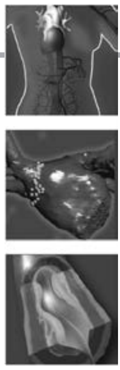

Radiation protection in the cardiac catheterization laboratory: special focus on the role of the operator

The use of ionizing radiation is associated with a risk of inducing malignant disease and causing skin or eye damage to the patient and the personnel. This article focuses on the role of the operator in limiting the radiation exposure of the involved persons during interventional cardiology procedures. There is a great variation in radiation doses between different experienced operators. The operator is responsible for all excess radiation exposure during a given procedure. Measures contributing to radiation reduction by the operator are reviewed herein. It can be concluded that the current proposed reference level of the mean radiation dose for interventional procedures is twice as high as is reasonably achievable and three-to-four-times higher than can be achieved by operators dedicated to dose reduction. Thus, there is room for improvement, and this can be achieved by focused learning of radiation-reducing measures.

KEYWORDS: catherization laboratory ▪ interventional cardiology ▪ radiation ▪ radiation protection ▪ radiation reduction ▪ x-ray

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Ionizing radiation is used extensively in cardiac diagnostic and percutaneous coronary interventional (PCI) procedures. The radiation is associated with a small but definite stochastic risk of inducing a malignant disease [1]. However, low-dose radiation exposure has also been shown to induce an increase in the number of circulating lymphocytes and chromosome aberrations, which represent surrogate biomarkers of cancer risk [1]. The long-term cancer risk increases with increasing cumulative dose and there is no known threshold value. Furthermore there is a deterministic risk of skin damage both to the patient and the operator, as well as a small risk of eye injury to the operator [2–5]. The risk by radiation exposure to the operator is by no means negligible as there are many operators who carry out up to 400–800 PCI procedures per year for more than 20 years.

The radiation exposure in interventional cardiology is determined by a series of factors that are partly administered by each procedure and partly dependent on the conduct of the operator and other personnel. The radiation management by the operator is the most important modifiable factor in radiation protection when using a given equipment.

Dose measurement & monitoring

The stocastic risk of radiation is related to the amount of radiation absorbed by the body. The unit of absorbed radiation is the Grey (Gy) [5]. As only a limited area of the body is radiated when x-rays are used in medicine, the absorbed dose is expressed as an effective dose (ED), which is a measure of whole body radiation resulting from a local radiation dose [5]. The unit of the ED is Sievert (S) [5]. The dose–area product (DAP) is the product of the area of the cross-section of the x-ray beam and the air kerma (kinetic energy released in matter) averaged over that cross-section and represents the radiation to the patient and the unprotected operator [5]. The unit of DAP is Gy × cm^2. Determination of the ED is complex as direct specific organ dose measurements are not possible. Therefore, indirect methods for a practical estimation of ED have been developed, requiring only measurement of DAP and using conversion factors listed in tables published by the National Radiation Protection Board, UK [6,101]. The DAP value is readily available for all modern x-ray equipment and it is thus a convenient measure of the amount of radiation during cardiac procedures.

Radiation dose-determining factors given for each procedure

■ Equipment

All x-ray equipment must meet regional and global regulatory safety standards (e.g., European Commission and International Organization for Standardization). Usually, the manufacturers provide annual maintenance service of the equipment according to mutual agreements. Further regular control is often provided by local engineers and technicians depending on local guidelines.

To date, there are only small differences between different products, which have significance for radiation safety. Not all machinery allows the operator to select cine frame rates below 15 frames/s or move the collimator shutters in place without fluoroscopy.

Patient weight

The radiation dose increases with increasing patient weight as more energy is needed to penetrate a larger mass [7–9]. Figure 1 shows this relation in our interventional laboratory. The DAP was only correlated to weight and not adjusted for other factors. In diagnostic coronary angiography (CAG), there was a linear increase of the median DAP value with the patient weight. PCI procedures were associated with a similar relationship but with a steep increase of the slope when patient weight exceeded 80 kg. The latter can be explained by an excessively increased need of fluoroscopy and cine runs in obese patients for satisfactory visualization.

The dose increase with the bodyweight is explained by the automatic exposure control used in current equipment, adapting tube voltage (kV) and tube current (mA) to preserve radiation levels at the image receptor for different levels of patient attenuation. During interventional procedures, the dose is less dependent on the patient's general body morphology than on weight [8]. When performing PCI, the x-ray field is focused on the lesion being treated and thus, the dose is dependent on the thickness of the patient at the site of interest, which is mainly determined by the body mass and tube angulation [8,9].

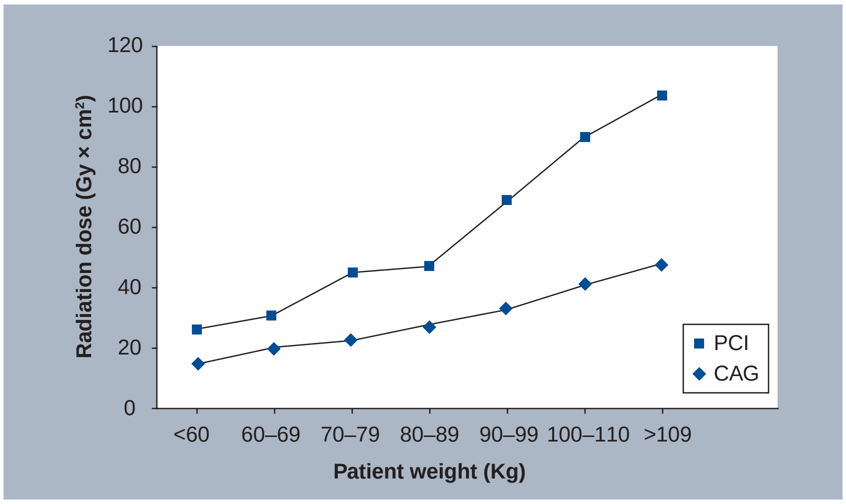

Figure 1. Relationship between patient weight and the dose–area value for coronary angiography and percutaneous coronary interventions. Recordings of 3338 CA and 662 PCI cases using Philips Allura Xper FD10 equipment in the Cardiac Cath Lab, The Heart Centre, Rigshospitalet, University of Copenhagen, Denmark (2009). There was a steady linear increase of dose with increasing weight for CAG. This was the case for PCI as well, but with a steep increase of the slope when the weight exceeded 80 kg.
CAG: Coronary angiography; pCI: Percutaneous coronary intervention.

Complexity of the procedure

Percutaneous coronary interventions in multivessel disease, chronic total occlusions and bifurcation lesions are associated with increased radiation dose compared with less complex lesions mainly due to longer procedure durations in complex cases [9,10]. In elective cases, careful planning before the procedure can contribute to reductions of procedure times and radiation doses. The planning can include advance selection of guiding catheters with maximal support instead of trying different catheters; advance selection of the most appropriate working projection; using buddy-wires primarily instead of first struggling over a single wire; using rotablators primarily in lesions that look nonballoonable instead of starting with a balloon; and opting for a simple main-vessel-only bifurcation technique; and planning of the technique for chronic total occlusion PCI.

Dose-reduction: factors dependent on the operator

Between-operator variation of radiation dose during PCI

In any given PCI procedure, the amount of necessary radiation is determined by the operator and varies by more than a factor of 2 between different experienced operators. Figure 2 shows median DAPs for PCI procedures for eight operators over a 10-year period in the author's catheterization laboratory. All operators were repeatedly instructed in radiation protection. At the end of the 10-year period, the operator with the lowest radiation dose (no. 2) had a DAP value of less than 40 Gy × cm^2 and the operator with the highest level (no. 4) had a value of more than 90 Gy × cm^2. Both had more than 20 years of PCI experience. The main difference was that operator no. 4 used many cine runs with 30 frames/s. Another difference was that operator no. 2 felt a special obligation to focus on dose reduction as the x-ray responsible cardiologist in the staff. Only one initially high-dose operator showed a steady decline of his dose through the years. Five out of eight operators had a median DAP of more than 50 Gy × cm^2 at the end of the observation period. Most operators maintained more or less their dose level, whether low or high, through all the years. Most median DAP values were between 45 and 70 Gy × cm^2.

Even more interoperator variation than in Figure 2 has been reported from other centers [9,11–13]. For comparison, a preliminary European proposal for Dose Reference Level for PCI has been a mean DAP of 75 Gy × cm² (75th percentile: 94 Gy × cm²), representing a fluoroscopy time of 17 min and the number of frames of 1300 [14].

Operator experience *per se* is not necessarily associated with a decrease of the radiation dose per procedure. Experienced operators can choose to make complex, time-consuming procedures and they can have different imaging habits.

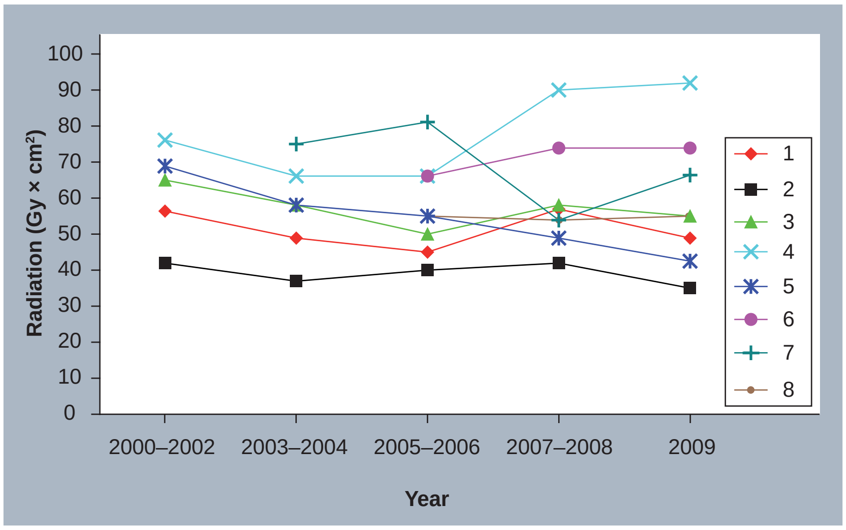

Figure 2. Dose–area product for eight percutaneous coronary interventional operators during a 10-year period (2000–2009). Conducted at Cardiac Cath Lab, The Heart Centre, Rigshospitalet, University of Copenhagen using Philips x-ray equipment. Most operators maintained their dose level over time whether it was low or high. Only one initially high-dose operator (no. 5) had a steady decline of dose ending 40% below his start level.

■ Number of cine runs

Cine runs are a major source of the radiation dose [11]. The operators should choose cine runs critically and avoid runs that do not contribute to diagnostic information. When documenting balloon inflation, the single shot function should be used if available on the equipment.

■ Cine frame rate

The radiation dose is directly related to the cine frame rate. A commonly used cine frame rate is 15 frames/s [5]. Good quality imaging has been reported with cine frame rates of 12.5 frames/s [13–15]. So far, there have been no published evaluations of the use of lower frame rates. In our center, we have experienced satisfactory imaging when using 7.5 frames/s with Philips Allura Xper FD10 equipment. Any operator can experiment with this option if available and decide when to use it. The choice of optimal cine rate depends primarily on the complexity of coronary anatomy and the heart rate. At higher heart rates, a higher cine frame rate might be necessary for proper visualization of tortuous and/or overlapping vessels.

■ Duration of cine runs

A long cine run is needed for collateral visualization, evaluation of contrast run-off or myocardial blush-grade. However, only one long run is usually necessary when taken in the most adequate projection. A diagnostic cine run should in most cases only last for one cardiac cyclus. To reduce the number of frames, the cine recording can often be started 1 s after starting of the contrast injection.

■ Diagnostic & working projections

Kuon *et al.* have carried out extensive work identifying tube angulations associated with the least possible radiation dose [16,17]. The left coronary artery can usually be sufficiently visualized in right anterior oblique (RAO) 30°, RAO 90° and in straight postero–anterior views with 30° cranial and caudal angulation, respectively. For the right coronary artery, left anterior oblique (LAO) 30° and RAO 100° views are adequate. These projections require much lower radiation doses than the traditionally used tube angulations applying to LAO caudal and cranial views. When supplementary projections are needed, they should be carefully collimated to the region of interest [17,18]. The RAO views are also most appropriate with respect to the operator dose as the x-ray entrance point into the patient is kept away from the operator. The RAO 90° exposes the operator for approximately threefold less scattered radiation than the traditional LAO 90° angle [17].

■ Fluoroscopy intensity & time

Sufficient fluoroscopic imaging can usually be carried out on lowest available pulse rate level.

Trainees should especially be reminded of moving their foot from the fluoropedal when not using fluoroscopy. There is no reason to observe the emptying of an angioplasty balloon by fluoroscopy. The balloon can simply be deflated for 5–10 s before removing it blindly.

■ Image amplification

The radiation dose increases with increasing image amplification [5,18,19]. The magnification can always be kept at the smallest level (i.e., 25 cm) when searching for a coronary ostium.

Many diagnostic cine runs can also be made with the smallest amplification. Bigger image sizes should only be used when specially indicated.

Collimation

To reduce the amount of absorbed and scattered radiation, the x-ray field at the entrance point to the patient should be kept as small as possible by using the collimators [5,18,19]. The radiation dose is directly related to the area of the x-ray field. The field should always be limited to the region of interest during PCI procedures. This should be kept in mind especially when intubating a coronary ostium or when visualizing left main stem in LAO caudal views.

Image intensifier & x-ray tube position

The radiation dose is reduced when the x-ray tube is as far as possible from the patient and the image intensifier as close as possible to the patient [5,18,19].

Arterial access site

Transradial procedures have been associated with larger radiation doses than transfemoral procedures [10,12]. However, this can mainly be explained by an initially more time-consuming intubation of the coronary ostia. A transradial PCI procedure itself is not more radiation costly than a transfemoral procedure.

Direct stenting

Direct stenting should always be considered as it shortens the procedure and radiation time [12]. However, an unsuccessful attempt of direct stenting results in excess fluoroscopy and increased radiation dose compared with a procedure with primary predilation.

What can be achieved by operators dedicated to dose reduction?

Kuon *et al.* have reported mean DAP values of 6.7 and 19.4 Gy × cm^2 in elective one- and three-vessel PCI, respectively [16]. In primary PCI for acute myocardial infarction, the mean DAP was 17.3 Gy × cm^2. These results were achieved through the authors′ dedication to dose-reduction [16–18]. These figures are just a fraction of the suggested preliminary reference levels, which represent current practice in European catheterization laboratories [14]. The work by Kuon *et al.* indicates that the proposed reference levels are much higher than reasonably achievable. This argues that a reference level should set an improved quality standard and not just reflect current practice.

Personal protection

Protective aprons with thyroid shields are standard protective clothing for interventional personnel. An apron equivalent of 0.25 mm lead allows 3.3% of the energy to be transmitted at peak tube voltage of 70 kVp [20–22]. Two-piece aprons with overlapping lead clothing anteriorly provides double thickness of 0.5 mm lead equivalence with 1.5% energy transmission at 70 kVp.

Protective drapes mounted on the table significantly protect the operator from scattered radiation [22,23].

Ceiling suspended transparent lead glass offers sufficient protection to the operator's eyes [22,23]. Lead goggles are an alternative but they can be heavy and uncomfortable. Further eye protection can be obtained by placing the TV monitor 60° to the right of the operator [24]. A lead cap has been suggested for brain protection but it can be uncomfortable to wear and it does not seem to provide significantly more protection than careful use of a lead glass shield [23–25].

The entrance site of the x-ray beam into the patient is the main source of scattered radiation to personnel. Staying as far from the scattered radiation source as possible dramatically reduces the radiation exposure to the persons in the room [5,17,18]. When doubling the distance to the source, the scattered radiation dose is reduced to a quarter. For the same reason, the operator should use RAO projections as much as possible for personal protection. Further protection of nontableside personnel is provided when standing behind a movable lead glass screen.

There are both international and national regulatory standards for radiation protection of both the personnel and the patients. These standards set the limits for maximum annual ED to the personnel, who have to wear personal dosimeters [5,22,26].

Radiation protection training

Both the International Commission on Radiological Protection and the International Atomic Energy Agency have proposed specific radiation safety courses [26,27]. All PCI operators get basic instruction in radiation protection in accordance with current guidelines [5]. Systematic radiation protection training programs for interventionalists have resulted in a 25–75% reduction of doses [9,13,28], but in spite of dedicated training, there are still great differences in doses between experienced operators (Figure 2) [11–13]. This seems to depend on the operators' primary focus on an optimal

PCI result compared with the radiation dose [13,19]. However, optimal dose administration is logical and easy to learn and it does not take place at the cost of the quality of image or PCI procedure.

Conclusion

Percutaneous coronary interventional operators are responsible for all unnecessary radiation dosages during cardiac interventional procedures. Unfortunately, radiation doses of 30–150% higher than necessary are very common.

The operators' less than optimal radiation administration is the number one source of excess scattered radiation in a catherization room. On the other hand, adequate use of protective clothing and shielding everybody's personal responsibility.

Appropriate radiation behavior is not difficult to learn. It requires a focused learning process after which it hopefully becomes automatic.

Financial & competing interests disclosure

The author has no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties. No writing assistance was utilized in the production of this manuscript.

Executive summary

- Ionizing radiation is associated with health risks.
- Radiation doses should be kept as low as reasonably achievable.
- During interventional procedures, the operators are responsible for all excess radiation.
- Current proposed reference levels for radiation per procedure are much higher than reported by operators dedicated to radiation reduction.
- Low radiation doses can be achieved by using the recommended measures for radiation reduction without compromising procedure quality.
- Focused learning is necessary to achieve a radiation dose below the level commonly used today.

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