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Efficiency of personal dosimetry methods in vascular interventional radiology

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ABSTRACT

Purpose: The aim of the present study was to determine the efficiency of six methods for calculate the effective dose (*E*) that is received by health professionals during vascular interventional procedures.
Methods: We evaluated the efficiency of six methods that are currently used to estimate professionals' *E*, based on national and international recommendations for interventional radiology. Equivalent doses on the head, neck, chest, abdomen, feet, and hands of seven professionals were monitored during 50 vascular interventional radiology procedures. Professionals' *E* was calculated for each procedure according to six methods that are commonly employed internationally. To determine the best method, a more efficient *E* calculation method was used to determine the reference value (reference *E*) for comparison.
Results: The highest equivalent dose were found for the hands (0.34 ± 0.93 mSv). The two methods that are described by Brazilian regulations overestimated *E* by approximately 100% and 200%. The more efficient method was the one that is recommended by the United States National Council on Radiological Protection and Measurements (NCRP). The mean and median differences of this method relative to reference *E* were close to 0%, and its standard deviation was the lowest among the six methods.
Conclusions: The present study showed that the most precise method was the one that is recommended by the NCRP, which uses two dosimeters (one over and one under protective aprons). The use of methods that employ at least two dosimeters are more efficient and provide better information regarding estimates of *E* and doses for shielded and unshielded regions.

1. Introduction

Physicians who perform interventional X-ray procedures are exposed to the highest radiation doses compared with all other health professionals [1]. Several studies have shown that such physicians are exposed to non-uniform radiation levels throughout their bodies during interventional procedures [2–4].

The effective dose (*E*) is a physical quantity that is used to measure the detriment that is caused by radiation in the human body, thus providing important information for radiological protection purposes. The *E* value depends on equivalent doses that are measured in different organs and tissues of the body, which are usually the most sensitive to stochastic effect induction [5]. During each procedure, professionals use a personal dosimeter on the chest or abdomen to estimate the *E* that is received [5].

Different methods are used to estimate *E* during interventional procedures [6]. In Europe, a single personal dosimeter that is positioned on the anterior chest below the radiological protective apron was previously considered a good estimate of *E* [5,6].

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However, this approach does not provide any information regarding unshielded regions of the professionals' body [5,6].

In the United States, the National Council on Radiological Protection and Measurements (NCRP) recommends the use of two personal dosimeters, one over and one under the radiological protective apron [7]. The dosimeter over the apron may be positioned on the neck [7], and the dosimeter under the apron may be placed on the chest or abdomen [7].

In Brazil, the Agência Nacional de Vigilância Sanitária (ANVISA) recommends the use of a single dosimeter over the protective apron. This dosimeter should be positioned on the torso region that is most exposed to radiation [8].

During interventional procedures, professionals are exposed to non-uniform radiation fields that are indicated by different absorbed doses throughout tissues and organs. Thus, a precise calculation of *E* is a major concern for radiation protection purposes [4,5]. However, to our knowledge, no studies have properly assessed the efficiency of several different methods that are used to calculate professionals' *E*. These different methods can either underestimate or overestimate the correct value of *E* [2,4].

The aim of the present study was to evaluate the efficiency of six methods that are used internationally to calculate the *E* that is received by health professionals in interventional radiology procedures. We also determine the best method for measuring the *E* that is received by health professionals during vascular interventional procedures.

2. Methods

The present study involved three main steps (Fig. 1). The first step consisted of a complete dosimetry assessment of seven physicians during 50 vascular interventional radiology procedures. Equivalent incident doses on the head, neck, chest, abdomen, feet, and hands were monitored (described in Section 2.1).

After monitoring the radiation doses in step 1, step 2 consisted of calculating *E* according to six different methodologies (described in Section 2.2).

To assess the efficiency of all six methods, a more accurate reference method was employed. For the reference method, correlation factors (*CF*s) were calculated between external and internal doses using an anthropomorphic phantom. Twenty-four internal organs and tissues were assessed according to the International Commission on Radiological Protection (ICRP) for *E* calculations [5]. After applying the *CF*s to the external doses that were monitored for each professional, the *E* was calculated for each procedure (described in Section 2.3).

All six estimated values of *E* that were obtained in step 2 were compared with the reference *E* of step 3, which allowed us to assess the efficiency of each procedure compared with the reference values.

These three steps were applied to 50 procedures that were performed in the Botucatu Medical School, São Paulo State University, Brazil. The procedures were performed using LCV Plus equipment (Advantx General Electric Medical Systems, Milwaukee, WI, USA). The equipment complied with all standard quality control tests. Lead blades were placed underneath the patient table for stationary shielding. Ceiling-suspended transparent shielding and a patient dosimeter were not used.

2.1. Dosimetry measurements for professionals during clinical practice

The physicians who conducted interventional vascular procedures were monitored for dosimetry assessment. Incident doses for different body regions of the professional were monitored using dosimeters during each procedure. Seven professionals who performed the 50 procedures were monitored. During all of the procedures, the physician remained approximately 0.5 m from the imaged patient.

Thermoluminescent dosimeters (TLDs; TLD-100; LiF: Mg, Ti Harshaw, Solon, OH, USA) were used for dose measurements. The pellets were square shaped with dimensions of $3.2 \times 3.2 \times 0.9\ mm^3$. Dosimeters were positioned on the head (top of the surgical mask), neck, chest, abdomen, feet, and hands (wrists) of the professionals, over the radiological protective aprons. All of the monitored professionals used radiological protective aprons, such as lead aprons, thyroid shields, and lead glasses. The protective aprons (Kiran, Nerul, Navi Mumbai, 400706, India), i.e. lead aprons and thyroid shields, were 0.5 mm lead-equivalent for exposition in X-ray fields produced with a range of 50 to 150 kVp. For each evaluated region, three dosimeters were used for a more accurate dose measurement [4].

For each procedure, a control group of three TLDs was used outside of controlled areas to monitor background radiation. Background measurements were subtracted from the professionals' dosimeter readings.

According to the current legislation in our country, the dosimeters were calibrated in Photon Dose Equivalent Hx (measured in Sv) using a known dose level (1 mGy). The calibration was performed using a Co-60 radiation source on a 4π geometry free air exposure using a 3 mm Lucite® build up plate. The mean ratio between the reading dose (nanoCoulombs) and equivalent dose (milliSievert) for each dosimeter was used as an individual calibration factor. The uncertainty of a single dose measurement was 5.37%. This uncertainty value is dependent of uncertainty in the calibration process, dose reading and uncertainty of control dose subtracted.

The procedure modalities that were monitored included lower limb and abdominal angiographies (20), lower limb and abdominal percutaneous transluminal angioplasty (15), and abdominal aortic aneurysm treatment with stent graft placement (15). These procedures were performed between 75 and 85 kVp, with automatic mA control, 1.9–3.8 frames/s, "medium" noise level, and 32 cm field of view.

2.2. Other methodologies to estimate the professionals' effective dose

After the dosimetry step, the *E* value was estimated according to six different methodologies. These estimates were performed for each professional who was monitored and compared with the reference *E* which is calculated using clinical and anthropomorphic phantom dosimetry.

In Brazil, regulations require that *E* is calculated with a dosimeter positioned at the most exposed torso region, over the protective apron. Dosimeter readings were corrected by a factor of 0.1 according to this normative guideline [8].

The dosimeter is usually used on the chest, without prior assessment of the most exposed region. The first two methods that were used to estimate *E* and compared with the reference *E* were based on Brazilian legislation:

- Method 1: Chest dose over protective aprons, corrected by a factor of 0.1;
- Method 2: Abdominal dose over protective aprons, corrected by a factor of 0.1.

In The United States, the NCRP recommends combining readings from the neck dosimeter outside the protective apron (indicating unshielded head doses) and readings from the abdomen (waist height) or chest measured inside the protective apron using Eq. (1) [6,7]:

$$E_{NCRP}(\text{estimate}) = 0.5\ H_{IN} + 0.025\ H_{OUT} \quad (1)$$