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Ionizing radiation exposure in interventional cardiology: current radiation protection practice of invasive cardiology operators in Lithuania

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Abstract

Ionizing radiation management is among the most important safety issues in interventional cardiology. Multiple radiation protection measures allow the minimization of x-ray exposure during interventional procedures.

Our purpose was to assess the utilization and effectiveness of radiation protection and optimization techniques among interventional cardiologists in Lithuania.

Interventional cardiologists of five cardiac centres were interviewed by anonymized questionnaire, addressing personal use of protective garments, shielding, table/detector positioning, frame rate (FR), resolution, field of view adjustment and collimation. Effective patient doses were compared between operators who work with and without x-ray optimization.

Thirty one (68.9%) out of 45 Lithuanian interventional cardiologists participated in the survey. Protective aprons were universally used, but not the thyroid collars; 35.5% (n = 11) operators use protective eyewear and 12.9% (n = 4) wear radio-protective caps; 83.9% (n = 26) use overhanging shields, 58.1% (n = 18)—portable barriers; 12.9% (n = 4)—abdominal patient’s shielding; 35.5% (n = 11) work at a high table position; 87.1% (n = 27) keep an image intensifier/receiver close to the patient; 58.1% (n = 18) reduce the fluoroscopy FR; 6.5% (n = 2) reduce the fluoro image detail resolution; 83.9% (n = 26) use a ‘store fluoro’ option; 41.9% (N = 13) reduce magnification for catheter transit; 51.6% (n = 16) limit image magnification; and 35.5% (n = 11) use image collimation. Median effective patient doses
were significantly lower with x-ray optimization techniques in both diagnostic and therapeutic interventions.

Many of the ionizing radiation exposure reduction tools and techniques are underused by a considerable proportion of interventional cardiology operators. The application of basic radiation protection tools and techniques effectively reduces ionizing radiation exposure and should be routinely used in practice.

Keywords: interventional cardiology, radiation safety, x-ray exposure

(Some figures may appear in colour only in the online journal)

Background/Introduction

Ionising radiation is an integral part of today’s cardiology: computed tomography, nuclear myocardial perfusion imaging and viability testing, electrophysiology, and interventional procedures are performed on a routine basis in many cardiac centres. Ionizing radiation carries potential health hazards for the patient and staff [1–3]. Education and training play an important role in balancing minimization of these risks and prevention of ‘radiation phobia’ which may affect decisions to provide effective diagnostic and treatment options for the patient or preclude the physicians themselves from pursuing carrier in invasive cardiology [4].

Studies have shown that interventional cardiologists have the highest exposure rates to x-ray among all interventional specialists [5]. Radiation hazards involve deterministic and stochastic effects, and pose potential risk for invasive cardiology workers [2]. Deterministic effects directly depend on the dose of ionizing radiation to which a subject is exposed, and are therefore preventable if good radiation protection practice is adhered to. In the meantime, stochastic effects may result from any radiation exposure, and there is no minimum beyond which ionizing radiation could be called safe [6]. The management of ionizing radiation should be of primary concern at every interventional cardiology department. Multiple radiation protection measures allow the minimization of radiation exposure during interventional procedures [4]. Keeping ionizing radiation exposure as low as reasonably achievable is one of the cornerstones of good interventional cardiology practice providing benefit to both—the patient and the attending staff [7–9].

In this article, we aimed to:

(A) Review which radiation safety measures are used by interventional cardiology operators in Lithuania;
(B) Assess and illustrate the effectiveness of good radiation safety practice in effective dose reduction for the patient during diagnostic and therapeutic percutaneous coronary interventional procedures.

Methods

To address the aims raised in this article, two different approaches were employed to collect information.

(A) Personal occupational protection was assessed by interviewing interventional cardiologists in cardiac catheterization laboratories of five tertiary cardiac centres in Lithuania using a standard fully anonymized questionnaire between September and December 2014. The questions addressed the personal use of occupational protective wear, shielding,
x-ray table/tube positioning, and x-ray optimization techniques (adjustment of FR, image magnification, resolution, and collimation). To our knowledge, all cardiac catheterization laboratories in Lithuania are universally equipped with tableside lower-body shields, thus this type of shielding was not addressed in questionnaires. The format of the questions was to allow responses of ‘yes/no’ or ‘check boxes’ type. No personal identifiable data or occupational x-ray exposure data of the operators was obtainable from the questionnaires.

(B) X-ray exposure data of PCI (percutaneous coronary interventional) procedures was collected and compared between two selected experienced high procedural volume operators (performing >500 diagnostic and >300 therapeutic coronary interventions per year) of similar height at the Hospital of Lithuanian University of Health Sciences Kaunas Clinics. The procedural data (radial/femoral approach, x-ray time (min), dose-area product (DAP, Gy·cm²) and patient’s body mass index (BMI, kg m⁻²)) were recorded for each case. The x-ray time and DAP values were obtained from angiography machine readings. The patient’s effective dose (mSv) was estimated by multiplying the DAP value by a conversion factor of 0.2 (mSv Gy⁻¹·cm⁻²) [10].

The first operator (working without optimization) has routinely been working on a standard angiography setting, predefined by the manufacturer for coronary artery imaging: fluoro FR 15 frames s⁻¹ (fps) with normal detail resolution, recording FR 15 fps with normal detail resolution, no use of collimation, no FOV modification for catheter exchange, no routine use of ‘store fluoro’ option, and routine image magnification to FOV of 12–16 cm during coronary imaging.

The second operator (working with optimisation) has routinely been adjusting the angiography machine settings to fluoro FR 7.5 fps with low-detail resolution, recording FR 15 fps with low-detail resolution, routine tight collimation limited to the region of interest, a routine increase of FOV to 30 cm upon catheter exchange, ‘store fluoro’ option utilization and limiting image magnification to FOV of 16–20 cm during coronary imaging.

Both operators adjusted an optimally high table position and image detector close to the patient. The procedural data containing a similar case mix of 300 consecutive conventional diagnostic coronary angiographies (CA) and 150 CA with uncomplicated ad hoc or primary PCI performed by each operator were documented. Diagnostic procedures involving coronary artery bypass graft catheterization, left ventriculography, and/or aortography were excluded from the analysis. Therapeutic interventions involving chronic total occlusion (CTO) interventions or managing clinical or procedure-related complications (patients in cardiogenic shock, cardiac arrest situations, device loss/extraction, etc) were not included in the study. The selection of the arterial access route was solely at the operator’s discretion. All procedures were performed with a GE Innova 3100 Cardiac Angiography System.

The Regional Ethics Committee approved the conduction of this study. Participants were informed in writing on the front page of the survey regarding the voluntary nature of the participation and use of collected data for research purposes upon return of the questionnaires. Due to the anonymized questionnaires and study, informed written consent has not been obtained from individual participants and was waived by the Regional Ethics Committee.

**Statistical analysis**

Data were processed and compared with the SPSS 21.0 statistics software package. Categorical variables (arterial approach site) were expressed as a number (%) and compared with the Chi-square test. Continuous variables (x-ray time, effective dose estimate, BMI, number of implanted stents) were expressed as medians, and compared with the Mann–Whitney test.
Thirty-one (68.9%) out of 45 interventional cardiologists practising in Lithuania participated in the survey: 38 out of 45 of them agreed to participate in the survey, and 31 returned the answered questionnaires.

The use of protective x-ray barriers is presented in figure 1. All interventional cardiologists universally use conventional radiation protection aprons. The majority, but not all interventionists use thyroid protection on a regular basis. Only a small proportion of operators regularly use protective leaded eyewear and radio-protective caps. Most of the operators routinely use a suspended ceiling shield, fewer an additional portable barrier. Abdominal and pelvic shielding of the patient to reduce the amount of scattered radiation during interventional procedures is used by a minority of operators.

Figure 2 illustrates the application of technical optimization equipment to minimize ionizing radiation exposure during interventional cardiac catheterization procedures. Approximately one third of operators aim to position the table as high (as far as possible from the x-ray emitter) as comfortably achievable. Most of the interventionists are aware of adjusting the image intensifier as close to the patient as possible. More than half of the respondents use reduced fluoroscopy FR. The majority of interventional cardiology doctors routinely use the ‘store fluoro’ option. Only a minority of doctors reduce the fluoro detail resolution. Less than half the operators reduce magnification to pass or exchange catheters (increase the FOV), and limit the image magnification during conventional angiographic imaging and interventions. Collimation is routinely used by a third of operators.

A small proportion of respondents admitted to not routinely wearing the assigned dosimeters ($N = 4$, 12.9%).

The results of the comparison of effective patient x-ray doses of interventional procedures (300 diagnostic CA and 150 PCIs using routine cardiac catheterization techniques) performed by two experienced high-volume interventional cardiologists at the Hospital of Lithuanian University of Health Sciences Kaunas Clinics are depicted in figures 3 and 4.

Results

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The selection of vascular access for CA procedures was similar: the operator not using the x-ray optimization techniques has used the radial approach for CA in 255 (85%) patients, and the operator using the x-ray optimization techniques—in 282 (94%) patients ($p = 0.4$). There was no statistically significant difference in the patient’s constitution or fluoroscopy time. Median effective patient x-ray doses were 2.6 times lower if CA was performed by the operator using the x-ray optimization techniques (DAP 17.5 Gy cm$^2$ versus 45.0 Gy cm$^2$, $p < 0.001$) (figure 3).

The operator not using the x-ray optimization techniques has used the radial approach for CA/PCI in 106 (70.7%) patients, and the operator using the x-ray optimization techniques—in 122 (81.3%) patients ($p = 0.2$). There was no significant difference in the patients’ constitution, fluoroscopy time or number of implanted stents (1.63 versus 1.56, $p = 0.6$). Median effective patient x-ray doses were significantly higher if CA/PCI was performed by the operator not using the x-ray optimization techniques (DAP 32.5 Gy cm$^2$ versus 83.5 Gy cm$^2$, $p < 0.001$) (figure 4).

**Discussion**

Interventional cardiologists and radiologists are exposed to more ionizing radiation than physicians in any other specialized medical field. Therefore, radiation safety is essential in the quality administration of cardiac catheterization laboratories [1, 5]. Understanding the risks inherent to radiation exposure and being conscious of the means to minimize these hazards are mandatory for every interventionist. The majority of risks related to occupational x-ray exposure are preventable if adequate radiation safety measures are taken. The main source of x-ray exposure to the operator results from radiation scatter from the patient. A reduction in
The patient’s dose translates into a proportional decrease in the scatter dose to the operator. Therefore, techniques that reduce the patient’s dose generally have the same effect in reducing occupational x-ray exposure [8, 9, 11].

In this survey, we have reviewed the status of radiation safety practice among Lithuanian interventional cardiologists in cardiac catheterization laboratories. We have addressed the main radiation safety components: (1) the use of personal protective measures designed to serve the operator’s protection purpose (protective wear and shielding) and (2) the use of technical optimization parameters aimed at primarily reducing the patient’s dose (and indirectly, but none the less importantly, the scatter dose to the operator).
The results of the survey quite strikingly demonstrate that a significant proportion of operators neglect some key personal radioprotection elements (eyewear, head protection, protective shielding use). The measures to reduce the patient’s x-ray exposure tend to be poorly managed: table positioning, technical optimisation parameters (fluoro FR, magnification, etc) are not adjusted to lower x-ray exposure during interventional procedures by a high proportion of respondents. The data comparing patient x-ray exposure during interventional procedures has illustratively demonstrated that technical equipment optimization contributes to a reduction in the patient’s dose by as much as a factor of 2.6 in both—diagnostic and therapeutic interventions.

The results and data obtained from anonymized questionnaires show that adherence to personal radiation safety measures has ample room for improvement. However, radiation protection is not solely the operator’s concern, and should ideally be addressed at departmental and institutional level by the joint efforts of physicians, responsible radiation protection and administrative authorities.

The mean reported x-ray exposure doses to patients during diagnostic and therapeutic interventional procedures exhibit tremendous variability between sites and between studies [12, 13]. Data regarding patient exposure during interventional procedures (CA, CA + PCI) of our study fall within the reported range of average doses provided in the literature. Occupational and procedural x-ray doses in invasive cardiology may be minimized multiple times by simply adhering to the use of radiation protection tools and optimization techniques as has been widely illustrated [4, 9, 14–16]. There is an ongoing discussion on the impact of the selection of a vascular access site (radial versus femoral) on x-ray exposure doses. Higher patient radiation exposure with the radial compared to the femoral approach is reported [17–19]. However, reports that the radial approach does not significantly increase patient exposure when performed by experienced operators are also present [20–22]. In terms of the left and right radial access, strong evidence of heterogeneity is present among the published studies. Some authors report shorter fluoroscopy times in left radial access procedures and comparable DAP values between the two radial access routes [23]. However, these differences were not depicted by other propensity-matched cohorts, and no significant differences in median DAP values were observed, either for diagnostic or interventional procedures [24]. Multiple technical (x-ray equipment, tube angulation, FR, resolution, etc), operator-dependent (skills and experience), and patient-related (body constitution, lesion complexity) factors account for a patient’s x-ray exposure and outweigh the influence of the access route. Adequate shielding provides equally efficient scatter radiation protection to the operator irrespective of the access route [25, 26]. The selection of the vascular access should be based on clinical and technical reasoning rather than radiation safety concerns, which may effectively be addressed by adhering to the good radiation protection practice rules that will be discussed further.

Many of the personal behavioural and physical protection means along with the x-ray control parameters installed in modern angiographic equipment have turned the cardiac catheterization laboratory, with routine ionizing radiation exposure, into a highly controlled and relatively safe working environment. These means involve the use of protective shielding, maintaining the distance from the x-ray source and being mindful of the positioning of basic equipment, the limitation of the time of exposure, and optimization of the x-ray emission parameters (table 1) [4, 8, 25]. Data on x-ray optimization parameters (FR, resolution, exposure dose expressed as air kerma and DAP) are by default provided in all modern angiography equipment for radiation exposure monitoring in real time. Real-time personal digital dosimeters available in some cath labs provide real-time data and alert staff on x-ray exposure, allowing immediate modification of behaviour.
Any invasive procedure should be undertaken only when potential diagnostic or therapeutic benefits to the patient outweigh the risks of radiation exposure and procedure-related complications. Establishing correct clinical indications for invasive cardiac procedures is beyond the scope of this article.

The primary source of occupational radiation exposure for staff is the scattered radiation reflected from the patient’s body. Techniques that reduce patient dose also reduce the occupational dose to the operator. If adequate shielding is applied, the amount of scattered radiation under the protective operator garments can be considered minimal or even negligible [27, 28]. The 0.5 mm lead equivalent absorbs up to 98% of scatter radiation [28, 29]. Protective personal garments should be inspected fluoroscopically on a regular basis to detect deterioration and defects in the protective material. Additional shielding (tableside lower-body shield, accessory vertical extension, suspended upper-body shield, additional portable barrier, radiation-absorbing pads) decreases the scattered radiation to an even greater extent [25]. Protective garments protect only against the scattered radiation, but not from direct x-ray beam. Therefore, exposure to a primary x-ray source (e.g. leaning over the patient’s body, placement of operator’s hands in the course of direct beam) results in substantially higher x-ray exposure, and should be avoided. Uncovered parts of the body (head, arms, legs) are exposed to much higher amounts of radiation, the hands being subjected to the highest exposure doses [30]. The best way to protect the operator’s hands is to keep them out of the radiation field and use abdominal/pelvic patient shielding. Leaded gloves may be of benefit, but will not provide protection upon direct x-ray exposure, and in contrast, may result in an increased dose when any shielding is placed in the primary beam course.

The lens of the eye is particularly susceptible to x-ray exposure and sustains irreversible damage from a relatively low dose of radiation resulting in subsequent cataract formation [31, 32]. Professional cataract is a well-known problem in invasive cardiology workers and is distinguished from naturally occurring cataract forms as it occurs in the posterior pole of the lens [33–35]. Since recognition of this issue, the permitted dose to the lens of the eye had been dramatically reduced from 150 mSv yr⁻¹ to 20 mSv yr⁻¹ in 2011 [36]. As standard shielding does not completely eliminate the measurable radiation scatter at the operator’s head level nor reduce the secondary radiation reflected from the operating room walls, the use of protective eyewear (leaded glasses with side panels or a 180° helmet) is highly recommended [8, 32, 36]. Current guidelines recommend the routine use of two personal dosimeters, with one worn outside the apron at the shoulder or neck and the other—under the apron at the waist level, allowing only approximate eye dose estimation. Additional dosimeters worn at eye level close to the left ear may be used to monitor lens doses of operators at potential risk of receiving higher exposure doses (e.g. young interventionists at the beginning of their career to ensure effective use of protective devices, high-volume or complex lesion (CTO-PCI) operators) [7, 8, 28, 30].

The organ tissues that have the greatest risk for cancer formation in invasive cardiology workers are the brain, skin, and thyroid [37]. Head and neck areas are not protected from radiation exposure by conventional radioprotective aprons. A thyroid collar is a must-wear radiation protection item as structural and functional changes of the thyroid tissue related to radiation exposure are widely recognized and reported [38, 39]. The routine use of thyroid shielding reduces the average annual effective operator’s dose by two-fold [40]. Recent reports and studies have suggested an increased risk of left-sided brain cancer development in the interventional cardiologists’ population [41, 42]. Radioprotective caps of 0.3–0.5 mm lead equivalence have been shown to significantly attenuate the radiation dose to the operator’s head [43, 44]. The prevalence of breast cancer has also been shown to be higher among female interventionists [3, 45]. Lead-equivalent garments providing snug fit, full chest coverage
(sleeved aprons) or dedicated breast shields are recommended for female operators to protect the breast tissue and axillary region.

An overhanging suspended ceiling shield placed over the patient protects the operator’s upper body from the primary source of scatter radiation (the patient); however, it is imperative to keep in mind the appropriate shield positioning to ensure an adequate protective effect. A ceiling-mounted upper body shield protects best from scatter radiation when it is positioned tightly to the patient’s body, just cephalad to the vascular access point (closer to the physician than the source of radiation). The protective effect is diminished if the shield is moved away from the patient or more cephalad from the operator. Accessory soft curtain extensions and/or patient contour cut-out along the bottom edge of the suspended upper body shield helps to maintain contact between the patient and shield, thus minimizing the amount of radiation scatter. The upper body shield requires constant repositioning during the procedure (after table repositioning, change in projections) to maintain effective protection [25, 26].

Abdominal and pelvic patient shielding has been proven to significantly reduce the radiation exposure to the operator [46–49], however the effects to the patient are controversial. Iqtidar et al report no significant difference in air kerma or DAP between unshielded patients and patients with enhanced shielding (a simple 0.5 mm lead apron placed across the patient’s abdomen) [48]. Another randomized study has demonstrated that with the use of equivalent

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<td>• Suspended ceiling shield</td>
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<td>• Abdominal/pelvic shielding of the patient</td>
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<td>• Maintain distance from the x-ray source</td>
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<td>• Avoid direct x-ray exposure</td>
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<td>• Limit the use of steep angulated views</td>
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<td>• Minimize fluoroscopy time</td>
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<td>• Reduce fluoro (whenever reasonable—and record) mode detail resolution</td>
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<td>• Limit image magnification</td>
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<td>• Use collimation</td>
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J. Radiol. Prot. 36 (2016) 695
abdominal lead shielding the radiation to the patient was doubled [49]. The scattered radiation is reflected from the shield back to the patient’s body, and an increase in the patient’s effective dose is an expected effect. A potential increase in patient radiation exposure raises certain ethical concerns. However, in most cases each patient undergoes angiography once or at most a few times in their lifetime. In the meantime, high-volume operators are exposed to hundreds of procedures during a single year, and as the effects of radiation exposure are cumulative, occupational safety is a reasonable priority. Such operator protection is extremely relevant in complex and prolonged procedures (CTO PCI), where radiation exposure for the operators is significantly greater. A recent study has shown that the use of a disposable radiation protection drape (Radpad) effectively reduces operator radiation exposure during CTO PCI to levels similar to less complicated cases [50]. Radpad shields are non-lead lightweight disposable radiation scatter-attenuating drapes designed for the operator’s protection during interventional x-ray-guided procedures. However, dedicated Radpads are unavailable in many catheterization laboratories, and add additional costs to the procedures. The use of a conventional 0.5 mm lead-equivalent lead drape to cover the patient’s abdomen and pelvic area is a reasonable and equally effective alternative, reducing radiation scatter to over 90% [46–48].

Increasing the distance from the direct or scatter x-ray source is one of the most effective means to reduce the exposure dose: even a distance of a few centimetres away from the x-ray tube and the patient makes a substantial difference in the dose received by the operator [8, 14]. Power injectors or extension manifolds enable operators to move further aside from the radiation source during contrast injection, and are a good investment in radiation safety when equipping contemporary cardiac catheterization laboratories. The patient’s table should be kept as high as comfortably achievable (away from the radiation source), while the image intensifier should be as close to the patient’s body as possible [8, 10, 14]. It is important to vary the imaging projections in order to avoid a focused high-dose region, which can lead to deterministic radiation-induced skin effects. Steep tube angulation angles increase the x-ray emission, and result in higher radiation doses and scatter. LAB projections are best avoided, as scattered radiation is highest on the side of the x-ray beam entrance (next to the operator) [4]. In addition, protective table-suspended side shielding cannot effectively protect the operator if the x-ray gantry (C-arm) is in a steep oblique or lateral position.

The procedural or x-ray time is a poor indicator of the ionizing radiation dose [8]. The actual calculated doses of radiation are most accurately recorded in terms of air kerma or DAP values with modern digital equipment, and influenced by multiple technical, procedure and patient-related factors as previously discussed. The fluoroscopy mode accounts for 95% of the total x-ray operation time, but results in only 40% of the total radiation exposure to staff and the patient [15, 51]. This is due to pulsed screening that reduces the exposure dose. In the meantime, cine imaging employs high-dose rapid-sequence screening for image acquisition. It regularly occupies only 5% of the total x-ray operation time, but accounts for 60% of the total radiation exposure during the procedure [51]. The ‘store fluoro’ option allows image documentation without the need for extra image acquisition [52]. Prolonged cine runs should be limited to collateral imaging or cases of slow flow. At all occasions, the x-ray screening time should be kept to the minimum required.

FR is one of the most significant contributors to increased x-ray emission. A reduction in fluoro FR from 15 fps to 7.5 fps results in a considerable reduction in the radiation dose with no significant deterioration of diagnostic information [14, 16]. In prolonged and complex procedures where anticipated x-ray exposure is likely to be high (rotablation, CTO PCI, multi-vessel interventions), a reduction in FR is highly recommended, also on record mode. This
feature is by default installed in modern angiography equipment provided by some manufacturers and enables the utilization of dedicated radiation-saving protocols as CTO-mode with fluoro and record modes set at 7.5 fps. Reduced FR used in routine practice has been shown to be advantageous in terms of radiation exposure and is non-inferior with regard to diagnostic or therapeutic information provision when compared to conventional protocols [53]. Limiting the image magnification and increasing the FOV while exchanging diagnostic or guiding catheters allow the reduction in the emitted and scattered radiation to an even greater extent. Tight collimation reduces the patient dose, radiation scatter, and improves the image quality by focusing on the field of interest and improving the image and contrast resolution [4, 16, 54]. A reduction in image resolution, whenever lower image quality is acceptable, considerably decreases x-ray exposure (‘low-detail’ option on most angiography systems) [14]. The ‘low-detail’ fluoro mode is often sufficient, and reversion to normal resolution is rarely needed even in patients with larger body constitution.

Robotic PCI has emerged as a novel solution to reduce professional radiation exposure to minimal levels [55]. However, not all subsets of interventions are or will be subjected to such an approach. The most unfavourable and radiation-consuming scenarios (difficult anatomic lesions, patients in unstable hemodynamic and peri-arrest conditions) will require the presence of an interventional cardiologist at the table.

As radiation doses delivered to patients and medical staff during interventional cardiology procedures are among the highest in medicine, it is particularly important that the operators and assisting staff utilize all available methods to minimize radiation exposure to the greatest possible extent. A lack of basic radiation protection and optimization knowledge may result in more ionizing radiation exposure to patients and staff, therefore appropriate education and training play a central role. Some operators may find it inconvenient and distracting to keep in mind multiple radiation safety measures during the procedures. However, if implemented early in the training process and used in routine practice, the skills to coordinate multiple radiation protection tools in the cardiac catheterization laboratory quickly become a fundamental part of good interventional practice [9, 16, 26].

Study limitations

The results of this survey represent the practice of a limited number of invasive cardiologists of a single country. Radiation protection strategies may greatly depend on the country and region.

Conclusion

Ionizing radiation exposure in cardiac catheterization laboratories is significantly reduced by the application of basic x-ray optimization tools and techniques; however many interventional cardiology operators underuse them.

Similar studies and audits are important in identifying the extent of this problem. Establishing better strategies for protecting physicians at the workplace include the promotion of a high level of radiation safety in the practice of interventional cardiology, improved radiation safety awareness, and the provision of appropriate training. Continuous collaboration among physicians, assisting medical staff, hospital administration and radiation protection services, national and international professional societies plays an essential role in achieving these goals.
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