



Management of doses from medical exposures in interventional radiology: an integrative review

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ABSTRACT

Interventional radiology (IR) uses minimally invasive image-guided procedures that may require long duration and deliver high radiation dose to the patient. The most current studies on management and dose reduction in IR have shown to be of fundamental importance in radiation protection practices. The objective of this study was to survey what has been published in the national and international literature on the doses received by patients undergoing IR procedures. It consisted of an integrative review study carried out in Scielo, Pubmed and INIS databases in the time frame of 2016-2021, using as descriptors: interventional radiology, radiation injuries, radiological protection, dosimetry; and their equivalents in english: interventional radiology, radiation injuries, radiological protection, and dosimetry. The initial sample consisted of 68 full articles related to the theme, published during the study period. Of these, 11 articles were selected and made up the final sample. The results indicate that the use of software in dose management and monitoring has proven to be an important tool in radiological protection. The implementation of dose reduction strategies and increased awareness about the use and effects of radiation result in significantly lower doses to both professionals and patients. No national study on dose management has been identified, highlighting the need to promote the subject in the country. The main recommendations identified were introduction of technologies and training of the workers involved.

Keywords: Interventional radiology, Radiation injuries, Radiological protection, Dosimetry of patients.



1. INTRODUCTION

Interventional radiology (IR) uses minimally invasive image-guided procedures for both diagnosis and treatment [1]. IR has fundamental importance in areas such as neurology and cardiology to diagnose and treat vascular pathologies [2].

Interventional procedures typically require long duration to obtain many radiographic images and consequently increase the dose of X-ray absorbed by the service user. Due to the increase in the quantity of procedures performed (10 to 20% per year) and in the complexity of the procedures, due to the great evolution in the field, IR has been replacing some surgical treatment modalities resulting, for most patients, in a shorter hospital stay, shorter recovery time and reduced risk of death [3, 4].

With the increasing performance and complexity of interventional procedures, public health concerns have also grown resulting from increased medical exposure to radiation. Medical exposure is defined as the exposure to ionizing radiation to which patients in the radiology service are subjected [5].

The high exposure time during the procedure makes additional care necessary. The increase in reported severe skin lesions highlights the need for education about radiation risks and the importance of strategies to optimize exposure [6,7].

According to current brazilian legislation, IR services must implement a program of continuing education for the entire team, including training that addresses topics on standards, routines and protocols, patient safety, and management of the risks inherent in the technologies used [8].

Several countries have participated in studies on the dose received in medicals procedures. These studies contribute to the determination of the exposure of the population to ionizing radiation, and the effects that this exposure may cause in society, such as the increase in the incidence of cancer cases [9].

Several studies have reported skin lesions resulting from IR procedures. Silva *et al.* (2011) conducted a study with users undergoing coronary intervention procedures in Pernambuco and reported that 53% of users exposed to high doses of ionizing radiation showed tissue reactions. Another study conducted in the United Kingdom, with patients undergoing neurointerventional

procedures, reported tissue reactions in the skin lining the skull at doses between 3 Gy and 4 Gy and hair thinning and hair loss above 4.5 Gy [10, 11].

Due to this an important initiative was taken in this direction in the state of Santa Catarina, through the State System of Ionizing Radiation (SIERI), in which IR services have the duty to register the doses of procedures, optimizing medical exposures [12].

In IR, the parameters related to medical exposures, and which are used to determine the doses received, are: dose area product (DAP) and product kerma area (PKA). These parameters are presented in the equipment monitors and allow correlating the dose with the possible biological damage and can be used to estimate the effective dose [13].

Since IR can deliver high doses to patients resulting in tissue damage, managing the doses received in these procedures is of great importance for radiological protection. The objective of the present work is to perform an integrative review of the literature on what has been done in management and reduction of doses from medical exposures in IR.

2. MATERIALS AND METHODS

This study is an integrative literature review and has the following guiding question: what has currently been practiced in management and dose reduction resulting from medical exposures in interventional radiology?

The descriptors selected were: *radiologia intervencionista*, *lesões por radiação*, *proteção radiológica* and *dosimetria*; and their equivalents in english: interventional radiology, radiation injuries, radiological protection, and dosimetry. In addition, the following keywords were also used: dosimetry of patients and radiation dose and their equivalents in english: dosimetry of patients and radiation dose.

The databases used were Scielo, Pubmed and INIS. The Scielo database was used to include brazilian scientific journals. Both Pubmed and INIS were selected due to their international relevance. It is worth mentioning that the International Nuclear Information System (INIS), which belongs to the International Atomic Energy Agency (IAEA), has one of the world's largest collections of published information in the field of radiological protection.

The Boolean operator used was AND, to correlate the descriptors and keywords to refine the search. The following filters were used: year of publication (2016 to 2021), languages (english and portuguese), published in scientific journals (journal article), and text availability (full text).

The initial sample was composed of 68 full articles related to the topic, published from 2016 to 2021, in portuguese and english languages, which dealt with tissue reactions involving patients in IR procedures, dose management and radiological protection of patients. After a careful reading of the titles of the selected papers, the abstracts were read. Those that were related to the proposed theme were chosen for a full reading, and finally those that presented greater conformity to the theme were selected. Thus, 11 articles were selected and made up the final sample of the study.

As exclusion criteria, articles that were not related to the topic of radiological protection of patients in interventional radiology, in languages other than those previously mentioned, published before the established date, as well as abstracts, book chapters, dissertations, and these were removed. Figure 1 shows the methodology applied.

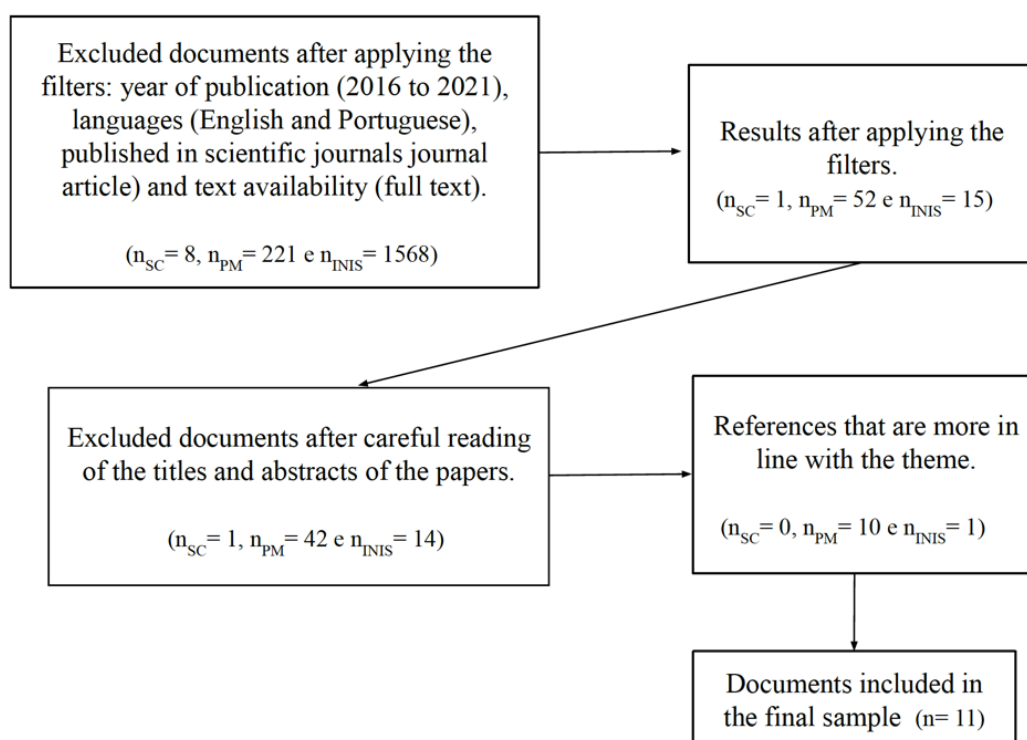


Figure 1: Methodology used in the integrative review.

3. RESULTS AND DISCUSSIONS

Of the 68 articles obtained, 11 were selected for this review. Of the articles included in the search, the period when most were published was between 2017-2018. The countries that published the most were: United States of America, England, and Ireland. The selected studies were published in several journals, highlighting Journal of Vascular and Interventional Radiology and Medical Physics of the American Association Physicists Medicine (AAPM) with the highest reported impact factor (3,177). Table 1 presents general data of the publications selected for this study.

Table 1: Data from the selected articles.

Author	Year	Country	Interventional Procedure	Journal
Harries e Platten	2020	England	Cardiac catheterization	BMJ Open Quality
Banerjee et al.	2019	Ireland and Italy	Interventional Cardiology	Health Physics
O'Hora, Ryan and Rainford	2019	Ireland and England	Cardiology, interventional neurology	Radiation Protection Dosimetry
Perry et al.	2018	USA	Interventional and diagnostic neuroradiology	Academic Radiology Elsivier
Sánchez et al.	2018	Spain	Interventional Cardiology	Physica Medica: European Journal of Medical Physics
Bijwaard, Valke de Waard-Schalkx	2018	Netherlands	Various interventional procedures	Health Physics
Greffier et al.	2017	France	Coronary angiography (CA), coronary angioplasty (CA-PTCA), chronic total occlusion coronary angioplasty (CTO)	Radiation Protection Dosimetry
Heilmaier et al.	2017	Switzerland	Vascular and non-vascular IR procedures	Journal of Vascular and Interventional Radiology
Schneider, Wyse e Pearl	2017	Germany	Digital subtraction cerebral angiography (DSA)	Journal of NeuroInterventional Surgery
Heilmaier et al.	2016	Switzerland	Fluoroscopy-guided interventional procedures	Journal of Vascular and Interventional Radiology
Rana, Rudin e	2016	USA	Neurovascular interventional	Medical Physics -

After the analysis, the articles were separated into three themes: dose management, dose reduction, and studies conducted nationally and internationally. Following is a description and discussion of the results obtained within each theme.

3.1 Theme 1: Dose Management

Seven articles were included in the "Dose management" theme. The article published by Banerjee *et al.* [14] investigated the awareness of radiation dose levels and the training experience of 18 interventional cardiology specialists from Ireland and Italy. The data collection instrument was a questionnaire consisting of 28 questions, subdivided into sections addressing demographic information and the frequency of procedures performed. Participants were asked to detail their knowledge and use of professional guidelines regarding the procedures performed and whether they routinely checked patients' histories prior to examination. The results obtained showed that less than 50% of the practitioners identified appropriate dose ranges for the procedures, underestimating the dose values received by patients based on recent European data.

It is of great importance that professionals performing IR procedures are familiar not only with dose values as well as the methods for dose reduction, but also with communicating the risks associated with the procedure, as recommended by the International Commission on Radiological Protection [15].

Jaschke *et al.* [16] emphasized in their work that the interventional physician should inform patients about the risk of injury and if the cumulative dose of the procedure exceeds a threshold level. In such cases, the justification and guidance on possible tissue reactions should be recorded, in addition to ensuring that the patient will receive follow-up if he or she manifests radioinduced lesions. In case of doses exceeding critical thresholds, the events should be discussed by a committee and appropriate measures to avoid future occurrences should be adopted.

Similarly, in Brazil, the RDC No. 611/2022 makes it mandatory to implement a Permanent Education Program (PEP) in diagnostic and interventional radiology services with the purpose of improving patient safety and the management of risks inherent to the technologies used, showing that improving the training and communication of professionals in interventional radiology is an international need [8].

In addition, the use of dose management software has proven to be an important tool in IR dose management. In the study by Harries and Platten [17], OpenSkin and OpenREM software were used to automate the process of investigating high doses to the skin of patients in IR procedures. The software reduced the time spent by the radiological protection team on dose investigation related tasks by 94%. This technology implementation has enabled the automation of the high dose location process that was previously performed manually in the logbook, and has also made it possible to assess which alerts require an immediate staff response.

In addition to assisting with dose records, software has been used in real-time dose monitoring. Perry *et al.* [18] performed a study in which he evaluated the implementation of DoseWatch[®] over a one-year period. The software automatically signaled the procedures that exceeded 5 Gy, considered a trigger level for radioinduced lesions. Of the 3,582 procedures performed in this period, 62 exceeded 5 Gy. The new technology allowed an effective process in the patient's clinical follow-up in which the physician examines the patient and discusses the possibility of tissue reactions, proving to be a good tool for data collection and analysis to improve the performance of IR departments.

The study mentioned above used the reference values of the US Society of Interventional Radiology (SIR), which is responsible for providing comprehensive guidelines for dose management. These values are used as an important reference in radiological protection actions. In Brazil, the RDC No. 611/2022 in its Normative Instruction (IN) No. 91 establishes national parameters for fluoroscopy and interventional radiology services. One can highlight in this normative the mandatory indication of the PKA or K_{ar} for equipment marketed as of December 2019. In Santa Catarina, Normative Resolution No. 002/DIVS/SES, [12] establishes only the maximum air kerma rate (≤ 50 mGy/min) in quality control tests performed in the equipment acceptance stage, which has annual periodicity or after repairs. This is the only reference value found in national standards [8, 18].

Still on the use of software in dose management, Dose Watch[®] was also used in the study by Heilmaier *et al.* [19]. In this study it was used to collect, track, and analyze dose data from several interventional procedures, which allowed estimating local reference levels (LRLs) for different levels of complexity within the same type of procedure. It is important to remember that these

levels should not be considered as dose limits, however they serve as guidance in IR as to what can be achieved in dose optimization.

In a previous study, the same group of researchers made combined use of a real-time patient and occupational dose monitoring system (DoseWatch[®] and RaySafe i2[®]) during fluoroscopy-guided interventions demonstrating a significant reduction in patient and occupational dose. Since the patient dose data was immediately available on the monitoring system, the practitioners were able to correlate their doses directly with the patient dose, offering more possibilities to improve behavioral and technical activities. Such monitoring systems increase awareness of radiation use, and in addition to allowing data collection, are valuable tools for improving patient and staff safety. Dose optimization is not only related to physical parameters, but also to professional conduct since the professional is directly responsible for medical exposure [20].

Another software (Biplane-DTS), capable of monitoring and displaying the dose distribution on the patient's skin in real time during neurointerventional procedures, was developed by Rana, Rudin and Bednarek [21]. A color-coded graphic display is updated every 30 milliseconds (immediately after dose calculation) and displays the dose map on the skin. The software provides a good estimate of the peak skin dose (PSD) and cumulative skin dose distribution during procedures. The real-time display of this information assists the interventional physician in preventing radiation-induced skin damage to the patient.

Considering that angiographic equipment can deliver higher doses of radiation to the skin than a single radiation therapy session, monitoring of exposed patients in the prevention of radioinduced injuries is critical. The introduction of real-time monitors and dose mapping considerably reduces the dose received by the patient, besides being fundamental in identifying areas with high risk of injury [16].

Detection of the patient's PSD can also be accomplished with GafChromic films. Greffier *et al.* [22] evaluated these films in the detection of PSD of patients in interventional cardiology and concluded that in procedures with a higher possibility of reaching a PSD above 2 Gy, such as CTO procedures the use of film remains the reference method for detection of PSD and improves patient management by locating the area of skin most exposed to high dose.

About the advantages between the use of software for real-time monitoring when compared with the use of GafChromic films we can mention possibility of monitoring the dose in real time

and, due to the color scale related to the dose, favoring the localization of the areas of the skin that received more and less exposure.

According to Sun, AbAziz and Yusof [23], the development of software based on dose distribution can be useful to alert interventional physicians when the dose value exceeds the threshold for tissue reactions. The introduction of dose management programs based on DRLs can be used to identify the risk of injury to patients. Also in this paper, the authors emphasize the importance of education and training programs in radiological protection for the professionals involved.

Education and training in radiological protection of professionals involved in interventional procedures have been frequently discussed to the point that the ICRP provides a series of recommendations in its Publication 113 [24]. This publication provides guidelines with specific recommendations on the knowledge that must be mastered by professionals, such as: dosimetric quantities, radiological risks and radiological protection of the staff and patients specific to interventional radiology.

3.2 Theme 2: dose reduction

Two articles were included in the "Dose Reduction" theme and their main results and discussions are presented below.

A new fluoroscopy protocol in interventional cardiology procedures for obese patients was presented by Sánchez *et al.* [25], in which it was possible to reduce K_{ar} and preserve image quality. When compared with the standard protocol for high dose rate, established by the angiograph manufacturer Philips Healthcare, the new protocol presented reduces K_{ar} by up to 70%. To optimize the protocol, the frame rate was halved (from 15 fr/s to 7.5 fr/s) and the copper (Cu) filter thickness was increased from 0.1 mm to 0.4 mm Cu.

In the same study using a polymethylmethacrylate (PMMA) acrylic phantom with a thickness greater than 32 cm, representing an obese patient, the entrance dose rate to the skin was reduced by 70%, for thickness greater than 37 cm there was a 10% reduction, and with 40 cm thickness the dose rate practically remained the same in both protocols. The use of the new protocol has been shown to be effective and may help to improve image quality and reduce the dose rate to the skin of obese patients [25].

The average in frame rate per second also demonstrated a significant dose rate reduction in digital subtraction angiography (DSA) procedures in the work of Schneider, Wyse, and Pearl [26]. The effectiveness of implementing radiation dose reduction strategies, such as reducing the rate of frames per second and fluoroscopy time, over four years resulted in a significant reduction of 65% K_{ar} and 63% PKA in adult patients and 78.6% K_{ar} and 77.4% PKA in pediatric patients. The strategy was implemented in 2010, in 2013 the total fluoroscopy time of the procedures showed a reduction of 23.3% in adult patients and 58.3% in pediatric patients.

It is evident that increased awareness about the use and effects of radiation and the implementation of dose reduction strategies result in significantly lower radiation doses in both professionals and patients. The topic meets once again the permanent education program established by RDC No. 611/2022 [8] and the training program, defined as one of the general requirements of radiological protection, specified in Normative Resolution No. 002/DIVS/SES [12], contemplating topics on equipment operation procedures and to minimize medical exposures.

Thus, several studies emphasize that careful planning of the procedure, optimization of technical parameters and training of employees are essential measures to avoid an excessive dose to patients [16, 24, 27].

3.3 Theme 3: studies conducted nationally and internationally

Two articles were included in the theme of "studies performed at national and international level". The research by O'Hora, Ryan and Rainford, [28] applied a questionnaire related to patient safety in groups of specialist and IR professionals in Ireland and England. The study presented that the dose to the patient's skin is not commonly reported, the procedure consent rarely includes all possible radiation effects, and less than half of the respondents use the substantial radiation dose levels (SRDL) to identify possible reactions and facilitate proper patient communication and follow-up. Although guidelines for optimizing practices in this area are available, they are not always followed. The study highlights the need for specific training on SRDL for IR staff, especially in cardiology, where the largest number of interventional procedures occur.

SRDL are used as "trigger levels" for additional dose management actions during a procedure and physician follow-up for a radiation level that may produce a clinically relevant injury in an average patient [15]. Although procedures that reach an SRDL may not result in tissue reactions,

SRDLs are considered the basis for identifying these possible effects, investigating the actual PSD, and assisting the physician in guiding the patient to the most appropriate post-procedure care. Staff awareness of SRDLs and their use is an essential dose optimization and management tool.

Bijwaard, Valk and de Waard-Schalkx I [29] performed a survey on radiological protection in interventional fluoroscopy with 20 Dutch hospitals with the main objective to investigate whether the institutions were following the recommendations established in a study performed 10 years earlier (2007). Recording tissue reactions was one of the recommendations. Three hospitals reported tissue reactions in 22 cases over the last five years, and only one of these hospitals reported it to the complication register of the IR section of the Dutch society of radiology. In the last five years, only three hospitals have reported tissue reactions, the issue should receive more attention from professionals involved with interventional procedures.

Another recommendation was to train the professionals involved in radiological protection. Almost all professionals in the IR department were trained. However, these professionals were not involved in interventional procedures performed outside the radiology department, such as pacemaker implantation and percutaneous coronary angioplasty procedures performed in the cardiology department. Although it is not a requirement under Dutch law that a radiological protection professional is present, it is recommended that they are more present in interventional procedures.

It can be observed that screening and follow-up of patients is performed, but in a very limited way. Of the 18 hospitals that responded to the survey, 16 hospitals perform some form of screening, pregnancy screening is standard, but on hereditary conditions, it is rare. Only seven hospitals indicate that some form of post procedure follow-up of their patients is performed.

It is noted that the introduction of DRLs, recommended by ICRP 135 [30] and the inclusion of the subject in training programs for health professionals, is an effective tool in optimizing the radiological protection of patients, which together with dose monitoring software in real time, serve as an aid in the evaluation and monitoring of possible tissue reactions with potential occurrence after interventional procedures.

4. CONCLUSIONS

It was observed that dose management in interventional procedures occurs using software and dose monitoring devices that present themselves as effective tools in the radiological protection of the patient. It was also evident that the deficit in training and qualification of professionals in this area is a reality present in the institutions.

It has been observed that new optimized protocols, which include mainly the reduction in the frames-per-second rate and fluoroscopy time, significantly reduce the dose rates in patients, and in some cases may even help in the improvement of the image quality. In addition, staff knowledge about DRLs and SRDL promotes patient protection.

In general, the main recommendations applied in the reported studies were the introduction of technologies that assist in real-time dose control and mainly the training of the professionals involved. The lack of studies on the subject published in Brazil is a worrisome factor. The theme is still little addressed in the training of professionals in the area, as in developed countries. National norms regulate the obligation of professional improvement programs involving the optimization of medical exposures, but they are still little respected. The awareness and professional training, as well as the introduction of professionals with knowledge in radiological protection, are determining factors for a relevant contribution in radiological protection, not only of the patients, but of all the professionals involved.

Thus, this work allowed to explore at an international level the problematic presented in this study and may contribute to raising awareness of the safe use of ionizing radiation in IR aiming at the reduction of deterministic effects in medical exposures.

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