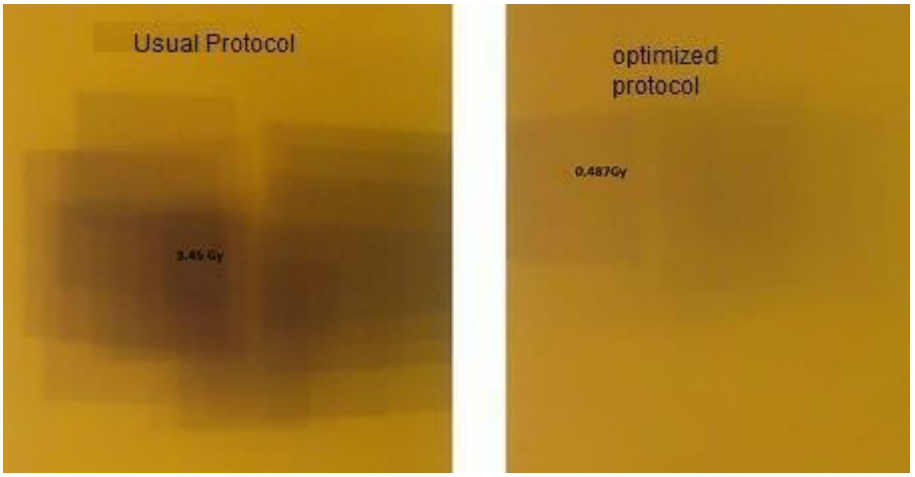

Figure 2- Patient skin dose distribution and radiation field beam variation observed on a radiochromic film used during a PAE procedures performed with the usual and optimized protocol.

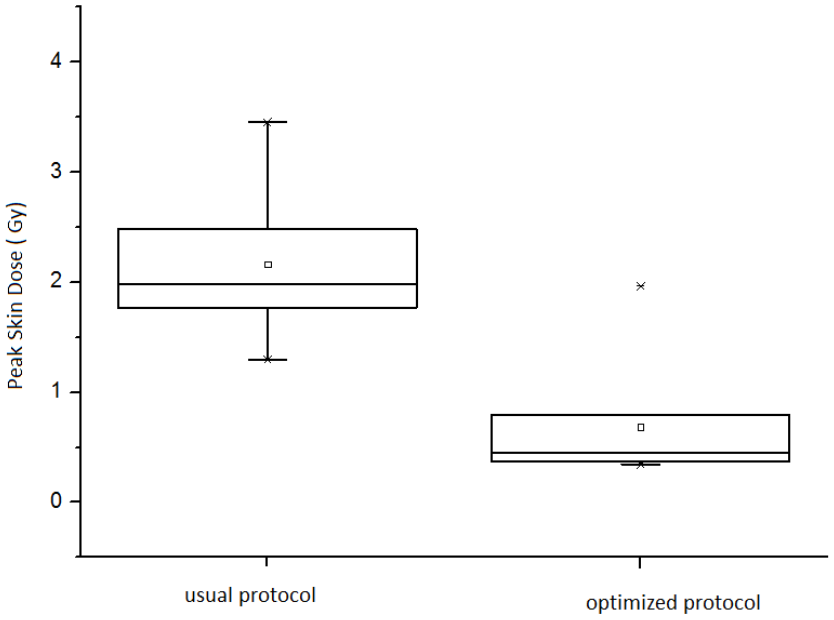

Figure 3- Distribution of the PSD values of the PAE procedure using the usual and optimized protocol

The results show that without optimization the PSD values obtained are higher than 2Gy, threshold for transient erythema. With the optimization of the procedure the PSD values decreased significantly, reducing the patient risk.

CONCLUSION

The results of this study showed that the protocol RECiFE implemented in the Interventional Department of the largest public hospital produced a significant reduction of the patient dose during the PAE procedures, and consequently the staff absorbed dose. This protocol is a result of the collaboration between the medical staff, medical physicists and the professionals of the equipment manufacturer that contributed to identify the ideal parameters to reduce the patient dose and obtain a suitable image for the procedure.

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OCCUPATIONAL EYE DOSES IN AN IRISH HOSPITAL SETTING
A six-year study in advance of the reduced eye dose limit

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Abstract

Protection of the eye lens from radiation has been in the spotlight since the International Commission on Radiological Protection (ICRP) recommended a significantly reduced eye dose limit in April 2011. Coincident with ICRP's landmark publication, in February 2011 a series of measurements were started to establish eye lens doses in key clinical areas in two Irish acute hospitals. Over the last six years, eye doses have been measured for (i) Gastroenterology (ERCP), (ii) Interventional Radiology, (iii) Interventional Cardiology, (iv) Positron Emission Tomography (PET) and (v) Endovascular procedures. In total, eye lens doses to 40 workers from more than 2,000 X-ray and PET procedures were monitored using a dedicated eye lens dosimeter to obtain results in terms of personal dose equivalent $H_p(3)$. All doses were monitored above the lead glasses (where worn) and represent dose to the unprotected eye lens. The results show that eye doses in PET and Endovascular are typically below the new ICRP limit of 20mSv/yr. Eye doses in Gastroenterology (ERCP) can be significant if the X-ray tube is used overcouch. Interventional Radiologists and Interventional Cardiologists may receive eye doses in excess of 20mSv per year, if appropriate measures are not put in place. These findings over six years have been used as evidence in establishing routine eye-dose monitoring programmes in advance of the new EU eye dose limit which will be in effect in Ireland from this coming February 2018.

1. INTRODUCTION

It is well established that occupational radiation doses from Interventional Radiology (IR), Interventional Cardiology (IC) and PET are comparatively high and can be a cause for concern [1-5]. In recent years, there has been a major focus on occupational eye doses due to the 2011 ICRP statement on tissue reactions (cataracts and other opacities of the eye lens) which recommended a reduced dose limit for the lens of the eye of 20mSv/yr [6]. The limit has been adopted into the new EU Basic Safety Standards directive [7] which must be transposed into national legislation within a period of four years; therefore it will apply in Ireland from February 2018. Gaps remain in the scientific literature in terms of reliable estimates of eye doses, particularly in terms of personal dose equivalent $H_p(3)$. Reduction of risk for radiation cataract is both possible and achievable [4] and should become part of standard radiation protection practice. Our goal was to carry out planned systematic eye dose studies in the highest risk areas to build a clear picture of eye doses in advance of legislative changes.

2. METHODS

A dedicated eye dosimeter (EYE-D™, RADCARD, Krakow, Poland) was used to measure eye doses; this had just become available at the time our work commenced in 2011 and was designed and calibrated specifically to measure $H_p(3)$ [8-10]. It was used to measure eye dose in five different diagnostic / interventional specialties across two Irish hospitals as shown in Table 1 below. The clinical setup in each room was observed prior to starting the eye dose measurements, and eye dosimeters were distributed to relevant staff based on their positions within the room. Following each measurement period (varying from 6 weeks to 5 months), all dosimeters (including background dosimeters) were returned to RADCARD in Poland to be read out. A dedicated logbook was also used during eye dose studies to record patient workload (Kerma-Area Product

(KAP) and fluoroscopy screening time for X-ray examinations; number of patients per day and typical activities for PET).

TABLE 1. CLINICAL SPECIALTIES AND STAFF MONITORED FOR EYE DOSE STUDIES

Clinical Speciality	Brief description of clinical work	Staff monitored
Gastroenterology	ERCP (Diagnostic and Therapeutic)	Gastroenterologists Nurses
Interventional Radiology (IR)	Angiography / embolization, biliary and genitourinary procedures, drainages and line placements	Interventional Radiologists
Interventional Cardiology (IC)	Coronary angiography/angioplasty, pacemakers, electro-physiology (EP) studies and Transcatheter Aortic Valve Implantations (TAVI)	Interventional Cardiologists Clinical Nurse Specialist
PET	FDG F-18 Oncology imaging	Radiographers Nurses Healthcare Assistants Physicist
Endovascular	Vascular angiography incl. EVAR	Vascular surgeons Nurses

3. RESULTS

A summary of results across all five clinical areas is shown in Figure 1 below. Results for the monitoring period have been extrapolated to estimate annual eye doses, $H_p(3)$, (mSv) based on typical workloads. Patient data was analysed to determine eye dose per procedure and eye dose per unit KAP. In total, eye doses to 40 workers from more than 2,000 X-ray and PET procedures were monitored.

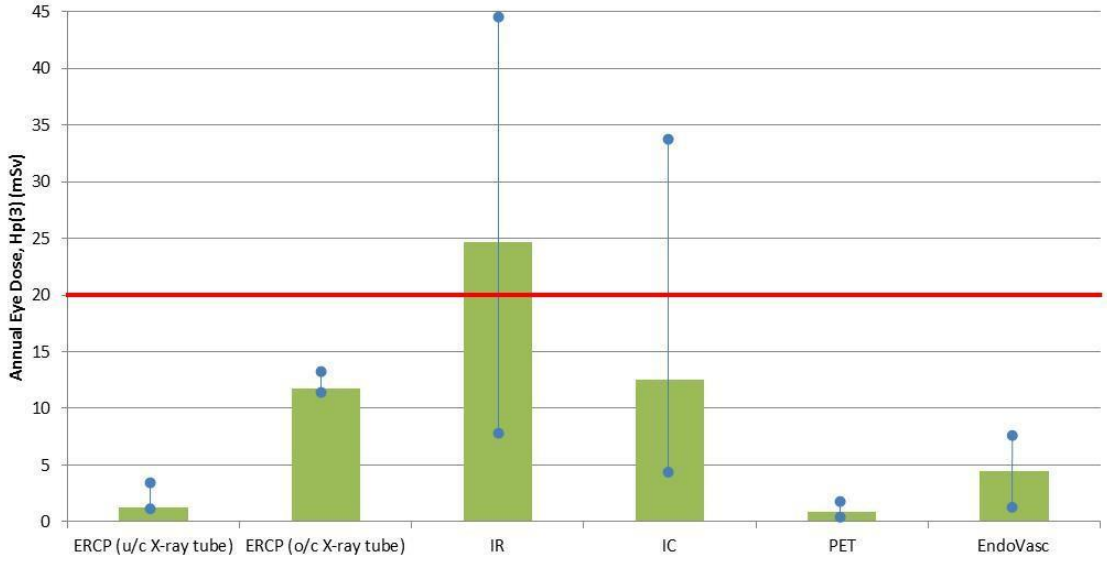

FIG 1: Annual equivalent dose to the lens of the eye from procedures in two Irish hospitals. The red line indicates the new ICRP and EU eye dose limit of 20mSv/year.

4. DISCUSSION

This series of studies across five clinical areas has established annual eye lens doses to PET and interventional workers in terms of $H_p(3)$ in an Irish hospital setting. Ongoing dissemination of results is contributing to the scientific literature in this area [11-13]. Eye dose per procedure and eye dose per unit KAP from our studies were found to be broadly in line with published figures, taking into account factors such as whether the X-ray tube was positioned overcouch or undercouch.

The eye doses quoted in this study are based on measurements taken over lead glasses, where they were worn. This was decided for pragmatic reasons largely because it is difficult to get the chosen eye dosimeter to fit securely and comfortably under lead glasses, and it is worth noting that at the time the dosimeter was chosen, it was one of the only available designs which could measure $H_p(3)$. Furthermore, the exact placement for the dosimeter under lead glasses to measure protection factors in a clinical setting, and the correction factor to be used for various styles of lead glasses is an area of debate [14, 15]. Therfore, we have taken the approach that measurements over lead glasses are repeatable, reliable in terms of positioning, unobtrusive and facilitate compliance. Doses measured above the lead glasses will overestimate eye dose where lead glasses are worn consistently, are appropriately fitted and have side shields/wraparound design. If there is no specific data available for measurements of the dose reduction, then a factor of about 2 - 3 may be applied [15, 16] provided the eyewear is of an approved design with either side shields or a wraparound design and a factor of 2 is a reasonable conservative assumption [17].

This study measured staff doses for their individual workload at one institution. Some staff will have additional radiation exposure from their workload at other institutions. Actual annual eye lens doses from all employers may further exceed the new eye dose limit, therefore sharing of personal dosimetry data amongst employers must be improved in order to protect the employee from cumulative doses exceeding annual limits [13].

Practical steps (adapted from IAEA [18]) that can be taken in advance of the reduction in the eye dose limit in February 2018 are to:

(a) identify workers that might receive a significant dose to the lens of the eye.
(b) ensure that equipment is optimised in terms of eye protection. This should be considered first and foremost at the design stage, when some degree of flexibility is still available. An example is the installation of a lead glass screen, and in some practices two ceiling-suspended screens should be considered. In addition, acquisition parameters and system positioning should be optimised to ensure adequate image quality at lowest possible dose.
(c) establish operational procedures or local rules to ensure that eye protection is optimised.
(d) require the use of appropriately fitted PPE when equipment and procedures are not sufficient. As mentioned previously, glasses should be fitted with side shields, should fit properly and should not impede operators' clinical work.
(e) provide regular updates / refresher training on importance of eye protection (including training on the protection of the patient); positioning of dosimeters, importance of compliance with dose monitoring, and advice on staff position / equipment orientation.
(f) give consideration to those with high workloads and take into account eye doses received from other facilities/employers.

5. CONCLUSION

Occupational eye doses from IR and IC procedures have the potential to exceed the new ICRP/EU eye dose limit, if adequate eye protection is not worn, for high workloads, and/or if the X-ray tube is overcouch. Primary operators performing fluoroscopically guided interventions may also exceed the new EU threshold for Category A workers of 15mSv to the lens of the eye. Lead glasses should be considered an absolute requirement for operators carrying out interventional procedures. Published correction factors for lead glasses may be used to estimate actual lens dose, however work still remains in this area. Our results show that eye doses in PET are

relatively low. Eye doses to Endovascular surgeons remain below the new limit with good radiation protection measures in place, and these must be maintained to keep doses ALARA.

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Improving the radiation safety during interventional radiological procedures- Is treatment planning a possible solution?

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Introduction:

The role of radiological procedures are increasing day by day for the diagnosis and management of various medical conditions.This necessitates the implementation of stringent radiation safety measures to be followed for the safety of the personnel , patient, and patient attendants. The safety of the radiation personnel has improved over the years and the work practices are very safe. The patients safety and patients attendants safety need to be improved.Patient attendants need to be in safe waiting areas and be provided with lead aprons in the case of they assisting the patients.

The safety of the patient needs lot of improvement. Radiation-induced injury to skin is an infrequent but potentially serious complication to complex fluoroscopically-guided interventional procedures. [1] The physician is more focussed on the treatment of the patient and less on the radiation safety aspects. The entire treatment team must be sensitized to improve the patient safety from radiation.

Aims and Objectives:

The purpose of this presentation is to report a case of radiation injury during interventional radiological procedure and suggest measures for improving the awareness and radiation safety during these procedures.

Materials and Methods:

A 49 year old male patient, medical doctor by profession, non smoker, non alcoholic, non diabetic, hypertensive with no history of major illness in the past.

He had narrowing of urinary stream for which a simple scan was done which showed a complex mass, on consulting an urologist, a CT Angiogram was done which diagnosed it as pelvic AVM of 15 x 16 cm size. (Arteriovenous malformation) with multiple feeders. After taking opinion from many physician and surgeons and looking at the complex nature, he opted for intravascular embolisation through interventional radiology.

A preliminary pelvic angiogram was done and was told that it was a not a complicated one and that the procedure would be completed in 1 to 1 ½ hour. Next day the case was posted. The procedure lasted 6hrs and It went uneventfully and patient got discharged after 2days.

After 14 days of discharge from the hospital there was discoloration, itching on forearm and both gluteal regions (buttocks) presenting like a geometrical area showing the marks of the radiation fields. Later it became painful and skin got peeled off. They were told that it is not related to the procedure, it could be contact dermatitis or Herpes, when it worsened, became more painful and whole area got denuded, they were asked to consult a dermatologist, who was not sure about the cause and that, it does not fit into any particular skin condition. Advised symptomatic treatment like pain killers and daily skin dressings, on daily dressings the lesions got healed except for a small area 3 x 2 cm on forearm and 10 x 8 cm on right gluteal region which become chronic and non healing.

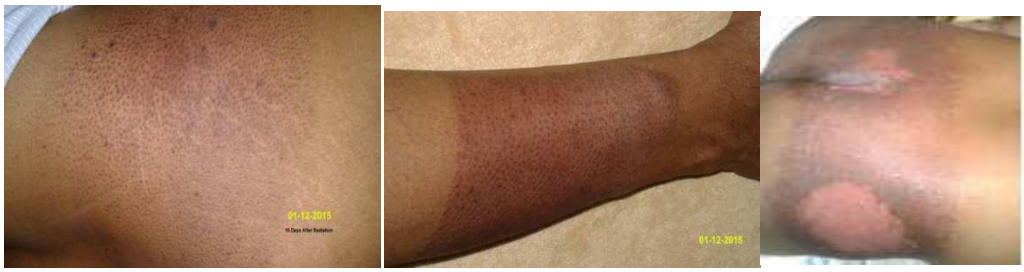

Figure1, Fifteen days after procedure

(Discoloration of skin on both gluteal regions and right forearm)

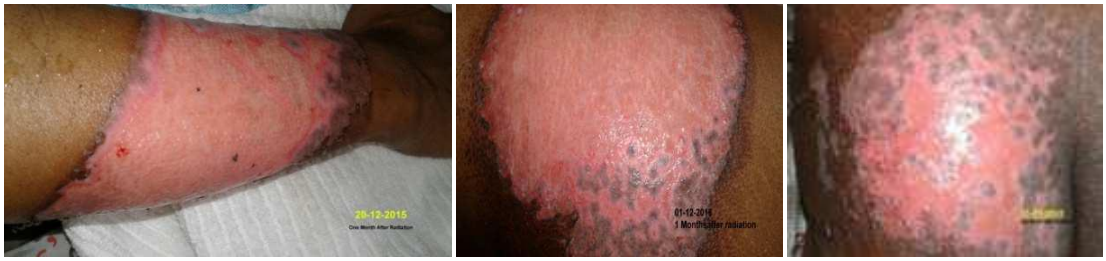

Figure-2 , One month after procedure
(Gradual denuding of skin on right forearm and both gluteal regions)

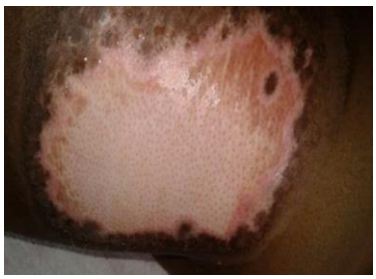

Figure-3, After two and half months of procedure

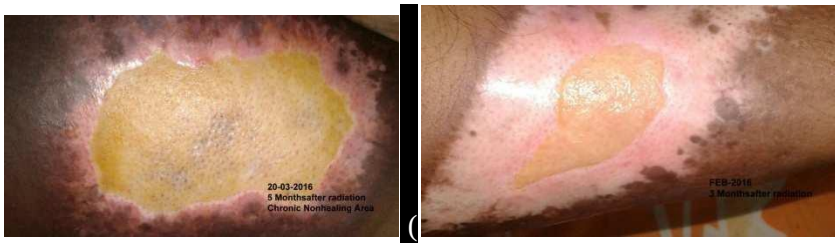

Figure-4, Five months after procedure. (Non healing ulcer on right gluteal region)

(Non healing ulcer on right forearm)

Result: The patient had to go around finding doctors who had the expertise to treat his radiation injuries. The patient had to undergo multiple grafts, hyperbaric oxygen treatments, had multiple infections needing multiple courses of antibiotics and had to go through severe pain and trauma necessitating multiple pain killers. Apart from the disfigurement and deformity there is debility. The patients life and his family life were disturbed for more than a year. There is the additional risk of malignancy due to this radiation.

Discussion: Definitely any physician will perform a procedure with the good intention of improving the quality of life of a patient. In this case too the physician must have done the same. But lack of awareness of the possible radiation injuries on prolonged radiation exposure and the precautions to be taken for avoiding radiation injuries seem to be missing. General practitioners and dermatologists, who are usually the first physicians to examine patients with these skin changes, should be familiar with radiation-induced erythema and a history of a relatively recent radiological procedure is important to recognize. Patients may not be aware that the radiological procedure he/she has had can lead to erythema and therefore, may not provide a history of recent radiological procedures unless specifically asked. In some cases, the dermatologist may not recognize radiation as the cause of the skin changes and proper diagnosis may be delayed, sometimes with serious consequences for the patient.

Informing the patient about the chances of radiation injuries is must so that patient is aware when he sees any change in skin colour. The physician must also look for any extra sensitivity of the patient to radiation. Definitely the injury to the arm could have been avoided or the severity could have been less, if the beam angles were changed instead of continuous exposure from the same entry point. The lesson here is how to improve the safety of these procedures and create larger awareness of radiation amongst the patients, staff and general public. In developed countries the regulations are followed, but in developing countries and under-developed countries the public awareness must be increased so that they will also demand for their safety from radiation. For example if there is awareness of seeking

lead apron while undergoing dental radiograph and also using thyroid guard or using a half skirt lead apron while taking chest radiograph will be practised.

One technique deserves comment. Based on the kerma-area product, one manufacturer produced a method of monitoring the collimation and the position of the X ray beam relative to the patient's skin surface in order to assess dose to the skin of the patient [2, 3]. The device also provided a real-time map of the dose that displayed a picture of how dose changed across the skin surface. The physician could see where dose was building. This proved to be a very useful device to some investigators, but the demand for the device was so low among users that the manufacturer ceased offering it as an option on their equipment[4]. It is very sad to note such a useful device providing instantaneous dose to the physician had no takers. It is not possible for the physician to spend more time on monitoring dose received by the patient as his primary concentration will be on performing the procedure. He has to maintain a balance between the procedure and the patient safety. The Interventional Radiologist must procure suitable devices for dose monitoring. The device must be easy for the physician to read and understand the dose received by the patient. Gafchromic film is another option for instantaneous reading of the radiation dose received by the patient. All this will require a technologist trained to monitor the machine parameters and also monitor the radiation doses.

Careful planning of the procedure, optimization of imaging parameters and training of staff are essential measures for the avoidance of an excessive dose to patients [5, 4, 6]. Routine evaluation of DICOM dose reports and real-time dosimetry are extremely helpful to optimize radiation protection of patients during interventional procedures. Some vendors even provide skin dose maps which can be of assistance in the identification of areas of skin at high risk [7].

Modern angiographic equipment provides very helpful tools for decreasing and monitoring patient dose and, therefore, avoiding skin injuries[8] . This reference which has come very recently has given in good detail about the various factors responsible for the doses received by the patient describing the genetic pre dispositions, underlying health conditions etc, this gives a good insight for the interventional radiologists. Those operating with older equipments must update their equipments with patient radiation dose monitoring devices before they continue to use them.

Most of the patients do undergo CT scan and with those 3 D images using a treatment planning soft ware the procedure must be planned and dose estimation must be done. This soft ware must take in to account the medical history including the genetic disorders, other chronic conditions, age of the patient, any drug therapy received, previous radiation exposure, BMI, complexity of the existing problem etc. The soft ware must give a plan for performing the procedure with multiple beam angles to be used, total treatment time and possible skin doses likely to be received by the patient. If there is a deviation from the given plan the angles, duration of exposure can be noted and replanned to get the actual dose delivered to the patient. This will help to estimate the risk of radiation injuries.

When all radiation deliveries in Radiation Oncology are planned using dedicated soft ware on treatment planning systems, the same benefit must be available for those undergoing fluoroscopy guided procedures. The Cathlabs and DSA machines cost a lot and adding planning system to it will not be a too much of burden. Also considering the volume of the machines the cost of planning systems can be made low. Already several planning systems with different soft wares for different radiation energies are available for radiotherapy. So developing one for diagnostic procedures must be easier. It must be made mandatory to have a planning system for planning any procedure under the guidance of ionising radiation. When a simple radiograph is obtained with a dose area product meter and dose delivered to the patient is recorded. The same approach must be given to the patients on CT and fluoroscopy, who constitute the patients receiving maximum radiation dose in diagnostic radiology[8].

Over the years cardiologists have acquired independent catheterization laboratories (cath labs) but have not been trained in the same way as radiologists[9]. This creates definite radiological protection problems for patients and for cardiologists themselves [10,11]. Still the situation has not improved radiologists get a brief exposure to radiation protection and other professionals are still in the dark. The radiation protection in medical procedures must be made part of the post graduate curriculum. At our institute we started a radiation safety lecture for all the medical post graduates of all specializations giving an brief exposure to radiation safety , possible hazards and protection methods.

It must be made mandatory to have a medical physicist in Diagnostic departments too who will also supervise the procedures in cathlabs in cardiology department. As it is mandatory for the presence of medical physicist in Radiation oncology department, the same must be implemented in radiology and nuclear medicine departments too. In addition to the medical physicist the technologists, doctors also must undergo reasonable training in dose monitoring and radiation safety. All this will result in net positive benefit for the patient with very minimal side effects.

Conclusions:

1, A **Simple Interventional Procedure Planning Software**(SIPPS) can be developed like that used in radiation therapy planning where we can determine the possible angles of radiation head, couch angles(table position) , collimation, which will give clear view of the patient anatomy for the procedure to be performed. They can have the possibility of 5-6 angles especially for complicated cases which involve larger beam on times. The output of the soft ware must give a projected estimate of skin dose mapping of the patient. The soft ware must have inputs of the dose rate at various skin distances, predisposing factors, complexity of the patient problem, anatomical location. This treatment planning must be made mandatory and will form the basic guidance for interventional procedure's involving radiation.

2, There must be time limitation for each angle and avoid overlapping of beam entry angles with proper collimation, with alarm when time limit is exceeded. **Avoiding sensitive organs** in the path of radiation like thyroids, female breast (in case of female patients), gonads etc.

3, Basic radiation safety **lectures to doctors** in the under graduate medical courses and advance level radiation safety lectures in the postgraduate medical courses and must be made part of their curriculum. The clinician and technologist must be imparted good knowledge about radiation machines they are operating and using.

4, **Patient consent forms** must have a mention of the possible radiation burns and instructions must be given to patients, how to identify the burns and ask them to report immediately. Medical history of the patient is very important to be aware of any predisposing risk factors like , coexisting diseases, medications usage, radiation history, pregnancy, hyperthyroidism, diabetes mellitus etc.

5, Public awareness about radiation safety and radiation hazards must be improved. There is a lack of radiation safety knowledge even amongst the health workers. Radiation safety awareness for patients must be disseminated through the investigation **order forms and posters.**

6, **Radiation safety posters** in vernacular languages must be **mandatorily** provided to the users along with the sale of machines. These posters must be put on the entrance of rooms housing radiation equipment's.

7,Thyroid shields, gonadal shields, half lead aprons, wrap around lead aprons, must be used when ever possible and required. Thyroid shields must be made **mandatory** for all interventional radiation procedures.

8, We all must strive to keep the **GSD(genetically significant dose) value as low** as possible. All unnecessary radiation exposures must be avoided to keep the doses low and avoid additional possible mutations.

9, Special care in the case of **paediatric patients** with regard to radiation protocol used and use of possible radiation shields to avoid any unnecessary dose to gonads and thyroids.

10, The presence of medical physicist in Radiology departments too must be made mandatory for safe use of radiation.

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EYE LENS EQUIVALENT DOSE $H_P(3)$ IN IC/IR: RELATION WITH $H_P(0.07)$ AND KAP

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Abstract

The ICRP has recently recommended reducing the occupational exposure dose limit for the lens of the eye to 20 mSv y^{-1}, averaged over a period of 5 years, with no year exceeding 50 mSv, instead of the current 150 mSv y^{-1}. This reduction will have important implications for interventional cardiology and radiology personnel. The paper investigates the relation between the eye lens equivalent dose $H_p(3)$ and the personal dose equivalent at 0.07 mm depth $H_p(0.07)$, measured at the left side of the thorax, on the lead apron, together with the relation between $H_p(3)$ and the Kerma area product (KAP). In spite of a good correlation between $H_p(3)$ and $H_p(0.07)$, a large variability of $H_p(3)/H_p(0.07)$ and $H_p(3)$/KAP ratios is observed. This

highlights the difficulties for finding a unique correction factor in order to estimate $H_p(3)$ from $H_p(0.07)$ or KAP, valid for all clinical procedures.

Based on our measurements the recommended correction factor is $H_p(3) = 0.8\ H_p(0.07)$ for physicians and $H_p(3) = 1.2\ H_p(0.07)$ for nurses. Larger variability is observed when comparing $H_p(3)$ and KAP. Therefore the use of a correction factor to derive eye lens dose from KAP is not recommended.

1. INTRODUCTION

ICRP 118 [1] recommends the reduction of the actual limit for the eye lens dose of 150 mSv/year to 20 mSv/year for workers exposed to ionizing radiation, based on epidemiological evidences on very late cataract manifestation. The new proposed dose limit of 20 mSv has been incorporated into the revised European and International Basic Safety Standards [2] and it should be implemented in national legislation of the European member states in 2018. This drastic change in the eye lens dose limit will have relevant consequences in radiation protection for interventional cardiology and radiology staff (IC/IR) [3].

Up to now, eye lens dose is not routinely measured and there are no general international recommendations regarding procedures on how correctly estimate the dose to the eye lens. At this regard, the present work investigates in real IC/IR conditions the relation between the eye lens equivalent dose $H_p(3)$ and other quantities, easier to measure such as $H_p(0.07)$ with an unprotected whole body dosemeter situated at the chest or the KAP registered for each performed procedure.

2. METHODS

A well-established calibration procedure and an easy-to-use dosemeter for the eye lens have been set-up to accurately measure eye lens doses in terms of $H_p(3)$ for photon radiation fields typical of IC/IR at the Calibration and Dosimetry Laboratory of the INTE-UPC [4]. The eye lens dosemeter is constituted by a LiF:Mg,Cu,P thermoluminescent detector and a polyethylene (PE) casing. The detector is a TLD-2000C type, with a diameter of 4.5 mm, a thickness of 0.8 mm and a corresponding density of 2.65 g/cm^3. Measurements were carried out at four Spanish hospitals. The monitored workers belonged to hemodynamic, vascular cardiology, endoscopy and electrophysiology units. The hospitals are anonymously identified by numbers from 1 to 4. 24 physicians and 12 nurses participated in the campaign. The monitoring period varied depending on the workload and availability of the participants. Eye lens dosemeters and whole body dosemeters were individually identified and assigned to all participants. $H_p(3)$ quantity is used to monitoring the dose to the eye lens. As the left side was usually the closest to the X-ray tube, the eye lens dosemeters were located on the external left side of the glasses or, when glasses were not worn, the dosemeter was stuck on the left side of the cap. An additional whole body dosemeter for the estimation of personal dose equivalent $H_p(10)$ and $H_p(0.07)$ was supplied to the staff and it was located on the left side of the thorax, on the lead apron. $H_p(0.07)$ is used to assess the dose to the skin and extremities.

The relationship between $H_p(3)$ and $H_p(0.07)$ or KAP is analysed. Only first operator physicians (not assistant physicians) who do not work with paediatric patients were considered in this study to improve the correlation between quantities. As regards the analysis of the relation between $H_p(3)$ and $H_p(0.07)$, the quantity $H_p(0.07)$ was chosen as no statistical differences were observed between $H_p(0.07)$ and $H_p(10)$, given by the same whole body dosemeter ($p>0.05$). Thus, both quantities could be used in the future to verify the correlation with $H_p(3)$. A least square fit was performed to derive the linear relationship between $H_p(3)$ and $H_p(0.07)$ and between $H_p(3)$ and KAP for both physicians and nurses. The square of the Pearson coefficient R^2 is used to measure the strength of the linear relationship. Mean, maximum, minimum, standard deviation of the mean, median, N, R^2 and the slopes of the linear regressions are tabulated for each hospital in Tables 1 and 2 for physicians and nurses respectively. The value N stands for the number of data values collected (not for participants).

TABLE 1. Descriptive statistics for the ratios $H_p(3)/ H_p(0.07)$ and $H_p(3)$/KAP for physicians from the four hospitals.

	Hospital 1		Hospital 2		Hospital 3		Hospital 4	
	$H_p(3) / H_p(0.07)$	$H_p(3)$ / KAP	$H_p(3) / H_p(0.07)$	$H_p(3)$ / KAP	$H_p(3) / H_p(0.07)$	$H_p(3)$ / KAP	$H_p(3) / H_p(0.07)$	$H_p(3)$ / KAP
Mean	0.78	0.7	1.6	0.9	0.7	0.6	2.6	1.9
Max	0.96	1.0	6.0	1.8	1.1	1.1	6.8	3.8
Min	0.56	0.3	0.5	0.1	0.4	0.2	0.8	0.4
sd (mean)%	12%	23%	35%	19%	11%	21%	15%	11%
Median	0.80	0.7	1.1	1.0	0.8	0.8	2.2	1.8
N	4	4	9	10	10	8	20	18
R^2	0.7	0.5	0.9	0.5	0.7	0.7	0.8	0.6
Slope	0.70	0.6	0.85	1.0	0.77	0.6	1.40	1.7

TABLE 2. Descriptive statistics for the ratios $H_p(3)/ H_p(0.07)$ and $H_p(3)$/KAP for nurses from Hospitals 2 and 4.

	Hospital 2		Hospital 4	
	$H_p(3) / H_p(0.07)$	$H_p(3)$ / KAP	$H_p(3) / H_p(0.07)$	$H_p(3)$ / KAP
Mean	1.3	0.5	1.3	0.4
max	1.9	1.6	2.4	3.2
min	0.7	0.04	0.8	0.1
sd (mean)%	7%	20%	12%	66%
Median	1.2	0.5	1.0	0.2
N	7	7	11	11
R^2	0.9	0.5	0.8	0.5
Slope	1.2	0.15	1.2	0.45

Data from Table 1 for $H_p(3)/ H_p(0.07)$ show variability of the mean ratios for physicians at each hospital within 11% (Hospital 3) and 35% (Hospital 2). Except for Hospital 2, there is a good consistency between the mean and the median values. The highest $H_p(3)/ H_p(0.07)$ is obtained for Hospital 4. The main difference between Hospital 4 and the other hospitals is the unusual use of the ceiling suspended screen during a procedure, or its misplacement. Then, the thorax may be better protected than the head. Lower variability is found for nurses. This is due to the fact that nurses are exposed to a more homogeneous radiation field than physicians because of different proximities to the source. Mean $H_p(3)/ H_p(0.07)$ is close to unity, and a low spread of values is observed (7% and 12% for Hospital 2 and Hospital 4, respectively). R^2 values show a good correlation between $H_p(3)$ and $H_p(0.07)$ for nurses (R^2 = 0.8, 0.9). Lower R^2 but still good correlations are found for physicians, as R^2 is within the range 0.7 to 0.9.

As regards the relation with KAP, the spread of values for physicians is about 20% and mean values range from 0.6 to 1.9. The highest $H_p(3)$/KAP is found again for Hospital 4. This confirms that the use of the ceiling suspended screen is not optimized. On the other hand, $H_p(3)$/KAP for nurses is about 0.5, which underlines the fact that eye lens equivalent doses for the same amount of KAP are, in general, lower for nurses with respect to physicians. The range of variability for nurses is wider than for physicians and the standard deviation measured for Hospital 4 is 66%.

3. DISCUSSION

$H_p(3)$ and $H_p(0.07)$ show a good correlation for all hospitals. Nevertheless, mean $H_p(3)$/ $H_p(0.07)$ vary from 0.7 to 2.6. Considering all hospitals together, the correlation between $H_p(3)$ and $H_p(0.07)$ for physicians is of about 0.7 but increases up to 0.9 when disregarding measurements from Hospital 4, which shows a different tendency with respect to the other hospitals. The slope of the lines may be considered the best correction factor to assess $H_p(3)$ from $H_p(0.07)$ measurements. A correction factor for physicians of $H_p(3) = 0.8\ H_p(0.07)_{thorax}$, is derived from the slope values of Hospitals 1, 2 and 3. The result is in agreement with ratios between eye lens dose and thorax dose found in literature [5, 6]. A correction factor of $H_p(3) = 1.2\ H_p(0.07)_{thorax}$ is obtained for nurses. The main difference between physicians and nurses is the proximity to the scattered field. This would explain the discrepancy in the two values (0.8 vs. 1.2).

The correlation of $H_p(3)$ with respect to KAP is, in general, worse than with $H_p(0.07)$. R^2 ranges between 0.51 and 0.69 for physicians and is 0.5 for nurses. Therefore, $H_p(3)$/KAP is not recommended as a good indicator of eye lens equivalent dose, especially for nurses. Furthermore, the KAP does not take into account the protection provided by the use of the room protection equipment, as the ceiling suspended screen. The reason why Hospital 4 presents again a different trend compared to the other hospitals may lie in the fact that the use of protection is not sufficiently promoted and in the different use of projections during interventional procedures with respect to the other hospitals [7].

4. CONCLUSIONS

Results on the relationship between eye lens equivalent dose and skin dose or KAP show that even when a good correlation is found, a large variability among values is observed. The relationship is dependent on the type of procedure, position of the monitored person and use of protection means. Results highlight that the relation between $H_p(3)$ and $H_p(10)$ or $H_p(0.07)$ measured on the chest with an unprotected whole body dosemeter is more reproducible than the relationship between $H_p(3)$ and KAP, in particular in the case of nurses. However, the variability of the ratio between $H_p(3)$ and $H_p(0.07)$ cannot be disregarded. Thus, the use of the equation $H_p(3) = 0.8\ H_p(0.07)_{thorax}$ for physicians is only recommended for monitoring of staff exposed to eye lens doses below 6 mSv or in order to identify which individuals are likely to require regular eye lens monitoring. For individuals at risk, the use of a dedicated eye lens dosemeter is strongly recommended. Furthermore, for Hospital 4, the high $H_p(3)$/KAP indicate a misuse of the protections. Therefore, a training campaign in order to improve the consciousness of the radiation risk and the use of protection tools should be performed for physicians especially coming from this hospital.

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A PILOT-STUDY OF PATIENT DOSES IN INTERVENTIONAL CARDIOLOGY SUITS IN LEBANON

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Abstract

The aim of the study is to investigate the current status of patient doses in interventional cardiology (IC) suits in Lebanon through the establishment of preliminary national Dose Reference Levels (DRLs) for coronary angiography (CA) and percutaneous transluminal coronary angioplasty (PTCA) procedures. A sample of online dose indicators was collected from 6 different facilities for CA and PTCA procedures. A total of 2000 examinations were registered. Patient exposure was investigated through the 75th percentile of the online dose indicators. Preliminary DRLs, proposed for CA and PTCA from a sample of 6 Lebanese hospitals, were higher than those reported in the literature especially for PTCA procedures revealing the use of non-optimized protocols and/or a lack of radiation protection awareness among the majority of the Lebanese cardiologists. Consequently, a dose optimization strategy should be implemented at a national level and the RP culture/laws should be reinforced in IC in Lebanon. A national registry of radiation-dose data for IC procedures is a necessary next step to refine these DRLs.

1. INTRODUCTION

Potential deterministic radiation effects on the patient's skin can be induced by the use of X-rays during IC procedures. Since the early 1990s, reports of radiation-induced skin injuries to the patients have dramatically increased as a result of complex procedures. Reported injuries range in severity from mild erythema and hair loss to deep skin necrosis, sometimes involving even deeper tissues in the level of bone and spine [1,2].

To monitor and optimize the radiation doses delivered to the patient in IC, DRLs have been increasingly considered [3] for interventional procedures. However, the setup of DRLs in IC is a difficult task due to the large variability of the Fluoroscopy Time (FT) and the Number of Acquisitions (NoA), differences in the techniques and protocols used, the variability in the complexity of the cases and the experience of the interventional cardiologist [4]. In Lebanon, approximately, 400 persons are working in IC suits: 175 interventional cardiologists (first operator) and 225 technologists and/or nurses (second operator). The number of private IC centers is 80 while only 5 centers are in public hospitals. The annual number of all IC procedures performed during 2016 varies from 10000 to 15000 per one million of inhabitants, from which 75% were for diagnostic purposes.

Unlike in radiotherapy, the presence of a medical physicist in radiology is not yet a national legal requirement. Furthermore, NRLs are still lacking in Lebanon. Hence, no dose reduction strategy is defined and the X-ray equipment is usually used with default fluoroscopy and acquisition parameters.

To enhance the legal situation in Lebanon, this paper aims at investigating the current status of patient doses in IC suits. A first sample of online patient dose indicators was collected and compared against RLs from previous publications for two most common cardiac procedures, CA and PTCA.

2. MATERIALS AND METHODS

The study was carried out from March 2016 to May 2017 and included 2000 patients, 1400 of whom underwent CA and 600 PTCA with stenting in one or more coronary stenosis in six different Lebanese hospitals. The 6 fluoroscopic units used were from a single manufacturer, General Electric healthcare, USA. Each unit undergoes regular maintenance and annual calibration by the supplier. Additionally, all the units are equipped with flat panel detectors, which are always positioned above the examination table and offer a choice of four imaging fields of dimensions 20 × 20, 17 × 17, 15 × 15 and 12 × 12 cm. In addition, all units are capable of performing low and standard dose fluoroscopy, with 15 or 30 pulses per second, and an image acquisition rate of 15 or 30 frames per second. kV and mA in both fluoroscopy and cine mode are regulated by an automatic exposure control system.

For each examination we recorded the following: FT, Dose Area Product (DAP), cumulative air kerma at interventional reference point (CD) as well as NoA. The patient's sex, age, height and weight were recorded, as was the name of the physician who performed the examination. The workload varied from 2 to 12 cases per day among the selected facilities. More than 22 interventional cardiologists performed all procedures included in this study.

Data were pooled for each procedure. Third quartiles from the total dosimetric databank were calculated and proposed as provisional national DRLs for FT, DAP, CD and NoA.

3. RESULTS

Patients range in age from 29 to 93 years (mean 63 years). Of the 2000 procedures, 1300 (65%) were performed on male patients and 700 (35%) were performed in female patient. Subjects' height and weight ranged from 149 to 193 cm (mean 170 cm) and from 41 to 140 kg(mean 80kg) respectively.

Online dose indicators are available on 40% of the interventional cardiology equipment (40 hospitals) in Lebanon. Six institutes were selected arbitrary to be included in this survey and dose indicators from 2000 examinations were collected: 1400 CA and 600 PTCA procedures. The mean, ranges and interquartile 3 (Q3) values for FT, CD, DAP and NoA dose indicators are shown in Table 1 and 2 for CA and PTCA procedures respectively.

TABLE 1. PATIENT DOSE DISTRUBUTIONS FOR THE SIX HOSPITALS INCLUDED IN THE STUDY FOR CA PROCEDURES

Hospital	FT (min)		CD (mGy)		DAP(Gy.cm²)		NoA	
	mean	Q3	mean	Q3	mean	Q3	mean	Q3
A	4 (1-28)	5	282 (20-1755)	337	20 (1-187)	24	316 (5-999)	373
B	4 (1-24)	5	819 (59-3379)	1002	54 (4-520)	64	521 (62-1857)	626
C	4 (1-18)	5	854 (75-3338)	1120	61 (8-210)	79	490 (172-1305)	586
D	3 (1-12)	5	539 (41-1745)	729	37 (3-115)	51	712 (217-2013)	909
E	3 (1-13)	5	608(99-2008)	749	47 (8-156)	63	635 (145-1802)	772
F	3 (1-25)	3	770 (245-2421)	898	68 (21-298)	80	504 (253-1058)	589

TABLE 2. PATIENT DOSE DISTRUBUTIONS FOR THE SIX HOSPITALS INCLUDED IN THE STUDY FOR PTCA PROCEDURES

Hospital	FT (min)		CD (mGy)		DAP(Gy.cm²)		NoA	
	mean	Q3	mean	Q3	mean	Q3	mean	Q3
A	12 (3-50)	13	785 (55-3381)	1140	55 (1-294)	78	603 (56-1365)	763
B	15 (4-133)	17	2337 (263-10690)	2739	144 (20-645)	166	1002 (326-2229)	1257
C	12 (3-44)	14	2630 (662-8533)	3036	170 (37-570)	205	1029 (289-4011)	1090
D	17 (4-49)	22	1337 (94-3543)	1842	88 (8-225)	120	1176 (270-3446)	1504
E	15 (5-53)	17	2439 (258-7187)	2967	185 (22-565)	224	1353 (397-2586)	1528
F	10 (3-33)	13	2157 (280-6255)	2819	189 (23-559)	237	865 (232-1564)	1032

Tables 1 and 2 reveal interesting features about the use of fluoroscopy in Lebanon. Maximum values of 28 and 133 min of fluoroscopy were collected in some cases for CA and PTCA procedures respectively. Moreover, more than 2000 (respectively 4000) acquisitions were acquired in some cases for the mentioned procedures. This leads to CDs as high as 3 Gy and 10 Gy and DAPs as great as 500 and 600 Gy.cm² for CA and PTCA respectively.

Additionally, the 75th percentile of online dose indicators of the data collected from the six hospitals, for both CA and PTCA, was compared against DRLs determined in the framework of SENTINEL (2008) [5] project and those established by Balter et al. (2008) [6] and the recent multicenter French study of Georges et al. (2016) [7]. The comparison is presented in Table 3.

TABLE 3. COMPARISON OF THE 75th PERCENTILE (RLs) VALUES FROM THIS STUDY AGAINST RELEVANT LITERATURE FOR CA AND PTCA PROCEDURES.

Type of examination	Study	Patient	FT (min)	CD (mGy)	DAP(Gy.cm²)	NoA
CA	This study	1400	5	869	62	597
	SENTINEL(2008) [5]	672	6.5	650	45	700
	Balter et al.(2008) [6]	NA	9	NA	50	1000
	Georges at al.(2016)[7]	51229	6	498	36	566
PTCA	This study	600	18	2405	158	1165
	SENTINEL(2008) [5]	662	15.5	1500	85	1000
	Balter et al.(2008) [6]	NA	22	NA	125	1355
	Georges at al.(2016)[7]	42222	15	1285	78	960

Preliminary Lebanese national DRLs, except for the FT and NoA for CA and PTCA, are higher than those reported in the literature. CDs of 0.8 and 2.4 Gy and DAPs of 62 and 158 Gy.cm² are proposed as initial NRLs for CA and PTCA procedures respectively.

4. DISCUSSION

Although the importance of education and training in radiation protection (RP) is acknowledged by all international bodies [8-13], only a few general courses about radiation physics/protection are given to the operators throughout their MD degree and, in general, no practical/day-to-day training on dose reduction techniques are available in Lebanon.

From the six hospitals mentioned in Tables 1 and 2, only the operators from hospital A follow continuous training in RP and participate in international conferences on dose optimization. Patient doses in this specific hospital are low when compared to the other hospitals mentioned in this study and those from the literature. This is due to a low number of acquisitions and dose per acquisition employed by hospital A's operators. In addition, all the operators working in this hospital use regularly all protective clothes including caps, leaded glasses, thyroid collar, lead apron in addition of the ceiling mounted shields and table lead skirts to reduce their occupational doses.

Diagnostic/interventional procedures demonstrated a wide variation in patient dose for the same examinations type. There is an expanding use of high radiation dose modalities to perform IC procedures in Lebanon which results in high patient exposures. The measured CD, for some patients, lies within the levels of causing transient erythema. Thus, to promote radiation safety, facilities performing IC procedures need to record radiation dose and to establish a radiation monitoring notification threshold for possible deterministic effects, a system of tracking CD and/or DAP in case of repeated procedures, a follow-up procedure to check the patients back for possible skin burns and a more accurate way of assessing patient maximum skin doses.

In view of the results presented above, the influence of operator's education on optimizing patient doses is patent. Bad practice among cardiologists is the sign of lack of radiation safety culture. Training on RP is one of the

basic components of optimization programs for medical and occupational exposure and reducing patient doses while maintaining a good image quality.

5. CONCLUSION

This work reviewed patient doses in IC suits in different public and private Lebanese hospitals. Patient online dose indicators collected from six different hospitals showed large variability. Proposed preliminary DAPs and CDs's NRLs, for CA and PTCA procedures, were beyond acceptable dose limits.

This paper is a first step towards the establishment of NRLs and the reinforcement of RP culture/laws in IC. Patient dose data presented here will help hospitals/authorities to visualize the status in Lebanon and will hopefully lead to increase the RP awareness among health professionals. Continuous collection and analysis of radiation-dose data from a large number of institutions will certainly permit considerable refinement in RLs.

ACKNOLEDGEMENTS

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MEASURING INSTRUMENT FOR ENERGY AND ANGLE DISTRIBUTION OF TYPICAL MEDICAL RADIATION FIELDS

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Abstract

The characterization of radiation fields at medical workplaces is mandatory to assess the radiation exposure of medical personnel and to recommend radiation protection procedures. Measurements with active direct reading are very challenging considering the pulsed radiation in these fields. Spectrometry with conventional set-ups fails due to the high photon flux during a short radiation pulse. In this study a portable detector system, which is capable of measuring pulsed fields, has been developed based on the conjunction of a $CeBr_3$ scintillator and a Geiger-Avalanche-Photodiode-Array. First measurements are shown.

1. INTRODUCTION

The characterization of the radiation fields at medical workplaces is necessary to assess the dose to the medical stuff and provide a database for necessary radiation protection precautions. In order to be able to determine several measuring quantities such as doses equivalent in different depths (*H'(0,07)*, *H'(3)*, *H*(10)*) the photon energy distribution shall be measured and the different measuring quantities will be extracted from the spectrum. The focus of the measurements lies especially on the dose to the eye lens since radiation protection measurements will be necessary to be installed. [1]

Difficulties of the spectrometry of typical radiation fields arise from the broad dynamic range in dose rate of the scattered radiation ranging from 10 µSv/h to 10 mSv/h in addition to the typical low energy region from 10 keV to 150 keV. Moreover, available active dosemeters and spectrometers do not take into account that the radiation at workplaces is distributed in pulses lasting between 10 ms and 200 ms. Due to the fact that passive measuring systems average over several medical procedures a direct measuring system is necessary.

2. ENERGY MEAUREMENT OF A SCINTILLATOR COMBINED WITH A GEIGER APD ARRAY The

incident X-ray photon generates scintillator photons in the scintillator crystal. The scintillator photons hit an array of avalanche photodiodes (APD) which operates in Geiger mode. These Geiger APDs work analogue to a Geiger-Müller counter creating an avalanche of charge carriers when hit by a photon. Each photodiode produces a fixed voltage which can be summed up to the main signal of the Geiger APD array.

The amount of scintillator photons is proportional to the energy of the incoming X-ray photon. Provided that one scintillator photon hits exactly one photodiode cell, the number of activated diodes corresponds to the number of scintillator photons and, thus, to the energy of the primary photon. The signals of all diodes are added up so that the area of the voltage signal is a measure for the energy of the incident photon. A diagram of the measuring principle can be seen in Fig. 1 and an example for the measured signal of an incoming X-ray photon in Fig. 2.

The energy measurement is based on the assumption that only one primary photon and, correspondingly, only the scintillator photons of one primary photon are contained in the scintillator at one point in time. If several photons are processed in the scintillator, their signals are overlaid and produce pile up. Therefore, the dead time of the detector is a limiting factor. That is why $CeBr_3$ is chosen as scintillator material. Its decay time is 19 ns [2]. The regeneration time of the applied Geiger APD array is 20 ns [3]. If a cell is hit again prior to the end of the regeneration process, the gain for this event is lower than expected.

The measuring signal from the Geiger APD array is digitized and processed further in an electronic system based on field programmable gate arrays (FPGAs). The sampling rate is 1 GS/s which yields one measurement point every nanosecond.

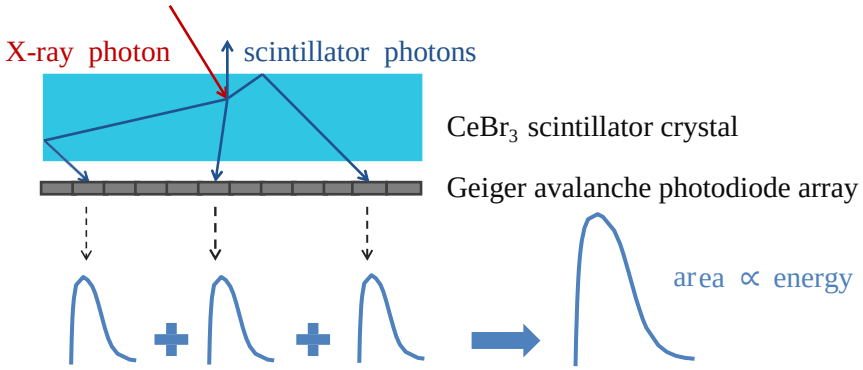

FIG. 1. Diagram of the measuring principle. An X-ray photon hits the scintillator crystal. It is converted to scintillator photons which hit in turn the Geiger avalanche photodiode array. The activated cells produce a fixed signal which accumulates to the measuring signal.

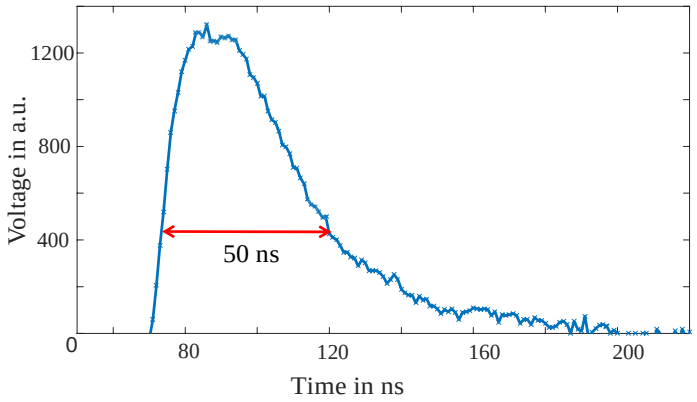

FIG. 2. Signal of the CeBr3 detector for an incoming X-ray photon after the preamplifier. Voltage is indicated in units of the digitizer. The maximum of the signal corresponds to 40 mV approximately.

3. MEASUREMENT SET-UP

The detectors were manufactured by the company Scionix[1] using crystals from Hellma Materials[2] and Geiger APD arrays from Hamamatsu[3]. The preamplifiers were bought from AdvanSiD[4].

The preamplifier is sensitive to electromagnetic disturbances. Therefore, the circuit board containing the preamplifier was put into aluminium housing. The detectors were enclosed in a connector which provides an easy way of changing different detectors. Connectors with detectors and the preamplifier in its housing can be seen in Fig. 3.

For the following measurements, a scintillator crystal with an edge length of 3 mm and a Geiger APD array with 14400 pixels with a length of 25 µm at each side was used.

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[1] www.scionix.nl

[2] www.hellma-materials.com

[3] www.hamamatsu.com

[4] www.advansid.com

FIG. 3. Measuring set-up consisting of detectors enclosed in connectors (left) and preamplifier in aluminium housing (right).

4. SIGNAL PROCESSING AND FIRST MEASUREMENTS

When the measurement signal crossed, a certain threshold level the signal was recorded and evaluated. The area of the signal was determined between the two points where the signal crossed the threshold. First measurements with radiation sources were performed. The radiation sources were selected in regard to the energy region of 15 keV to 150 keV, see Table 1. The measurements can be seen in Fig. 4 – 5. Additionally, as a proof of concept a spectrum measured at a high dose rate K_a = 240 mGy/h is displayed in Fig. 6.

TABLE 1. ENERGIES OF MAIN X-RAY AND GAMMA EMISSIONS

	X-ray Emissions	Gamma-Emissions
Ba-133	31 keV	81 keV
Cd-109	22 keV	88 keV
Co-57	7 keV	14 keV, 122 keV, 136 keV

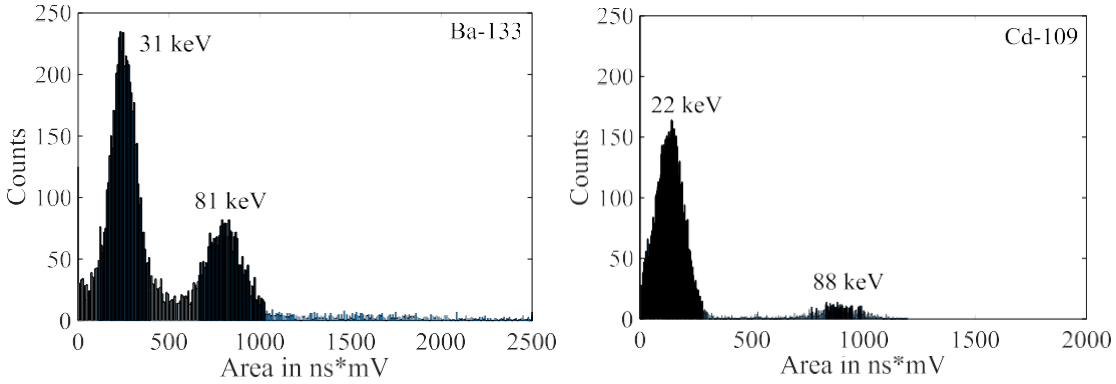

FIG. 4. Energy spectrum of Ba-133 (left) and Cd-109 (right). The two peaks in the Ba-133 spectrum can be identified with the spectral lines at 31 keV and 81 keV, the two peaks in the Cd-109 spectrum with the spectral lines at 22 keV and 88 keV.

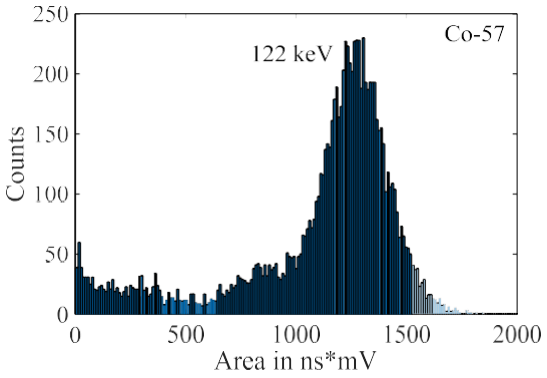

FIG. 6. Energy spectrum of Co-57. Only the main gamma emission line with an energy at 122 keV can be measured.

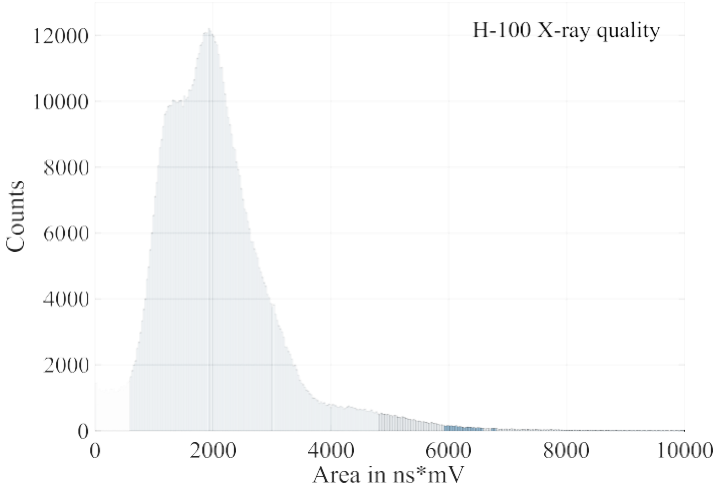

FIG. 7. Energy spectrum of a H-100 X-ray quality [4] collimated with a 1 mm pinhole plane. The dose rate of the radiation field is K_a = 240 mGy/h.

5. CONCLUSIONS

It is feasible to use this kind of measurement set-up to evaluate spectra in the typical energy region (10 keV to 150 keV) of scattered radiation with dose rates of at least up to 240 mGy/h at medical workplaces. More measurements have to be conducted concerning different dose rates as well as different pulse lengths.
Moreover, Monte Carlo simulations are in progress. They will be used to construct a response matrix of the detector and, ultimately, deconvolute the measured spectra into fluence spectra.

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RESULTS AND FUTURE PERSPECTIVES OF RADIOLOGICAL PROTECTION IN PEDIATRIC INTERVENTIONAL CARDIOLOGY FOR CHILE

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Abstract

The aim of paper is to show the main results achieved in Chile during the years following the Bonn Conference on paediatric interventional cardiology (IC) procedures and discuss further actions to improve radiation safety in this medical practice. All the X-ray systems used in paediatric IC procedures in Chile have been characterized in terms of dose and image quality. In addition diagnostic reference levels by age ranges and weights have been established. Furthermore, it has been measured the scatter dose levels at the cardiologist's position, for 10 common types of paediatric IC procedures and categorized for four age groups using phantoms to simulate patients. To maintain and improve radiation safety in paediatric IC it is expected to revise and update the legislation governing the use of ionizing radiation, including the improvement of the Quality Assurance programs and training in Radiation Protection.

1. INTRODUCTION

During paediatric interventional cardiology (IC) procedures, patients and medical staff can be exposed to relevant levels of radiation [1-4]. Therefore, optimization programs on radiation safety, including the characterization of dose, x-ray image quality, imaging systems, measurement of patient doses (including the estimation of organ and effective doses), optimization audits using diagnostic reference levels (DRLs) and measurement of occupational doses should be a priority [2].

A successful approach to reduce radiation exposure is the measurement of incident air kerma (IAK) or entrance surface air kerma (ESAK) (with backscatter) [5] for patients, and scattered doses or dose rates at the eye's and lower extremities for the staff, under real or simulated conditions using phantoms and defined technique factors. Applying the attenuation factors for protective devices can enable estimation of eye lens and lower extremities doses for operators [6, 7].

The International Atomic Energy Agency (IAEA), from 2008 has implemented a pilot study on paediatric radiation protection in cardiology for Chile, as part of three technical cooperation projects entitled "Strengthening Radiological Protection of Patients in Medical Exposures (TSA3), RLA/9/057", "Ensuring Radiological Protection of patients during medical exposures (TSA3), RLA/9/067" and "Strengthening National Infrastructure for End-Users to Comply with Regulations and Radiological Protection Requirements, RLA/9/075- output 4 [8]. The aim of paper is to show the main results achieved in Chile during the years following the Bonn Conference, on paediatric IC procedures and discuss further actions to improve radiation safety in this medical practice.

2. MATERIAL AND METHODS

2.1. All the X-ray systems (three with image intensifiers and three with flat detectors) used in paediatric IC procedures in Chile have been characterized in terms of dose and image quality, using the protocols agreed during the DIMOND and SENTINEL European program and adapted in our case to paediatric procedures. The third quartile values for the ESAK quantity were used as investigation levels (ILs), for

different polymethyl methacrylate (PMMA) phantom thicknesses for setting the interventional cardiology systems [9].

2.2. Likewise, using the appropriate experimental arrangement has been measured the scatter dose levels. The detectors measuring scatter radiation were positioned at the usual cardiologist distance during working conditions to estimate doses to:

2.2.1. The eyes position [6].

2.2.2. The lower extremities position [7].

2.3. The collection of a large sample of patient dose data allowed to calculate national DRLs (the used data were collected from January 2011 to September 2013). For each patient, the procedure identification, age, gender, weight, height, dose-area product (DAP) and cumulative dose (at the patient entrance reference point), total number of cine images and fluoroscopy time were registered. Data were extracted from the patient dose reports available in the different X-rays systems [10, 11].

2.4. Finally, patient organ doses and effective doses were also calculated using the PCXMC 2.0 Rotation software. This software is based on the Monte Carlo method, and has been developed by STUK (Radiation and Nuclear Safety Authority in Finland) [12].

3. RESULTS AND DISCUSSION

3.1. The ratio between the maximum and the minimum value of dose rates for the different evaluated systems was 555 times (considering the different imaging modes and the different simulates patient thicknesses, from 4 to 16 cm of PMMA). For low fluoroscopy mode, ESAK rates ranged from 0.11 to 33.1 mGy min^{-1}. For medium fluoroscopy mode values ranged from 0.18 to 53.8 mGy min^{-1} and for high fluoroscopy mode from 0.34 to 61.0 mGy min^{-1}. For cine mode, the ratio between the maximum and the minimum value of ESAK per frame for the different systems was 41 times and their values ranged from 1.9 to 78.2 mGy fr^{-1}. On the other hand, the ILs obtained during the survey for the different PMMA thicknesses and fluoroscopy modes (low, medium and high dose) were as follows: 0.62, 1.59 and 3.43 mGy min^{-1}, respectively, for 4 cm PMMA; 1.41, 3.08 and 6.01 mGy min^{-1}, respectively, for 8 cm PMMA; 2.82, 5.96 and 11.93 mGy min^{-1}, respectively, for 12 cm PMMA and 6.72, 14.27 and 18.10 mGy min^{-1}, respectively, for 16 cm PMMA [9].

3.2. The scattered dose values (if a ceiling-suspended screen is not used) were:

3.2.1. At cardiologist's eye lens for the ten kind of simulated procedures ranged from 0.20 to 116 μSv per procedure (factor of 580). If we assume a typical workload of twenty procedures per month, exclusively examining patients aged between 0 to <1 yrs could mean a scattered dose from 4 to 152 μSv per month. In the case of patients aged between 10 to <15 yrs, the monthly range may be from 340 to 2320 μSv. The use of personal protective shielding should also be used in paediatric IC procedures [6].

3.2.2. At cardiologist's lower extremities for the ten kind of simulated procedures ranged from 1 to 375 μSv (factor of 375). If a typical workload of 20 procedures per month is assumed, exclusively examining patients aged between below 15 y of age could mean a scattered dose from 580 to 7500 μSv per month [7]. Therefore, the maximum annual dose that may reach the cardiologist's lower extremities would be ~90 mSv, which represents 18 % of the limit for extremities established by the International Commission on Radiological Protection [2].

3.3. The 3rd quartile values obtained for DAP by diagnostic and therapeutic procedures and age ranges were 1.17 and 1.11 Gy cm2 for <1 yr; 1.74 and 1.90 Gy cm^2 for 1 to <5 yrs; 2.83 and 3.22 Gy cm^2 for 5 to <10 yrs; and 7.34 and 8.68 Gy cm^2 for 10 to <16 yrs, respectively (see figure 1). According to TABLE 1, the 3rd quartile value obtained for the DAP/body weight ratio for the full sample of procedures was roughly 0.17 (Gy cm^2/kg) for diagnostic and therapeutic procedures [11].

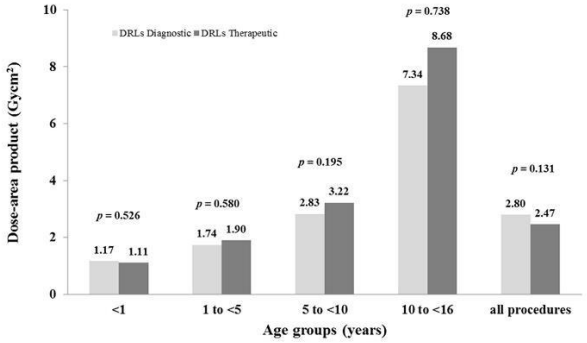

FIG. 1. 3rd quartile values for dose-area product grouped by procedure type (diagnostic and therapeutic) and age range [11].

TABLE 1**.** Mean, standard deviation (SD), median and 3rd quartile (Q75) values for the DAP/body weight ratio for diagnostic and therapeutic procedures [11].

Procedure	DAP/body weight (Gy cm^2 kg^{-1})			
	Mean	SD	Median	Q75
Diagnostic	0.132	0.108	0.100	0.163
Therapeutic	0.140	0.147	0.093	0.170
All	0.137	0.133	0.096	0.166

3.4. The analysis of dose in organs and effective doses, has been performed on a larger sample (data were collected over a seven-year period from January 2008 to December 2015). A sample of 1506 procedures were divided into four age and seven weight groups. Organ doses (median values) for diagnostic and therapeutic procedures were: active bone marrow 0.90 and 0.64 mGy; heart 1.99 and 1.46 mGy; lungs 3.56 and 2.59 mGy; thyroid 1.27 and 0.83; and breast (in the case of females) 1.78 and 1.36 mGy. The ranges for effective doses (median values) and weight bands were 1.2-3.9 mSv for diagnostic procedures and 1.0-2.5 mSv for therapeutic procedures (see figure 2) [12].

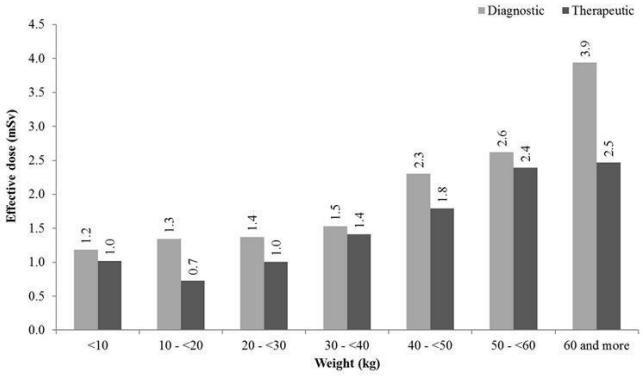

FIG. 2. Median values for effective dose grouped by procedure type (diagnostic and therapeutic) and seven weight bands [12].

5. CONCLUSION

This survey for Chile allowed to obtain a preliminary set of typical ESAK values in X-ray systems (fluoroscopy and cine acquisitions) used in paediatric IC procedures and third quartile (proposed as ILs). Medical

physicists and service engineers can consider these values for guidance in setting cardiac equipment and paediatric protocols and suggesting further potential optimisation actions when appropriate. Furthermore, these values, together with image quality, could also serve as criteria to consider replacement of old X-raysystems.

For the ten common procedures selected, scattered dose at cardiologist eye lens ranged from 0.20 to 116 μSv per procedure. Large differences between the X-ray systems were found in our study. Furthermore, the maximum annual occupational doses for the cardiologist's lower extremities was estimated in 90 mSv (if protection curtains are not used). To maintain and improve radiation safety in paediatric IC it is expected to revise and update the national legislation on the use of ionizing radiation, promoting the use of the Quality Assurance programmes and training in Radiation Protection.

The DRL values obtained for Chile could be used by other hospitals in the Latin America region to compare their current values and consider whether optimization actions are needed.

The values obtained for organ and effective dose were similar for diagnostic and therapeutic procedures, diagnostic procedures showing slightly higher values than therapeutic procedures. The resulting set of dose values will permit comparisons with other imaging procedures (comparing the same age bands) for justification purposes.

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USING REAL TIME SKIN DOSE MAPS TO OPTIMIZE INTERVENTIONAL PROCEDURES

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Abstract

During interventional radiology practices, it might be necessary to deliver high radiation doses to the patient's skin. When procedures are complex or when various procedures are necessary to treat patients, high peak skin doses (PSD) may produce skin injuries. To avoid or minimize skin injuries, interventionists usually have limited information (kerma area product and kerma at the patient entrance reference point) displayed on the interventional laboratories screens. The DICOM radiation dose structured report (RDSR) is currently available on updated X-ray units. This report includes detailed information at radiation event level and can be used to estimate the patient skin dose distribution but it is only available at the end of the procedure, so that no actions can be taken to minimize the PSD during the procedure. In this work, the first year evaluation of a skin dose distribution estimator in real time is presented. The graphic interface allows specialists to change the X-ray beam orientation and optimize the skin dose distribution to reduce the PSD if clinical conditions permit. The system is able to identify patients needing clinical follow-up and to perform an active optimization during the procedures to reduce peak skin dose.

1. INTRODUCTION

The International Commission on Radiological Protection (ICRP) published in the year 2000 a report on "Avoidance of radiation injuries from medical interventional procedures" [1]. The report contained recommendations to mainly avoid skin injuries in patients and lens opacities in staff. Acute radiation doses may cause erythema at 2 Gy, permanent epilation at 7 Gy, and delayed skin necrosis at 12 Gy. According to the ICRP recommendations, maximum cumulative absorbed doses that appear to approach or exceed 1 Gy (for procedures that may be repeated) or 3 Gy (for any procedure) should be recorded in the patient record, and a patient follow-up procedure should be implemented for such cases. But this resulted difficult in practice and required the support of experienced medical physicists. In the year 2013, ICRP published recommendations on radiation protection for cardiology [2] and it was predicted that "in the near future, it may be possible to obtain skin dose estimates and skin dose maps in real-time using automated methods".

In 2009 the Society of Interventional Radiology (SIR) and the European Society of Cardiovascular and Interventional Radiology (CIRSE) published the "Guidelines for patient radiation dose management" [3] introducing the "peak skin dose" (PSD) as the dosimetric parameter of interest to consider for a potential clinical follow-up of the patients after interventional procedures. It is possible to establish some correlation between PSD and the two main dosimetric quantities reported by interventional X-ray systems: Kerma Area Product -KAP-(also used as Dose Area Product -DAP-) and Air Kerma at the patient entrance reference point (AK) [4] but with large inaccuracies for individual patients and procedures. SIR and CIRSE suggested the value of 3 Gy of PSD as threshold for patient follow-up.

The new European Directive on Basic Safety Standards (BSS) [5] considers interventional radiology as part of the "special practices" requiring special attention to the quality assurance programmes and the assessment of patient dose. The Directive requires that equipment used for interventional radiology shall have a device or a feature informing the practitioner of quantity of radiation produced by the X-ray system during the procedure and the capacity to transfer the patient dose information to the record of the examination. The International BSS [6] indicates, as part of the dosimetry of patients, the need to obtain "typical" dose values for image guided procedures and the information necessary for retrospective assessment of doses, including the duration of the fluoroscopic component and the number of images acquired.

But PSD is usually not available. Slow films or radiochromic films [7] have been used to obtain patient skin dose maps at the end of the interventional procedures. In the last years, several calculation methods to

estimate the PSD at the end of the procedure have been developed using the detailed information from the DICOM Radiation Dose Structured Report (RDSR). Unfortunately, X-ray units deliver the RDSR at the end of the procedure, so that no actions can be taken to minimize the PSD during the procedure. In many cases, manufacturers do not include all the event parameters necessary to accurately calculate the PSD values.

In this work, we show the experience and initial results after the first-year evaluation of a skin dose distribution estimator in real-time, implemented in a new interventional radiology system and its impact on "active" optimization during and after the clinical procedures.

2. MATERIAL AND METHODS

The system developed to estimate the patient skin dose distribution is commercially available under the name "Dose Tracking System" (Toshiba Medical) [8-9] and has been installed in a new interventional radiology laboratory at the San Carlos University Hospital (Madrid, Spain). The system captures, in real time and for every radiation pulse, the information relative to all physical parameters during patient irradiation, i.e. C-arm position and angulation, couch height and position, tube and generator settings as kV, mA, pulse time, filtration, beam collimation and compensator wedges. The system computes the skin dose using an anthropomorphic model and displays the results on one of the screens inside the interventional laboratory (see fig. 1).

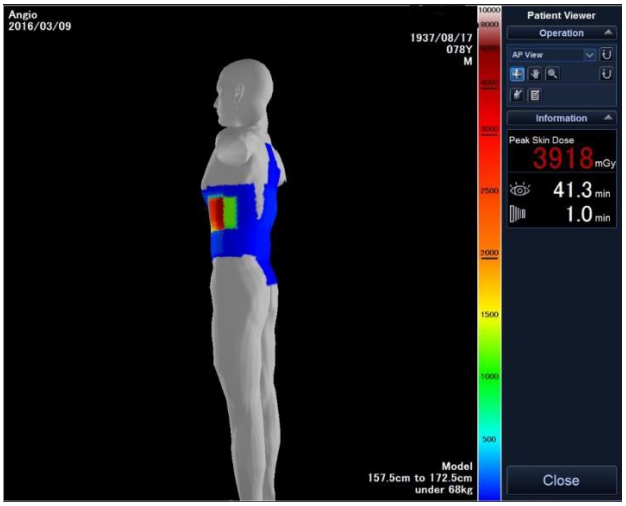


FIG. 1. Example of the skin dose map show in real time inside the catheterization room (from ref. 13, with permission)

Along with the skin dose map, the system shows the patient region where the X-ray beam is pointing and the maximum skin dose in the beam area. The user selects the anthropomorphic model (when starting the procedure) to fit as close as possible to patient actual dimensions, including male and female models and paediatric patients.

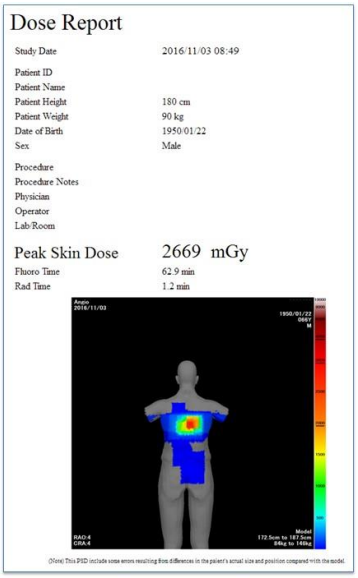
The system was tested using a Rando anthropomorphic phantom (Radiology Support Devices, USA) and radiochromic films Gafchromic XR RV3 (ISP, USA) [9]. Since the system was installed, skin dose map reports for every patient have been stored in html format in an independent server as the current version still does not integrate this information into the RDSR or into the folder study stored in the PACS.

In addition to the real-time optimization made by interventionists during the procedure, the existing (home-made at the San Carlos hospital) DOLIR (Dose On Line for Interventional Radiology) software [10] allows a post procedure analysis of the skin dose maps and the data contained in the RDSR, using a graphical interface ("event by event" timeline) (see fig. 3); from the completed procedures, we try to learn if a reduction of PSD values could be possible for future procedures in the same patient or in other patients with similar pathologies.

3. RESULTS

After the system had been installed and over a period of 12 months, a sample of 800 skin dose maps were recorded. Most of the procedures were short interventions with low PSD values. Only a 22% of the procedures have PSD values > 0.1 Gy, 8.4% have values > 0.5 Gy and 4.4% (34 procedures) have values > 1.0 Gy.

Fig. 2 shows an example of the content of the "dose report" produced by the X-ray system (still not integrated as part of the DICOM RDSR). The timeline of the radiation events during the same procedure, produced by DOLIR software from the data contained in the RDSR, is shown in Fig. 3.



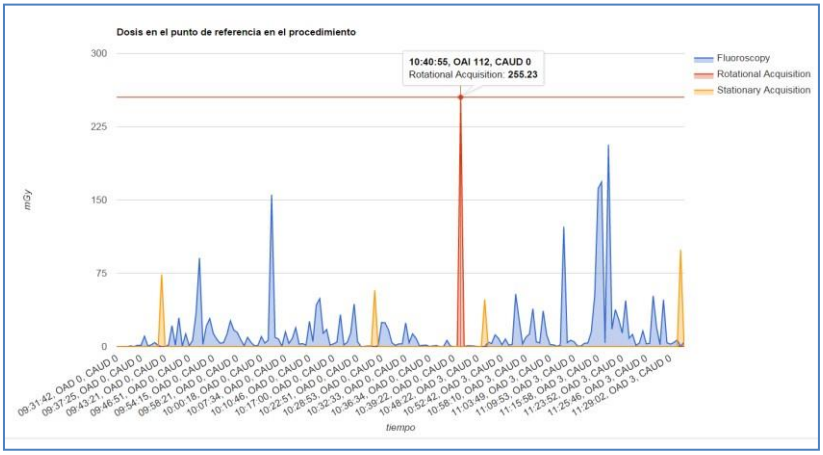


FIG. 2 (left) and 3 (right): Dose report with skin dose map produced by the Toshiba X-ray system. Right: Timeline of the radiation events during the same procedure, produced by DOLIR software from the data contained in the RDSR. Vertical axis shows the mGy at the patient entrance reference point. Horizontal axis shows the C-arm angulations for the different consecutive radiation events.

Table 1 summarizes the main results extracted from the data base for the 34 procedures with PSD> 1 Gy.

TABLE 1: Main results extracted from the data base

Peak Skin Dose (PSD)(from 800 procedures)	
Sample (PSD > 1Gy)	34
Mean (mGy)	1629
median (mGy)	832
3rd quartile (mGy)	1723
Min (mGy)	1001
Max (mGy)	3918

4. DISCUSSION

One of the relevant aspects of the database analysis is that the air kerma at the patient entrance reference point displayed at the angiography room may be lower than the PSD (sometimes 50% lower) showing that this cumulative AK parameter is not always sufficient (or a good indicator in all the cases) to discriminate high PSD values. In some cases, the PSD can be higher than the cumulative AK, if in some projections (usually in the lateral projection) the skin of the patient was closer to the X-ray tube focus than the patient entrance reference point. The graphic interface with the real-time skin dose map allows specialists to change the beam orientation and to use collimation and other technical and geometry factors to optimize the skin dose distribution trying to

reduce PSD values during the procedure. The aspects to be improved in the future should be the integration of this information in the RDSR and the possibility to generate automatic alarms suggesting clinical follow-up at the end of the procedures.

The analysis of the RDSR post-procedure, with all the radiation events and the graphical presentation of the events as shown in Fig. 3, allows identifying the contribution of the different fluoroscopy runs, DSA acquisitions (shown as "stationary acquisition") and the rotational acquisitions, to the cumulative AK. In this way, interventionists may be able to know the quantitative contribution to the skin dose distribution of the different radiation events and to learn how to save radiation doses in future procedures. This may be relevant, especially if some of the procedures need to be repeated in the same patient.

5. CONCLUSIONS

The availability of the skin dose map in real-time during the interventional procedure allows interventionists to optimize the radiation doses by applying collimation, modifying the X-ray beam angulation, reducing the dose per image if possible, and reducing the number of images per second. The parameter air kerma at the patient entrance reference point can underestimate in some cases, the peak skin doses when lateral projections happen to be predominant. The analysis of the patient skin dose maps and the RDSRs after the procedures, allows proactive optimization strategies by refining ulterior potential procedures on the same patients (e.g. reducing over-irradiation of certain skin areas).

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EYE LENS DOSIMETRY, A TOOL FOR RADIATION PRACTICE IMPROVEMENT IN A UROLOGY DEPARTMENT
Case study

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Abstract

The paper presents the results of the introduction of eye lens dose monitoring of the medical staff in a busy urology department. A fixed fluoroscopy system with an over-table X-ray tube was used to guide endourological procedures performed by a team of two urologists, nurses and anesthesiologist. Lead aprons and collars were in routine use but eye glasses and screens were not available. Active and passive thermoluminiscent (TL) dosemeters were used to measure eye lens dose and the data was extrapolated to assess annual doses. The first measurements were performed during a period of one month for the main urologist with an electronic dosemeter EDD30 (Unfors), and registration of all patient and staff exposure related factors for the procedures. The dose to the operator's eye lens was estimated to be 40.0 mSv a^{-1}. Recommendations for dose reduction measures were communicated to the medical staff. An year later, a six-month monitoring was performed for the entire medical team with TL dosemeters EYE-D^{TM} calibrated in the operational dose quantity $H_p(3)$. The eye-lens dose was assessed to be 8.2 mSv a^{-1} for the main urologist. A strong correlation was found between the patient dose and the eye dose of the main operator but no correlation between the eye lens dose and the whole body dose, routinely monitored with under apron TL dosemeters. The analysis showed strong decrease in eye lens dose and patient doses: five-fold reduction in the typical patient dose for percutaneous nephrolithotripsy (PCNL) and ureterorenoscopy (URS), two-fold in the typical fluoroscopy time for the same procedures and five-fold in the eye lens dose to the urologist. The study demonstrated the positive effect of the implementation of dose reduction measures into the daily working practice, due to the established close collaboration between the endourology team and the medical physicists.

1. INTRODUCTION

The ICRP has recommended a new annual dose limit of 20 mSv a^{-1} in 2011 [1]. Previous studies suggested that there is a risk for exceeding this new limit by not only medical teams working in interventional radiology and cardiology, but also by those performing fluoroscopy guided procedures outside these specialities [2]. Over the recent years, the use of fluoroscopy to guide surgical urologic interventions has been constantly

growing. Minimally invasive procedures for the treatment of kidney stones such as ureterorenoscopy (URS) and percutaneous nephrolithotripsy (PCNL) require fluoroscopy guidance. PCNL is a common procedure for treatment of upper urinary tract calculi, tumors, and structures which replace open surgery for the treatment of stones unsuitable for extracorporeal shockwave lithotripsy or URS [3]. URS is a well-established treatment approach for management of renal and ureteral stones and shockwave lithotripsy failures. Developments in ureteroscope and laser technology have resulted in easier access to the entire ureter and decreased complication rate, thus making URS management of ureteric stones much more attainable [4]. Patient doses from these procedures are much below the threshold for deterministic effects. Cumulative dose and risk increase when patients with stone disease require multiple interventions, and multiple CT and other diagnostic exams before treatment [5].

Endourological procedures are recognized as a potential for relatively high doses to the medical specialists due to their close proximity to patient during the procedure, especially in a busy department where cumulative dose from many procedures can be significant [6].

The patient and staff doses can be minimized by shortening exposure time, increasing distance from the X-ray source, using appropriate shielding and improving the operator's knowledge and skills on proper use of equipment features. The physicians awareness about radiation dose has been recognized to be an important barrier for minimizing patient and staff exposure [5, 7].

The aim of this study is to present the estimated staff eye lens doses, received by urology team, to compare the results with the previously reported data by Hristova-Popova et al. [8] and to discuss the impact of optimisation actions of radiation protection at a clinical level.

2. MATHERIALS AND METHODS

The survey was performed in the Department of Urology and Nephrology of Military Medical Academy, Sofia. A fixed fluoroscopy system Siemens Access Uroskop with an over-table X-ray tube was used to guide endourological procedures performed by a team of two urologists, nurses and anesthesiologist. Lead aprons and collars were in routine use but eye glasses and screens were not available.

Active and passive trermoluminiscent (TL) dosemeters were used to measure eye lens dose and the data was extrapolated to assess annual doses. Data on patient dose in total air kerma-area product, P_{KA} (cGy cm^2), fluoroscopy time, FT (min), number of images acquired and clinical patient data were also collected.

The initial measurements were performed during a period of one month for the main urologist with an electronic dosemeter EDD30 (Unfors) with its sensor attached to the surgical cap. The dosemeter was calibrated in terms of operational quantity personal dose equivalent $H_p(0.07)$ in mSv. The results of this study have been published previously [8].

A second round of eye dose measurements was performed from September 2015 to February 2016. The entire medical team was covered, consisting of one main urology surgeon, one assistant surgeon, two anesthesiologists, five nurses and two health-officers. Eye lens doses were measured with the EYE-D^{TM} thermoluminescence dosemeter, calibrated in terms of personal dose equivalent $H_p(0.3)$ in mSv. The dosemeters were placed at the head close to the most irradiated eye. All dosemeters were traceable to the national Secondary Standard Dosimetry Laboratory - Sofia.

Spearman's test was used for the statistical analysis, due the small sample and a lack of normal distribution of the data [9].

3. RESULTS

3.1. Patient data

Table 1 and Table 2 summarize patient doses assessed during the two periods of data collection. The data includes number of patients included in the study, average, minimum, maximum values and medians of P_{KA}, FT and number of images, separately for URS and PCNL. The median patient dose for URS and PCNL was 228 cGy cm^2 and 664 cGy cm^2 respectively, and the median fluoroscopy time was 0.6 min for URS and 4.1 min for PCNL [8]. The median patient dose for URS and PCNL during the second period was assessed to be

39 cGy cm^2 and 132 cGy cm^2 respectively, and the median fluoroscopy time was estimated to be 0.3 min for URS and 2.3 min for PCNL.

TABLE 1. PATIENT DATA IN TOTAL AIR KERMA-AREA PRODUCT, FLUOROSCOPY TIME AND NUMBER OF IMAGES FOR URS.

	Number of patients	P_{KA}, cGy cm^2 average (min-max) med	FT, min average (min-max) med	No. of images
2014 [8]	15	365 (22-1393) 228	1.0 (0.1-3.6) 0.6	2 (0-10) 1
Current study 2015/2016	140	121 (0.4-2139) 39	0.7 (0.01-6.2) 0.3	2 (0-5) 1

TABLE 2. PATIENT DATA IN TOTAL AIR KERMA-AREA PRODUCT, FLUOROSCOPY TIME AND NUMBER OF IMAGES FOR PCNL.

	Number of patients	P_{KA}, cGy cm^2 average(min-max)med	FT, min average(min-max)med	No. of images
2014 [8]	16	1010 (196-4267) 664	5.2 (0.9-12.9) 4.1	6 (1-19) 5
Current study 2015/2016	58	208 (20-756) 132	2.6 (0.3-9.0) 2.3	2 (0-5) 2

3.2. Eye lens dose measurements.

TABLE 3. RESULTS FOR STAFF EXPOSURE IN TERMS OF PERSONAL DOSE EQUIVALENT $H_P(d)$, IN mSv.

Medical staff	$H_p(0.07)$, mSv [8]* eye lens	Hp(3), mSv ** eye lens	Hp(3), mSv *** eye lens	Hp(10), mSv **** whole body
Main urologist	40.0	4.1 ± 1.2	8.2	0
Assistant-urologists	-	1.4 ± 0.3	2.9	0
Rest	Close or below recording level	Close or below recording level	Close or below recording level	0

*One months period **Six-month period ***Annual assessment ****Under lead apron, six-month period

Table 3 summarizes staff eye lens doses for the main operator and the assistant-urologist. For the rest of the team the assessed annual eye lens dose is as it follows: 0.16 mSv a^{-1}and 0.11 mSv a^{-1} for the two of the nurses respectively, and below the recording level of 0.10 mSv for the rest of the staff.

Figure 1 shows the correlation between cumulative P_{KA} and measured eye dose ($H_p(3)$) for the main operator. Strong Spearman's correlation was found between $H_p(3)$ (mSv) and cumulative P_{KA} (cGy cm^2) for the entire measurement period, with $\rho = 0.94$, $p < 0.05$ (0.01). Experimental mean conversion coefficient of 8090^{-1} cGy cm^2 mSv^{-1} was calculated. No correlation was observed between the eye lens dose and the whole body dose, routinely monitored with under apron TL dosemeters.

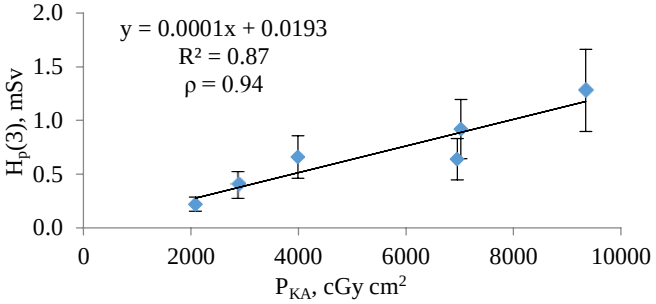

FIG. 1. Correlation between dose equivalent $H_p(3)$ to the operator's head and patient dose in terms of P_{KA}.

4. DISCUSSION

At the first period of the patient and staff dose assessment in this department Hristova-Popova et al. [8] assessed the eye lens dose for the main operator to be 40 mSv a^{-1}. Written guidelines were provided to the medical staff how to reduce radiation exposure, using the concept of time, distance and shielding, and briefings organized to discuss the practical measures. Installation and use of lead shields in the endourology room and personal use of lead glasses were recommended.

Considering the results from the first study, the endourology team has made efforts to reduce the staff and patient exposure by implementing better radiation protection practices, like reducing the fluoroscopy time, beam collimation, increasing the use of last-image hold function, use of low dose pulsed fluoroscopy, decreasing the use of unnecessary magnification modes, as well as reducing the number of medical staff in the operating theater as much as possible. The analysis showed strong decrease in median patient dose values: five-fold reduction in typical patient dose for PCNL and URS, two-fold respectively in median fluoroscopy time value for the same procedures. There is also a reduction in the number of acquired images on account of the preferred use of the last-image hold function. Lead shields are still not available in this department but for the eye lens dose to the main operator result show five-fold dose reduction due to improved radiation protection practices.

5. CONCLUSIONS

Dose measurement and evaluation provide important information on the status of radiation protection. They are a useful tool for quantification of the optimization actions. Dose reporting itself is not sufficient, if separated from the clinical practice. This study demonstrated the positive effect of the implementation of dose reduction measures into the daily working practice, due to the established close collaboration between the endourology team and medical physicists.

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