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Alternative Methodology for Occupational Dose Estimation in Cardiac Electrophysiology Procedures

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ABSTRACT

Fluoroscopy-guided cardiac electrophysiology procedures are among the most critical X-ray exposures. However, occupational doses are still little-known. In this study, an alternative methodology was developed to estimate the occupational dose and evaluated its optimization in cardiac electro-physiology procedures. The procedures were reproduced by simulation and the dose rates of the staff were measured at chest and eyes height through electronic dosimeters. The dose rate for different modes of operation and FOV were evaluated. The occupational dose was estimated through the product of the dose rate in the staff's position in the room, the median time of exposure and the mean of these procedures performed by the HCPA in 2019. As a result, it was observed that the decreasing order of the estimated occupational dose was Physician A - Physician R - Nursing Staff and Radiographer - Physician B and Supplier, with the following values in mSv/year of 6.16 - 3.98 - 2.54 - 2.17, respectively. A 37.04% reduction in the occupational dose was observed with the change in FOV, up to 59.26% with different modes of acquisition and 31.82% distancing 50 cm from the most exposed position. The dose of staff is significant. However, due to the optimization of protocols already implemented in HCPA, the estimated doses are in accordance with the recommended dose limits. As optimization actions verified in this study, it is suggested the proper selection of FOV, the adoption of acquisition modes with dose reduction and the distance from the X-ray source.

Keywords: **Cardiac Electrophysiology, Occupational Radiation Protection, Radiation Dosage.**

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1. INTRODUCTION

In recent years, the frequency of Interventional Radiology procedures has increased due to the decrease in the surgical complexity of this specialty, which makes the procedures less invasive with faster recovery of patients [1].

One of the situations of exposure to X-ray of these staff occurs when using C-arm (fluoroscopy) to guide interventional procedures. Despite the advantages of interventional radiology, the long exposure time, among other parameters, makes it one of the modalities that provides the highest doses to patients and professionals [1].

Originally, only radiologists performed these fluoroscopically guided techniques. Currently, this field has conquered other areas of expertise [1]. Among the physicians most exposed to radiation are interventional cardiologists and electrophysiologists [2]. In the last decade, cardiac electrophysiology has increased X-ray image-guided procedures, resulting in increased radiation dose to the patient and the staff involved. [3].

According to Brazilian legislation, Resolution RDC No. 661 published in 2022, every occupationally exposed workers must use at least one individual dosimeter during the work and while they remain in a controlled area, that is, in areas subject to special radiological protection rules [4]. Unfortunately, individual dosimeters are not always used by all professionals and are often used incorrectly [5]. Therefore, occupational doses may become largely unknown [6].

The individual monitoring of workers is opportune to verify the effectiveness of radiological protection practices in the workplace [6]. Information on the optimization of protection and control of the doses of professionals in relation to the limit established by the regulations are characteristics of an individual monitoring program [7]. The National Nuclear Energy Commission (CNEN) sets the dose limit for worker of 20 mSv/year (on average over a period of 5 years; not exceeding 50 mSv in any year) [8]. Even so, every effort to reduce the dose to the lowest possible levels should be considered [6].

It is known that exposure to X-rays in professionals who work with fluoroscopy can be more expressive when adequate processes of radiological protection are not used. Knowledge of workers doses in procedures using fluoroscopy is relevant to optimize radioprotection processes [6]. This knowledge can also be used to identify changes in the work routine and establish dose reduction measures [6].

Seeking optimization improvements and due to concerns about occupational dose, the recommendations in ICRP Publication No. 117 suggest conducting an individual monitoring assessment based on the results of workplace monitoring and information about that location and the time of worker exposure [6].

Thus, the objective of this study is to apply the recommendation of ICRP Publication No. 117 with the construction of an alternative methodology to estimate the occupational exposure of the cardiac electrophysiology staff of the Hospital de Clínicas de Porto Alegre (HCPA) through electronic dosimetry in the workplace and the evaluation of its optimization.

2. MATERIALS AND METHODS

This is a cross-sectional observational study with quantitative analysis of the estimate of the occupational dose of the cardiac electrophysiology staff at HCPA. In order to characterize the procedures for simulation and estimates of the study, cardiac electrophysiology procedures were monitored at the Cardiovascular Diagnostic and Therapy Department of the HCPA, as well as a search in the DICOM header of the images of the stored procedures in the HCPA PACS and literature review. The information collected manually through an observational study of each procedure were protocol, FOV (*Field Of View*), X-ray beam incidence angle, procedure time and positioning of the staff involved.

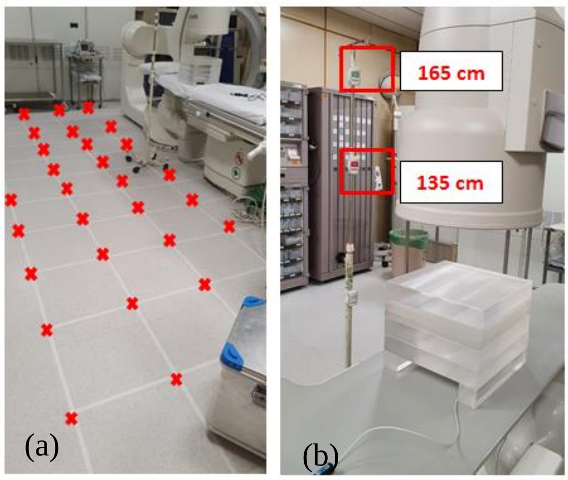
To estimate the percentiles, median, minimum and maximum exposure time per procedure, the procedures performed in the period from 2017 to 2019 were retrospectively evaluated, stored routinely using the “Electrophysiology” protocol in the study procedures, varying the modes “Continuos FOV 31 cm”, “1/2 dose FOV 31 cm”, “1/4 dose FOV 31 cm” and “Continuos FOV 23 cm”. For the experimental measurements, the BV Pulsera Philips C-arm equipment was used, the same equipment used by the electrophysiology staff, with a half-value layer of 5.7 mm Al for 80 kVp. The equipment is regularly subjected to quality control routine as recommended by national legislation and international recommendations, and has remained in compliance with the limits [4]. The simulation was performed at the electrophysiology staff's procedure room, using a 20 cm thick simulator of polymethyl methacrylate (PMMA) plates measuring 30 x 30 cm, like a typical adult patient [9,10].

Incident air kerma was measured using a calibrated Accu Dose equipment, with an ionization chamber (model 10X6-60) positioned on the patient´s support at a distance of 52 cm from the source, with the PMMA simulator positioned at the isocenter of the C-arm. This measurement was used to observe possible variations in the energy of the primary beam that could lead to variations in the measurement of electronic dosimeters.

To estimate the workers doses, Hp(10) doses were measured in rate mode (mSv/h) using calibrated *RaySafe i3* solid-state active dosimeters (electronic dosimeters), with detection limit of 0.03 mSv/h [11]. The reading of doses from electronic dosimeters was performed using the *RaySafe Dose Viewer v1.1.13.0 software*. The electronic dosimeters were distributed at 77 points at the intersections in a 50 x 50 cm grid covering a total area of 25 m², as illustrated in Figure 1 (a).

The dosimeters were fixed on different supports at two different heights from the floor: 135 cm and 165 cm, corresponding, respectively, to the chest and eyes of a typical adult worker, as illustrated in Figure 1 (b). For each position in the grid, three dose rate measurements were performed for each height, and the results were presented as the mean of these values. Considering the variations evaluated (acquisition modes and dosimeter height) for each measured point, a total of 1848 dose rate measurements were performed. Figure 1 illustrates the experimental setup.

Figure 1: *(a) Measuring points represented on a 50 x 50 cm grid covering a total area of 25 m². (b) Positioning of the dosimeters at the height of the chest (135 cm) and eyes (165 cm) of a typical adult.*



Source: The author (2020)

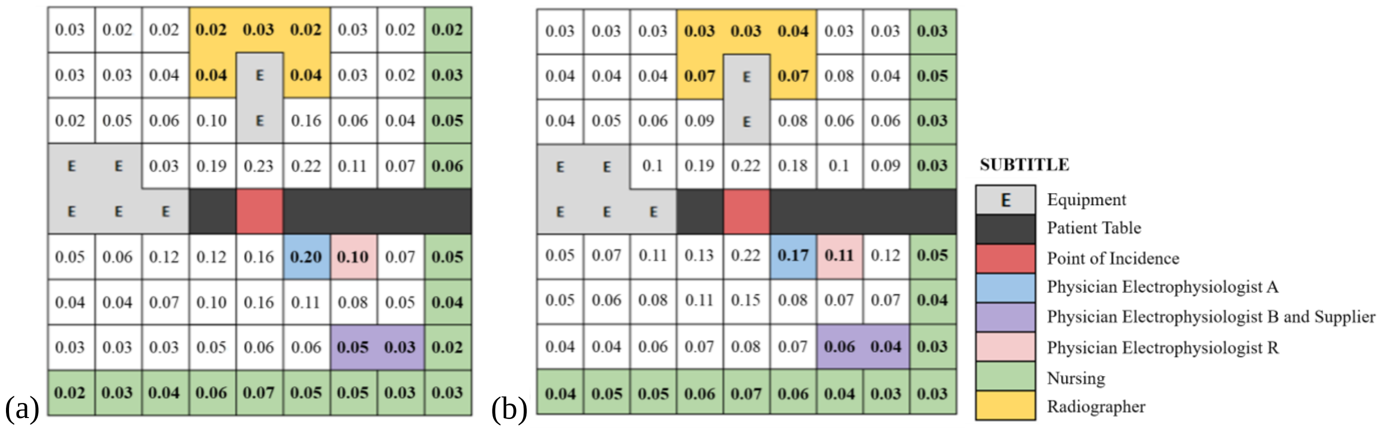
To estimate the annual dose of professionals in cardiac electrophysiology procedures at the HCPA, the dose rate measured at the point where each professional was located in the room, the mean number of procedures performed in the year and fluoroscopy time for the two most performed procedures.

3. RESULTS

The study of the procedures allowed the verification of the most frequent positioning of each professional in the room. The C-arm was maintained during all procedures observed in positioning PA (Postero-Anterior) and in automatic dose rate control. The DICOM header of the procedures performed in the year 2017 to 2019 was evaluated and the protocol used to perform these procedures was the “Electrophysiology”, in acquisition mode alternated between “1/2 dose FOV 31 cm” and “1/4 dose FOV 31 cm”. Therefore, for a conservative assessment of occupational dose, dose estimates by simulation in “1/2 dose FOV 31 cm” mode were considered.

Figure 2 shows the dose rate measurements, performed with the aid of electronic dosimeters, distributed in the distances in relation to the point of incidence of the primary beam of X-rays in the procedure room of the Cardiovascular Diagnosis and Therapy Department of the HCPA. The points where the reading was not performed, “E”, refer to the regions occupied by equipment present in the room, making it impossible to locate a professional. In the same condition, the black regions illustrate the positioning of the patient support. The points demarcated in different colors defined in the legend of Figure 2 correspond to possible locations of workers. The red point illustrates the region of incidence of the primary X-ray beam, equivalent to the position of a patient's chest. It was observed that the routine of the procedures is performed with two doctors close to the patient (Physician Electrophysiologist A and Physician Electrophysiologist R), being the region with the greatest exposure to scattering radiation. A Physician Electrophysiologist B and a Supplier, in the position of the polygraph machine, are located near the door of the procedure room as indicated in Figure 2. The Radiographer is positioned around the C-arm, while the nursing staff circulates in the region at patient's feet and on the right side of the patient, where the supply cabinets are located.

Figure 2: *2D dose rate mapping (mSv/h for the different acquisition points considering a 50 x 50 cm grid in a total area of 16 m2 (Acquisition in "½ dose FOV 31" mode - 77 kV and 1.39 mAs) measured at the height of the eyes, and at the height of the chest (b).*



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The mean number and standard deviation of procedures performed by electrophysiologists in 2019 was 98±11 procedures, distributed between 44% (43±7 procedures) in Diagnostic Electrophysiological Study and 56% (55±4 procedures) in Electrophysiology Therapies. The percentage distribution between diagnostic or therapeutic studies was considered to compose the annual occupational dose estimate.

Table 1 presents the estimated occupational dose values for a cardiac electrophysiology staff composed of Physician Electrophysiologist A, Physician Electrophysiologist B, Physician Electrophysiologist R, Nursing, Radiographer and Supplier, located at different points in the procedure room as indicated in the Figure 2. In order to carry out an analysis of the dose difference between professionals, in this evaluation a staff that participates in the same procedures during a period of one year was considered. The result of the occupational dose considered the exposure time for the Diagnostic and Therapeutic Electrophysiological procedures, respectively, of 13.47 min and 28.98 min for median, 0.73 min and 4.97 min for minimum, 74.88 min and 83.48 min for maximum, 5.45 min and 13.8 min for 25th percentile and 29.83 min and 37.73 min for 75th percentile.

Table 1: Estimate of the annual occupational dose of a cardiac electrophysiology staff that participated in 98 procedures in the year.

Occupational Dose (mSv/ano)						
	Measure	Electrophysiologist Doctor A	Physician Electrophysiologist B and Supplier	Electrophysiologist Doctor R	Nursing	Radiographer
Chest	Median	6.16	2.17	3.98	2.54	2.54
	Minimum	0.24	0.08	0.16	0.10	0.10
	Maximum	16.84	5.95	10.90	6.94	6.94
	25th Percentile	1.31	0.46	0.85	0.54	0.54
	75th Percentile	9.51	3.36	6.16	3.92	3.92
Lens	Median	7.24	1.81	3.62	2.17	1.45
	Minimum	0.28	0.07	0.14	0.08	0.06
	Maximum	19.82	4.95	9.91	5.95	3.96
	25th Percentile	1.54	0.38	0.77	0.46	0.31
	75th Percentile	11.19	2.80	5.60	3.36	2.24

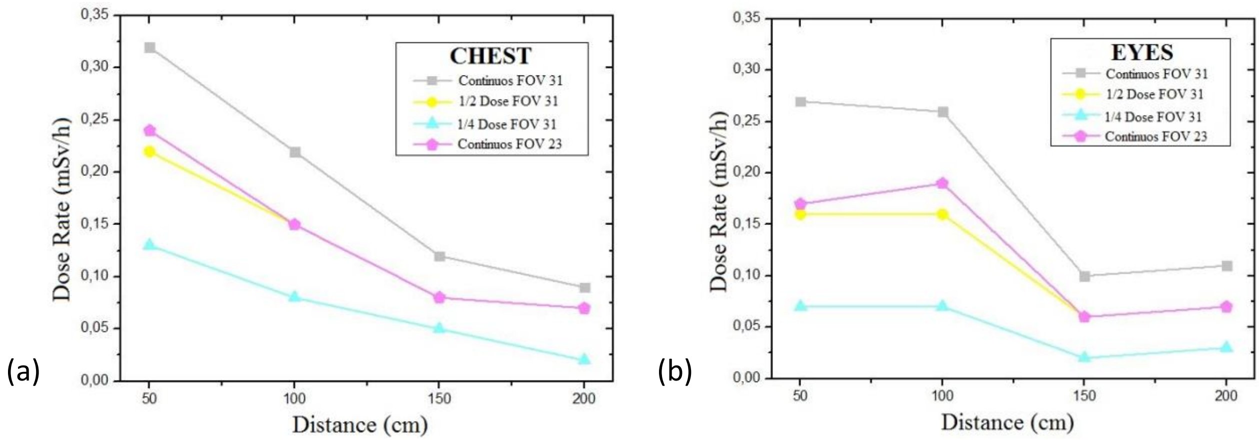
Table 2 presents the measured values of the incident air kerma rate as a function of the technical parameters for each acquisition mode, ensuring the reproducibility of the primary beam emission.

Table 2: Technical parameters, mean and standard deviation of the incident air kerma rate in the different acquisition modes.

Acquisition Mode	Voltage (kV)	Current (mA)	Incident Air Kerma Rate (mGy/min)
Continuos FOV 31	75	2.77	14.3±0.3
1/2 Dose FOV 31	77	1.39	8.7±0.5
1/4 Dose FOV 31	77	0.70	4.5±0.2
Continuos FOV 23	77	2.78	15.0±0.3

Figure 3 illustrates the difference in dose rate for different distances from the point of incidence of the X-ray beam (X-rays scattering region) considering the location of a worker with the most critical dose rate measurement at 50 cm, evaluating its distance. This difference is shown for the different acquisition modes simulated at the height of the chest (a) and eyes (b).

Figure 3: *(a) Comparison of the dose rate (mSv/h) in relation to the distance from the point of incidence of the X-ray beam for different acquisition modes, at chest height; (b) and at the height of the eyes.*



Source: The author (2020)

4. DISCUSSION

For the geometry and simulation parameters constructed, a cardiac electrophysiology staff that participated in the same procedures, presents in descending order of the dose rate measured at chest height, Physician Electrophysiologist A – Physician Electrophysiologist R – Nursing Staff and Radiographer – Physician Electrophysiologist B and Supplier, with the following values of the personal dose equivalent, Hp(10) of 0.17 – 0.11 – 0.07 – 0.06 mSv/h, respectively. This difference is characteristic of the positioning of the professional in the operating room, as shown in Figure 2.

The estimated values in Table 1 can be analyzed according to the annual occupational dose limits established by CNEN [8]. Physician Electrophysiologist A and Physician Electrophysiologist R are the workers that have the highest dose rates due to their proximity to the X-rays scattering region, when estimating the median exposure time to calculate the occupational dose at chest height, the result for these professionals is 6.16 mSv/year and 3.98 mSv/year, respectively. It is observed that the occupational dose of electrophysiologists remains below the annual limit of 50 mSv for effective dose; however, there must always be a critical eye due to the potential to exceed the average value of 20 mSv in 5 years. This demonstrates the importance of individual monitoring as a monitoring tool and optimization of interventional procedures.

The Physician Electrophysiologist B and the Supplier, who operate the polygraph machine during the procedure, are positioned in the region of lowest exposure according to the Radiation Protection Officer's orientation and, therefore, have the lowest occupational doses. The estimate considering the median time was 2.17 mSv/year, being approximately 2 times lower than the Physician Electrophysiologist R and about 3 times lower than the Physician Electrophysiologist A.

The Radiographer remains in the region highlighted in yellow in Figure 2, around the C-arm. Considering the most critical point in this region and the median exposure time, the estimate was 2.54 mSv/year. Likewise, considering the dose rate at the most critical point for Nursing, the annual dose estimate was the same as for the Radiographer, 2.54 mSv/year.

Among the professionals considered, Physician Electrophysiologist A is the only one who presents doses in the eyes region higher than doses at chest height, probably due to the geometry of the scattered radiation beam. According to the CNEN, the annual equivalent dose limit for the eyes lens is 20 mSv for workers [8]. The median value was 7.24 mSv/year, however, when considering the maximum procedure time, it can reach 19.82 mSv/year, close to the annual limit. This result highlights the importance of using lead glasses and/or ceiling mounted screen during these procedures. For the other staff members, using the maximum procedure time for dose estimation, the dose value in the eyes is below the annual limit established for the public of 15 mSv [8].

However, during the follow-up of the procedures, it was observed that the HCPA electrophysiology staff makes adequate use of Personal Protective Equipment (PPE) such as an apron with the equivalent of 0.5 mm of lead, thyroid protector and lead glasses, as well as Collective Protective Equipment (CPE) such as a lateral shield/table curtain and ceiling mounted screen. Therefore, it would still be advisable to think about inferring a reduction of the estimated annual doses to the chest by a factor of 10, given that this protective equipment provide an attenuation greater than 90% of the X-ray beam, depending on the characteristics of the X-ray beam [12].

The law of the inverse square of the distance guides the reduction of radiation exposure due to the distance from the source, in ideal situations. This way, when the distance between the professional and the source increases by two times, the exposure reduces to ¼ [13]. Thus, the position of the professional in relation to the X-rays scattering region is an important factor in reducing occupational exposure. Figure 3 presents a comparison of the dose rate at the height of the chest and the eyes of a professional as a function of the distance from the X-rays scattering region. As expected, it is possible to observe from both evaluations that the dose rate decreases with increasing distance. The percentage difference of 31.82% of the dose rate received at chest height can be obtained by the professional present at the 50 cm line compared to another professional who took a step back and remained at the 100 cm line, considering the highest exposure point.

During the evaluation to characterize the X-ray beam, the decreasing order of incident air kerma rate was Continuous FOV 23 – Continuous FOV 31 – ½ Dose FOV 31 – ¼ Dose FOV 31 mode, with the following values in mGy/min of 15.0 – 14 .3 – 8.7 – 4.5, respectively. This behavior is propagated for the scattering radiation measurements with the exception of the change of the FOV to continuous mode, which will be discussed in the following.

One way to optimize the procedure is to evaluate the image acquisition modes, which can be selected according to the availability of the equipment. In this study, the difference between continuous, ½ dose and ¼ dose modes was evaluated. It is possible to observe a significant difference between the acquisition modes through Figure 3, which can be explained by the technical parameters present in Table 2. Considering the most critical positioning of a professional in the room (Physician Electrophysiologist A), a dose rate difference of 37.04% is obtained from continuous mode to ½ dose and 35.29% from ½ dose to ¼ dose mode, considering the height of the chest. Thus, assuming that the use of the ¼ dose mode was able to provide the necessary information throughout the procedure, there would be a 59.26% reduction in the exposure of Physician Electrophysiologist A when compared to the continuous mode. For eyes height, these differences are even more representative, corresponding to 39.39%, 70% and 81.82%, respectively.

Another point to be considered is the selection of the image FOV, which is determined by the physical size of the image intensifier, so that the available magnifications generate a higher spatial resolution for a smaller FOV [13]. International recommendations suggest avoiding the use of magnification, as when this mode is activated the brightness gain of the image intensifier decreases as the magnification increases, resulting in an increase in the exposure rate to the patient due to signal compensation [13,14]. However, when analyzing the behavior of the scattered radiation shown in Figure 3, a decrease in the dose rate can be seen with the use of magnification. This is due to automatic beam restriction when changing the FOV from 31 cm to 23 cm, decreasing the irradiated area. Considering again the most critical position occupied by a professional in the room

(Physician Electrophysiologist A), a dose rate difference of 37.04% of FOV 31 cm to 23 cm is obtained, considering the height of the chest. For eyes height, this difference is even more representative, corresponding to 39.39%. However, it should be noted that the FOV used must always be adequate for the procedure performed, seeking the best dose-image quality relationship for the effective patient treatment.

5. CONCLUSION

Electronic dosimetry is useful for monitoring the workplace as an alternative individual monitoring method for occupational dosimetry. This is possible by mapping the dose rate of the workplace, knowledge of the exposure time of procedures, as well as the number of procedures in which each professional worked. In this way, it was possible to estimate the annual occupational dose value of a cardiac electrophysiology staff at the HCPA. The dose of professionals in the cardiac electrophysiology staff is significant, but it complies with the dose limits established in national regulations.

It was verified that the evaluated staff works optimally using image acquisition modes with dose reduction, which is positive for the patient and staff. Among the recommended actions for optimizing the procedure are the adequate selection of image magnification, the adoption of acquisition modes that consider dose reduction, distance from the X-ray source and the proper use of personal and collective protection equipment.

As the minimum legally required individual monitoring must estimate the effective dose and be positioned at the height of the worker´s chest, the dose to the eyes lens of these workers in Brazil is little known. Therefore, the proposed methodology for estimating the dose at the height of the eyes lens becomes essential for monitoring these indicators.

The proposed methodology can be adapted and applied to any specialty in interventional radiology. For this, it must be adapted to the reality of the workplace, the procedures and the care staff involved. Thus, the study provides for the performance of safety measures, optimization and education in relation to the dose received by a staff exposed to X-ray.

REFERENCES

[1] L. Canevaro, “Aspectos físicos e técnicos da Radiologia Intervencionista,” *Rev. Bras. Física Médica*, vol. 3, no. 1, pp. 101–115, 2009.

[2] H. J.W. *et al.*, “2018 ACC/HRS/NASCI/SCAI/SCCT Expert Consensus Document on Optimal Use of Ionizing Radiation in Cardiovascular Imaging: Best Practices for Safety and Effectiveness,” *Catheter. Cardiovasc. Interv.*, vol. 92, no. 2, pp. E35–E97, 2018, doi: 10.1002/ccd.27659.

[3] K. A. Wunderle, M. K. Chung, S. Rayadurgam, M. A. Miller, N. A. Obuchowski, and B. D. Lindsay, “Occupational and patient radiation doses in a modern cardiac electrophysiology laboratory.,” *J. Interv. Card. Electrophysiol. an Int. J. Arrhythm. pacing*, vol. 56, no. 2, pp. 183–190, Nov. 2019, doi: 10.1007/s10840-018-0462-8.

[4] ANVISA, “Resolução Da Diretoria Colegiada - RDC Nº 661, de 9 de março de 2022,” *Diário Of. da União*, vol. 51, no. 1, p. 107, 2022.

[5] E. Vano, N. J. Kleiman, A. Duran, M. M. Rehani, D. Echeverri, and M. Cabrera, “Radiation Cataract Risk in Interventional Cardiology Personnel,” *Radiat. Res.*, vol. 174, no. 4, pp. 490–495, Oct. 2010, doi: 10.1667/RR2207.1.

[6] ICRP, “ICRP Publication 117: Radiological Protection in Fluoroscopically Guided Procedures Performed Outside the Imaging Department,” 2010. doi: 10.1016/j.icrp.2012.03.001.

[7] IAEA, “Assessment of Occupational Exposure Due to External Sources of Radiation. Safety Standard RS-G-1.2,” 1999.

[8] CNEN. Ministério da Ciência Tecnologia e Inovação, “Norma CNEN NN 3.01: DIRETRIZES BÁSICAS DE PROTEÇÃO RADIOLÓGICA,” vol. 05, pp. 1–22, 2014, [Online]. Available: http://appasp.cnen.gov.br/seguranca/normas/pdf/Nrm301.pdf.

[9] AAPM, *Cardiac Catheterization Equipment Performance*, no. 70. 2001.

[10] SEFM-SEPR-SERAM, *Protocolo Español de Control de Calidad en Radiodiagnóstico*, vol. 5, no. 1. 2011.

[11] “RaySafe i3 Product Leaflet,” [Online]. Available: http://mediabank.raysafe.com/downloadAsset.jsp?catalog=RaySafe+Media+Bank&id=299&.

[12] W. M. B. e S. V. Juliana Pimentel, “AVALIAÇÃO DA ATENUAÇÃO DE AVENTAIS PLUMBÍFEROS COM DIFERENTES EQUIVALÊNCIAS DE CHUMBO PARA USO EM SERVIÇOS DE RADIOLOGIA,” *Soc. DEPROTEÇÃO RADIOLÓGICA*, pp. 0–5, 2014.

[13] J. T. Bushberg, J. A. Seibert, E. M. Leidholdt, J. M. Boone, and E. J. Goldschmidt, *The Essential Physics of Medical Imaging*, vol. 30, no. 7. 2003.

[14] IAEA, “10 Recomendações para proteção de pacientes em fluoroscopia 64,” pp. 1–2.