

## Research Article

# Calculation of Conversion Coefficient for Effective Dose to Patient and Physician in Interventional Cardiology Procedure Using the Monte Carlo Method

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## Abstract

Radiation doses to patients and to medical staff from coronary angiography procedures are relatively high when compared to conventional radiographic procedures. Due to the long image obtainment time, the high doses of radiation can result in deterministic and stochastic effects. In this work, the effective and equivalent tissue doses for the patient and medical staff were calculated and normalized to kerma-area product, to produce kerma-area to an equivalent dose in tissue conversion coefficients for this procedure. Simulations were carried out for four X-ray spectra (60, 70, 80 and 90 kVp) using the radiation transport MCNPX2.7.0 code. The physician in the standing position and the patient in the supine position were represented by a pair of adult mathematical anthropomorphic phantoms. The Conversion Coefficients (CCs) were obtained for irradiation geometry Antero-Posterior (AP), Postero-Anterior (PA), Left Anterior Oblique (LAO90°) and Right Anterior Oblique (RAO90°). The computational results demonstrated that the estimated organ dose values for the physician and patient vary significantly with the organ location and X-ray spectrum. The CCs of effective doses for the patient and physician determined in this study were compared to previous experimental and calculated results presented in the literature and found to be similar.

**Keywords:** Interventional cardiology; Anthropomorphic phantoms; Medical and occupational exposures; Monte carlo simulation

## Introduction

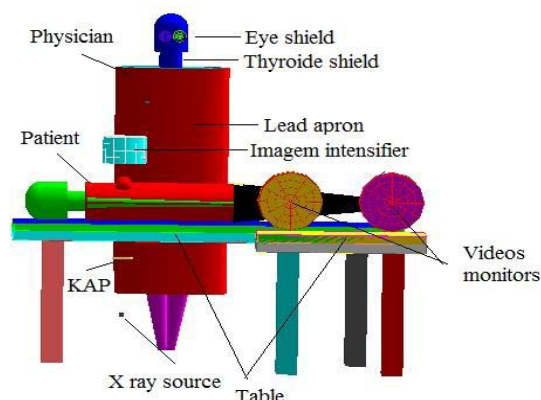
Coronary Angiography (CA) plays an important role in the diagnosis and treatment of vascular disease and other conditions that can lead to heart attack and stroke. The technique uses radiography to guide the passage of a catheter into the region of the patient's heart. In general, the patient is examined for long periods of time during the procedure and a large number of radiographic images are obtained [1,2]. The catheter is positioned either in the heart or at the entrance of the arteries supplying the heart, and a special fluid (called a contrast medium or dye) is injected. This fluid is opaque to X-rays, and the images obtained are called angiograms. Due to the relatively long time to obtain the images, the patient and medical staff can receive high doses of radiation, which could result in stochastic effects and which have caused deterministic effects in certain cases [3,4].

Conversion Coefficients (CCs) obtained in this study are normalized to dosimetric quantities that can be obtained by direct measurement such as the Kerma-Area Product (KAP), which can be obtained from the ionization chamber installed in the X-ray equipment used in the procedure. Knowing the measured KAP, it is possible to calculate the dose that patients and physician staff are exposed to during the coronary angiography procedure. CCs for use in radiological protection have been recommended by ICRP publication 116 [5]. However, the use of these CCs is not appropriate for the calculation of effective doses in interventional radiology, because the field size and the beam quality used for these

processes are not covered by the ICRP geometries. The aim of this study is to evaluate the influence of variations in tube voltage, the use of protective equipment and beam projection to the medical and occupational exposure, through the CCs for effective dose using the Monte Carlo method.

## Materials and Methods

In this study we used the radiation transport MCNPX2.7.0 code [6]. This code can handle the transport and interaction of neutrons, photons and electrons in a wide range of energies and for



**Figure 1:** Irradiation scenario represented the patient (supine) and the physician (standing), irradiated by an X-ray equipment in IC procedure.

**Table 1:** CCs of equivalent dose and effective dose normalized to KAP in mSv/Gy.cm<sup>2</sup> obtained for the patient.

	PA	AP	LAO90	RAO90	PA	AP	LAO90	RAO90
	60 kVp				70 kVp			
Bone surface	9.2E-02	1.2E-01	9.4E-02	9.2E-02	1.1E-01	1.4E-01	1.1E-01	1.1E-01
Lung	3.9E-01	3.6E-01	3.7E-01	4.2E-01	4.7E-01	4.5E-01	4.7E-01	5.3E-01
Heart	6.8E-02	4.9E-01	6.1E-02	4.4E-02	9.4E-02	5.8E-01	8.6E-02	6.3E-02
Liver	2.9E-02	5.9E-02	9.8E-03	6.2E-02	4.3E-02	8.1E-02	1.7E-02	8.9E-02
Esophagus	2.3E-01	2.1E-01	1.0E-01	9.9E-02	3.3E-01	2.8E-01	1.6E-01	1.5E-01
Skin	8.9E-02	1.2E-01	1.4E-01	1.4E-01	9.4E-02	1.2E-01	1.5E-01	1.5E-01
Colon	3.7E-04	6.9E-04	4.0E-04	4.4E-04	7.3E-04	1.2E-03	8.4E-04	8.9E-04
Stomach	1.3E-02	2.6E-02	3.2E-02	5.7E-03	2.0E-02	3.8E-02	4.9E-02	1.0E-02
Breast	8.7E-02	6.1E-01	2.6E-01	2.6E-01	1.2E-01	6.7E-01	3.1E-01	3.1E-01
Gonads	1.9E-04	1.4E-03	3.8E-04	4.6E-04	3.6E-04	1.8E-03	5.2E-04	5.4E-04
Bladder	4.8E-05	1.8E-04	4.9E-05	5.9E-05	9.3E-05	2.4E-04	9.6E-05	1.1E-04
Thyroid	4.1E-03	1.0E-02	5.5E-03	5.4E-03	7.0E-03	1.6E-02	9.3E-03	9.5E-03
Brain	1.0E-04	1.4E-04	1.7E-04	1.7E-04	1.9E-04	2.6E-04	3.1E-04	3.2E-04
Adrenals	6.6E-02	4.0E-02	3.1E-02	3.3E-02	9.2E-05	5.9E-05	4.9E-05	5.1E-05
Gall bladder	5.0E-03	1.2E-02	4.1E-03	7.0E-03	8.8E-03	1.9E-02	7.4E-03	1.2E-02
Kidneys	7.6E-03	6.1E-03	5.5E-03	5.7E-03	1.2E-02	1.0E-02	9.4E-03	9.8E-03
Spleen	2.2E-02	1.7E-02	5.4E-02	4.6E-03	3.3E-02	2.7E-02	7.9E-02	8.6E-03
Thymus	7.5E-02	4.5E+00	1.2E-01	1.3E-01	1.2E-01	5.0E+00	1.8E-01	1.9E-01
Pancreas	2.7E-02	4.2E-02	3.7E-02	1.7E-02	4.2E-02	6.3E-02	5.9E-02	2.8E-02
Prostate	4.3E-05	1.7E-04	4.1E-05	4.2E-05	7.1E-05	2.0E-04	8.9E-05	1.1E-04
Small intestine	4.7E-04	8.0E-04	4.9E-04	5.2E-04	9.2E-04	1.5E-03	1.0E-03	1.1E-03
E/KAP	1.1E-01	8.9E-01	1.3E-01	1.3E-01	1.3E-01	1.0E+00	1.7E-01	1.7E-01
	80 kVp				90 kVp			
Bone surface	1.2E-01	1.6E-01	1.3E-01	1.3E-01	1.4E-01	1.7E-01	1.5E-01	1.5E-01
Lung	5.4E-01	5.3E-01	5.8E-01	6.5E-01	6.2E-01	6.1E-01	6.7E-01	7.5E-01
Heart	1.1E-01	6.6E-01	1.1E-01	8.4E-02	1.5E-01	7.3E-01	1.4E-01	1.0E-01
Liver	5.4E-02	1.0E-01	2.5E-02	1.2E-01	7.2E-02	1.3E-01	3.3E-02	1.5E-01
Esophagus	3.9E-01	3.6E-01	2.1E-01	2.0E-01	5.5E-01	4.4E-01	2.7E-01	2.5E-01
Skin	9.9E-02	1.3E-01	1.6E-01	1.6E-01	1.0E-01	1.3E-01	1.6E-01	1.6E-01
Colon	1.2E-03	2.0E-03	1.4E-03	1.5E-03	1.8E-03	2.7E-03	2.0E-03	2.1E-03
Stomach	2.7E-02	5.2E-02	6.7E-02	1.6E-02	3.7E-02	6.5E-02	8.5E-02	2.1E-02
Breast	1.5E-01	7.4E-01	3.5E-01	3.5E-01	1.8E-01	7.9E-01	3.9E-01	3.9E-01
Gonads	4.4E-04	2.1E-03	6.3E-04	7.9E-04	6.6E-04	2.4E-03	9.6E-04	1.0E-03
Bladder	1.3E-04	3.5E-04	1.5E-04	1.5E-04	2.1E-04	4.5E-04	2.1E-04	2.1E-04
Thyroid	1.0E-02	2.3E-02	1.5E-02	1.4E-02	1.5E-02	3.0E-02	1.9E-02	1.9E-02
Brain	3.0E-04	4.2E-04	4.9E-04	5.2E-04	4.5E-04	5.9E-04	6.9E-04	7.0E-04
Adrenals	1.2E-04	8.4E-05	6.8E-05	7.2E-05	1.5E-04	1.0E-04	8.8E-05	9.2E-05
Gall bladder	1.2E-02	2.7E-02	1.2E-02	1.9E-02	1.9E-02	3.5E-02	1.6E-02	2.5E-02
Kidneys	1.7E-02	1.5E-02	1.4E-02	1.5E-02	2.3E-02	2.0E-02	1.9E-02	2.0E-02
Spleen	4.3E-02	3.8E-02	1.1E-01	1.4E-02	5.6E-02	4.9E-02	1.3E-01	1.9E-02
Thymus	1.3E-01	5.5E+00	2.4E-01	2.6E-01	2.1E-01	5.9E+00	2.9E-01	3.1E-01
Pancreas	5.6E-02	8.7E-02	8.3E-02	4.1E-02	7.8E-02	1.1E-01	1.1E-01	5.5E-02
Prostate	8.2E-05	3.3E-04	1.0E-04	1.4E-04	1.6E-04	3.9E-04	1.7E-04	1.9E-04
Small intestine	1.5E-03	2.4E-03	1.8E-03	1.8E-03	2.3E-03	3.3E-03	2.6E-03	2.7E-03
E/KAP	1.6E-01	1.1E+00	2.2E-01	2.0E-01	2.0E-01	1.2E+00	2.6E-01	2.4E-01

arbitrary three-dimensional geometries. We developed a realistic irradiation scenario represented by a patient and a physician in the Interventional Cardiology (IC) procedure. Both were represented by two mathematical anthropomorphic phantoms [7]. The physician wearing a lead apron, thyroid shield and glasses with thick of 0.5mm lead was positioned on the left to the patient. The Figure 1 shows an operating table with the characteristics described.

In the scenario has been introduced an image intensifier, video

monitors and an X-ray source emitting photons isotropic ally in the chest region of the patient. Four projections were simulated: Antero-Posterior (AP), Postero-Anterior (PA), Left Anterior Oblique (LAO) and Right Anterior Oblique (RAO). In all projections were used voltages of 60, 70, 80 and 90 kVp in tube, a filtration of 3.5 mmAl and field size of 10 x 10 cm<sup>2</sup>. The focus-to-skin distance was 50 cm AP/PA and 55 cm LAO90/RAO90. In this study, the physician was placed at the left of the patient, separated by a 17 cm gap so as to simulate realistic patient/physician geometry as closely as possible.

**Table 2:** CCs of equivalent dose and effective dose normalized to KAP in  $\mu\text{Sv}/\text{Gy}\cdot\text{cm}^2$  obtained for the physician Using (U) or Not (N) the personal protective equipment.

	PA	AP	LAO90	RAO90	PA	AP	LAO90	RAO90
	U				N			
	60 kVp							
Bone surface	2.5E-03	5.8E-03	3.9E-03	3.1E-03	1.2E-01	7.2E-01	1.1E+00	1.7E-01
Lung	2.3E-03	6.8E-03	3.2E-03	5.4E-04	1.5E-01	1.1E+00	6.0E-01	3.5E-01
Heart	1.4E-04	1.9E-04	2.0E-04	2.7E-04	3.5E-02	2.5E-01	1.3E-01	9.2E-02
Liver	6.6E-04	1.6E-03	1.2E-03	2.1E-03	3.0E-01	2.1E+00	2.1E+00	4.9E-01
Esophagus	1.9E-03	4.7E-03	1.2E-04	2.2E-03	4.6E-02	2.4E-01	1.3E-01	3.4E-02
Skin	1.3E-01	1.5E-01	8.2E-02	1.1E-01	9.2E-01	1.6E+00	3.2E+00	5.2E-01
Colon	1.3E-05	6.0E-04	4.4E-04	5.0E-04	7.7E-02	4.8E-01	7.4E-01	1.1E-01
Stomach	6.6E-06	6.0E-04	1.0E-05	8.5E-05	5.9E-02	6.8E-01	3.4E-01	1.5E-01
Breast	8.3E-03	1.7E-02	1.3E-02	7.2E-03	6.5E-01	5.3E+00	3.5E+00	1.3E+00
Gonads	3.9E-02	1.1E-02	1.9E-02	2.4E-02	1.6E+00	1.5E+00	1.4E+01	6.5E-01
Bladder	3.5E-16	1.2E-05	6.0E-04	1.4E-05	1.1E-01	2.7E-01	1.3E+00	6.7E-02
Thyroid	1.3E-02	4.9E-02	2.1E-02	1.7E-02	6.5E-02	4.4E-01	1.4E-01	2.7E-01
Brain	2.5E-02	2.1E-01	2.8E-02	1.1E-01	5.9E-02	3.6E-01	1.7E-01	1.5E-01
Adrenals	2.0E-07	2.6E-07	2.2E-07	2.4E-07	2.8E-16	8.1E-05	3.2E-04	1.4E-04
Gall bladder	1.9E-14	2.4E-03	4.2E-03	1.6E-14	1.5E-01	1.4E+00	1.3E+00	2.3E-01
Kidneys	3.9E-16	4.2E-04	5.9E-04	5.9E-16	3.8E-02	8.9E-02	1.8E-01	4.4E-02
Spleen	1.7E-05	2.7E-05	2.5E-05	2.6E-02	4.5E-02	1.3E-01	5.3E-02	4.6E-02
Thymus	4.8E-04	5.6E-03	2.2E-04	6.0E-03	2.6E-01	1.9E+00	4.7E-01	6.9E-01
Pancreas	1.3E-15	4.3E-05	5.2E-05	4.5E+00	1.4E-02	2.7E-01	1.7E-01	8.8E-02
Prostate	2.1E-03	2.1E-04	1.4E-04	1.1E-05	1.4E-01	4.0E-01	1.7E+00	1.6E-02
Small intestine	1.3E-04	9.4E-04	1.3E-03	5.1E-05	1.1E-01	5.4E-01	7.3E-01	1.1E-01
E/KAP	7.1E-03	1.1E-02	6.5E-03	6.8E-01	3.9E-01	1.9E+00	2.6E+00	5.3E-01
	70 kVp							
Bone surface	4.7E-03	1.1E-02	8.8E-03	6.3E-03	1.9E-01	9.4E-01	1.4E+00	2.6E-01
Lung	5.7E-03	1.5E-02	8.4E-03	8.4E-03	2.7E-01	1.5E+00	9.8E-01	5.3E-01
Heart	6.1E-04	1.1E-03	3.1E-04	1.1E-03	5.5E-02	3.6E-01	2.2E-01	1.2E-01
Liver	3.6E-03	9.9E-03	7.9E-03	9.3E-03	5.1E-01	2.9E+00	2.9E+00	8.0E-01
Esophagus	3.5E-03	1.4E-03	6.1E-03	3.6E-03	9.2E-02	2.0E-01	1.4E-01	1.8E-01
Skin	1.8E-01	1.9E-01	1.2E-01	1.5E-01	1.2E+00	2.0E+00	3.9E+00	7.2E-01
Colon	1.3E-03	2.5E-03	3.7E-03	2.1E-03	1.4E-01	7.1E-01	1.1E+00	1.6E-01
Stomach	4.2E-04	4.5E-04	7.2E-04	1.1E-03	1.2E-01	9.5E-01	4.9E-01	2.7E-01
Breast	1.3E-02	3.4E-02	1.7E-02	1.8E-02	1.0E+00	6.6E+00	4.3E+00	2.0E+00
Gonads	4.2E-02	2.4E-02	7.7E-02	2.4E-02	2.2E+00	2.2E+00	1.7E+01	1.1E+00
Bladder	2.0E-03	8.5E-04	5.0E-03	1.0E-03	1.4E-01	3.3E-01	1.5E+00	1.0E-01
Thyroid	1.5E-02	6.9E-02	1.9E-02	5.7E-02	2.1E-01	5.6E-01	4.9E-01	3.8E-01
Brain	4.3E-02	3.0E-01	4.7E-02	1.6E-01	9.0E-02	5.0E-01	2.7E-01	2.2E-01
Adrenals	8.6E-06	1.2E-17	4.9E-07	1.9E-05	2.4E-04	2.2E-04	2.2E-04	8.4E-05
Gall bladder	5.5E-04	6.8E-03	3.4E-04	7.8E-03	3.5E-01	1.8E+00	1.5E+00	4.3E-01
Kidneys	1.2E-04	1.4E-05	1.8E-03	3.2E-04	7.8E-02	2.5E-01	4.2E-01	9.3E-02
Spleen	5.0E-04	1.4E-05	1.1E-15	4.1E-05	4.0E-02	2.0E-01	6.2E-02	8.6E-02
Thymus	5.3E-03	1.9E-02	5.9E-03	1.2E-02	2.8E-01	2.8E+00	1.2E+00	1.0E+00
Pancreas	1.9E-04	4.6E-03	7.5E-04	1.7E-03	1.9E-01	6.2E-01	3.2E-01	2.4E-01
Prostate	4.2E-03	6.9E-04	1.3E-02	1.3E-05	2.3E-01	4.5E-01	2.3E+00	1.2E-01
Small intestine	2.0E-03	4.0E-03	3.9E-03	1.9E-03	1.4E-01	8.2E-01	1.2E+00	1.9E-01
E/KAP	1.1E-02	2.2E-02	1.7E-02	1.5E-02	6.2E-01	2.6E+00	3.5E+00	8.6E-01
	80 kVp							
Bone surface	8.1E-03	2.0E-02	1.9E-02	1.3E-02	2.8E-01	1.2E+00	1.8E+00	3.7E-01
Lung	1.0E-02	2.7E-02	1.4E-02	2.1E-02	3.9E-01	2.0E+00	1.4E+00	7.4E-01
Heart	1.4E-03	1.6E-03	1.5E-03	3.1E-03	9.4E-02	4.9E-01	3.1E-01	1.9E-01
Liver	1.3E-02	3.0E-02	2.1E-02	2.7E-02	7.5E-01	3.7E+00	4.0E+00	1.1E+00
Esophagus	7.3E-04	2.2E-02	1.2E-02	3.9E-03	1.9E-01	5.4E-01	4.8E-01	1.5E-01
Skin	2.3E-01	2.4E-01	1.8E-01	2.0E-01	1.5E+00	2.4E+00	4.6E+00	9.3E-01
Colon	3.5E-03	1.0E-02	1.4E-02	6.1E-03	2.2E-01	1.0E+00	1.6E+00	2.6E-01

Stomach	1.6E-03	5.1E-03	3.4E-03	4.5E-03	2.1E-01	1.2E+00	7.3E-01	4.7E-01
Breast	2.1E-02	5.3E-02	2.4E-02	4.1E-02	1.3E+00	7.8E+00	5.5E+00	2.4E+00
Gonads	8.6E-02	4.6E-02	1.4E-01	4.3E-02	2.8E+00	3.0E+00	2.1E+01	1.4E+00
Bladder	2.2E-03	8.2E-03	2.0E-02	4.3E-03	2.1E-01	5.6E-01	2.1E+00	1.6E-01
Thyroid	2.4E-02	1.0E-01	9.2E-02	8.3E-02	2.3E-01	1.2E+00	8.2E-01	5.5E-01
Brain	6.8E-02	4.0E-01	7.5E-02	2.5E-01	1.4E-01	6.8E-01	3.8E-01	3.2E-01
Adrenals	2.0E-17	1.4E-05	1.3E-05	1.5E-16	3.0E-04	7.8E-05	4.0E-04	1.2E-04
Gall bladder	1.3E-02	1.6E-02	8.2E-03	1.6E-02	5.8E-01	2.5E+00	2.8E+00	5.9E-01
Kidneys	3.1E-03	5.4E-03	5.5E-03	3.7E-03	1.1E-01	4.5E-01	5.5E-01	1.6E-01
Spleen	5.6E-04	1.3E-03	2.5E-03	1.1E-03	8.0E-02	3.4E-01	1.8E-01	8.2E-02
Thymus	5.9E-03	3.1E-02	2.6E-02	1.3E-02	5.5E-01	3.2E+00	1.3E+00	1.6E+00
Pancreas	2.3E-03	6.1E-03	4.4E-03	4.0E-03	2.0E-01	7.8E-01	5.9E-01	3.3E-01
Prostate	4.7E-04	8.2E-03	1.6E-02	5.0E-04	4.5E-01	4.2E-01	3.1E+00	1.9E-01
Small intestine	4.4E-03	1.1E-02	1.6E-02	9.3E-03	2.5E-01	1.1E+00	1.6E+00	2.7E-01
E/KAP	2.0E-02	4.0E-02	3.8E-02	2.9E-02	9.0E-01	3.4E+00	4.7E+00	1.2E+00
90 kVp								
Bone surface	1.4E-02	3.2E-02	3.6E-02	2.2E-02	3.9E-01	1.5E+00	2.3E+00	5.0E-01
Lung	1.9E-02	4.1E-02	2.5E-02	3.7E-02	5.6E-01	2.5E+00	1.8E+00	1.0E+00
Heart	3.4E-03	5.5E-03	3.8E-03	8.3E-03	1.4E-01	6.4E-01	4.1E-01	2.7E-01
Liver	3.2E-02	6.7E-02	5.4E-02	5.9E-02	1.1E+00	4.9E+00	5.1E+00	1.5E+00
Esophagus	8.7E-03	1.9E-02	7.1E-03	1.5E-02	2.0E-01	8.4E-01	5.7E-01	4.5E-01
Skin	2.8E-01	2.9E-01	2.3E-01	2.4E-01	1.8E+00	2.9E+00	5.4E+00	1.2E+00
Colon	9.0E-03	2.2E-02	3.5E-02	1.6E-02	3.3E-01	1.4E+00	2.1E+00	3.7E-01
Stomach	5.0E-03	1.2E-02	5.9E-03	1.7E-02	3.0E-01	1.6E+00	1.0E+00	6.4E-01
Breast	3.7E-02	8.2E-02	4.4E-02	7.2E-02	1.8E+00	9.1E+00	6.8E+00	3.1E+00
Gonads	9.9E-02	5.5E-02	2.6E-01	4.1E-02	4.0E+00	3.7E+00	2.6E+01	2.0E+00
Bladder	5.5E-03	1.1E-02	4.5E-02	4.6E-03	3.2E-01	8.7E-01	2.9E+00	2.1E-01
Thyroid	3.1E-02	1.1E-01	5.1E-02	1.1E-01	3.6E-01	1.5E+00	7.0E-01	7.7E-01
Brain	1.0E-01	5.1E-01	1.0E-01	3.1E-01	2.3E-01	9.3E-01	5.4E-01	4.4E-01
Adrenals	2.1E-05	6.3E-07	1.0E-16	3.0E-05	1.7E-04	5.2E-04	6.0E-04	2.1E-04
Gall bladder	1.5E-02	4.9E-02	3.8E-02	4.8E-02	7.5E-01	3.4E+00	3.6E+00	9.9E-01
Kidneys	4.7E-03	1.1E-02	1.2E-02	1.2E-02	1.6E-01	5.5E-01	8.0E-01	2.1E-01
Spleen	4.5E-03	6.6E-03	2.2E-03	3.5E-03	8.7E-02	3.2E-01	2.8E-01	1.5E-01
Thymus	8.7E-03	5.1E-02	2.5E-02	1.1E-02	9.2E-01	4.1E+00	1.9E+00	1.9E+00
Pancreas	6.5E-03	2.4E-02	8.4E-03	1.6E-02	2.4E-01	1.1E+00	8.0E-01	4.5E-01
Prostate	9.9E-03	9.3E-03	3.6E-02	3.2E-03	4.9E-01	7.9E-01	4.1E+00	2.8E-01
Small intestine	8.8E-03	3.3E-02	3.5E-02	1.9E-02	3.7E-01	1.6E+00	2.2E+00	3.9E-01
E/KAP	3.2E-02	6.8E-02	6.7E-02	5.1E-02	1.2E+00	4.3E+00	6.0E+00	1.6E+00

The X-ray spectrum was obtained using the software Report 78 [8] with radiographic parameters commonly used in clinical practice for the examination of CA [9]. The main parameters were: voltages of 60, 70, 80 and 90 kVp, total filtration of 3.5 mm Al, anode angle 12°. The KAP was calculated by the product of the air kerma by irradiated area of the object built in the output of the X-ray tube.

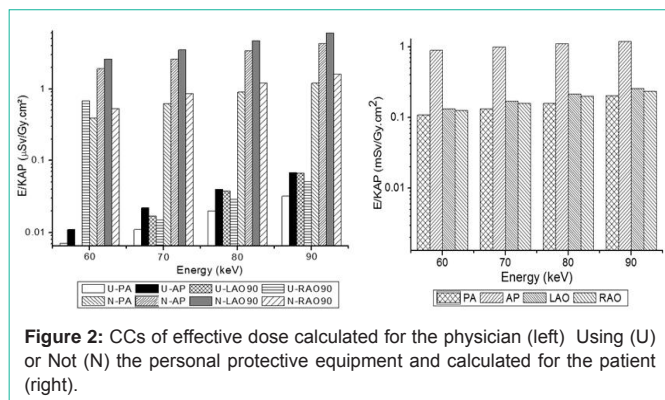
### Results and Discussion

Organ doses were calculated for 21 organs for the physician and for the patient. In order to obtain the CCs, 10<sup>8</sup> histories were run generating statistical errors below 5%. Simulations were performed for different voltages in the tube and beam projections with the patient and physician Using (U) or Not (N) the personal protective equipment. The Tables 1 and 2 show the main results of CCs for equivalent dose and effective dose normalized by KAP calculated for the patient and physician, respectively, for a coronary angiography procedure.

As it can be seen in Tables 1 and 2, there are significant variations

in the values of CCs between organs. Variations in the CCs were found due to location, depth size and shape of organs within the phantoms and due to the use of different radiographic techniques for angiography examinations. The projection beam is another aspect that should be taken into account and that further increases the dose in the patient and in the physician. The organs of the patient with greater weight factors are located closer to the radiation source. For the physician, the organs receiving higher doses were those of higher volume and located closer to the patient. Another important factor is the increase in tube voltage. Figures 2 and 3 show those variations of the beam projection and of the tension in the tube results in different average values of CCs effective dose to the physician and patient respectively. In all situations evaluated, it is observed an increase of CCs with a higher voltage in the tube. The values for the physician are even greater when he does not use the protective equipment.

Higher CCs to the physician were observed in the irradiation side of the patient. Results show that the use of protective equipment with 0.5 mm of lead cannot be dropped because it reduces the average dose



to the physician by a factor of 80 during examination. The critical position for the patient and physician were that when the beam direction in AP and lateral projections were used respectively.

## Conclusion

The exposure of personnel to radiation in an operating room radiation was simulated realistically. As expected, the patient organ dose values are significantly higher than the physician dose values. The results demonstrated that the estimated organ dose values for the physician vary significantly with the using the personal protective equipment. Furthermore, the impact on the estimated dose values depends on the organ location and source energy. The main values of CCs of equivalent dose and effective dose in this study presented to the patient and physician procedure after CA is of utmost importance in radiological protection, because through them it is possible to assess with good accuracy the effective dose obtained from these individuals knowing only provided by the KAP meter installed in the proper X-ray equipment.

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