Journal Pre-proof

Radiation Protection Practices in Diagnostic and Interventional Cardiology: A position paper from the Portuguese Association of Interventional Cardiology

Diana Ribeiro Bruno Brochado Graciano Paulo Hugo Vinhas Elisabete Jorge Ana Felício Carlos Braga Pedro Sousa Rita Calé

PII: S0870-2551(25)00318-X

DOI: https://doi.org/doi:10.1016/j.repc.2025.07.006

Reference: REPC 2496

To appear in: *Revista Portuguesa de Cardiologia*

Received Date: 29 April 2025

Accepted Date: 14 July 2025

Please cite this article as: Ribeiro D, Brochado B, Paulo G, Vinhas H, Jorge E, Felício A, Braga C, Sousa P, Calé R, Radiation Protection Practices in Diagnostic and Interventional Cardiology: A position paper from the Portuguese Association of Interventional Cardiology, *Revista Portuguesa de Cardiologia* (2025), doi: https://doi.org/10.1016/j.repc.2025.07.006

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

© 2025 Sociedade Portuguesa de Cardiologia. Published by Elsevier España, S.L.U.

Journal Pre-proof

Radiation Protection Practices in Diagnostic and Interventional Cardiology: A position paper from the Portuguese Association of Interventional Cardiology

Práticas de Proteção Radiológica em Cardiologia de Diagnóstico e Intervenção: Artigo de Opinião da Associação Portuguesa de Cardiologia de Intervenção

Diana Ribeiro[a,*], Bruno Brochado[a], Graciano Paulo[b], Hugo Vinhas[c], Elisabete Jorge[d], Ana Felício[e], Carlos Braga[f], Pedro Sousa[g], Rita Calé[h]

[a] Centro Hospitalar do Porto – Hospital de Santo António, Porto, Portugal
[b] H&TRC- Health & Technology Research Center, ESTeSC - Escola Superior de Tecnologia da Saúde de Coimbra, Polytechnic University of Coimbra, Portugal
[c] Hospital de Faro EPE, Faro, Portugal
[d] Centro Hospitalar e Universitário de Coimbra – CHC, Coimbra, Portugal
[e] Centro Hospitalar de Lisboa Ocidental – Hospital de Santa Cruz, Carnaxide, Portugal
[f] Hospital de Braga, EPE, Braga, Portugal
[g] Centro Hospitalar de Leiria, EPE – Hospital Santo André, Leiria, Portugal
[h] Hospital Garcia de Orta EPE, Almada, Portugal

*Corresponding author:
E-mail adress: dianaataribeiro@gmail.com
Address: Largo do Prof. Abel Salazar, 4099-001, Porto, Portugal
Institutional phone number: 00 351 22 207 7500

ABSTRACT

Introduction: Interventional cardiovascular procedures are increasingly complex, raising concerns about heightened radiation exposure for both patients and healthcare professionals. This exposure can lead to serious complications, including skin injuries, cataracts, and cancer. A range of protective tools—such as lead aprons, thyroid collars and glasses, ceiling-mounted shields, and table skirts—are available to minimize occupational exposure. Effective radiation protection relies not only on equipment but

Journal Pre-proof

also on procedural strategies such as improved beam collimation, reduced fluoroscopic pulse rates, fluoroscopy intensity and the number of cine acquisitions, and maintaining distance from the X-ray source. Staff education, ongoing training, and routine audits are essential to ensure adherence to radiation safety protocols. While interventional cardiology teams show general awareness and use of protective measures, significant gaps remain—particularly in the consistent use of eye protection, personal dosimeters, and standardized practices across cath labs. Strengthening these areas is critical to promoting a unified national approach to radiation safety and safeguarding the long-term health of Cath lab personnel.

Objectives: This position paper aims to raise operator awareness and propose novel strategies for minimizing ionizing radiation doses, thus mitigating associated risks.

Methods and results: This working group conducted a review of the scientific literature and the most recent international guidelines on radiation protection in cardiac cath labs. Based on this analysis, effective protective measures and best practices were identified and systematized, adapted to the Portuguese context.

Conclusion: Minimizing radiation exposure in the cath lab requires a comprehensive, multidisciplinary approach that combines protective equipment, procedural adjustments, and collaborative safety protocols to safeguard both patients and healthcare providers without compromising clinical outcomes.

RESUMO

Introdução: Os procedimentos de intervenção cardiovasculares são cada vez mais complexos, suscitando preocupações quanto ao aumento da exposição à radiação para pacientes e profissionais de saúde. Esta exposição pode levar a complicações graves, incluindo lesões cutâneas, cataratas e cancro. Existe uma variedade de equipamentos de proteção — como aventais, colares tiroideus e óculos de chumbo, escudos montados e saias de mesa — que minimizam a exposição ocupacional. Uma proteção radiológica eficaz depende não só do equipamento, mas também de alterações nos procedimentos, tais como a melhor colimação do feixe, uma menor taxa de pulso fluoroscópico, menor intensidade da fluoroscopia e número de cineaquisições e o aumento da distância entre o operador e a fonte de raios-X. A educação contínua, a formação e auditorias regulares são essenciais para assegurar o cumprimento dos protocolos de segurança radiológica.

Journal Pre-proof

Apesar de as equipas de cardiologia de intervenção demonstrarem uma consciencialização dos protocolos de segurança radiológica e utilização de medidas protetoras, persistem lacunas significativas — sobretudo na utilização consistente de proteção ocular, dosímetros pessoais e práticas padronizadas nos laboratórios de hemodinâmica. O reforço destas áreas é fundamental para promover uma abordagem nacional unificada de segurança radiológica e proteger a saúde a longo prazo dos profissionais.

Objetivos: Este documento de posição visa aumentar a consciencialização dos operadores e propor estratégias para minimizar as doses de radiação ionizante, reduzindo assim os riscos associados.

Métodos e Resultados: Este grupo de trabalho realizou uma revisão da literatura científica e das recomendações internacionais mais recentes sobre proteção radiológica em laboratórios de hemodinâmica. Com base nesta análise, foram identificadas e sistematizadas medidas protetoras eficazes e boas práticas, adaptadas ao contexto português.

Conclusão: A minimização da exposição à radiação nos laboratórios de hemodinâmica exige uma abordagem abrangente e multidisciplinar que combine equipamento de proteção, ajustes procedimentais e protocolos de segurança colaborativos, salvaguardando tanto os pacientes como os profissionais de saúde, sem comprometer os resultados clínicos.

Key words: Interventional Cardiology, Radiation, Radioprotection, Exposure, Risk

Palavras-chave: Cardiologia de intervenção, Radiação, Radioproteção, Exposição, Risco

Journal Pre-proof

Journal Pre-proof

INTRODUCTION

In the last decades, percutaneous coronary and structural heart interventions have rapidly expanded. Exposure to ionizing radiation is increasing as more progressively more complex procedures are performed, such as multivessel and chronic total occlusions (CTO) percutaneous coronary intervention (PCI), transcatheter heart valve interventions and balloon pulmonary angioplasty.[1] Personnel at risk include the patient, interventional cardiologists, nurses, technologists, ancillary operators such as interventional echocardiographers and anesthesiologists, as well as fellows in training.[2,3] In cath labs, the primary source of ionizing radiation exposure for staff is scatter radiation generated by the patient during fluoroscopic procedures. Direct exposure to the primary x-ray beam is uncommon among personnel. The extent of scatter depends on the patient's radiation dose—commonly measured by the cumulative kerma-area product (KAP)—as well as the operator's proximity to the source and the adequacy of protective shielding in use. Ionizing radiation poses a risk to the entire team in the form of tissue reaction and stochastic adverse effects. Tissue reaction effects including, for example, cataracts and skin lesions, appear at established radiation doses where, below a certain threshold, cell loss is insufficient to cause detectable tissue or organ injury; stochastic effects are those that can occur at any dose level and whose probability of occurrence is proportional to the received radiation dose (e.g., cancer development due to somatic cell mutations).[4-8]

Education and continuous training on radiation protection are essential components in minimizing occupational exposure and ensuring patient safety in interventional cardiology. Comprehensive training programs significantly increase awareness and correct use of protective measures, leading to substantial reductions in radiation doses received by healthcare workers. For instance, the International Atomic Energy Agency (IAEA)[9] and the International Commission on Radiological Protection (ICRP)[10,11] highlight education as a fundamental pillar in radiation safety culture, recommending regular competency assessments and updated training to adapt to evolving procedural complexities. Despite the availability of protective equipment, gaps in proper usage and monitoring often persist without adequate education, underscoring the need for structured training initiatives and institutional support to enforce radiation safety

Journal Pre-proof

protocols effectively. These measures not only protect staff from deterministic and stochastic radiation effects but also contribute to sustaining high standards of patient care.

Interventional cardiology professionals generally adhere to safety protocols and utilize protective equipment, yet there is space for improvement, particularly in the areas of eyewear protection and exposure monitoring.[12]

OBJECTIVES

This position paper aims to raise awareness among healthcare professionals working in Portuguese cath labs about the potential health risks associated with occupational exposure to ionizing radiation. The paper seeks to underscore the importance of a culture of safety, reinforce current scientific evidence on radiation-induced health effects, and present a set of practical, evidence-based recommendations designed to reduce exposure. By promoting best practices in radiation protection, this document aspires to support the long-term health and well-being of cath lab personnel, while maintaining high standards of patient care.

RADIATION EXPOSURE AND AWARENESS

Teams in the cardiac cath lab need to consider minimizing radiation use and adhere to the ALARA principle—as low as reasonably achievable. This principle dictates that even minor doses of radiation should be avoided if they confer no direct benefit.[13,14]

Thus, interventional cardiology teams need to work to implement radiation protection methods to reduce short- and long-term deleterious effects. According to Costa et al.,[12] there is still a lack of certified radiation protection education and training for all the cath lab members. Nevertheless, the adoption of protection measures has been more frequent, notably through the use of personal protective equipment, collimation, reducing the distance to the radiation source, avoiding angled projections and using low-dose protocols. The goal is not the absence of radiation, as precise imaging remains vital for executing complex procedures safely and effectively, but the continuous assessment of the balance between the radiation exposure-associated risks and its benefits.[15,16]

Journal Pre-proof

The whole-body dose limit for occupational exposure to ionizing radiation for cath lab staff is 20 mSv per year, averaged over defined periods of five years, with no individual annual exposure to exceed 50 mSv. In the United States, the National Council on Radiation Protection and the Occupational Safety and Health Administration (OSHA) permit a higher annual whole-body radiation exposure limit of 50 mSv.[17] However, the ICRP recommends a more conservative limit of 20 mSv per year, averaged over a five-year period.[11] This lower threshold is increasingly cited in modern guidelines and is widely regarded as the preferred standard for reducing long-term health risks.[10,11]

The ICRP has also proposed revised dose limits to the lens of the eye of workers of 20 mSv per year averaged over five consecutive years (100 mSv in 5 years) and of 50 mSv in any single year as well as an equivalent dose to the extremities (hands and feet) or to the skin of 500 mSv in a year; these recommendations were adopted by the European Union and Portugal.[11,11,18,19]

The IAEA[9] highlights the importance of standardized dose descriptors in fluoroscopy-guided procedures. These descriptors are essential for evaluating patient exposure, guiding optimization strategies, and ensuring adherence to radiation safety standards.

Among the most relevant metrics is the air kerma at the patient entrance reference point (K_a,r), which represents the cumulative radiation dose delivered to a predefined reference point. This value serves as a proxy for estimating skin dose and assessing the potential for deterministic effects. Another key descriptor is the kerma-area product (PKA or DAP), which reflects the total energy delivered to the patient by integrating the air kerma across the entire X-ray beam area. This metric is particularly relevant for evaluating stochastic risk. Fluoroscopy time is also commonly used, providing a basic indication of procedural duration and exposure potential, although it does not directly quantify radiation dose. In procedures that involve digital subtraction angiography or cine runs, the number of acquired images becomes an important metric, as each image acquisition significantly contributes to the total dose. These dose descriptors are typically available on modern fluoroscopy equipment and are crucial for both real-time dose monitoring and retrospective analysis. They support informed decision-making during procedures and play a key role in identifying opportunities for dose reduction.

Journal Pre-proof

GENERAL RECOMMENDATIONS TO MINIMIZE EXPOSURE FOR PATIENTS AND PROFESSIONALS

For patients, radiation exposure largely originates from the primary beam. Conversely, for operators and other personnel, scattered radiation from the patient is the primary source of exposure. Overall, adopting practices that protect the patient also minimizes risks to health care professionals (Figure 1).[20-21] To reduce radiation exposure effectively for both patients and healthcare personnel, the following best practices should be implemented during procedures involving ionizing radiation:

- Avoid unnecessary use of ionizing radiation by ensuring proper justification for each procedure (justification principle); when performed, procedures should follow the ALARA principle—keeping radiation as low as reasonably achievable while still ensuring diagnostic or therapeutic adequacy;
- Make good use of time-distance-shielding principles: minimize exposure time, maximize distance from the source as clinically possible and use appropriate shielding;
- Keep the X-ray tube below the table, not at the same level or above it;
- Maximize, whenever possible, the distance between the X-ray tube and the patient;
- Minimize the distance between the patient and the image receptor (image intensifier or flat-panel detector);
- Minimize both fluoroscopy and cine acquisition time;
- Use pulsed fluoroscopy with the fewest pulses possible to obtain acceptable-quality images;
- Store fluoroscopy images when appropriate to prevent unnecessary repeat exposures;
- Utilize Last Image Hold (LIH) and Last Series Hold (LSH) features to reduce additional radiation exposure;
- Avoid irradiating the same skin area from multiple projections; vary beam angles to distribute skin dose;
- Oblique projections increase entrance skin dose (ESD), which increases the likelihood of skin injury;

Journal Pre-proof

- Minimize magnification mode utilization;
- Record the radiation dose received by the patient in the procedure report.

RECOMMENDATIONS TO MINIMIZE EXPOSURE SPECIFICALLY FOR PROFESSIONALS

Education and training, as well as proper utilization of protective equipment is paramount for optimal radiation protection. Strategies to reduce occupational radiation exposure are listed in Table 1.[11,,20-29]

Recommendations specifically for minimizing exposure for professionals
Use personal protective equipment
Use ceiling-mounted shields, side shields, lead curtains below the table and, if possible, mobile cabins
Use protective screens for ancillary operators (e.g., interventional echocardiographers and anesthesiologists)
Increase the distance to the radiation source
Keep hands away from the primary X-ray beam
Use personal dosimeters specific for every cath lab or institution
Update education and training in radiation protection periodically
Refer radiation protection doubts to radiation protection officer
Ensure the safe operation of fluoroscopy equipment through quality control measures and employ proper equipment usage to minimize patient and team radiation exposure
Promote clear communication and role awareness among all team members regarding radiation safety
Encourage a safety culture where all staff are empowered to speak up about radiation concerns

Table 1 Strategies to reduce occupational radiation exposure for professionals.

Personal protective equipment

Journal Pre-proof

All professionals in the cath lab must be protected with, at least, a lead apron and thyroid shielding. Lead aprons are essential for reducing radiation exposure among staff and should provide a lead-equivalent thickness of at least 0.5 mm at the front and 0.25 mm at the back, in line with current recommendations.[17] While two-piece aprons can help distribute weight more evenly, increasing protection beyond these values significantly adds to the physical burden. The use of lightweight or composite protective materials in cath labs offers effective radiation shielding while significantly reducing the weight of protective garments—up to 30% lighter than traditional lead aprons—thereby improving comfort and reducing musculoskeletal strain, fatigue, and the risk of orthopedic injury during prolonged procedures.[11,20] Personalized aprons improve ergometry and optimize protection.[11,21] Thyroid shielding is also recommended, as there is a well-established association between radiation exposure and risk of thyroid cancer. The protection of an area of approximately 300 cm^2 and a thickness of 0.25 to 0.5 mm of lead is required for exposure reduction.[3] The use of leaded glasses should also be encouraged. The goal of protective eyewear is to provide maximal shielding from front, lateral and angular radiation. Radiation-induced cataracts are among the most frequent problems, and the use of lead glasses reduces radiation risk by up to 98%.[4] Additional personal protective equipment, such as caps and gloves, may be used in the cath lab[2,11,20]; however, protective gloves should never be placed in the path of the primary x-ray beam. This is because the attenuation provided by leaded gloves is insufficient to prevent significant radiation exposure to the hands, and their presence in the primary beam can trigger the automatic exposure control system to increase the x-ray output, paradoxically resulting in a higher radiation dose to the operator's hands.[16,30] Additionally, the use of gloves in the primary beam may create a false sense of security, leading to riskier hand positioning and increased cumulative exposure.[30] Caps, gloves, sleeves and boots were reported as the least accessible protection equipment within the Portuguese cath labs.[12]

Other protective equipment

There are other ways to reduce radiation exposure, particularly with the use of ceiling-mounted shields, which allow significant protection for the upper trunk, especially the head, thyroid and crystalline lens. The shield should be positioned near the patient to

Journal Pre-proof

intercept scatter radiation at its origin, maximizing attenuation effectiveness.[10,20-29] Table lead skirts offer effective protection of the operator's lower trunk, especially for the gonads. A ceiling-suspended screen and a curtain shield under the table reduce scatter radiation by approximately 80% to 90%.[22]

Additional commercially available devices, such as suspended or portable shields and cabins, provide an opportunity to reduce radiation exposure as well as reduce the risk of orthopedic lesions.

Artificial intelligence (AI) solutions are emerging and rapidly evolving as promising tools to enhance occupational safety and reduce radiation exposure in cath labs. By enabling real-time dose monitoring, optimizing imaging settings, and improving collimation precision, AI helps limit unnecessary radiation.[31] These technologies also support workflow through automated alerts and improved use of protective equipment.[31] While their potential is clear, broader adoption will depend on continued research and seamless integration into clinical systems.

PROCEDURAL ASPECTS

Angiography Equipment and Image Quality

General angiography system characteristics should be well understood to optimize imaging quality and safety. The following aspects and recommendations should be taken in account:

- Geometry: the X-ray tube and image receptor rotate around a point called the "isocenter" where the anatomical region under study should be positioned. Minimize the use of steep angles for the X-ray beam, as extreme angulations are associated with higher cumulative air kerma at the patient entrance reference point ($K_{a,r}$) values. Placing the C-arm within 0° to 20° angulation can significantly reduce scattered radiation during fluoroscopic acquisition, with the left anterior oblique (LAO) view showing the highest scatter exposure to the operator. Minimizing LAO use greatly reduces both the patient and operator exposure;
- Fluoroscopy modes: pulsed fluoroscopy reduces patient radiation exposure by allowing the operator to decrease both the number of x-ray pulses per second (pulse rate) and the intensity (dose) of each pulse. Since total radiation dose is the

Journal Pre-proof

product of pulse rate, pulse intensity, and exposure time, adjusting these parameters can lead to substantial dose reductions. For instance, reducing the pulse rate from 15 frames per second (fps) to 7.5 fps or lower, combined with a low-dose setting, can decrease radiation exposure by at least 67% compared to standard fluoroscopy.[2-6,26] Implementing a low-radiation protocol resulted in significant reductions in PKA —also referred to as KAP or DAP, all meaning air kerma-area product, measured in Gy·cm² —alongside decreases in $K_{a,r}$, without increasing procedural complications, fluoroscopy time, or contrast volume. Recent studies state that PKA, KAP, and DAP are equivalent terms[32-34], representing the total radiation energy related to stochastic risk, while $K_{a,r}$ is often used as a surrogate for the patient's peak skin dose and reflects tissue effects[32], supporting the need to report both in dose optimization protocols.

- Fluoroscopy storage: this allows storing up to 500 fluoroscopy sequence images without additional cine;
- Cine acquisition should be limited as much as possible (accordingly with the ALARA principle), as the radiation level usually is a factor of 10 higher than during fluoroscopy;
- Novel technologies, such as stent enhancement software, intracoronary imaging and hybrid cardiovascular imaging are associated with reduced contrast usage and radiation dose;
- Filters assist in image quality and patient's dose control. Edge filters allows a partial reduction of the primary beam corresponding to low attenuation parts of the body;
- Collimation adjustment: using collimators and focusing only on the fields of interest reduces patient and operator´s dose and improves image quality; virtual collimation, guided by software or AI, further enhances this by dynamically shaping the x-ray beam in real time to limit exposure to only the necessary area.
- Avoiding using magnification (e.g., decreasing the field of view by a factor of 2 will increase the radiation dose by a factor of 4);
- Anatomic programming: allows control of dose management and image quality, selecting the anatomical region and patient size to be irradiated;

Journal Pre-proof

- Digital acquisition: the Digital Images and Communications in Medicine (DICOM) provides important information about the protocols used in the center for each procedure;
- Robotic PCI may, after overcoming technical and financial challenges, be an option to completely exclude professional radiation exposure in the cath lab.[20-29]
- Radiation Dose Structured Report (RDSR): a standardized DICOM format that automatically captures detailed radiation exposure data—such as cumulative air kerma, KAP, fluoroscopy time, and technical settings—for each fluoroscopic or interventional procedure. It enables accurate and consistent dose documentation, supports cumulative dose tracking, facilitates integration with dose management systems for real-time or retrospective analysis, and plays a key role in quality assurance, regulatory compliance, and radiation safety in cath labs.[17]

Radiation exposure measurements and data

All cath lab members should have their radiation exposure monitored with a dosimeter. According to the ICRP publication 118[10] and the ICRP publication 139[11], the use of at least two dosimeters is recommended for exposed individuals:

- Primary personal dosimeter under the lead apron at chest level, directed toward the radiation source;
- Second dosimeter located above the apron, at neck level;

Using these two dosimeters offers the most accurate available estimate of effective dose. Additionally, the dosimeter worn under the apron serves as confirmation that adequate protective shielding was consistently used.[11]

Eye dose can be measured using a dosimeter worn over the lead apron at collar or neck level, or with a separate dosimeter mounted on a plastic strip attached to a headband, positioned near the temple closest to the X-ray source.[11] Dosimeters positioned near the eyes must be designed so they do not obstruct the wearer's field of vision. An additional dosimeter located on the hand region can be used.

Most healthcare professionals use whole-body passive dosimeters, typically read monthly to assess cumulative dose.[11] While these devices are small and unobtrusive, their lack of real-time feedback limits their effectiveness for dose optimization and

Journal Pre-proof

behavioral guidance. A significant proportion of staff still do not use dosimeters consistently[12], highlighting the need for improved compliance and monitoring practices. The introduction of active personal dosimeters (APDs), which provide immediate dose rate feedback, enables staff to adjust behavior during procedures and adopt real-time dose-reduction strategies.[3,11] APDs also support procedural analysis, correlate staff and patient exposures, and help audit proper usage by recording exposure times.[11]

At the end of the procedure, an automatically generated report with the values of $K_{a,r}$ and PKA should be included in the patient's medical records; [20-29]

In case of exceeding the trigger levels for possible tissue reactions (peak skin dose (PSD) ≥ 3 Gy, $K_{a,r}$ ≥ 5 Gy, PKA ≥ 500 Gy.cm^2 or fluoroscopic time ≥ 60 min), a clinical follow-up is mandatory to evaluate relevant skin injuries.[35]

PSD is the highest radiation dose received by a localized area of skin and is the most important predictor of radiation-induced skin injuries, such as erythema, epilation, and necrosis. The risk and severity of these effects increase with higher PSD. Although PSD can't be directly measured in clinical settings, it can be estimated using air kerma and X-ray geometry. Thus, PSD is a key parameter for identifying patients at risk, guiding real-time dose management (e.g., adjusting beam angle, reducing fluoroscopy time), and planning appropriate follow-up to prevent and manage skin injuries.[13,16]

Tissue reaction follow-up is essential after high-dose procedures to detect and manage delayed skin injuries. When radiation exceeds safety thresholds, proper documentation, patient notification, and follow-up are required. [13,35]

After procedures where $K_{a,r}$ exceeds 5 Gy, patients and their primary care providers should be notified, and the patient educated about possible skin changes. A follow-up phone call is recommended at 30 days, with an office visit if symptoms arise. For $K_{a,r}$ above 10 Gy, a medical physicist should promptly estimate the PSD, and the patient should return for a clinical exam 2 to 4 weeks postprocedure to check for skin effects. If the PSD exceeds 15 Gy, this must be reported as a sentinel event, with hospital risk management and regulatory agencies notified within 24 hours.[13] Personal dosimeters results must be listed in the Registo Central de Doses of the Agência Portuguesa do Ambiente.[36]

The promotion of clinical audits is essential to stimulate optimization processes, reinforce radiation protection measures, and ensure compliance with clinical guidelines

Journal Pre-proof

and safety standards.[11] By systematically evaluating current practices, clinical audits help identify areas for improvement and support the continuous enhancement of quality and safety in radiological procedures.

Special conditions

Heightened awareness of radiation risks is essential during complex fluoroscopy-guided procedures[1,37] and when treating patients with higher body mass index (BMI) or larger body size, as these scenarios are associated with increased radiation exposure to both patients and staff.[9,10,37] Patients with obesity receive higher radiation doses due to greater x-ray attenuation[5], which prompts automatic exposure controls to increase tube output, resulting in more scatter and higher operator dose.[17] In such cases, optimal collimation to restrict the irradiated area, use of additional external shielding, and minimizing fluoroscopy time are critical strategies to reduce exposure. [9,10]

Complex procedures require longer fluoroscopy times and more imaging, further elevating cumulative dose, so real-time monitoring of dose metrics (such as air kerma and kerma-area product) and judicious use of dose-saving features (e.g., pulsed fluoroscopy, low-dose modes) are recommended to maintain exposures as low as reasonably achievable.[1,17,37]

It is also recommended that operators remain vigilant regarding dose accumulation during prolonged or technically challenging procedures, using the lowest acceptable dose settings, minimizing field size, and documenting dose indices for quality assurance and follow-up, especially when thresholds for deterministic effects may be approached.[17,37]

Journal Pre-proof

Journal Pre-proof

Radiation exposure during pregnancy and breastfeeding

Radiation exposure often discourages women from pursuing a career in interventional cardiology.[38,39] Generally, the risks of fetal exposure to ionizing radiation are highest at the beginning of pregnancy and decrease as the fetus matures. The highest risk of pregnancy loss is within the first two weeks, while organogenesis in weeks two to eight weeks makes the embryo most vulnerable to malformations, growth retardation and cancer.[28,38,40]

The International Atomic Energy Agency (IAEA)[41] and the ICRP[42] recommends a cumulative dose < 1 mSv for the entire pregnancy (the same as the annual limit for public exposure) and, accordingly with many European and North American directives, pregnancy does not mandate exclusion from the cath lab.[28,38,40-44]

Despite guidelines from international and European authorities, the application of policies on pregnancy and occupational radiation exposure varies widely between countries.[39] Current Portuguese legislation, despite different local legal interpretations, states that the pregnant or breastfeeding professional must immediately inform the radiation-generating device custodian and this entity must provide the necessary mechanisms for monitoring and preventing fetal radiation-related lesions.[19]

The radiation safety principles and recommendations are similar to those for other professionals, however; there are additional considerations, which include minimizing time of exposure, maximizing distance, shielding and fetal and professional dosimeter monitoring (Table 2).

A survey conducted by the European Heart Rhythm Association (EHRA) highlighted limited awareness of regulations related to occupational radiation exposure—especially during pregnancy—and inconsistent application of fundamental radiation protection practices.[44] Thus, radiation protection training should be mandatory for all staff exposed to radiation, including pregnant professionals, with content that is regularly updated and compliant with current guidelines. [44]

Journal Pre-proof

Radiation safety principles and recommendations for pregnant and breastfeeding professionals
Unborn and breastfed children limit for radiation exposure is < 1 mSv / annually
Keep exposure as low as reasonably possible (ALARA principle)
In addition to the standard personal dosimeters, use fetal dosimeter under the lead at waist level
Real-time radiation dosimeters should be available to allow prompt action in case of excessive radiation exposure
Use lead aprons specifically designed for pregnancy: lightweight lead aprons with a minimum of 0.5 mm lead equivalency
Use novel radiation protection systems as upper and lower-body shields and lead-free systems as mobile cabins
Limit use of fluoroscopy with hybrid cardiovascular imaging

Table 2: *Strategies for reducing occupational radiation exposure among pregnant and breastfeeding professionals.*

Journal Pre-proof

Journal Pre-proof

CONCLUSION

The harmful effects of radiation exposure are widely recognized and efforts to minimize them as much as possible should be made, as complete avoidance is unfeasible. The primary source of radiation for the operator is the scatter from the patient, thus decreasing the radiation dosage used during the procedure will yield benefits for both parties.

Creating a radiation safety program for cath labs requires the collective involvement of physicians, technologists, medical physicists, radiation protection officers, quality assurance personnel and hospital administration, with the aim of enhancing safety for patients and health care providers.

Relying solely on radiation protection tools does not offer optimal safeguarding for staff members; instead, employing a comprehensive combination of tools, as outlined in this paper, proves to be the most effective approach. Research indicates that integrating lead glasses, thyroid collars, aprons, and table lead skirts significantly diminishes operators' radiation exposure. Procedural adjustments, such as enhanced beam collimation, decreased fluoroscopic pulse rate, and increasing operator distance from the x-ray source, are equally critical in reducing the overall procedure dosage. However, it is vital to ensure that diagnostic and therapeutic outcomes are not compromised amidst these efforts.

Ethics in publishing

1. Does your research involve experimentation on animals?:

No

2. Does your study include human subjects?:

No

3. Does your study include a clinical trial?:

No

4. Are all data shown in the figures and tables also shown in the text of the Results section and

discussed in the Conclusions?:

Yes

Journal Pre-proof

FUNDING

The authors did not receive payment related to the development of the manuscript.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

Journal Pre-proof

Journal Pre-proof

REFERENCES

1. Stocker TJ, Abdel-Wahab M, Möllmann H, et al. Trends and predictors of radiation exposure in percutaneous coronary intervention: the PROTECTION VIII study. EuroIntervention. 2022;18(4):e324-e332. doi: 10.4244/EIJ-D-21-00856.
2. Williams MC, Stewart C, Weir NW, et al. Using radiation safely in cardiology: what imagers need to know. Heart. 2019;105(10):798-806. doi: 10.1136/heartjnl-2017-312493.
3. Ghallab M, Abdelhamid M, Nassar M, et al. Assessing and improving radiation safety in cardiac catheterization: a study from Cairo University Hospital. Egypt Heart J. 2024;76(1):17. doi: 10.1186/s43044-024-00449-7.
4. Elmaraezy A, Ebraheem MM, Tarek MA, et al. Risk of cataract among interventional cardiologists and catheterization lab staff: a systematic review and meta-analysis. Catheter Cardiovasc Interv. 2017;90(1):1-9. doi: 10.1002/ccd.27114.
5. Abbott JD. Controlling radiation exposure in interventional cardiology. Circ Cardiovasc Interv. 2014;7(4):425-8. doi: 10.1161/CIRCINTERVENTIONS.114.001815. PMID: 25139083.
6. Bar O. Understanding and Minimising Occupational Radiation in the Catheterisation Laboratory with PISAX and the ACIST CVi® Contrast Delivery System. Interv Cardiol. 2013;8(1):36-40. doi: 10.15420/icr.2013.8.1.36.
7. Wassef AW, Hiebert B, Ravandi A, et al. Radiation dose reduction in the cardiac catheterization laboratory utilizing a novel protocol. JACC Cardiovasc Interv. 2014;7(5):550-7. doi: 10.1016/j.jcin.2013.11.022.
8. Venneri L, Rossi F, Botto N, et al. Cancer risk from professional exposure in staff working in cardiac catheterization laboratory: insights from the National Research Council's Biological Effects of Ionizing Radiation VII Report. Am Heart J. 2009;157(1):118-24. doi: 10.1016/j.ahj.2008.08.009. ´
9. International Atomic Energy Agency, Patient Radiation Exposure Monitoring in Medical Imaging, Safety Reports Series No. 112, IAEA, Vienna (2023)
10. Stewart FA, Akleyev AV, Hauer-Jensen M, et al. ICRP publication 118: ICRP statement on tissue reactions and early and late effects of radiation in normal tissues and

Journal Pre-proof

organs--threshold doses for tissue reactions in a radiation protection context. Ann ICRP. 2012;41(1-2):1-322. doi: 10.1016/j.icrp.2012.02.001.

11. López PO, Dauer LT, Loose R, et al. ICRP Publication 139: Occupational Radiological Protection in Interventional Procedures [published correction appears in Ann ICRP. 2019 Sep;48(1):99. doi: 10.1177/0146645318773608.]. *Ann ICRP*. 2018;47(2):1-118. doi:10.1177/0146645317750356
12. Costa H, Vinhas H, Calé R, et al. A report on a survey among Portuguese Association of Interventional Cardiology associates regarding ionizing radiation protection practices in national interventional cath-labs. Rev Port Cardiol. 2024;43(4):177-185. doi: 10.1016/j.repc.2023.07.008.
13. Chambers CE, Fetterly KA, Holzer R, et al. Radiation safety program for the cardiac catheterization laboratory. Catheter Cardiovasc Interv. 2011;77(4):546-56. doi: 10.1002/ccd.22867.
14. Agarwal S, Parashar A, Bajaj NS, et al. Relationship of beam angulation and radiation exposure in the cardiac catheterization laboratory. JACC Cardiovasc Interv. 2014;7(5):558-66. doi: 10.1016/j.jcin.2013.12.203.
15. Durán A, Hian SK, Miller DL, et al. REcommendations for occupational radiation protection in interventional cardiology. Catheter Cardiovasc Interv. 2013;82(1):29-42. doi: 10.1002/ccd.24694.
16. Heidbuchel H, Wittkampf FH, Vano E, et al. Practical ways to reduce radiation dose for patients and staff during device implantations and electrophysiological procedures. Europace. 2014;16(7):946-64. doi: 10.1093/europace/eut409.
17. Writing Committee Members, Hirshfeld JW, Ferrari VA, Bengel FM, 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. 2018;92(2):E35-E97. doi:10.1002/ccd.27659
18. European Parliament. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. Off J Eur Commun. 2014;L13:1-73.

Journal Pre-proof

19. Presidência do Conselho de Ministros, Decreto-Lei n.º 139-D/2023, de 29 de dezembro. Diário da República n.º 250/2023, 4º Suplemento, Série I de 2023-12-29, páginas 23-53.
20. Haines DE, Beheiry S, Akar JG, et al. Heart Rythm Society expert consensus statement on electrophysiology laboratory standards: process, protocols, equipment, personnel, and safety [published correction appears in Heart Rhythm. 2015 Jul;12(7):1703]. *Heart Rhythm*. 2014;11(8):e9-e51. doi:10.1016/j.hrthm.2014.03.042
21. Badawy MK, Deb P, Chan R, et al. A Review of Radiation Protection Solutions for the Staff in the Cardiac Catheterisation Laboratory. Heart Lung Circ. 2016;25(10):961-7. doi: 10.1016/j.hlc.2016.02.021.
22. Power S, Mirza M, Thakorlal A, et al. Efficacy of a radiation absorbing shield in reducing dose to the interventionalist during peripheral endovascular procedures: a single centre pilot study. Cardiovasc Intervent Radiol. 2015;38(3):573-8. doi: 10.1007/s00270-014-0997-8.
23. Brilakis ES. Innovations in Radiation Safety During Cardiovascular Catheterization. Circulation. 2018;137(13):1317-1319. doi: 10.1161/CIRCULATIONAHA.117.032808.
24. Gutiérrez-Barrios A, Camacho-Galán H, Medina-Camacho F, et al. Effective Reduction of Radiation Exposure during Cardiac Catheterization. Tex Heart Inst J. 2019;46(3):167-171. doi: 10.14503/THIJ-17-6548.
25. Donadille E, Carinou M, Brodecki J, et al. Staff eye lens and extremity exposure in interventional cardiology: Results of the ORAMED project. Radiat Meas. 2011 Nov;46(11):1203-9. doi: 10.1016/j.radmeas.2011.06.034.
26. Abdelaal E, Plourde G, MacHaalany J, et al. Effectiveness of low rate fluoroscopy at reducing operator and patient radiation dose during transradial coronary angiography and interventions. JACC Cardiovasc Interv. 2014;7(5):567-74. doi: 10.1016/j.jcin.2014.02.005.
27. Plourde G, Pancholy SB, Nolan J, et al. Radiation exposure in relation to the arterial access site used for diagnostic coronary angiography and percutaneous coronary intervention: a systematic review and meta-analysis. Lancet. 2015;386(10009):2192-203. doi: 10.1016/S0140-6736(15)00305-0.
28. Tamirisa KP, Alasnag M, Calvert P, et al. Radiation Exposure, Training, and Safety in Cardiology. JACC Adv. 2024;3(4):100863. doi: 10.1016/j.jacadv.2024.100863.

Journal Pre-proof

29. Gupta R, Malik AH, Chan JSK, et al. Robotic Assisted Versus Manual Percutaneous Coronary Intervention: Systematic Review and Meta-Analysis. Cardiol Rev. 2024;32(1):24-29. doi: 10.1097/CRD.0000000000000445.
30. Miller DL, Vañó E, Bartal G, et al. Occupational radiation protection in interventional radiology: a joint guideline of the Cardiovascular and Interventional Radiology Society of Europe and the Society of Interventional Radiology. *J Vasc Interv Radiol*. 2010;21(5):607-615. doi:10.1016/j.jvir.2010.01.007
31. Fazli Z, Sadeghi M, Vali M, et al. The role of artificial intelligence in occupational health in radiation exposure: a scoping review of the literature. *Environ Health*. 2025;24(1):32. doi:10.1186/s12940-025-01186-3
32. Fisher RF, Applegate KE, Berkowitz LK, et al. AAPM Medical Physics Practice Guideline 12.a: Fluoroscopy dose management. *J Appl Clin Med Phys*. 2022;23(3):e13526. doi:10.1002/acm2.13526
33. ICRP PUBLICATION 154. Optimisation of Radiological Protection in Digital Radiology Techniques for Medical Imaging. *Ann ICRP*. 2023;52(3):11-145. doi:10.1177/01466453231210646
34. Modarai B, Haulon S, Ainsbury E, et al. Editor's Choice - European Society for Vascular Surgery (ESVS) 2023 Clinical Practice Guidelines on Radiation Safety. *Eur J Vasc Endovasc Surg*. 2023;65(2):171-222. doi:10.1016/j.ejvs.2022.09.005
35. International Atomic Energy Agency. Technical Meeting on Radiation Protection in Fluoroscopically Guided Interventional Procedures, 7-9 March 2022.
36. Ministério do Ambiente e da Transição Energética, Portaria n.º 136/2019, de 10 de maio, Diário da República n.º 90/2019, Série I de 2019-05-10, páginas 2390-2391.
37. Fetterly KA, Lennon RJ, Bell MR, et al. Clinical determinants of radiation dose in percutaneous coronary interventional procedures: influence of patient size, procedure complexity, and performing physician. JACC Cardiovasc Interv. 2011;4(3):336-343. doi:10.1016/j.jcin.2010.10.014
38. Manzo-Silberman S, Velázquez M, Burgess S, et al. Radiation protection for healthcare professionals working in catheterisation laboratories during pregnancy: a statement of the European Association of Percutaneous Cardiovascular Interventions (EAPCI) in collaboration with the EHRA, the European Association of Cardiovascular

Journal Pre-proof

Imaging (EACVI), the ESC Regulatory Affairs Committee and Women as One. EuroIntervention. 2023;19(1):53-62. doi: 10.4244/EIJ-D-22-00407.

39. Adeliño R, Malaczynska-Rajpold K, Perrotta L, et al. Occupational radiation exposure of electrophysiology staff with reproductive potential and during pregnancy: an EHRA survey. *Europace*. 2023;25(9):euad216. doi:10.1093/europace/euad216
40. Cheney AE, Vincent LL, McCabe JM, et al. Pregnancy in the Cardiac Catheterization Laboratory: A Safe and Feasible Endeavor. Circ Cardiovasc Interv. 2021;14(4):e009636. doi: 10.1161/CIRCINTERVENTIONS.120.009636.
41. International Atomic Energy Agency. Radiation protection and safety of radiation sources: international basic safety standards 2014. IAEA safety standards series, ISSN 1020–525X; no. GSR Part 3. STI/PUB/1578. ISBN 978–92–0–135310–8.
42. International Commission on Radiological Protection. Pregnancy and medical radiation. Ann ICRP. 2000;30(1):iii-viii, 1-43. doi: 10.1016/s0146-6453(00)00037-3.
43. Council E. European Council. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. [14 Oct 2022].
44. Sarkozy A, De Potter T, Heidbuchel H, et al. Occupational radiation exposure in the electrophysiology laboratory with a focus on personnel with reproductive potential and during pregnancy: A European Heart Rhythm Association (EHRA) consensus document endorsed by the Heart Rhythm Society (HRS). Europace. 2017;19(12):1909-1922. doi: 10.1093/europace/eux252. Erratum in: Europace. 2018;20(4):574. doi: 10.1093/europace/euy023.

Journal Pre-proof

FIGURES AND TABLES

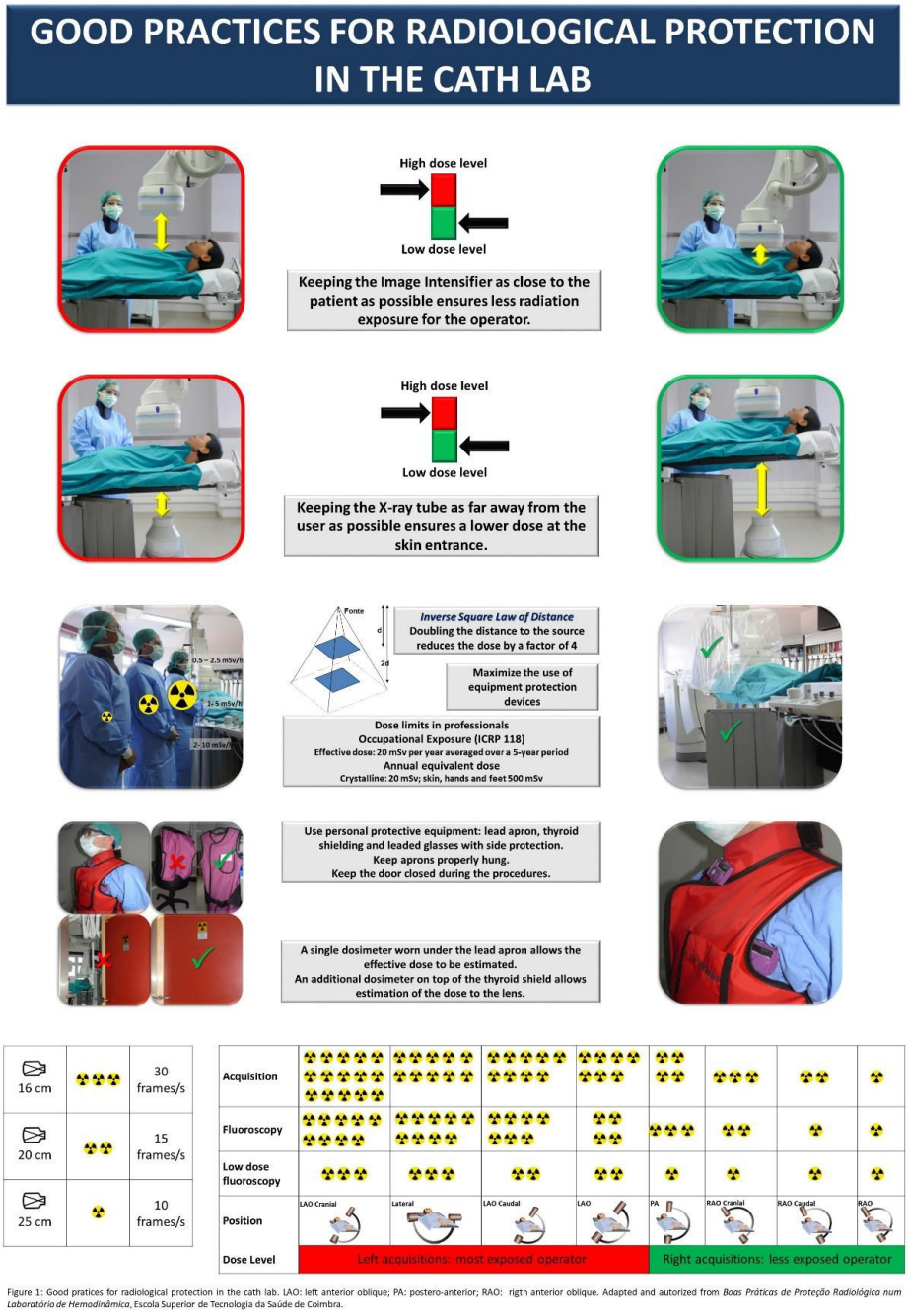

Figure 1: Good pratices for radiological protection in the cath lab. LAO: left anterior oblique; PA: postero-anterior; RAO: rigth anterior oblique. Adapted and autorized from *Boas Práticas de Proteção Radiológica num Laboratório de Hemodinâmica*, Escola Superior de Tecnologia da Saúde de Coimbra.

Figure 1. Good practices for radiological protection in the cath lab. LAO: left anterior oblique; PA: posteroanterior; RAO: right anterior oblique. Adapted and authorized from *Boas Práticas de Proteção Radiológica num Laboratório de Hemodinâmica*, Escola Superior de Tecnologia da Saúde de Coimbra.