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Original paper

# Conversion factors of effective and equivalent organ doses with the air kerma area product in patients undergoing coronary angiography and percutaneous coronary interventions

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ABSTRACT

To derive effective dose (E), organ dose ($H_T$) and conversion factors with the air kerma area product (KAP) in coronary angiography (CA) and percutaneous coronary intervention (PCI) by the radial route, using the ICRP 103 tissue weighting factors.

The study included 34 patients referred for CA and 31 for PCI. E and $H_T$ were derived from in-the-field KAP measurements using Montecarlo methods.

Median KAP of 23.2 and 56.8 Gy cm$^2$ and E of 6.9 and 20.0 mSv were found for CA and PCI, respectively. Mean KAP and E were significantly higher in males than in females (52.4 ± 40.0 vs 32.3 ± 16.6 Gy cm$^2$; p = 0.02) and (16.8 ± 13.6 vs 10.7 ± 5.8 mSv; p = 0.04). KAP (r = 0.39; p = 0.001) and E (r = 0.34; p = 0.005) showed a significant correlation with the patient's weight.

Conversion factors between KAP and E (E/KAP) were 0.30 ± 0.04 mSv Gy$^{-1}$ cm$^{-2}$ for CA and 0.33 ± 0.05 mSv Gy$^{-1}$ cm$^{-2}$ for PCI. No significant differences in the E/KAP between males and females were found (0.31 ± 0.05 vs 0.33 ± 0.05; p = 0.08). Again, no significant correlation was found between E/KAP and patient's weight (r = 0.23; p = 0.07).

The correlation between E and KAP was excellent for CA (r = 0.99) and PCI (r = 0.96). The correlation between $H_T$ and KAP ranged from r = 0.87 to r = 1 and from r = 0.71 to r = 0.98 for CA and PCI, respectively.

A single factor, the total KAP, could be used for a specific acquisition protocol to reliably estimate E and $H_T$ without the need of a patient's specific analysis. Conversion factors might be installation, X-ray beam quality or protocol dependent.

## 1. Introduction

The femoral route has traditionally been the preferred access site for percutaneous coronary intervention (PCI) and coronary angiography (CA). The radial route access was first introduced in 1989 [1] and since then its use has increased mainly because of less bleeding, not prolonged post-procedure bed rest and fewer vascular complications and due to improvement in catheter design. Initial small randomized trials and observational studies have suggested that the use of radial access leads to higher radiation doses for both patients and healthcare workers compared with femoral access [2–4]. Successive single center and multicenter studies involving a higher number of patients have demonstrated that procedures performed by the radial route are not associated with higher radiation exposure of patients than selected procedures performed by the femoral route [5,6]. A recent systematic review and meta-analysis showed that transradial access was associated with a small but significant increase in patient's radiation exposure in both diagnostic and interventional procedures compared with transfemoral access [7].

However, all these studies used as indexes of radiation exposure the fluoroscopy time, the air kerma area product (KAP) or the effective dose (E). Recently, the new ICRP recommendations [8] while still

*Abbreviations:* CA, coronary angiography; PCI, percutaneous coronary intervention; KAP, air kerma area product; E, effective dose; $H_T$, equivalent organ dose

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maintaining E as the central quantity for dose assessments in radiological protection, also state that its use for assessing the exposure of patients has severe limitations. Indeed, E is age and sex averaged, and, although it can be used to enable comparison of relative detriment between procedures that utilize ionizing radiation, it should not be used to determine individual risk for patients. The equivalent doses deposited in critical organs ($H_T$) should be considered as more appropriate quantities for planning the patient's exposure and risk-benefit assessments.

$H_T$ would be effective and practical to use if conversion factors calculated by Monte Carlo methods could be applied to KAP measurements. Previously, these factors have been provided in the literature [9] for PCI and CA performed with the femoral access, using voxel phantoms (VIP tomographic) [10] and mathematical phantoms [11] and ICRP 60 tissue weighting factors [12].

In this study, E, $H_T$ for eleven critical organs/tissues, and conversion factors E/KAP and $H_T$/KAP have been derived in CA and PCI with a radial access to provide a database for doses in those procedures, updated with the current ICRP 103 [8] weighting factors.

## 2. Materials and methods

### 2.1. Patient population

The patient population included 65 patients who were prospectively and consecutively recruited from the population referred for elective CA and PCI with radial access in 2015.There were four interventional cardiologists working within the unit during the entire observational period, with experience both in the radial and femoral approach. Radial approach was usually right sided (left sided in 3 CA and 2 PCI). Exclusion criteria included intracoronary imaging procedures and atherectomy. Controls of coronary artery bypass grafting and chronic total occlusion percutaneous coronary intervention were included in the sampled population.

Of the 65 patients, 34 underwent CA procedures for diagnostic purposes (3 for evaluation of coronary artery bypass grafting control): they were 22 males and 12 females with a mean age of 64 years and a median weight and BMI of 70 kg and 24.4 kg/m$^2$, respectively. The other 31 patients underwent ad hoc (CA + PCI) procedures (herein after referred as PCI), for therapeutic purposes (2 for chronic total occlusion percutaneous coronary intervention): they were 18 males and 13 females with mean age of 67 years and a median weight and BMI of 73 kg and 25.4 kg/m$^2$, respectively. Twenty-nine patients underwent insertion of 1 stent; 2 patients underwent insertion of 2 or more stents. Data were recorded during routine sessions. In Table 1, the complete demographic patient data for each procedure are reported. All patients provided informed consent.

### 2.2. Angiographic equipment

The angiographic equipment with flat panel detector used was the Allura XPER FD10c (Philips Healthcare, Eindhoven, The Netherlands), fitted with the Philips MRC X-ray tube. The X-ray generator had 100 kW

**Table 1**
Patients demographic information for each procedure. Data are mean ± standard deviation and (range).

| | Coronarography | Percutaneous coronary interventions |
|---|---|---|
| No. of subjects | 34 | 31 |
| Age (yr) | 64 ± 13 (41–83) | 67 ± 11 (40–89) |
| Males (%) | 65 | 58 |
| Weight (kg) | 72 ± 11 (44–107) | 76 ± 14 (58–105) |
| Height (m) | 1.68 ± 0.07 (1.55–1.80) | 1.68 ± 0.08 (1.55–1.87) |
| BMI (kg/m$^2$) | 25.4 ± 4.3 (17.2–41.8) | 26.4 ± 3.4 (21.6–31.6) |

of power. The tube had a rotating anode with 0.5/0.8 mm nominal focal spot values and the housing had a filtration of 3.5 mm Al. The system had three different filters (0.2, 0.5, and 1.0 mm Cu equivalent) inserted automatically during the fluoroscopy by the equipment over all the field of view, according to both the patient's size and the program selected by the radiographer, as set up by the system engineers. When the system operates in cine mode, no filters are used. Moreover, a "partial filtration" can be used to shutter only some anatomic regions (e.g., lungs) to blacken the areas too much bright in the image. The digital detector field of view can be set between 18 × 18, 14 × 14 and 11 × 11 cm$^2$. Tube settings (e.g., peak voltage and anode current) were controlled by the automatic exposure control.

Collimation and magnification were used during the procedures according to the clinical requirements. Pulsed fluoroscopy (15 frames/s), typically operated in the low dose mode, and cineangiography (15 frames/s) were used. The high, normal and low fluoroscopy modes differ regarding image quality, dose rate and image processing. In Table 2, the tube potential and current and incident air Kerma rates measured at the surface of a 20-cm PMMA phantom on the side facing the X-ray tube were reported for the different field of view and the protocol of acquisition used in the clinical practice, separated in the fluoroscopy and digital acquisition modes.

The kilovolt (kVp) accuracy and total tube filtration of the angiographic unit are measured annually as part of quality assurance program. Acceptance, status, and constancy tests are performed by the Medical Physics Department.

### 2.3. Dosimetry

Radiation doses were measured using a calibrated KAP meter (DIAMENTOR, PTW; Freiburg, Germany) fitted on the top of the collimator assembly. The installed KAP meter was calibrated by means of an independent KAP meter (Kerma X-plus Scanditronix-Wellhofer) with traceable calibration [13]. Two calibration curves with and without patient table attenuation were calculated for potentials ranging from 60 to 120 kVp. The KAP of each acquisition and fluoroscopy run was corrected for the appropriate calibration value. The calibration curve with patient table attenuation was only used for postero-anterior projections (LAO = 0 in Table 3).

For each patient, the angiographic equipment monitor was recorded during the entire procedure by a radiographer. Successively, a physicist reviewed the video recording and recorded the tube potential and current, time, position of the X-ray tube (both rotation and cranial/caudal) field size, source-to-imaging detector distance and partial KAP values for each projection in fluoroscopy mode. Besides, a structured dosimetric report with detailed information on tube potential, position of the X-ray tube (both rotation and cranial/caudal angulation), exposure time and current, field size, images number, source-to-imaging detector distance and partial KAP was available for fluorography runs. An example of the structured dosimetric report for the cine runs is provide in Fig. 1. In this way, a distinction could be made between the fluoroscopy and cine run KAP contributions.

E and $H_T$ were derived from in-the-field KAP measurements together with geometrical data and X-ray beam qualities using the PCXMC 1.5 rotational computer software (STUK [Radiation and Nuclear Safety Authority], Helsinki, Finland) [14], which employs Monte Carlo methods and the mathematical phantoms model of Christy and Eckerman [15,16] and ICRP 103 tissue weighting factors. Each angiographic procedure was assumed to be isocentric and centred in the middle of the phantom hearth, obtaining two isocenter positions for men and women, respectively. To simulate irradiation conditions corresponding to each fluorography and fluoroscopy runs, the Excel application of PCXMC Rotation (AutocalRotation-Sheet.xls) was used, allowing the evaluation, separately for fluoroscopy and fluorography components, of E and $H_T$ for the following organs/tissues: active bone marrow, breasts, colon, hearth, liver, lungs, oesophagus, skeleton, skin,