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# Optimization of the double dosimetry algorithm for interventional cardiologists

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## HIGHLIGHTS

- Flexible and adaptive double dosimetry algorithm building methodology was proposed.
- Monte Carlo calculations were performed for variety of interventional cardiology irradiation conditions.
- More precise and less conservative algorithm was developed for effective dose assessment in interventional cardiology.

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## ABSTRACT

A double dosimetry method is recommended in interventional cardiology (IC) to assess occupational exposure; yet currently there is no common and universal algorithm for effective dose estimation. In this work, flexible and adaptive algorithm building methodology was developed and some specific algorithm applicable for typical irradiation conditions of IC procedures was obtained. It was shown that the obtained algorithm agrees well with experimental measurements and is less conservative compared to other known algorithms.



## 1. Introduction

Interventional radiology (IR) is a fast developing medical discipline that is quite special in terms of radiation dosimetry of the involved personnel and patients. Medical staff wears protective gear that shields the body only partially, so the traditional personal single-dosimetry method for estimation of the effective dose becomes inappropriate. Currently the double dosimetry is quite common approach to solve this problem. According to a double dosimetry protocol, one of the two simultaneously exposed dosimeter is worn over the protective garment yielding readout $H^O$ for estimation of exposure of unshielded parts of the body and another is placed under a protective apron providing $H^U$ value, which takes into account protective properties of the garment. Then an effective dose estimate $E'$ is achieved as a linear combination of two dosimeters readouts:

$$E' = \alpha H^U + \beta H^O \tag{1}$$

Unfortunately, there is no international consensus on universal double dosimetry algorithm for the effective dose estimation under variety of irradiation conditions (Jarvinen et al., 2008). This conclusion was made after the comparison performed in the framework of CONRAD project (Schuhmacher and Fantuzzi, 2008) for a number of currently used algorithms, which were developed both experimentally and/or by calculations under typical IR conditions. The double dosimetry algorithms (Rosenstein and Webster, 1994; Niklason et al., 1994) seem to underestimate effective dose, while algorithms given by Wambersie and Delhove (1993) and Clerinx et al. (2008) seem to be rather conservative and overestimate effective dose by a factor of about two to three. Jarvinen et al. (2008) stated that among all tested double dosimetry algorithms, the variants given in the Swiss Ordinance for personal dosimetry (1999) and McEwan (2000) seem to give the closest estimation of effective dose in typical IR with no underestimation and minimum overestimation. However, the authors notified that the results might not be generic and highly recommended further investigation concerning application of algorithms under specified IR conditions.

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Our purpose was to elaborate a new algorithm, which, on one hand, should be based on some universal and expandable approach, and, on the other hand, could account for more or less specific conditions of exposure, i.e. in the specific area of interventional cardiology (IC), a sub-discipline of interventional radiology.

## 2. Calculations and experimental validation

It is well known that main factors affecting surgeons' exposure are geometry and energy, i.e. relative position of all parts of the cardiovascular angiography system including operation table height, the distance between source and detector, the position of C-arm (projection) defined by two angles (Fig.1), the field of vision (*FOV*), and the tube voltage and current (NCRP, 2011).

To determine the most common situations during procedures and to study the variability of these significant parameters, experimental investigations were performed at A.A. Shalimov National Institute of Surgery and Transplantology, National Academy of Medical Science of Ukraine in the operation room equipped with a Toshiba Infinix CS Cardiovascular Angiography System (model INFX-8000F).

As a result of these investigations the following parameter ranges were selected for Monte Carlo simulation of photon transport and respective dose calculation:

1. photon energy (12 values): 30, 40, 45, 50, 55, 60, 65, 70, 80, 90, 100, and 110 (keV);
2. C-arm angulation (projection) (9 values) (see Fig. 1 for explanation): 0 (vertical), RAO90 (right side), CAU20, RAO30-CRA20, LAO35, RAO30, CRA20, RAO35-CAU30, and LAO35-CRA30;
3. field of vision (*FOV*) (4 values): $15\times15$, $20\times20$, $25\times25$, and $30\times30$ (cm$^2$);
4. table height (fixed): 80 cm;
5. source–detector distance (fixed): 80 cm.

For adequate reconstruction of real-life surgeon's exposure conditions it was planned to perform Monte Carlo calculations on each of the partial static irradiation scenarios, essentially a combination of "photon energy, $\varepsilon$" ; "C-arm angulation, $\Omega$" and "field of vision, *FOV*" (in total 432 partial calculations).

Calculation geometry consisted of the following parts (Fig. 2):

- a point source with a square (pyramidal) aperture representing various *FOV*;

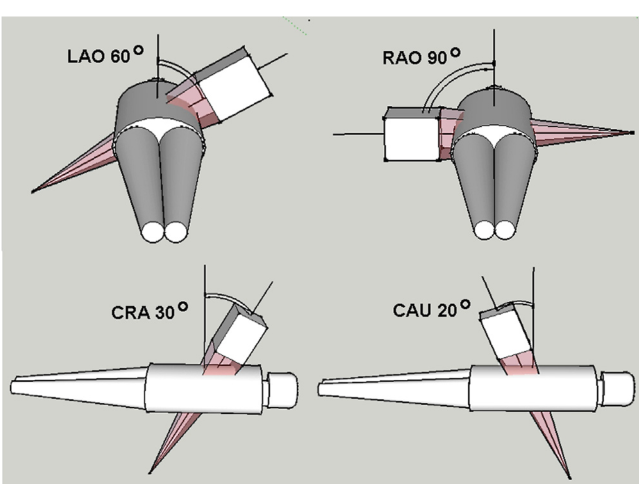


**Fig. 1.** Illustration of radiographic projection angles and their names.

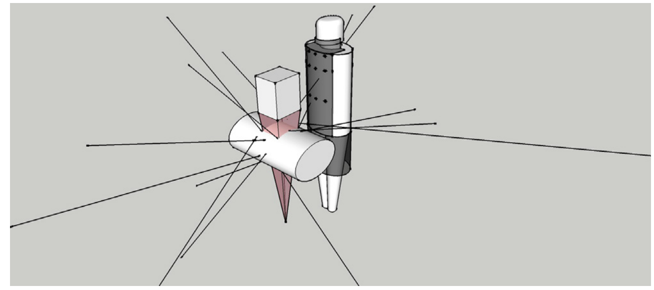

**Fig. 2.** Illustration of geometry model used in Monte Carlo simulations.

- a detector modeled as a parallelepipe absorbing all incoming photons;
- an anthropomorphic phantom ADAM (Kramer, 1999) used for modeling the surgeon (the phantom was modified by adding a wrap-around lead apron and a collar of 0.35 mm thickness (Fig. 3);
- the patient was represented by a simplified phantom—a torso of ADAM phantom without detailed internal structure.

Doses were calculated in doctor's organs and in 22 simplified *Hp*(10) dosimeters: 16 on the front (9 over- and 6 under-apron, arranged in three levels and 1 dosimeter over the collar) and 6 on the phantom's back (3 over and 3 under apron). All simulations were performed using MCNP-4B code (Briesmeister, 1997).

In order to validate the newly developed algorithm (see Section 3), in situ measurements were performed using lead apron and collar dressed RANDO-Alderson phantom with LiF detectors planted inside. The results of phantom measurements were used for direct (conventionally true) estimation of organ doses and, consecutively, effective dose. Harshaw 8814 personal dosimeters with LiF:Mg, Ti (TLD-100) detectors, calibrated in terms of *Hp*(10), were located on the surface of the phantom over and under the apron in the places equivalent to the ones modeled in Monte Carlo calculations. Uncertainty of *Hp*(10) measurements is estimated at about 2%. Organ doses were estimated as average of respective readouts of LiF:Mg, Ti (MTS) detectors planted in appropriate positions inside RANDO-Alderson phantom. Typical uncertainty of phantom planted detectors was about 5%; however, for some most shielded (lower dose) locations this uncertainty of individual detector measurements could be as high as 50%. Yet, since both effective and organ dose estimates incorporate multiple detector readouts, integral uncertainty of the estimation of $E$ and $H_T$ does not exceed 5%.

## 3. Results

Having pre-calculated partial effective dose values $E(U_i, \Omega_j, FOV_k)$ and knowing an X-ray tube spectrum and relative frequency (weight) $w(U_i, \Omega_j, FOV_k)$ of each irradiation condition we can calculate total doses $E_{MCNP}$ as weighted sums of partial values of $E$ obtained from Monte-Carlo simulations:

$$E'_{MCNP} = \sum_{i,j,k} w(U_i, \Omega_j, FOV_k) E(U_i, \Omega_j, FOV_k), \tag{2}$$

where conversion from the tube voltage $U_i$ to the X-ray photon spectrum can be achieved using tabulated X-ray spectra data (Sutton and Reilly, 1997):

$$E'(U_i, \Omega_j, FOV_k) = \sum_l A_l(\varepsilon_l) E(\varepsilon_l, \Omega_j, FOV_k), \tag{3}$$

where $U_i$ is the tube voltage and $A_l$ is the intensity of the $l$th tube emission spectrum line, which is determined by the tube voltage for a specific tube type and filtration.