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Original paper

Exposures in interventional radiology using Monte Carlo simulation coupled with virtual anthropomorphic phantoms

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ABSTRACT

In this work we investigated the way in which conversion coefficients from air kerma-area product for effective doses (CC_E) and entrance skin doses (CC_{ESD}) in interventional radiology (IR) are affected by variations in the filtration, projection angle of the X-ray beam, lead curtain attached to the surgical table, and suspended shield lead glass in regular conditions of medical practice. Computer simulations were used to model an exposure scenario similar to a real IR room. The patient and the physician were represented by MASH virtual anthropomorphic phantoms, inserted in the MCNPX 2.7.0 radiation transport code. In all cases, the addition of copper filtration also increased the CC_E and CC_{ESD} values. The highest CC_E values were obtained for lateral, cranial and caudal projections. In these projections, the X-ray tube was located above the table, and more scattered radiation reached the middle and upper portions of the physician trunk, where most of the radiosensitive organs are located. Another important result of this study was to show that the physician's protection is 358% higher when the lead curtain and suspended shield lead glasses are used. The values of CC_E and CC_{ESD}, presented in this study, are an important resource for calculation of effective doses and entrance skin doses in clinical practice.

Introduction

Interventional radiology (IR) plays an important role in the diagnosis and treatment of vascular diseases, and other conditions that can lead to heart attacks and strokes. The technique uses fluoroscopy to guide the passage of a catheter into the region of the patient's heart. In general, the patient is examined for long periods of time during the procedure, and a large number of radiographic images are obtained [1,2]. To avoid the undesirable effects from ionizing radiation to the human health, it is necessary to maintain the radiation levels as low as reasonably achievable, taking into account economic and social factors [3].

The common principles of radiological protection, with respect to time, distance and shielding, are difficult to fully follow during IR procedures. This is mainly due to the complexity of the examinations, the necessary proximity of the physician to the patient and the need for a large set of images using different technical parameters, beam projection angles and additional protective equipment. Additionally, the elevated number of procedures performed contribute to increase the levels of radiation doses in medical professionals. To minimize the occupational dose absorbed by physicians, it is essential that they receive training in radiological protection, education about ionizing radiation sources and prior knowledge of the radiation levels they will be exposed to [4].

Considering the radiation exposure, it is impossible to directly determine the doses to the organs and tissues of the patient and physician. Therefore, computational exposure scenarios are necessary to determine conversion coefficients which allow the determination of organ doses, effective doses (E) or entrance skin doses (ESD) from a dosimetric quantity that can be easily obtained through experimental measurements, such as the air kerma-area product (KAP).

In recent years IR techniques have become quite common. The exposure of the personnel involved in IR procedures is relatively

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high, mainly due to their proximity to the irradiated part of the patient's body, and the time involved in these procedures. In the last years several studies have been presented about dose evaluation in patients and staff during IR procedures. Although several studies have been performed on occupational exposure IR with the Monte Carlo simulations [5,6], none of those calculated the dose conversion coefficients, in a realistic scenario of IR procedure, utilizing a *M*ale *A*dult me*SH* (MASH) virtual anthropomorphic phantom [7].

To calculate the conversion coefficients for E, some authors employed computational mathematical anthropomorphic phantoms (as in the work of Ferrari et al. [8]) while other authors have used voxel anthropomorphic phantoms [9]. In the latter study, the physician was represented by a voxel anthropomorphic phantom built in a lying position. In comparison with the anatomy of a standing person, this position causes the direction displacement of the internal organs. There may be also a sagittal diameter reduction, in particular at the abdominal region, which in turn can influence the estimated absorbed dose of organs and tissues. Thus, this type of phantom is not a realistic representation of an individual in a standing posture.

The anthropomorphic phantoms used in our study (MASH) were built on the basis of surface mesh and polygons, and were available in two postures, standing and lying. These are the most suitable faithful representations of the physician and the patient, and they have not previously been used in IR. Moreover, they were positioned in an IR room with the standard set of equipment that may influence the values of conversion coefficients by means of radiation scattering.

The virtual anthropomorphic MASH phantom was aimed to radiological protection studies, and therefore, it is necessary to maintain consistency in posture and anatomy. To maintain a realistic representation, the voxels of the matrices (that form the phantom) were resized to an edge of 0.24 cm long. This size is smaller than those from the literature, where normally larger voxel sizes are employed, which limits the precision on the contour of the organs. Consequently, with better organ definitions and contouring, results will be more accurate [7]. Furthermore, the results presented in the literature consider the physician as a “copy” of the patient. Therefore, the gravitational effects, which cause the overlap and displacement of the organs, were not evaluated. In this study, we employed phantoms in a lying and standing postures, aiming for a more realistic simulation.

We also used a detailed description of the components of a typical IR room, as well as the individual protection equipment, used by the staff and medical team. Within this, we could evaluate the efficiency of the lead curtain and suspended shield lead glass. These equipments are normally employed to protect the medical and staff from exposures from the primary and, mainly, the scattered radiation (from the operating table and the patient).

The mean absorbed doses to the tissues or organs may be low, but the concentrated dose depositions on a single spot may lead to a necroses of the organ or tissues. In the literature, there are several cases of skin injuries induced by the radiation on patients, from IR procedures [4].

Due to the high possibility of acute radiation symptoms for the skin, in this work, we presented the conversion coefficients (CC) results for the ESD as a function of the KAP, which take into account information regarding the place and field dimensions. These data allow the evaluation of the distribution of the absorbed dose in the irradiated skin of the patient.

The knowledge of the entrance skin doses may be used as a significant clinical information for the risk management to the patient and to the medical staff. The NCRP 168 [10] highlights the importance of the awareness regarding the high increase of medical exposition to ionizing radiation. In this sense, the doses received by the medical staff must be quantified. Therefore, one of the objectives of this work was to develop a methodology to determine the CCs for the skin. In the literature there are only a few papers that use Monte Carlo simulation to estimate this quantity, but they employed mathematical phantoms, or they did not consider the anatomical differences in position (laying and standing postures) [5,6,8,9,11–15]. Therefore, the methodology used in our work, and the results, provide a reliable estimative of the patient's entrance skin dose during an IR procedure, not addressed in previous papers.

In this study, a dosimetric evaluation using conversion coefficients calculated for a patient and a physician under different technical parameters and image acquisition conditions used in an angiographic system was carried out. In this work, a much more realistic representation was performed, utilizing a realistic IR room and a MASH virtual anthropomorphic phantom, for both patient and physician. Besides that, parameters not considered in previous studies were considered, such as the lead curtain and suspended shield lead glass. Although most information is specific to procedures performed in an angiographic system, some aspects of the results are relevant for all IR procedures.

Materials and methods

In IR procedures, the main focus for radiological risk is the patient who is exposed to the primary beam, and the physician who is mainly exposed to the photons scattered by the patient, the operating table and the image intensifier [16]. Therefore, estimating the radiation doses for both patient and physician requires the use of two computational anthropomorphic phantoms: a model to represent the patient lying on the surgical table and another to represent the physician, in a standing position.

In this study, two irradiation scenarios were modelled: in the first one, the lead curtain attached to the surgical table and shield suspended lead glass were not available, while in the second one, the use of these protective equipment was considered. The complete computational scenario was elaborated, and two anthropomorphic phantoms, IR equipment, and a room with real dimensions and real material walls were included, as can be seen in Fig. 1.

Seven types of beam projection angles were studied: left anterior oblique, 45° (LAO45), posterior anterior (PA), right anterior oblique, 45° (RAO45), caudal, 30° (CAUD30), left lateral, 90° (LAO90), right lateral, 90° (RAO90) and cranial, 30° (CRAN30) to focal surface distances (FSD) of 56.6, 50, 40, 43.6, 40, 40 and 45 cm, respectively. The physician was positioned 17 cm from the left side at the waist level of the patient.

To represent the patient and the physician, a modified MASH adult anthropomorphic phantom [17] was used in each case. This phantom was developed by the Computational Dosimetry Group/Federal University of Pernambuco (Brazil). It was based on anatomical and physiological data of a reference male from ICRP 89 [18]. It presents more than 100 organs and tissues that are relevant for dosimetry. The main physiological data of the adult anthropomorphic phantom were height of 175.6 cm and body mass of 72.7 kg. To avoid computational memory problems, the original phantom matrices were resized for a voxel edge of 0.24 cm. It is important to note that as in any simulation, some limitations may be observed. Given the static nature of the simulations, the variation in size of some organs, due to the movement of the patient or the blood flow, were not considered in this work.

We used the MCNPX 2.7.0 [19] radiation transport code. This code can handle the transport and interaction of neutrons, photons and electrons in a wide range of energies and for arbitrary three-dimensional geometries. The technical parameters used in the