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ARTICLE

Comparison of crystalline lens dose rates in interventional cardiology for systems with and without dose optimization software

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Abstract – During the last years, the use of Interventional radiology (IR) has been increasing, because compared to other clinical methods IR techniques are minimal invasive. Nevertheless, these types of surgical procedures are guided by current time images that are produced by X-rays. In the case of interventional cardiology (IC), the complexity of the procedures and production of images that are required expose the medical staff to ionizing radiation. Thus, a dosimetric control of radiation to people who are constantly involved in this type of environment is highly necessary. As most of Latin American countries, Colombia still has not implemented the crystalline lens dosimetry for professionals who are in charge of IR procedures. In addition, if we consider the decrease of the dose limit to the lens Hp(3) from 150 to 20 mSv/year proposed by the ICRP, it is important to take into account this parameter in order to optimize the practice, so the radiological risks to which interventional doctors are exposed can be reduced. In this work we investigated the level of radiation to the lens of 6 doctors dedicated to treat coronary conditions. They belong to 2 clinical centers and have conducted a total of 227 procedures of diagnostic and therapeutic type. The radiation dose measurements were made with thermoluminescent dosimeter (TLD) for both eyes. The results showed that doctors who do not use plumbed glasses exceeded the dose limit for crystalline lens with very few procedures per month. We also found that a recently developed dose optimization software for image processing during angiograph procedures is a factor that strongly reduces the dose to the crystalline lens. Finally, the catheter route (radial or femoral) is an irrelevant factor for the Hp(3) dose to the lens.

Keywords: Catheter route / dose optimization software / crystalline lens dosimetry

1 Introduction

Recently, medicine in general has markedly progressed, and one of its main allies have been the diagnostic techniques based on ionizing radiation from external sources as the X-rays or from internal sources with radionuclides. One of the techniques developed during the last decades is the interventional radiology (IR). It consists in transporting a catheter through the patient's arteries to the place of interest, as the heart, brain, kidneys, limbs, etc. The idea is to give a solution to the injury with instruments that are transported by the catheter. The catheter is introduced in the patient's body through a little surgical cut either in the leg for a femoral route or in the arm for a radial route in order to intervene the specific organ using an angiography equipment.

Due to the high complexity of procedures, the exposure time can even last for hours. Therefore, the medical staff in charge face the risk of receiving high levels of radiation produced in the procedure. Moreover, these doctors stay very close to the X-rays source during the whole intervention. In this way, they reach considerable dose levels of radiation during their complete professional life, and this induces a high probability of stochastic effects such as cancer (Picano and Vano, 2011) or tissue effects as opacity in the eye' lens (Canevaro, 2009).

The link between ionizing radiation and lens opacity is clearly established (Wassilieff, 2009) and a recent epidemiological study (Jacob *et al.*, 2011) clearly demonstrated a dose-response relationship between radiation exposure and occurrence of lens opacity among medical staff in interventional cardiology.

For these reasons, ICRP decided to adopt a new protection recommendation and chose to reduce the dose limit of Hp(3) from 150 to 20 mSv/year (ICRP, 2012). Nevertheless, with a low response by the third-world countries, the Hp(3) follow-up is not asked for, not even implemented in any specialty exposed to high radiation doses such as in the IR.

The interventional cardiology (IC) is a very special case. IC requires very complex procedures in a high number of patients,

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which means that the staff receives a high percentage of the total effective dose. Moreover, doctors dedicated to IC present an exposure in their heads between 2 and 3 times higher than other radiologists (Picano and Vano, 2011), which induces a higher probability in the time to harmful consequences as mentioned previously.

With the objective to improve de radiological practice of IC, evaluating the Hp(3) of the interventional doctors in Medellin (Colombia), and searching possible causes of the dose rise in the crystalline lens, we made an Hp(3) dosimetric survey in 227 IC cases of diagnosis and therapeutic procedures carried out by 6 hemodynamic doctors with a high experience in radial and femoral techniques.

The procedures were done in 2 clinics from Medellin which are equipped with angiographs. The Hp(3) measures were carried out to know the mean local levels of this operational quantity. We also investigated the correlation between the medical parameters as the catheter route or techniques as the angiograph equipment type, and the dose value to the lens. To calculate the measures we used TLD dosimeters with metrological traceability. For each of the measurement we used dosimeters above the eyebrows of the doctor. After carrying out this procedure, we noticed high doses on the eyes. The results also show that the value of the dose is strongly linked to technical parameters such as the operation technology but is independent from the catheter route.

2 Material and methods

A total of 227 measures were collected during the study from which 184 were taken from the clinic number 1 equipped with a PHILIPS ALLURA angiograph and 43 were taken from the clinic number 2 equipped with a PHILIPS ALLURA angiograph that includes the CLARITY optimization software, which diminishes the dose of radiation through digital process mechanisms such as compensation of respiratory movements, real time pixel changes and advanced filtering. Each equipment had an optimal quality of image evaluated technically with the TOR test for quality in fluoroscopy control. Besides the angiograph equipment, during the research, the hemodynamic rooms had always radiological protection elements and the lead screen hanging on the roof. These radiological protection equipment were sporadically used by some cardiologists, of which only 2 used lead glasses due to visual troubles.

To evaluate Hp(3), LiF: MgTi TLD100 dosimeters with a measuring range of 10 pGy to 10 Gy were packed in approximately 1.5 cm^2 bags. Each package always contained 3 dosimeters to make mean calculations and to determine the measurement variability. To diminish the effect of natural background, dosimeters were transported (over land) in a lead container to the clinic where the IC procedures were programmed. Before carrying out these procedures, the dosimeters were submitted to a thermal annealing of 400 °C for 4 h to eliminate any remaining information from previous measures that the crystals could contain. For each coronary procedure the dosimeters were located above each eyebrow of the doctor in charge of the intervention (see Fig. 1) and returned to the lead box after completing the procedure. Additionally, at the end of each procedure the fluoroscopy time shown by the angiograph monitor was registered. The doses measured by the dosimeters (represented by the two gray boxes in Fig. 1) were not affected by the lead glasses in those doctors who used them, but they were taken into account (when calculating the true dose) using correction factors for this type of glasses, as proposed in previous works (McVey, 2013; Carinou *et al.*, 2015)

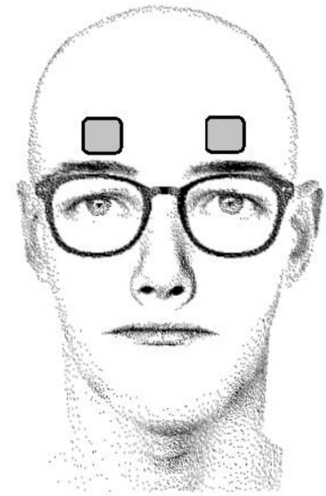

Fig. 1. Position of the dosimeter packages on the Interventional Cardiologists head.

Finally, after finishing the Hp(3) measures to the doctor in charge of the IC procedures of the day, the dosimeters were transported (over land) to a near radiological physics laboratory, and were processed by a HARSHAW 3500 digital reader within 24 h to avoid information loss because of the inherent fading of the crystal lens.

In order to know if the differences between values of the means were statistically correct, we used a student's *t* test. This was applied in two samples assuming uneven variances, with a significance level of 5% ($\alpha = 0.05$). The results were compared in aspects such as the dose, the dose rate between left and right eyes, angiographs equipment in both institutions (with and without dose optimization software), and the influence of the catheter route (radial or femoral) in the dose of the crystalline lens of the doctors.

3 Results

Table 1 presents the summary of the data collected. It shows the mean values of the Hp(3) for the right and left eyes of the 6 doctors. The sample is composed by 131 diagnostic procedures (coronary angiography and additional examinations) and 96 therapeutic procedures (coronary angiography and angioplasties with stents location).

The results of the student's *t* test for the eye variable, show a P value of 6.8×10^{-11} which indicates that the mean doses between right and left eye have a statistically significant difference. Likewise, the dose rate between right and left eye, with a P value of 0.0055, shows the same feature.

As we mentioned before, both clinics work with the same model of angiographs. Nevertheless the clinic 2 was equipped with an optimization software, which allows a noticeable

Table 1. Mean values of dose and dose rate for the right and left lens of the participating hemodynamic doctors.

Number of procedures	Values	Dose [μSv]		Dose rate [μSv/min	
		Right eye	Left eye	Right eye	Left eye
227	Mean ± SD	120.0 ± 47.3	161.7 ± 80.6	35.6 ± 35.2	45.8 ± 42.1
	Min	33.5	47.1	2.6	4.3
	Max	356.2	669.3	310.8	315.3

Table 2. Mean values of dose rate to the right and left lens in each clinic and P values of the student's t test done to determine if there were statistically significant differences between the dose rate means to right and left crystalline (received by the hemodynamist) in institution 1, and institution 2.

Institution	Number of procedures	Cases	Dose rate [μSv/min]							
			Right eye				Left eye			
			Mean ± SD	P value	Min	Max	Mean ± SD	P value	Min	Max
1	184	Diagnoses + Therapeutics	38.8 ± 37.3	6.33E-05	3.3	310.8	49.9 ± 44.6	1.35E-05	5.7	315.4
2	43		22.1 ± 19.3		2.6	79.2	28.3 ± 22.7		4.3	94.5
1	93	Diagnoses	55.6 ± 42.8	4.86E-03	8.4	310	70.9 ± 49.5	2.74E-03	13.9	315.4
2	13		36.3 ± 17.0		19	79.2	46.4 ± 20.4		19.8	94.5
1	76	Therapeutics	19.6 ± 7.2	5.85E-08	5	36.7	26.9 ± 13.9	2.26E-07	9	76.6
2	20		6.6 ± 3.5		2.6	18.3	10.0 ± 4.5		4.3	19.7

Table 3. Mean values of the dose and dose rate for the right and left lens according to the catheter access route and P values of the student's t test done to determine if there were statistically significant differences between the mean values of dose and rate to each route (received by the hemodynamist in the lens).

Catheter route	Number of procedures	(Mean dose ± SD) [μSv]			
		Right eye	P value	Left eye	P value
Radial	120	119.7 ± 46.3	0.742	158.1 ± 77.7	0.816
Femoral	86	117.6 ± 44.3	160.8 ± 83.9		
		(Mean dose rate ± SD) [μSv/min]			
Catheter route	Number of procedures	Right eye	P value	Left eye	P value
Radial	120	37.4 ± 30.1	0.861	47.0 ± 36.5	0.864
Femoral	86	36.4 ± 43.5		48.1 ± 51.6	

reduction of dose to the patients and to the medical staff that are exposed. Table 2 compares the results from each clinical institution. It shows the mean dose rates for the crystalline lens. For a better understanding, Table 2 is divided in three groups. First group means all diagnostic and therapeutic cases, second group means only the coronary angiography and the third group means therapeutic cases with variable procedures depending on each patient.

The information collected from the student's t test revealed that, for left and right eye, the difference of the mean dose rate to the crystalline (received by the hemodynamist) between institution 1 (with no optimization software) and institution 2 (with optimization software) is statistically significant, because all the values in P are lower than $\alpha = 0.05$ (see Tab. 2).

Since the interventional coronary treatments are carried out by a catheter that is transported through either the femoral artery or the radial artery of the patient to his/her heart, and since the choice of the route is made by the doctor in charge of the procedure, it is important to know, as far as possible, the advantages and disadvantages in each route from a radiation protection point of view. That is why we compared the dose to the crystalline lens according to the catheter route. Table 3 presents the results of this comparison. It shows the dose mean

Table 4. Mean values of the fluoroscopy time and dose for the right and left lens according to procedures type.

Procedures	Number of procedures	(Mean fluoroscopy time ± SD) [min]	(Mean dose ± SD) [μSv]	
			Right eye	Left eye
Diagnosis	131	3.68 ± 2.22	114.11 ± 35.7	146.61 ± 51.5
Therapeutic	96	13.83 ± 9.21	128.06 ± 58.8	182.37 ± 105.3

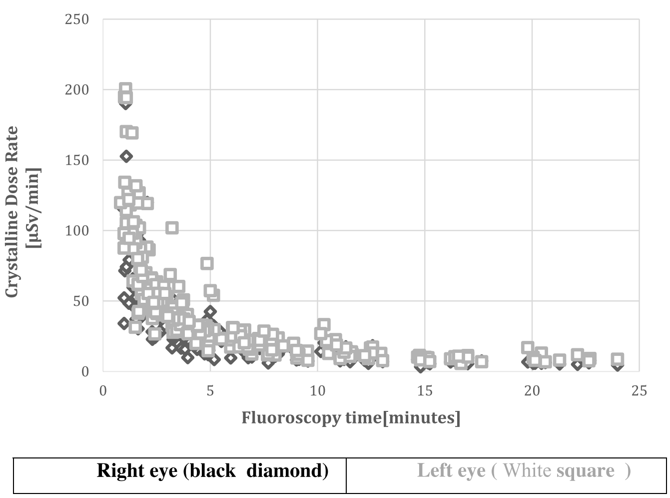

Fig. 2. Distribution of dose rates to right and left eye based on the fluoroscopy time for left and right eye.

and the dose rates for procedures that are developed through the radial and femoral route.

In this variable, we found that in any case the means (dose and dose rate to the crystalline lens) do not have differences statistically significant. The student's t test showed that all of the P values are higher than 0.05 (see Tab. 3).

Due to the division of the IC procedures (first period (diagnostic), *i.e.*, coronary angiography and second period (therapeutic) *i.e.* angioplasties and colocation of stents) it is important to clearly know during which procedure period exists a higher irradiation risk. Moreover, as dosimeter give a final dose value and not a dose description, we collect the dose rates of lens sample based on the fluoroscopy time (see Fig. 2). In this graphic, blue spots represent the dose rate to right eye, and red spots represent dose rate to left eye in each procedure. These were calculated with the dosimeters dose, and the fluoroscopy time that corresponded to each procedure. Moreover, Table 4 shows the mean times of the diagnostic and therapeutic interventions, and the mean Hp(3) to the right and left eyes of the cardiologists in both institutions. The analysis of these comparisons is addressed deeply in the discussion.

4 Discussion

According to all the information gathered in this study, radiation in IC procedures tend to affect the doctors' left eye more than the right one. This is because in these type of procedures, the X-ray tube is by the left side of the doctors, and causes a higher exposure in this part of his body due to the scattered radiation.

Taking into account the mean value of Hp(3) that we found to the left eye (161.7 μSv, Tab. 1), an IC doctor could easily exceed the dose limit of 20 mSv/year, because with only 124 diagnostic and therapeutic procedures, the left eye will have a projected dose of 20.05 mSv. This represents a problem for interventional cardiologists, because the number of procedure per month is about 200. Nevertheless, according to the study of (Carinou *et al.*, 2015) the lead glasses reduces crystalline lens dose by a factor between 5 and 33, with a mean reduction factor of 10 according to different authors. Considering this reduction factor, if an IC doctor uses lead glasses in each procedure carried out, the mean dose for the crystalline lens of the left eye would be 16.17 mSv. This allows a doctor to do about 1236 procedures per year without exceeding the dose limits for Hp(3) to the left eye. This analysis is also valid for the radiological protection of the right eye.

One of the radiological protection methods recently implemented is the improvement of real time digital image processing by a software. This offers a significant reduction in the radiation dose to the patients and to the medical staff. This dose reduction is investigated in this work. However, the dose to the eyes depends on several parameters, including the total time of fluoroscopy and the complexity of the procedure, these two parameter being independent from the equipment. So, to delineate the possible benefits of using the optimization software, we choose to analyze the dose rate that doctors received to their crystalline lens during the procedures in each clinic (Tab. 2). We found that the measurements to the crystalline lens of the doctors who did procedures in the clinical institution 2 (equipped with the optimization software) showed large reductions of dose rate as compared to the institution 1 (not having this software). In all procedures, the mean reduction to both eyes was of 43%. In diagnostic procedures the reduction of dose rate to both eyes was of 32% and in therapeutic procedures, the reduction was of 66% and 63% to the right and left eye respectively.

During IC procedures, the therapeutic benefits that offers a catheter route have been highly studied. Cardiology doctors generally choose one of the route for therapeutic reasons, independently from radiation protection considerations. Due to this, this parameter is investigated comparing the mean dose and the dose rates to the crystalline lens of the doctors who proceed through radial artery and the doctors who proceed through femoral artery. As it is shown in Table 3, we found very similar results of Hp(3) and dose rates for both route (right and left eyes), even, there is not enough evidence to state that the difference between the means of the populations is statistically significant.

Figure 2 shows that the dose rates to both eyes are higher within the first 5 minutes of fluoroscopy. This demonstrate that most of radiation received by the lens is induced in the first 5 minutes of the procedure. In fact, as it is shown in Table 4, the diagnostic procedures have a mean time of 3.68 min with a standard deviation of 2.22 min, 4.9 min in total. Like this, we can conclude that a large proportion of the diagnostic procedures have a length time of less than 5 min. However, if mean dose to the lens in diagnostic procedures and mean dose to the lens in therapeutic procedures are compared based on data in Table 4, near to 89% and 80% of the dose to the right and left lens respectively, are received during the diagnostic procedure. Although the time to develop the coronary angiography period is usually short, it is during this period that the high dose rate mode is used (also called cinema mode). In addition, the patient receives a high Z contrast agent to examine arteries using high quality cinematographic records. This produces high levels of radiation and rises up the personal dose to the lens. During the therapy period images do not require an HD video. Medical tools are guided using the fluoroscopy mode, and this reduces significantly the dose per image, the spread of radiation and the crystalline lens dose of the staff in charge of the procedure.

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