Influence of Various Setup Parameters on Scattered Fraction in Interventional Cardiology

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Abstract. It is important to examine the positions of the medical staff involved in interventional cardiology in order to minimize their accumulated scattered radiation doses. This study used the design of experiment (DOE) method with three parameters (C-arm gantry tilt, position and height), each at three levels (low, medium and high), on both the left and right sides of the patient, to analyse the interactions between the parameters that influence the scattered fraction in interventional cardiology. In this experiment, a RANDO phantom and an Unfors Xi survey detector were used to measure the rate of the scattered dose exposed to staff without protective shielding in a Cath lab. The parameters that significantly influenced the scattered fraction at a confidence level of 95% (P< 0.05) to the right of the patient were the gantry tilt and the height. To the left of the patient, all parameters significantly influenced the scattered fraction.

Keywords: Design of Experiment, scattered fraction, interventional cardiology, occupational radiation.

1. Introduction

The occupational radiation exposure of medical staff during interventional radiology and cardiology (IRC) is a critical issue for medical workers. Therefore, it is important to measure the scattered radiation dose during interventional cardiology procedures in Cath labs [1]–[5]. The maximum effective dose recommended by the International Commission on Radiological Protection (ICRP) for an interventionalist is 20 mSv/y. With the proper use of radiological protection devices and techniques, the effective dose is typically only 2–4 mSv/y when averaged over a 5-year period, which is well below the dose limit [4].

The basic elements of occupational radiological protection during interventional fluoroscopy are time, distance and shielding. According to ICRP Publication 120, published in 2013, there are many ways to reduce the staff’s radiation exposure, including the use of appropriate personal protective shielding and increasing their distance from the patient (the source of scattered radiation) whenever possible. Another method is to station the staff in an area with low scattering. Scattered radiation is higher at the X-ray tube side of the gantry and lower on the side of the image receptor [4] of the portable X-ray (PX) and intraoperative fluoroscopy (C-arm) systems that are often used in general wards, intensive-care units and operating rooms [6].
One group has performed measurements 1 m and 2 m away from the isocentre at seven measurement points in order to determine the reduction in the scattered dose with increasing distance [1], [7]. The height of the staff is also important. Interestingly, there are two contradictory results for this parameter. The first finding is that a significant negative correlation exists between operator height and the average monthly equivalent dose, with shorter operators receiving more radiation [8]. In contrast, a retrospective analysis of 20 operators and staff from a particular laboratory revealed that the doses measured at the body with a thermoluminescent dosimeter (TLD) during a cardiovascular intervention were higher in operators who were shorter than 165 cm than in those taller than 165 cm. However, the ICRP mandates for dosimeter locations have not previously accounted for height differences, since distance also affects the exposure [9].

In this paper, measurements were conducted 50 cm from the staff because the staff were positioned near the patient and the machine during IRC procedures. Based on this scenario, we have attempted to analyse which parameters have an influence on the scattered fraction by combining all parameters by placing a RANDO phantom in a Cath lab. The results of this experiment were analysed statistically as described in [10]. This paper is associated with previous research presented in [11]. However, while the previous paper focused on the distribution of the scattered fraction, here we focus on parameters and levels that were set based on the DOE method using the Taguchi approach, which is typically used to improve the quality of products and processes [12]. The analysis reveals the highest possible influence on the scattered fraction by determining the optimum combination of design factors from each parameter. The fraction of incident radiation scattered off the patient is an important parameter for the design of radiation protection barriers [13]. We are also able to calculate the scattered fraction at any distance using the inverse square law. These results will help staff be aware of their safety during interventional cardiology.

2. Materials and Methods
In this study, we used a RANDO phantom, an Unfors Xi survey detector and a flat panel detector (FPD) with dimensions of 25x25 cm. There were three parameters studied. The first parameter was the C-arm gantry tilt (Figure 1 (a)), the second was the position of the staff relative to the patient (Figure 1(b)) and the third was the height on the staff (Figure 1 (c)). All of the parameters were categorized into three levels, as shown in Table 1: low (1), medium (2) and high (3).

| Parameter                     | Level                  |
|------------------------------|------------------------|
| C-arm gantry tilt (A) [14]   | Low (1) 20° cranial    |
| Staff position (B)           | Medium (2) 0°          |
| Height on staff (C)          | High (3) 20° caudal    |
|                             | lower extremity        |
|                             | chest                  |
|                             | head                   |
|                             | 25 - 70 cm             |
|                             | 85 - 130 cm            |
|                             | 145 - 175 cm           |

Because there were three parameters that could each be set at three levels, there were 3³ or 27 possible combinations. These permutations are well known as Taguchi orthogonal arrays [15]. The measurements were conducted while the staff inside the Cath lab were not using protection and the distance was set at 50 cm away from the isocentre. During the measurement, we ensured that the standing tool was at a 90° angle from the floor.
Figure 1. Measurement setups for the parameters (a) gantry tilt, (b) position and (c) height

In this experiment, we first measured the air dose rate without the RANDO phantom when the primer beam was at 98 cm, the source to image distance (SID) was 100 cm from the X-ray tube and a 25x25 cm FPD was used. The result was used to determine the air dose rate at the isocentre by using the inverse square law, yielding 17.43 μGy/s. A flowchart of the general method used in this paper is shown in Figure 2.

Figure 2. Flowchart of experimental method

Since the voltage and current fluctuated during the measurement, we calculated the dose rate at the isocentre for each gantry tilt angle based on the voltage and current (Table 2) measured over 180 seconds. These values were then used to calculate the scattered fraction from the measurement.

Table 2. Dose rate at isocentre for each gantry tilt angle

| Tilt angle    | kV | mA | Dose rate (mGy/s) |
|---------------|----|----|-------------------|
| 0°            | 89 | 6.2| 1.062             |
| 20° caudal    | 91 | 6.8| 1.217             |
| 20° cranial   | 88 | 5.8| 0.971             |

3. Results and Discussion
We analysed the results for measurement locations to the left (L) and right (R) of the patient because these are the areas in which most staff will interact with the patient during interventional cardiology procedures. As shown in Figure 3, for some parameter combinations, the scattered fraction has almost
the same result in the R and the L areas. However, the scattered fraction is lower on average in the R area.

![Scattered fraction plot calculation of R and L area](image)

**Figure 3.** Scattered fractions in the R and L areas

The summarized results of the scattered fraction distribution found in this paper can be seen in **Table 3.** The L and R areas have the same result for the minimum scattered fraction. Meanwhile, the L area has a higher maximum and mean scattered fraction, at 0.035 and 0.019, respectively. On the other side, the mean scattered fraction in the R area is 0.016 and its maximum is 0.027. Although the scattered fraction was higher in the left area, this difference was not significant (P=0.231).

| Parameter   | Scattered fraction |   |
|-------------|--------------------|---|
|             | L                  | R |
| Mean        | 0.019              | 0.016 |
| Minimum     | 0.006              | 0.006 |
| Maximum     | 0.035              | 0.027 |

**Table 3.** Scattered fraction distribution

![Boxplot of Scattered fraction](image)

**Figure 4** shows a boxplot of the scattered fraction calculations for the experiment. The range of the scattered fraction in the L area is wider than in the R area. This means that the left area exhibits a greater chance of exposure to scattered radiation than the right area, which is of particular concern to the staff.

![Boxplot of Scattered fractions in the L and R areas](image)

**Figure 4.** Boxplot of the scattered fractions in the L and R areas
The main effects plots for the means of the L and R areas are shown in Figure 5. The levels of each parameter were statistically significant (P<0.05) in the L area. The different levels of the gantry tilt (A) have significantly different scattered fractions, as do the different levels for position (B) and height (C). It is shown that a level 3 gantry tilt, which is the caudal position, caused a higher scattered fraction. A level 1 position, which is near the leg area of the patient, was the position that was most influenced by the scattered fraction. A level 2 height, which is 85–130 cm and corresponds to the abdomen to the neck of the staff, is the area most influenced by the scattered fraction.

![Figure 5. Main effects plot for means of (a) left area and (b) right area](image)

Meanwhile, in the R area (Figure 5(b)), the different levels of gantry angle and height had significantly different (P<0.05) results, but this was not the case for the staff’s position. A level 3 gantry angle and a level 2 height showed higher scattered fractions compared to other levels of all parameters. The staff position during the IRC procedure did not have significant differences between its levels. This is because the right area has additional shielding connected to the patient table to protect the genital area of the patient. Thus, the results in the right area at any position are near the mean value of the measurement.

These experimental results show us that the gantry tilt is the parameter that most influences the scattered fraction. The height is another parameter that needs to be considered since a level 2 height had a higher scattered fraction 50 cm from the patient during the measurement. As for the staff position, although it does not have any differences between its levels, this does not mean that it can be neglected. Staff should at least consider that the left area at the level 1 position has a higher result compared to the right area.

4. Conclusion
Based on this study, all of the studied parameters have a significant influence on the scattered radiation in the left area at the levels studied. However, on the right side, only two parameters significantly influence the scattered fraction at these levels. The parameters that had the highest scattered fractions on both sides of the patient were the gantry tilt at the caudal position and heights of 85-130 cm, which correspond to the abdomen to the neck of the staff. This result justifies that staff must wear proper protection shields while doing interventional cardiology in Cath labs.

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