Medical staff monitoring in interventional cardiology: over apron dosemeter placement based on measurements and simulations

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Abstract

Interventional cardiology is characterized by high radiation exposure for both the patient and the operator. Adequate shielding and monitoring of the operator are fundamental to comply with radiation protection principles. In a previous work, the effect on the dose of the dosemeter position on the chest was studied. In this paper, the investigation has been completed, employing an anthropomorphic thorax phantom, equipped with arms. Although there are differences between the Monte Carlo simulations and the measurements, similar trends are observed, showing that the reduction in dose, due to the arms, is between 20 and 60%, compared with the situation without arms. For that reason, considering a dosemeter placed on the chest, the upper position, which is the least affected by the arms, should be preferred while the extreme lateral position, near the armpit, should be avoided.

Introduction

Interventional cardiology is known to be an effective practice for treating specific cardiological and circulatory diseases, but it is also characterized by high radiation exposure, both for the patient and the operator [1–4]. Because of population aging and sedentary lifestyle impact, the number of these procedures is expected to grow in the near future [5–6], implying a possible increasing of the dose to the medical personnel involved. In such a context, adequate operator shielding [7–9] and monitoring [10–12] are fundamental to ensure the reduction of doses, in compliance with the radiation protection ALARA (As Low As Reasonably Achievable) principle. Many parameters can influence the doses received by the staff as the type of procedure, the type of access (femoral or brachial), the type and number of shielding, the operator position and height [13–15].

For those reasons, several studies in EURADOS (European Radiation Dosimetry Group) Working Group 12 Dosimetry in medical imaging (WG12) have been dedicated to the different aspects affecting the radiation protection and the dose monitoring in this field [16]. In the last period a peculiar attention has been devoted to the quality of the measurement of the personal dose equivalent, H_p [10], for its implications on personnel monitoring. Studies were performed on the characterization [17, 18] and usage of active personal dosemeters [19, 20], worn over the apron, at the chest level, in interventional practices.

In a previous work [21], the MCNP Monte Carlo code [22] has been employed with a modified version of MIRD type model to simulate the 'typical' interventional cardiology practice. Operators' arms have been bent to obtain a 'realistic' configuration and a series of idealized dosemeters were placed in a grid of points on MIRD model chest.

In the cited work [21] the quantity H_p [10] has been calculated in each dosemeter considering different beam projections and beam qualities (energy and filtering combination). Moreover, additional calculations have been done removing the operators' arms to determine their possible shielding effect on the evaluated doses. The measurements were performed in an interventional theater of Morgagni-Pierantoni Hospital in Forlì (Italy) employing a trunk of Rando type anthropomorphic thorax phantom, representing the operator and a block of PMMA mimicking the patient. The absorbed dose has been evaluated on the Rando anterior surface facing the patient couch, through an ionization chamber, during a cardio protocol in Postero-Anterior (PA) projection.

In the same previous study [21], within the limit of the comparison, there was a satisfactory agreement between simulations and measurements showing that, considering an operator to the right side of the patient, moving the measuring point from the center to the right side of the chest could imply a diminution of the order of 40% in the absorbed dose. Moreover, the simulations proved that beam qualities and projections have a direct effect on the amount of radiation reaching the operator, but have a reduced effect on the variability associated to measuring points, while the arms can affect the measurement results depending on the measuring point. More details can be found in the cited paper [21].

In this work, such shielding effect has been studied through measurement performed on an anthropomorphic thorax phantom equipped with arms. The results will provide some additional data to quantify the variability of a measurement performed with a dosemeter placed at the operator's upper chest level, contributing indeed to the evaluation of the global uncertainty associated to that measurement [23].

Materials and methods

The measurements have been performed in an interventional theater of 'S. Maria delle Croci' Hospital in Ravenna (Italy). The first step was trying to replicate the configuration and the results obtained in Forlì hospital [21] with different equipment and dosemeter. For this reason, the Philips Allura FD10 system was employed with the same Rando type anthropomorphic thorax phantom (height 42.5 cm) and with a 20 × 20 × 20 cm [3] PMMA slab, mimicking the patient. The two phantoms were, respectively, at 110 and 90 cm from the floor and the reciprocal distances were ~70 cm, in the direction along the patient couch, and 50 cm away from the center of the patient couch. No ceiling shielding was employed but the table shielding was present.

The absorbed dose rate has been evaluated employing a RTI solid state probe dosemeter (RTI Dose

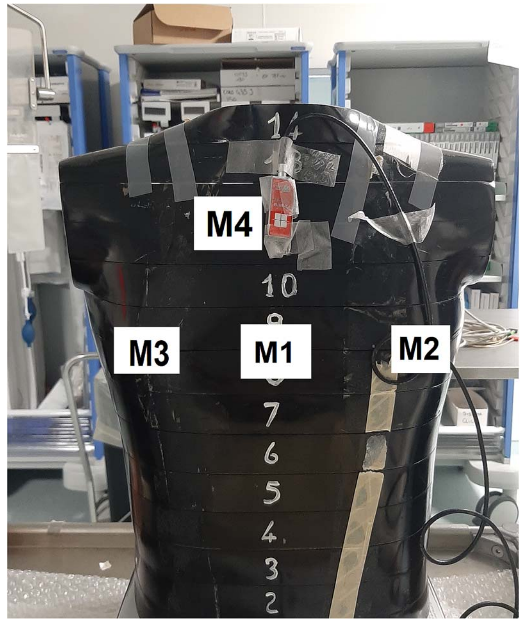

Figure 1. Measurement positions of the anthropomorphic thorax phantom.

Probe; https://rtigroup.com/products/probes/rti-dose-probe/), designed to perform dose rate measurements, and calibrated with X-ray beam qualities consistent with medical field (in the energy range 20–140 kV and in air kerma). Being shielded, the dosemeter is unsensitive to the backscatter from the phantom and due to the intrinsic angular variability of its response (of the order 40% for angles higher that 25°), during the measurements, it was tilted toward the tube/scatterer with the aim of making the incoming radiation nearly perpendicular to the dosemeter's surface.

The measuring positions on the Rando type phantom are shown in Fig. 1: on the center of the phantom's chest (M1), 10 cm to the left (M2), 10 cm to the right (M3), and 9 cm above (M4).

PA projection and angiography protocol (69 kVp, FOV 25 cm) has been selected and the measurements were repeated in each positions.

In the second step, the same measurements have been repeated with the arms (a water filled plastic shell, with plastic bones, reproducing human skeleton) attached to the phantom (Fig. 2).

Results

In Table 1, the results of the first step measurements, normalized to M1 (center of the chest) position, are shown together with the measurements obtained at the Forlì [21] hospitals. Each point in the table is a

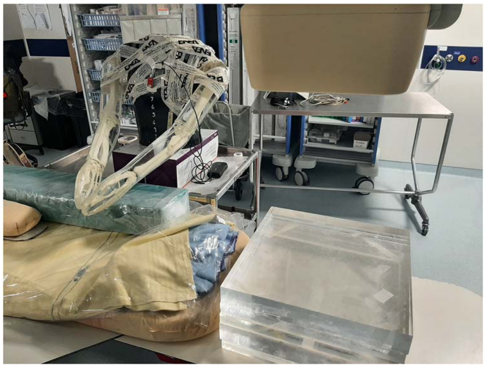

Figure 2. The anthropomorphic thorax phantom representing the operator, with both arms inserted, and the slab transparent phantom representing the patient on the couch.

Table 1. Measurements ratios with respect to the central value on the chest in Ravenna, this work, and Forlì [21] hospitals - phantom without arms (with % error).

Position (Fig. 1)	Ravenna H. meas.	Forlì H. meas.
M1	1 (2%)	1 (4%)
M2	1.2 (2%)	1.03 (4%)
M3	0.68 (2%)	0.53 (4%)
M4[a]	0.72 (2%)	0.62 (6%)

[a]Please note that M4 in this table correspond to M5 of table 1 of the previous work [21] (see Fig. 1).

Table 2. Measurements ratios with respect to the central value on the chest in Ravenna hospital - phantom with arms (with % error). Only M1 and M3 measurements have been repeated with both arms inserted.

Position	Ravenna H. with left arm only.	Variation with respect Table 1 values	Ravenna H. with both arms.
M1	0.32 (2%)	−68%	0.37 (2%)
M2	0.48 (2%)	−60%	—
M3	0.26 (2%)	−62%	0.23 (2%)
M4	0.60 (2%)	−16%	—

mean of a set of measurements in the same position, the reported uncertainty is the standard deviation of the set of measurements (k = 1). Within the limits due to the different equipment employed, the trend in operator exposure is similar: not decreasing, or slightly increasing (for Ravenna Hospital) moving the measuring point toward the left (M2) of the phantom chest and decreasing moving the detector to the right (M3) and toward the upper part of the phantom (M4). This variability in the exposure along chest height can be roughly estimated from the plot in Fig. 3, where the scattering field, obtained with Monte Carlo simulations (mesh tally) is superimposed to an image of the anthropomorphic thorax phantom adopted in the measurements.

The results obtained attaching the arms to the phantom are reported in Table 2. The variation with respect to the values of Table 1 are supplied and show ∼60% reduction for the measurement position in the median line of the chest (M1, M2, and M3) while the reduction for the upper position (M4) is lower (∼15%). That implies that the possible ‘shielding effect’ due to the operator’s arm is reduced if the dosemeter is moved toward the upper part of the chest (see Fig. 4).

Discussion

The measurements performed in Ravenna Hospital, described in the present work, confirm overall what was obtained in the previous Monte Carlo simulation [21] (Fig. 5) and not repeated here. The previous simulations have been done with the modified MIRD type numerical model with and without the arms. In Fig. 6, some results of those simulations are plotted. The ratios between the values calculated with arms and without arms are reported for an ideal dosemeter put in the position corresponding to M1 (central position along the central line on the chest) and for dosemeters put 10 and 15 cm on the left and on the right of it. A second group of values represents the ratios for dosemeters put 10 cm above the central line (corresponding to M4 height).

The values have been calculated for 70 kV and PA beam projection and more data can be found in the previous work [21].

Notwithstanding that the ratios calculated through the Monte Carlo simulations and the present measurement are different (in the present study, the dosemeter is almost unsensitive to the backscatter radiation and the sensitive volume is smaller) the trend is fairly similar, i.e. the higher dosemeter row is less affected by the presence of the arms, as can be seen by the ratios at 10 and 15 cm from the center (corresponding to the direction toward the left arm). The difference between simulations and measurements estimated in the center of the chest (0 cm in the simulation) showed that this point in the simulations is less affected by the presence of the arms than M1 in measurements. This is mainly due to two reasons: the MIRD surface representing the thorax (see Fig. 5) is an elliptical cylinder and the 0 cm position correspond to one of the vertex of its minor axis, while, as can be seen from the images of the measurements, the anthropomorphic thorax phantom model is nearly flat at this height (see Fig. 3); the shape and dimensions of simulated and plastic arms

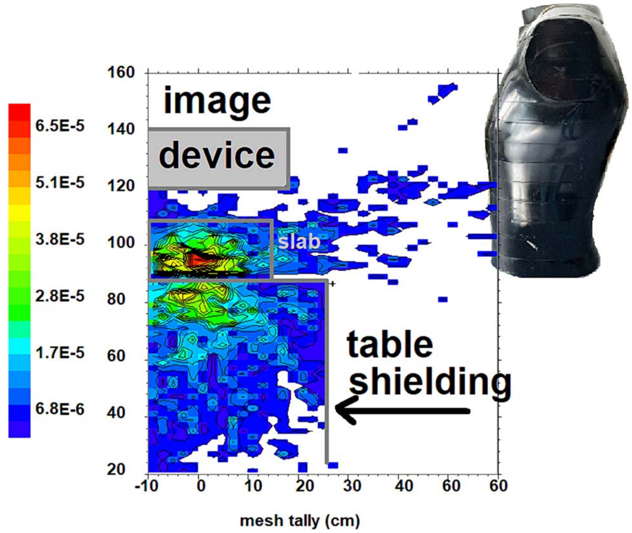

Figure 3. Simulation of the scattering field produced by the PMMA slab phantom. The image is a section at 5 cm from the beam axis in the operator direction, cutting the slab; the gray scale refers to the scattered fluence (a.u.).

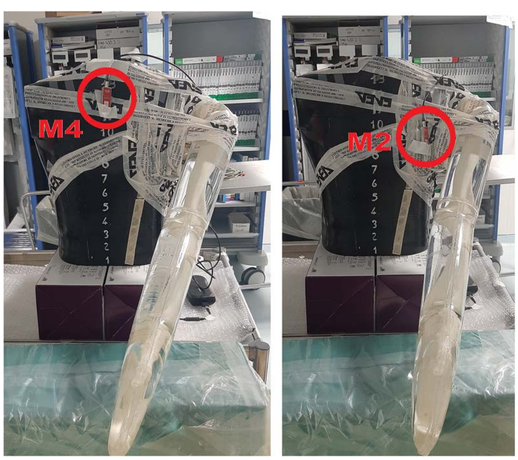

Figure 4. Upper position (M4) and left position (M2) during the measurements with the left arm present.

are different and the position, i.e. the angle between the arm and the body, is not the same.

Conclusions

In this work, the possible shielding effect of the arms on a dosemeter put over the apron, on the operator's chest, has been investigated through measurements performed in hospital, employing a proper anthropomorphic thorax phantom. These results confirm overall the trends that were predicted in the previous Monte Carlo simulations [21].

From this and the previous studies, some general conclusions can be drawn on interventional cardiology medical staff monitoring.

- In case of a single dosemeter employed over apron, or in case of double dosimetry, it is advisable to put the dosemeter on the chest in the central (or in a central-left position) and high, at the level of the clavicles, possibly, in order to reduce the effects of the arms possible shielding (see Table 2 and Fig. 6). This result is consistent with what was found also by Schultz and Zoetelief [24]. This situation refers to a condition in which the X-ray tube is on the left of the operator (see Fig. 5), if the tube is on the right the dosemeter should be put in the center, center-right part of the chest.
- The extreme lateral position on the chest, near the armpit, must be avoided because (see Fig. 6) it is very sensitive to the arm positioning.
- About double dosimetry, it is important to underline that, due to the complexity of the scattering field reaching the operator (see Fig. 3), special attention should be paid that the position of the over apron dosemeter required by the algorithm corresponds, as much as possible, to the real dosemeter position on the operator.
- Also considering the variability of the placement of a real dosemeter in practice, besides the possible misplacing between over and under dosemeters when double dosimetry is performed, at least a variability in the response of the order of 20–60% (see Table 2 and Fig. 6) should be considered for

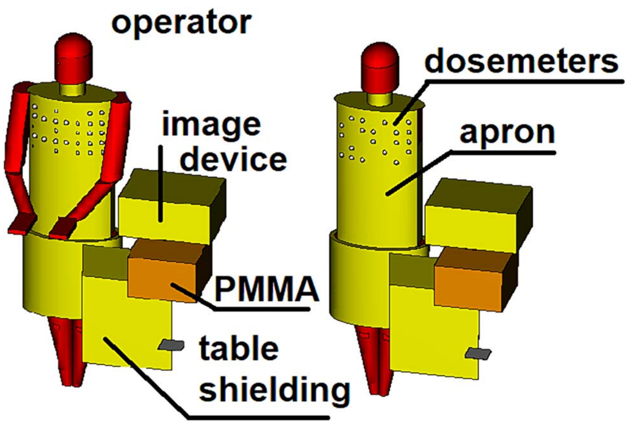

Figure 5. Models employed in the Monte Carlo simulations [21] with and without the arms.

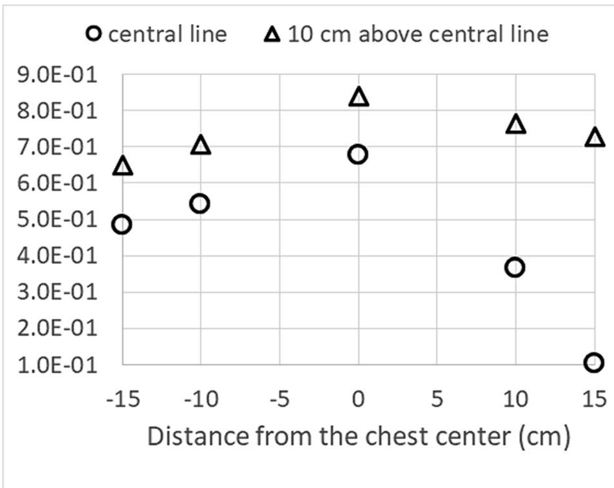

Figure 6. Selected results from the Monte Carlo simulations [21]: ratios between the values calculated with and without the arms for some dosemeter positions.

the dosemeter reading and that variability should also be taken into account in the effective dose evaluation [25].

Conflict of interest

None declared.

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