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Occupational exposures during abdominal fluoroscopically guided interventional procedures for different patient sizes — A Monte Carlo approach

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ABSTRACT

In this study we evaluated the occupational exposures during an abdominal fluoroscopically guided interventional radiology procedure. We investigated the relation between the Body Mass Index (BMI), of the patient, and the conversion coefficient values (CC) for a set of dosimetric quantities, used to assess the exposure risks of medical radiation workers. The study was performed using a set of male and female virtual anthropomorphic phantoms, of different body weights and sizes. In addition to these phantoms, a female and a male phantom, named FASH3 and MASH3 (reference virtual anthropomorphic phantoms), were also used to represent the medical radiation workers. The CC values, obtained as a function of the dose area product, were calculated for 87 exposure scenarios. In each exposure scenario, three phantoms, implemented in the MCNPX 2.7.0 code, were simultaneously used. These phantoms were utilized to represent a patient and medical radiation workers. The results showed that increasing the BMI of the patient, adjusted for each patient protocol, the CC values for medical radiation workers decrease. It is important to note that these results were obtained with fixed exposure parameters.

1. Introduction

Some of the factors that contribute to an increasing number of Fluoroscopically Guided Interventional Radiology Procedures (FGIP), carried out in recent years, are related to advances in the image acquisition techniques and the increasing number of experts [1]. Moreover, advances arising from this technique allowed more complex procedures. Thus the option to avoid a surgical procedure brings benefits to critically ill patients, and also reduces the hospital stay time. Despite the benefits of the FGIP, it is not possible to ignore the risks for patients and medical radiation workers.

One of the abdominal FGIP is the percutaneous transhepatic biliary drainage (PTBD) procedure. It is used to drain the bile ducts in the presence of a blockage or damage, that prevents the normal biliary drainage. This is a medical technique that uses fluoroscopic images obtained with X radiation to access the treatment site, usually using a guide catheter for percutaneous or other access, accompanied by a contrast medium to view the organs and radiolucent structures.

During an interventional radiology procedure, patients and medical radiation workers may receive high doses of radiation in their organs and tissues. One of the reasons is the long duration of these procedures. In the case of the medical staff, another reason is the proximity of these professionals in relation to the patients (center of scattered radiation), which emit radiation in different directions, reaching various parts of their bodies. The doses involved in these procedures may vary a lot. The factors that influence these doses are: irradiation geometry, energy spectra, thickness of the examined area, field size, use of personal protective equipment (PPE) and also professional experience.

The direct determination of the doses in organs and tissues of patients and medical staff, during clinical procedures, is a difficult task for most situations. In the literature, it is common to express the results of doses in organs and tissues by a ratio between the estimated, or

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measured dosimetric quantity, by another quantity, which can be obtained more easily by experimental arrangements, such as, for example, the dose area product (DAP). The result of this ratio is called dose conversion coefficient (CC), which is a function of the field and radiation source parameters (X-ray tube voltage, filtration, field size, field position, focus-skin distance, etc.). This ratio depends also on the anatomical properties of the anthropomorphic phantoms, such as the elementary composition of relevant tissues of the body, and the applied radiation transport method. Thus, dosimetric measurements can be interpreted in terms of absorbed dose, by multiplying the value obtained from the instrument by the appropriate CC for exposure situations, similar to the actual exposure.

For consistency, in this study, the estimated doses to organs, and all other evaluated quantities, such as equivalent dose and effective dose, will also be presented in this format.

In the interventional radiology, the published works using Monte Carlo (MC) simulation focused mainly on the protection of workers and patients, involved in cardiac angiography and coronary angioplasty procedures [2–8]. However, to our knowledge, there are no dosimetry studies with MC simulation assessing occupational exposures in PTBD, or any other abdominal procedure. The few data from the literature are related to clinical exposures in patients [1,9–12], and some experimental studies regarding occupational radiation exposure in vascular interventional exams [13,14].

In recent years, the Body Mass Index (BMI) of the population has increased, and the use of virtual anthropomorphic phantoms, with higher body mass to represent a specific patient, is a necessity [15–19]. In addition, to the evaluation of medical exposures, another objective of this paper was to evaluate the influence of patients with higher BMI on occupational exposures. This assessment was made by CC values to effective (CC[E]) and equivalent (CC[H_T]) doses, of patients of different heights and body weights, which are subject to a PTBD procedure. To achieve these goals, a realistic exposure model was created using three virtual anthropomorphic phantoms simultaneously, two medical radiation workers and one patient. Finally, we build the scenarios of the energy fluence maps, that allow the knowledge of the most critical points in the interior of the procedures room.

2. Materials and methods

In this study, we used the adult virtual anthropomorphic phantoms FASH3 and MASH3, to represent the medical radiation workers. They were built on mesh surfaces, at the *Department of Nuclear Energy*, *Federal University of Pernambuco* (UFPE) [16,20]. In this work, we will name the professionals as *main physician* and *assistant physician*, due to their positions in relation to the X-ray tube. However, other professionals may be positioned in their places.

The patients were represented by a set of virtual anthropomorphic phantoms, with different heights and body masses. The images of the virtual anthropomorphic phantoms, and their anthropometric characteristics, are shown in Fig. 1 and Table 1, respectively.

All of the virtual anthropomorphic phantoms used in this study have voxel edges of 0.24 cm long. These virtual anthropomorphic phantoms were coupled to the radiation transport code MCNPX 2.7.0 [21]. This code describes the transport radiation through matter, including photons and electrons, that may be transported individually, or simultaneously photon/electron, in three-dimensional geometry and heterogeneous systems.

In addition to the anthropometric characteristics, we also evaluated the effects of technical parameters, such as tube voltage and angle of the beam on the CC[H_T] and CC[E] to medical radiation workers and patients.

In this study, the CC values were calculated for a set of organs and tissues of dosimetric importance, from three beam projections: posteroanterior (PA), right anterior oblique (RAO25°) and left anterior oblique (LAO25°). In all cases, the radiation beam is focused on the patient's liver, to mimic a PTBD procedure, with fields of view (FOV) of 20 cm × 20 cm and 30 cm × 30 cm. Different FOV were employed in the simulations to evaluate the influence of its size on the CC values. The source-skin distances were set at 60 cm for PA projection, 56 cm for LAO25° and 54 cm for the RAO25° projections. The focus detector distance was 100 cm, 116 cm and 114 cm for the PA, LAO25° and RAO25° projections, respectively.

The X-ray tube was simplified to a point source that emits radiation isotropically, in a solid angle specified by the field size and focal length. The X-ray spectra were generated following the recommendations of the catalogue of X-ray spectra IPEM report number 78 (SR-78 software) [22], which enables the combination of several radiographic parameters. They were: maximum photon energies of 80, 100 and 120 keV, tungsten as target material, anodic angle of 12°, filtration/half-value layer set at 4.0/4.8; 4.7/5.0 and 3.8/5.5 mmAl, with effective energies of 38.8, 44.0 and 45.4 keV, respectively.

In order to make the radiation scenarios as close to reality as possible, the most common objects, present within the intervention room, were modeled, by computational method, to evaluate all effects generated in the medium, such as scattering, absorption and production of secondary particles. In this sense, we built a room of concrete walls and filled with atmospheric air. Within this area, in addition to medical workers and patient, the major components of the X-ray equipment were inserted. The X-ray tube was composed of Pb with a density of 11.35 g/cm^3; and the image intensifier was composed of a CsI crystal, with a density of 1.25 g/cm^3 (composition: Cs (50%), I (50%)); Al_2O_3 substrate, density of 1.25 g/cm^3 (composition: Al (40%), O (60%)) and a shield, with density of 7.87 g/cm^3 (composition: Mn (0.5%), Fe (99.5%)).

A 15 cm thick surgical table made of carbon fiber with a metal base was also modeled. It had a density of 1.25 g/cm^3 and a composition of: H (5.7441%), C (77.4591%) and O (16.7968%). The table was positioned at a height of 90 cm from the room floor. Two medical radiation workers were positioned at the right side of the surgical table, at the level of the patient's groin, and in front of a video monitoring system.

We also simulated an ionization chamber, filled with atmospheric air to measure the DAP. In all situations the ionization chamber was positioned 15 cm from the focal spot. The ionization chamber's size was modeled in such a way that its dimensions would be compatible to those of the X-ray beam. For the 20 cm FOV the dimensions were $(5 \times 5 \times 1)$ cm^3 and for the 30 cm FOV $(15 \times 15 \times 1)$ cm^3. With those dimensions, the ionization chamber was within the area perpendicular to the X-ray beam.

Fig. 2 shows the computational exposure scenario with three virtual anthropomorphic phantoms, representing the patient and medical radiation workers, involved in PTBD procedures. In this figure, the PPE, and other typical components of an interventional radiology room were also included.

The PPE, used by medical radiation workers, were carefully modeled. These devices are generally made of 0.5 mm thick lead equivalent in front of the operator. Among the most important equipment are the apron, thyroid shield and lead eyewear (composed by lead glass). This apron model is 1.20 m long and 55 cm wide, extending from the chest level until the region of the knees, with the sides of the shoulders and arms of the workers exposed. The lead eyewear, shaped as glasses, was also inserted, as well as the thyroid shield, with a ring shape, covering the entire neck. The suspended curtain and lead glass shields with equivalent thickness of 0.5 mm lead were also inserted. These devices are often used for the protection of radiation workers who are exposed to the primary radiation beam, and especially the scattered radiation from the patient and the surgical table.

The absorbed doses in the main radiosensitive organs and tissues, of the male and female virtual anthropomorphic phantoms, were determined considering the energy deposited in the region of interest of all primary and secondary radiation. Since the w_R weighting factor for photons is 1, the absorbed dose is numerically equal to the equivalent