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VIEWPOINT

Challenges and Opportunities in the use of Ionizing Radiation for Cardiovascular Diseases

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Introduction

Cardiovascular diseases are the leading cause of global death, accounting for 31% of deaths in 2015 according to the World Health Organization (WHO). Three-quarters of these deaths occurred in low- and middle-income countries.[1] In Brazil, in 2011, there were approximately 350,000 deaths of cardiovascular origin, becoming the most important cause of death since the epidemiological transition of the 60's.[2] The diagnosis in the early stages and the management of more severe cases are among the most important methods in the fight against cardiovascular diseases. Imaging procedures with ionizing radiation has a major role in this area.

According to data from public outpatient health services of the Brazilian Unified Health System (SUS, *Sistema Único de Saúde*) (Figure 1),[3] in the last 10 years, the number of procedures performed for evaluation of cardiovascular diseases using ionizing radiation has increased (73% in nuclear medicine, 18% in interventional radiology and 12% in cardiac catheterization), except for conventional radiology, in which a decreased has been seen (-58%). These numbers, however, underestimate the number of tests performed with the general population, since diagnostic methods such as coronary angiotomography have not been incorporated into the SUS yet, and the time for inclusion of new techniques to public health care is much higher than to supplementary health care.

Keywords

Cardiovascular Diseases/mortality; Nuclear Medicine; Diagnostic, Imaging;/methods; Nuclear Energy; Air Ionization/radiation effects; Radiation/protection.

Although the benefits are undeniable, the increased use of procedures with ionizing radiation results in a greater potential risk for patients, who may undergo 8 to 10 procedures in a single year, and for workers, who may be exposed to radiation for more than 40 hours of work a week.

Studies in the United States have shown that the estimated effective dose of radiation due to medical imaging procedure for an individual increased five times from 0.6 mSv/year in 1987 to 3.2 mSv/year in 2006, surpassing the natural sources of radiation (Figure 2).[4] For instance, the exposure for medical purposes in 2006 would be comparable to 160 chest x-ray examinations per person per year.[5]

The technological progress is a constant in this market, valued at billions of dollars. New methods and applications have quickly emerged, requiring that health professionals from all areas be involved in continuing education processes for the rational use of radiation.

However, studies have already shown that those responsible for requesting examinations and performing procedures involving ionizing radiation have very low knowledge of the principles of radiation protection.[6,7] It is common to observe the unfamiliarity with the principles of radioprotection by health professionals and even situations of unjustifiable fear when mentioning the use of radioactive elements.

Requirements of radiation protection

Cardiologists and health professionals should generally be aware of the basic requirements for radiation protection (Justification, Optimization and Limitation of Individual Dose), as defined by the

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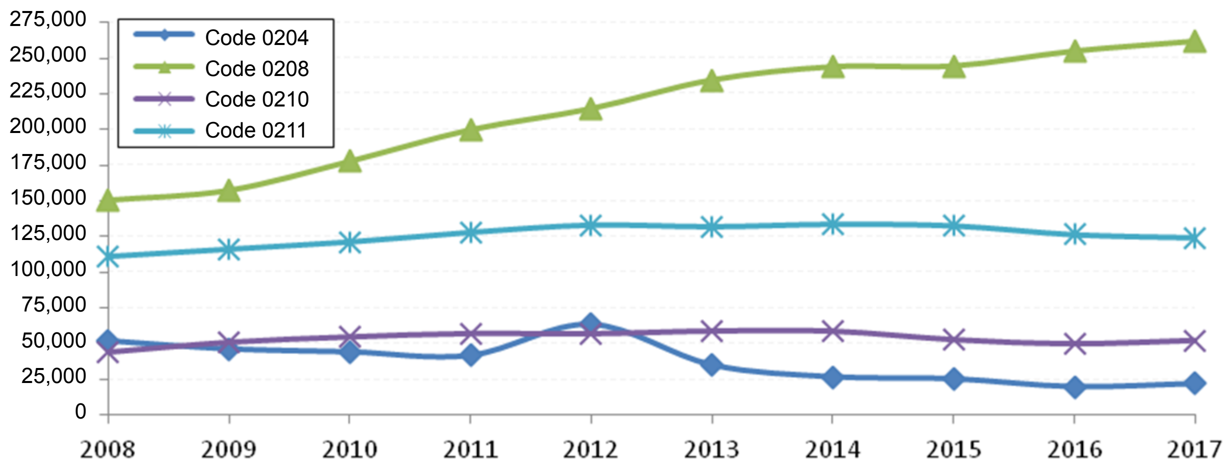

Figure 1 - Evolution of the number of procedures with ionizing radiation in the Brazilian Unified Health System (SUS). Codes of procedures: 0204 (Conventional Radiology), 0208 (Nuclear Medicine), 0210 (Interventional Radiology) e 0211 (Cardiac Catheterization).
Source: DATASUS – Portal da Saúde[3]

Brazilian National Commission for Nuclear Energy (CNEN, from Portuguese: *Comissão Nacional de Energia Nuclear*) regulation NN-3.01[8] and presented in Table 1. Poor understanding of these concepts and of the risks involved can lead to failures across the chain of decisions and increase the potential risks for patients and workers.

Risk assessment and biological effects of radiation

Risk assessment involves the understanding of specific factors of each technique such as: the type of radiation, the intensity or quantity used, the time of exposure and possible effects. Recently, a consensus paper was published, the result of a task force of the American College of Cardiology, which reviewed

Table 1 - Basic requirements for radiation protection

Justification	No practice or source associated with this practice is accepted by CNEN, unless the practice produces benefits to exposed individuals or to society sufficient to compensate for the corresponding detriment, taking into account social and economic factors, among other relevant factors. Medical exposures must be justified considering the diagnostic and therapeutic benefits they will produce in relation to corresponding detriment, taking into account the risks and benefits of available alternative techniques that do not involve exposure.
Optimization	Related to the exposures caused by a particular source associated with a practice, radiation protection should be optimized so that the magnitude of individual doses, the number of exposed persons, and the likelihood of exposures occurring remain as low as reasonably achievable, taking into account economic and social factors. In case of medical exposures of patients, the medical optimization of radiation protection should be understood as the application of the dose of radiation necessary and sufficient to achieve the intended purposes.
Limitation	The normal exposure of individuals should be restricted in such a way that neither the effective dose nor the equivalent dose in the organs or tissues of interest, caused by the possible combination of exposures originated from authorized practices, exceeds the specified dose limit except to special circumstances authorized by CNEN. These dose limits do not apply to medical exposures.

Source: CNEN regulation 3.01 - Basic Guidelines for Radiation Protection[8]

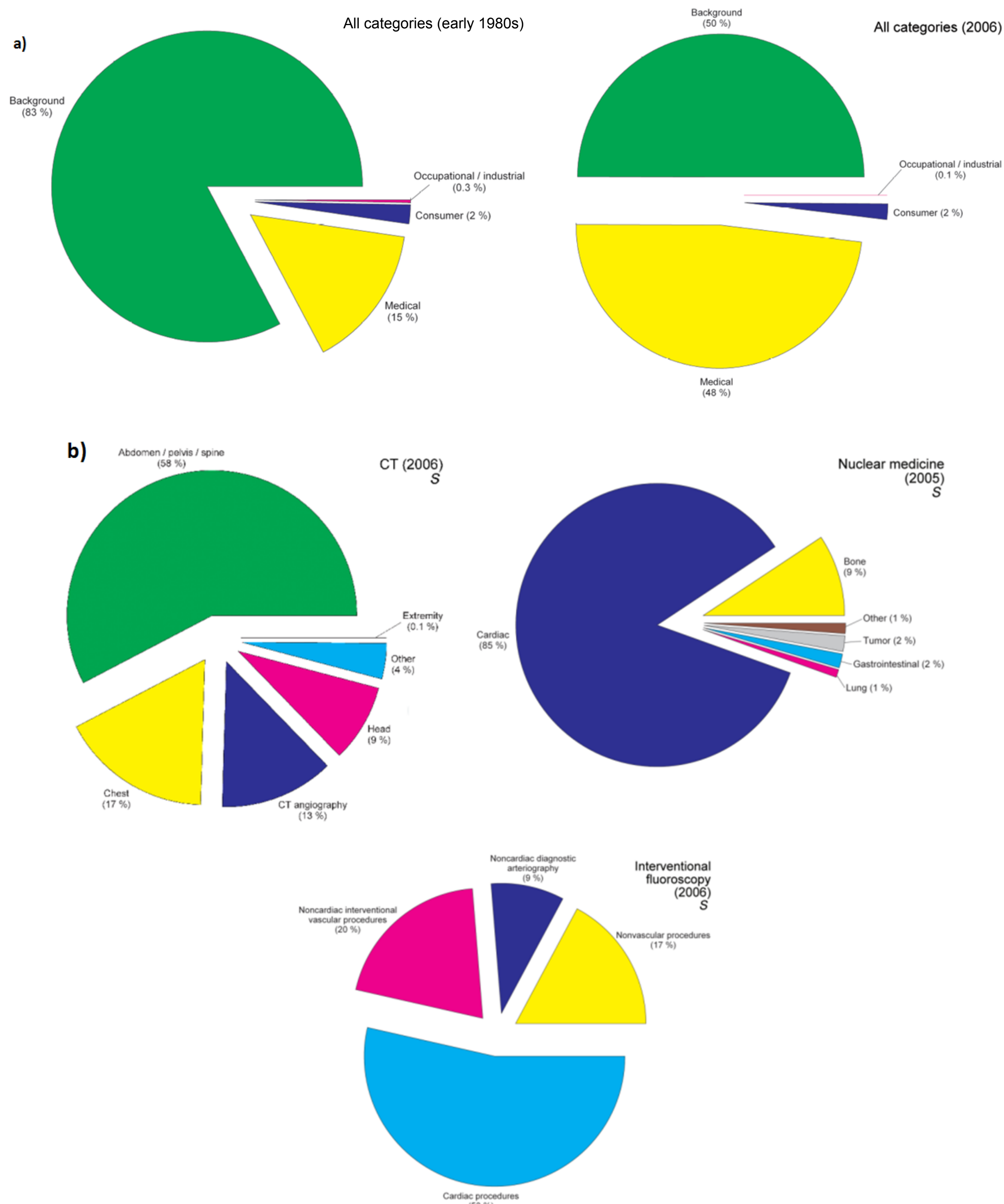

Figure 2 - a) Comparison of the effective dose per individual of the American population in 1980 and 2006. b) Distribution of the collective dose by application and by type of examination.
Source: Adapted from NCRP Report no. 160[4]

concepts, best practices and their effectiveness in Cardiovascular imaging.[5] Biological factors such as the sensitivity of irradiated tissues, the biodistribution of radioactive material (when administered or absorbed), age, gender and even health condition of the individuals are important.

Among the various ways of estimating the exposure of individuals to ionizing radiation, the absorbed dose (which is a measure of the energy deposited by the radiation in an exposed tissue through interaction with its molecular constituents) and the effective dose (estimated sum of absorbed doses for each organ weighted by the sensitivity to radiation and the type of radiation) are the main concepts when the objective is the evaluation of the potential biologicl effects in the diagnosis by image. These effects can be separated into deterministic and stochastic.

The occurrence of deterministic effects is rare in the diagnostic routine due to the type and the amount of radiation used. Also referred today as tissue reactions, these effects are characterized by having a minimum dose below which they probably will not occur. In practice, the most observed reactions are skin lesions from prolonged exposures or from excessive radiation use such as invasive procedures guided by X-ray Fluoroscopy.[5,9]

Stochastic effects are the most relevant for cardiology and should always be considered, although they do not represent a high risk of damages. Even in very low doses of radiation, indirect interactions (through free radicals) and direct interactions with DNA can generate mutations. Experimental difficulties have limited a precise evaluation of the effects of low doses, an unanswered research question, and limits and recommendations have been established based on data obtained from the extrapolation of large nuclear accidents and researches with human cells.[10] We are not used to dealing with probabilistic concepts and, therefore, we seek unique values for our decision making. According to the lifelong risk model presented in the Biological Effects of Ionizing Radiation VII,[10] one person in 100 is expected to develop life-long cancer due to a single dose of 100 mSv above background radiation levels, while 42 people would develop cancer from other causes (Figure 3). Similarly, 1 person in 1,000 would result in a single dose of 10 mSv.

In general, among professionals working with radiation, those involved with interventional techniques and, to a lesser degree, those who are involved in manipulation of radionuclides or with ergometry are the most exposed to risks.[5]

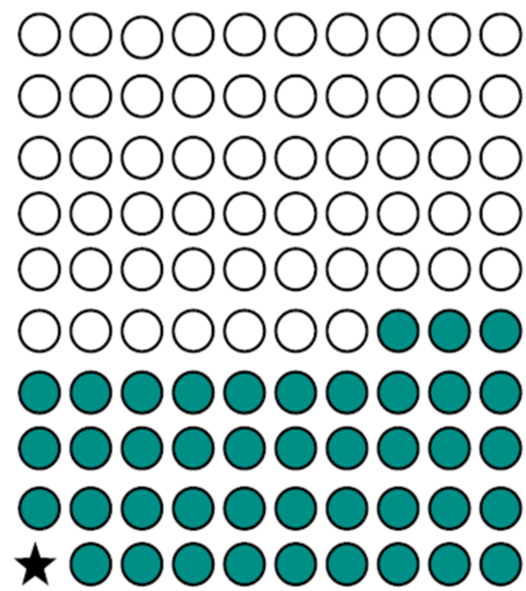

Figure 3 - Expectation of developing cancer due to a single dose of 100 mSv.
Source: BEIR VII[10]

Dose reductions: initiatives and advances

Aware of the current role of ionizing radiations in health care and of the perspective for growth in applications and indications, several initiatives have recently been developed mainly by the International Atomic Energy Agency (IAEA).

The 2012 International Conference on Radiation Protection in Medicine held in Bonn, Germany, resulted in the Bonn Call for Action that published the 10 main actions considered essential for the strengthening of radiation protection in medicine in the decade that would come.[11]

In 2017, a new edition of the Conference held at the IAEA headquarters reinforced its importance. Among the actions are: to increase the implementation of the principles of justification and optimization, to strengthen the role of manufacturers and the education of health professionals, to increase the availability of information on occupational and medical exposures, and to nurture increased dialogue on risk-benefit of radiation.

The IAEA also promotes training and courses, and the development of tools and applications. The QUANUM (Quality Management Audits in Nuclear Medicine

Practice) methodology was developed to guide quality audits of nuclear medicine practices and audit groups were trained in a number of countries. A research with the experience and the impact in a Brazilian Hospital was published recently.[12]

Coordinated researches such as the INCAPS study are also part of global initiatives to improve practices. It investigated the application of eight good practices in 308 Nuclear Medicine Services in 65 countries. Only 45% of them showed a satisfactory index.[13] Subsequently, a similar study performed in healthcare centers in Brazil reported an even lower number, 25% with satisfactory index, and a correlation between a higher level of qualification of the service and presence of an interdisciplinary team, resulting in more appropriate and precise indications of tests involving ionizing radiation.[14]

International alliances supported by WHO and the IAEA, such as the Image Gently, Image Wisely, EuroSafe, LatinSafe, Canada Safe Imaging, ArabSafe, AfroSafe and others, have made relevant contributions in the standardization of procedures, information production and dissemination of radiation protection.

Knowledge as one of the pillars of radiological safety

The global impact and the growth of cardiovascular diseases, the greater number of medical applications, and consequently, of the radiation doses to patients and workers, the constant technological advances and the complexity regarding the use of ionizing radiations for health care make it clear that the understanding of the concepts and responsibilities is critical for the continued growth of the benefits and mitigation of risks and potential effects.

The Bonn Call for Action 10 actions are a step towards this direction and the consensus of the American College of Cardiology and four other societies is even more direct suggesting that specialists have the responsibility to understand the basics of radiation protection first to make appropriate choices and after to conduct optimized procedures. The publication also suggests that this topic should be part of the training and certification of physicians.[5]

In Brazil, there are similar initiatives to international ones in radiology, but not in nuclear medicine. In many cases, concerns about radiation protection are still restricted to the legal obligations established by the CNEN and the Brazilian Health Regulatory Agency.

The safe future of the field is linked to the recognition of the value of multidisciplinary teams and of the quality of professional training. However, there are no specific certifications for radiology technicians and technologists, pharmacists and nurses in Brazil. On the other hand, medical physicists are considered specialists in nuclear medicine or in radiology when approved for this title by the Brazilian Association of Medical Physics. However, these professionals usually do not get support from the community for the certification. In addition, despite legal difficulties, the maintenance of expertise certificates should be tied to the continuing education of specialists. Finally, patients' care is the main objective and the involvement of patients in medical and therapeutic decisions, considering accepted risks and benefits has increased, and needs to be fostered with knowledge.

Author contributions

Conception and design of the research: Fernandes AF, Mesquita CT. Acquisition of data: Fernandes AF. Analysis and interpretation of the data: Fernandes AF, Mesquita CT. Writing of the manuscript: Fernandes AF. Critical revision of the manuscript for intellectual content: Fernandes AF, Mesquita CT, Oliveira A, Santos AASMD.

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Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors.

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