The optimization of radiation protection to interventional cardiologists

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Abstract. Scattered dose radiation to occupational in interventional cardiology cannot be neglected due to the long time for each procedure. The limit dose for occupational is 20 mSv per year or 0.01 mSv/h. The aim of this study is to calculate the effective dose of occupational and to analyse the optimization of radiation protection in the Cath lab. The simulation has been done using Rando phantom as a patient and Unfors Xi as scattered dose measuring instrument (in mGy/h). The data is collected in 6 different positions from altitudes 25 cm to 75 cm with a range of 15 cm without protective shielding. Field size of primary beam is varied to 20x20 cm and 25x25 cm, while gantry tilt is varied to caudal, cranial, and Left Anterior Oblique (LAO). The obtained data is multiplied by weighting factor based on its height. The result shows that the effective dose of occupational is in the range of 0.18 - 0.94 mSv/h, which is exceed the limit dose. To accommodate the limit dose for occupational, we propose the limitation of procedure time to 21-110 hours a year or the use of protective shielding as thick as 1-1.6 mm lead.

1. Introduction

Interventional cardiology is a heart catheterized procedure that using fluoroscopy x-ray as guidance in order to provide visualisation of heart chambers, valves and surrounding blood vessels [1]. Interventional cardiology is counted as alternative to heart surgery because of its relatively non-invasive [2]. However, due to the complexity and the workloads of the procedure, interventional cardiologist is concerned to receive high radiation dose [1, 3, 4].

The worldwide population of medical radiation exposure and the use of high radiation dose have been increasing steadily [4-7]. Although only 12% of all radiological examinations are accounted by interventional cardiology procedures, they contribute 50% of the total collective effective dose which is the highest radiation dose [8].

Moreover, the closeness of interventional cardiologists’ position and the source (x-ray beam and patient that considered as scattered radiation) [9], they experience much more radiation exposure than other medical staff. Regarding ICRP Publication 103, effective dose limit for occupational exposure is...
20 mSv per year averaged over 5 years (100 mSv in 5 years) and 50 mSv maximum in any single year [10].

There are many publications that measure equivalent doses received by interventional cardiologists using personal dosimetry (TLD). However, these measurement doses are intended for one particular area, for example the eyes, chest, and extremities. To measure total effective dose, many TLDs will be needed to place all over the staff’s body. This method is considered relatively more expensive than using surveymeter. Therefore, the aim of this study is to estimate the effective dose that received by interventional cardiologist using surveymeter in order to evaluate the optimisation of radiation protection.

2. Materials and Method

The measurements were conducted by placing a rando phantom on the patient’s table. Absorbed dose rate was taken using Unfors Xi alternately at 6 positions around the patients and 11 altitudes for each positions. The positions are at 0°, 30°, 150°, 180°, 210°, 330° as shown in figure 1, whereas the altitudes are varied from 25 cm to 175 cm from the floor with a range of 15 cm. Gantry tilt and field size of x-ray machine was also varied to 0°, 20° CAU, 30° CAU, 20° CRA, 30° CRA, 40° LAO, 50° LAO (as shown in figure 2) and 20x20 cm, 25x25 cm, respectively. Radiation energy and intensity of x-ray machine in this study dependently varied to 71-74 kV and 26.5-28.2 mAs.

Effective dose cannot be measured directly and must be calculated from other operational quantities that can be measured with personal dosimeters [11]. The dose rate (D) that obtained from the measurements are multiplied by specific weighting factor (Wt) and radiation factor (Wr). The weighting factors that shown in table 1 have different value based on exposure tissue that distinguished by particular height. For diagnostic x-ray, the number of the radiation factor is one. Consequently, staff’s effective dose can be calculated by following the equation 1.

\[ E = \sum (D \times W_R \times W_T) \]

The result of effective dose calculation will be compared to the radiation limit. The effective dose that exceed the radiation limit needs further radiation protection. There are 3 basic principles to
optimise radiation protection, which are exposure time limitation, inverse square law distance, and using shielding, that can evaluated by following equation 2-4, respectively.

\[
\dot{E} = \frac{dE}{dt} 
\]
\[
\dot{E}_1 \cdot r_1^2 = \dot{E}_2 \cdot r_2^2
\]
\[
\dot{E}_2 = \dot{E}_1 \cdot e^{-\mu x}
\]

Table 1. Tissue weighting factors (WR) according to ICRP 103/2007

| Height of Occupational (cm) | Tissue      | Weighting Factor (dimensionless) |
|-----------------------------|-------------|----------------------------------|
| 25                          | skin        | 0.01                             |
| 40                          | skin        | 0.01                             |
| 55                          | skin        | 0.01                             |
| 70                          | gonad       | 0.08                             |
| 85                          | bladder     | 0.04                             |
| 100                         | stomach     | 0.12                             |
| 115                         | liver       | 0.04                             |
| 130                         | breast      | 0.12                             |
| 145                         | thyroid     | 0.04                             |
| 160                         | salivary    | 0.01                             |
| 175                         | brain       | 0.01                             |

3. Results and Discussion

The effective dose measurement results for 6 positions of occupational showed a range of 0.18-0.94 mSv/h, as shown in figure 3. The effective dose calculation is based on explanation of ICRP 60 in Journal written by McCollough and Schueler [12]. Overall, the lowest value was obtained at 330° position for field size of 25X25 and gantry tilt of 50° LAO, while the highest value was obtained at 0° position for field size of 20X20 and gantry tilt of 0°. In the table 2, it can be seen that the dominant position giving the lowest dose is located at 210° position, while the dominant position giving the highest dose is located at 0° position. It is because the left side of the patient tends to give a higher dose than the right side of the patient. In interventional cardiology procedures, the primary beam leads to the heart or left side of the patient. Thus, the scatter radiation from the patient body contribute the high level radiation to left side.

The dose rate that received by occupational has exceeded the dosage limit. The dosage limit allowed for radiation worker is 20 mSv per year, regarding to ICRP Publication 103 [11]. If a worker is assumed to have a working time of 8 hours a day and 5 days per week, then the worker has approximately 2,000 hours of working time. So, in other words, the effective dose rate that a worker can receive is 0.01 mSv/h. To limit the excess dosage, optimization of radiation protection needs to be
done by minimizing the exposure time, by maximizing the distance from the radiation source, and/or by installing protective shielding [13].

![Figure 3. The effective dose measurements in six different positions (mSv/h)](image)

| FPD (cm²) | Gantry Tilt | Lowest Effective Dose | Position | Highest Effective Dose | Position |
|-----------|-------------|------------------------|----------|------------------------|----------|
| 20x20     | 0°          | 0.573                  | 150°     | 0.937                  | 0°       |
| 25x25     | 0°          | 0.249                  | 210°     | 0.146                  | 0°       |
| 25x25     | 20° CAU     | 0.413                  | 210°     | 0.621                  | 0°       |
| 25x25     | 30° CAU     | 0.466                  | 210°     | 0.770                  | 0°       |
| 25x25     | 20° CRA     | 0.317                  | 30°      | 0.477                  | 0°       |
| 25x25     | 30° CRA     | 0.308                  | 30°      | 0.566                  | 330°     |
| 25x25     | 40° LAO     | 0.216                  | 330°     | 0.654                  | 210°     |
| 25x25     | 50° LAO     | 0.183                  | 330°     | 0.672                  | 210°     |

Limiting irradiation time can be done using equation 2, where the limit dose \( (E = 20 \text{ mSv}) \) is divided by the measured effective dose rate \( (E') \). From this calculation, the duration allowed for radiation exposure is between 21-110 hours a year. The greater the dose rate received at a certain position, the shorter the duration allowed, and vice versa. So that, in figure 4 shows the shortest duration is at 0° position for field size of 20X20 and gantry tilt of 0° and the longest is at at 330° position for field size of 25X25 and gantry tilt of 50° LAO.
In addition to limiting irradiation time, optimization of radiation protection can also be done by maximizing the distance. However, this is difficult to do because the occupational must be close to the patient to carry out the intervention procedure. The safest distance is in the range of 214–484 cm away from primary beam, as shown in figure 5. This value is obtained by inverse square law, as in equation 3, where $E$ is effective dose and $r$ is the distance.

The last principle to optimise the radiation protection is to install a shielding. The appropriate type of shielding for photon radiation is lead material. This is because lead has enough material to absorb photon radiation such as x-ray and gamma ray. The recommended thickness of lead from this study
using equation 4 is 1-1.6 m, where μ is linear attenuation coefficient and x is thickness of shielding material. The result is shown in figure 6.

![Figure 6](image-url)

**Figure 6.** Protective shielding (in mm Lead).

4. Conclusion
The measurement range of the effective dose rate from this study has exceeded the dose limit, with a measurement range of 0.18-0.94 mSv/hour. The radiation protection optimization can be done by limiting the irradiation time between 21-110 hours per year and/or using a protective shielding of 1-1.6 mm Lead.

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