

APSIC best practices for safety and effectiveness in the use of ionising radiation and mitigation of occupational health hazards in the Asia-Pacific region



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ABSTRACT

The As Low As Reasonably Achievable (ALARA) principle remains central to radiation safety in cardiac catheterisation laboratories, complemented by the As Low As Diagnostically Acceptable (ALADA) and As Low As Diagnostically Acceptable, being Indication-oriented and Patient-specific (ALADAIP) principles. Increasing procedural complexity, longer case durations, and larger teams require careful workflow planning, optimised room design, and protective technology. This Asian Pacific Society of Interventional Cardiology (APSIC) document reviews regional practice gaps, core radiation safety principles, occupational and patient dose limits, musculoskeletal hazards of lead garments, dosimetry, artificial intelligence-assisted dose reduction, emerging radioprotection, and strategies to protect the expanding catheterisation laboratory team. This paper offers guidance on standardising safe practices across the region, providing educational opportunities to limit radiation exposure in practice, and extending the protection strategies to include the continually expanding teams in the catheterisation laboratory.

X-rays, along with iodinated contrast media, are used to visualise cardiac arteries and chambers, which is a necessity for cardiac interventions. The visualisation of cardiac structures and arteries in real time is essential to facilitate percutaneous coronary and structural interventions. However, unlike plain film radiographs, fluoroscopy and digital acquisitions require multiple frames, which are taken in quick succession to produce moving images. As such, radiation usage and patient exposure are much higher than for plain film radiography. Furthermore, the duration and complexity of the procedure often expose patients and staff to higher radiation rates compared with other medical imaging studies.

Radiation exposure to the patient results from the interaction of X-rays with the patient's tissues and organs. X-rays travel through the patient, reaching the detector and contributing to the production of an image. They are also absorbed by the patient, resulting in radiation exposure for the patient, or they

are scattered off the patient's tissues and into the surrounding environment, including the staff performing the procedure.

Current International Commission on Radiological Protection (ICRP) recommendations set an occupational effective dose limit of 20 mSv/year averaged over 5 years, with no single year >50 mSv. The lens limit is 20 mSv/year averaged over 5 years (no single year >50 mSv), while skin and extremity limits remain 500 mSv/year. The public limit is 1 mSv/year. Patients have no fixed numerical limit; medically indicated exposure is governed by justification, optimisation, and diagnostic reference levels (DRLs).^{1,2} These limits are summarised in **Table 1**.

Staff exposure is primarily from scatter and is associated with cataracts, cellular/chromosomal injury, and possible cancer risk.³⁻⁵ Prevention relies on minimising the cumulative dose, shielding, and dosimetric surveillance.

Unlike the hazards above, musculoskeletal injury in the cardiac catheterisation laboratory (CCL) arises from

KEYWORDS: best practices; protection; radiation

61 **Table 1. Current radiation dose limits – occupational workers, the public, and patients.**

Population	Dose limit	Notes
Occupational workers (effective dose)	20 mSv/year, averaged over 5 years; no single year >50 mSv	ICRP recommendation 1
Occupational workers (lens of eye)	20 mSv/year, averaged over 5 years; no single year >50 mSv (reduced from 150 mSv/year)	Since ICRP 2011 statement on tissue reactions 2
Occupational workers (skin, extremities)	500 mSv/year	ICRP recommendation 2
Members of the public	1 mSv/year	ICRP recommendation 1
Patients (medical exposure)	No fixed numerical dose limit	Controlled by justification and optimisation (DRLs) rather than a dose limit, as each exposure is clinically indicated

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Current radiation dose limits for occupational workers and members of the public and the optimisation-based approach used for medically indicated patient exposure. Patients do not have a fixed numerical dose limit; exposure is governed by clinical justification, optimisation, and DRLs. DRL: diagnostic reference level; ICRP: International Commission on Radiological Protection; mSv: millisievert

61 cumulative mechanical loading rather than from radiation
62 itself. The principal cause is the 5-10 kg weight of a lead
63 apron, borne asymmetrically over years of practice,
64 combined with prolonged static standing and awkward
65 cervical/spinal positioning while viewing overhead
66 monitors. The most commonly reported injuries are
67 lumbar disc disease, cervical spondylosis, and knee or hip
68 osteoarthritis. Orthopaedic problems related to protective
69 wear were the most frequently reported radiation-associated
70 health hazard in the European Association of Percutaneous
71 Cardiovascular Interventions (EAPCI) survey (19.5%), with
72 an association noted with increasing years of exposure;⁶
73 furthermore, two-thirds of respondents to a 2024 European
74 survey reported garment-related orthopaedic injury
75 personally or in coworkers.⁷ In the Women-in-Asian Pacific
76 Society of Interventional Cardiology (WIN-APSIC) survey,
77 orthopaedic injury was the most commonly reported
78 occupational health effect (13.4%), with lumbar disc
79 injury the most frequent, yet only 32% of respondents
80 had any exercise routine to mitigate this risk, and very few
81 institutions offered structured support.⁸
82 Because these injuries are mechanical rather than
83 radiobiological, prevention should be addressed separately
84 from radiation-dose mitigation. Measures include weight-
85 distributing two-piece aprons, lightweight or suspended
86 protection systems, ergonomic positioning, strengthening and
87 stretching programmes, scheduled breaks or operator rotation,
88 and access to physiotherapy or occupational health review.

106 **RADIATION PROTECTION TECHNIQUES**

107 Radiation reduction is based on minimising exposure time,
108 maximising distance, and shielding. Patient dose can be

reduced through lower frame rates, fewer and shorter cine
runs, and efficient procedures (**Table 2**).⁹ Beam collimation,
low pulse/frame rates, limited magnification and steep
angulation, spectral filtration, optimised source-detector
geometry, last-image hold, and avoidance of unnecessary cine
runs reduce primary and scatter radiation.^{9,10}

Dose area product (DAP), or kerma area product (KAP),
combines dose and the area of the patient exposed and is
widely used to compare procedures and establish DRLs.
The American College of Cardiology (ACC) recommends
investigation when a CCL's median KAP exceeds the 75th
percentile.¹¹⁻¹⁴

The Asian Pacific Society of Interventional Cardiology
(APSIC) provides an Asia-Pacific (APAC) perspective on
radiation safety. Regional DRLs vary: Japanese studies report
59.3-64 Gy·cm² for diagnostic angiography,¹² Australian
data 30-59 Gy·cm²,^{13,14} Thailand reports 91 Gy·cm² for
percutaneous coronary intervention (PCI),¹⁵ and India 20
Gy·cm² and 50 Gy·cm² for diagnostic angiography and
PCI, respectively.^{16,17} A European study reported 35 Gy·cm²
for diagnostic angiography and 85 Gy·cm² for PCI.¹⁸ No
coordinated APAC-wide DRL survey has been completed;
standardised regional reporting is needed to quantify variation
and guide dose reduction.

Variation in radiation dose amongst APAC countries is
noted, and the Asia-Pacific region may benefit from further
coordinated reporting. Global variations in available
resources, practice, and policy are noted. The WIN-APSIC
radiation safety survey,⁸ evaluating radiation hazards and
safety among physician and allied health care professionals in
invasive cardiology, reveals significant international variability
in radiation safety practices and training internationally and

Abbreviations			
ALADA	As Low As Diagnostically Acceptable	DRL	diagnostic reference level
ALADAIP	As Low As Diagnostically Acceptable, being Indication-oriented and Patient-specific	IE	interventional echocardiographer
ALARA	As Low As Reasonably Achievable	LMIC	low- and middle-income countries
APAC	Asia-Pacific	PCI	percutaneous coronary intervention
APSIC	Asian Pacific Society of Interventional Cardiology	PPE	personal protective equipment
CCL	cardiac catheterisation laboratory	WIN-APSIC	Women-in-Asian Pacific Society of Interventional Cardiology

Table 2. Measures of radiation exposure.

Measure	Definition
Fluoroscopy time	The duration for which the main operator has the X-ray system's fluoroscopy function activated. Fluoroscopy is a low-dose imaging mode used to position catheters and wires, though with lower image quality than digital acquisition, and images are not routinely stored. It indicates procedure complexity/length but does not measure dose.
Air kerma	This is the "kinetic energy released per mass unit of air". It is an important measure that can be used to quantify the output of the X-ray system and the intensity of the exposure to the patient. It does not include the area of patient exposed.
Kerma area product	Also referred to as dose area product, it measures air kerma and the area of the patient exposed. It is the most useful radiation metric as it captures the total radiation used during the procedure and correlates to exposure to staff in close proximity.
Number of digital acquisitions	Also referred to as the number of "cine runs". It dates back to when cinematography with film cameras was used in angiography.
Absorbed dose	This is the amount of energy deposited per unit mass of tissue and is useful to assess the biological risk to that tissue. It is reported in Gy or mGy.
Effective dose	This is a whole-body dose that assesses an individual's stochastic risk, which is useful when comparing risks between exposed individuals. It is measured in Sv or mSv.
Exposure	This is the total charge of ions produced by radiation at a specific point. It assesses the level of risk at the specified location where energy is released. It is measured in Gy.
Equivalent dose	This is the dose quantity that factors in the relative biological damage and type of radiation used. It is used to measure risk for specific tissues for staff and is measured in Sv or mSv.

Summary of commonly used radiation exposure and dose metrics in the cardiac catheterisation laboratory, including what each measure represents and its principal unit or clinical interpretation. Gy: gray; mGy: milligray; mSv: millisievert; Sv: sievert

in the Asia-Pacific region. Further comparative DRL data from the Asia-Pacific region documenting exposure rates with comparative methodology are important to accurately quantify the impact of these differences and minimise exposure and risk.

Global differences

Radiation practices and regulation vary substantially across APAC. In the United States, cardiology procedures account for approximately 45% of the mean cumulative medical radiation exposure, and interventional cardiologists historically have among the highest occupational exposures, although this difference is narrowing within the medical profession.¹⁹

In the 2012 EAPCI survey of 615 CCL workers, 64.4% always used a collar dosimeter, whereas 7.0% never did. Thyroid shields were used by 87.2%, lead glasses by 38.4%, and leg shields by 31.9%. Orthopaedic problems from protective garments were reported by 19.5%, cataracts by 2.0%, blood-count abnormalities by 2.4%, and malignancy by 2.2%. Most respondents (62.1%) reported workplace restrictions for pregnant workers.^{6,20}

A more recent (2024) survey conducted among European countries (where the majority of respondents were electrophysiologists) found that 57.3% of respondents reported mandatory radiation training was required for clinical practice.⁷ Although a European directive on radiation use (Euratom 2013/59) exists, 54.5% reported being unfamiliar with this document. Two-thirds reported radiation protection garment-related orthopaedic injuries (personally or in coworkers) as a result of working with occupational radiation, with similar proportions not knowing if these were recognised as occupational hazards in their countries. The majority of respondents (78.7%) were unaware of the identity of their centre's radiation protection officer.⁷

A European Association of Cardiovascular Imaging (EACVI) survey of 258 respondents showed substantial variability in protection for interventional echocardiographers (IEs): only 28% received periodic radioprotection training, 33% lacked dedicated architectural shielding, and 72% did not know their annual dose; 72% called for improved protection.²¹

The WIN-APSIC radiation safety survey (2024-2025),⁸ evaluating radiation hazards and safety among physician and allied health care professionals in invasive cardiology, reports important variation in practice. In this survey, 76.6% of respondents worked in APSIC member countries (72.84% interventional cardiologists, 3.97% electrophysiologists, and 25.2% allied health professionals). Survey respondents reported that 86.8% wore lead aprons and 83.2% wore thyroid collars, 30% wore lead glasses, 4.3% used shin/leg guards, and 13.33% of females reported the use of paldron breast protection shielding (lead gowns fitted with a lead paldron).¹⁵

WIN-APSIC also found limited use of advanced protection and dosimetry: 4.6% had Zero-Gravity systems (TIDI Products), 25% wore no dosimeter, 63.2% received dosimeter feedback, 55.9% used radiation dose as a CCL quality metric, and 57.7% had a radiation officer. Mandatory radiation-protection education was reported by 73.4%.⁸

Orthopaedic injury was the most commonly reported occupational health effect (13.4%), predominantly lumbar disc injury; however, only 32% reported preventive exercise. Most respondents were unaware whether radiation-related hazards were formally recognised as occupational hazards.⁸

Regarding pregnancy, 37% reported national laws prohibiting pregnant females from CCL work, and 71.2% reported that such work was discouraged.⁸

Resource disparities were marked: compared with higher-income settings, low- and middle-income country (LMIC) respondents were less likely to receive dosimeter data (52.2% vs 71.7%), use radiation exposure as a quality

metric (43.28% vs 66.67%), or have ceiling-suspended (58.57% vs 77.36%) and under-table shielding (55% vs 77.9%); economic barriers were more frequent (35.9% vs 15.79%; all $p<0.001$).⁸

The WIN-APSIC survey⁸ made it clear that, globally, there is significant variability in radiation safety, its hazards, education, and training among interventional cardiologists, with opportunities to further develop and improve training, education, and standardisation, particularly in the Asia-Pacific region. **Table 3** highlights the most salient differences in the surveys conducted in the APSIC region compared with Europe and the USA.^{21,22}

WIN-APSIC data identify five immediate APAC priorities: appoint radiation protection officers; provide at least quarterly dosimeter feedback; prioritise basic shielding upgrades in LMICs; formally recognise radiation-related and orthopaedic occupational hazards; and integrate structured radiation-safety training into national interventional cardiology curricula.

The As Low As Reasonably Achievable (ALARA) principle remains foundational, but excessive dose reduction may compromise image quality.²³ The As Low As Diagnostically Acceptable (ALADA) principle anchors dose reduction to diagnostically acceptable imaging, while the As Low As Diagnostically Acceptable, being Indication-oriented and Patient-specific (ALADAIP) principle further individualises exposure to indication and patient factors. In CCL practice, this supports greater dose reduction in routine or radiation-sensitive cases while preserving adequate imaging for complex interventions. APSIC recommends incorporating ALADA/ALADAIP into regional training and protocols.²³

Real-time dosimeters provide immediate exposure feedback and enable behavioural correction.²⁴ Modern platforms use automated exposure control, pulse-rate modulation, artificial intelligence (AI)-assisted noise reduction, and dynamic collimation to preserve image quality at a lower dose.²⁵ APSIC supports considering these technologies during equipment procurement or upgrades, subject to resource availability.

Pharmacological radioprotection remains investigational. Amifostine is approved for selected radiotherapy indications but is unsuitable for routine chronic occupational CCL exposure.²⁶ Antioxidants including vitamins C and E, N-acetylcysteine, and melatonin show experimental radioprotective effects, but robust occupational clinical data are lacking. No pharmaceutical is currently recommended for routine CCL use.²⁶

Radiation safety in pregnancy

Average total doses of occupational radiation of an appropriately shielded working interventional cardiologist are estimated to reach 0.09 mSv over an entire pregnancy.²⁷ For context, the average annual background radiation exposure worldwide is 2.4 mSv.²⁸ The developing foetus is highly sensitive to radiation, but the threshold for foetal injury is 100 mSv,^{20,28} a dose much higher than likely exposure (**Figure 1**). When the foetus is exposed to <1 mSv, the risk of childhood cancer or congenital malformation is barely altered, changing from a 4.070% risk to 4.078% risk. If exposure is <0.5 mSv, the risk changes from 4.070% to 4.072%.²⁸

Pregnancy policies vary widely (**Table 4**).^{28,29} Australia, India, Bangladesh, Indonesia, Japan, the United Kingdom, and Israel use a ≤ 1 mSv pregnancy limit; Canada recommends 4 mSv and the United States 5 mSv. Some countries, including Singapore and several European nations, prohibit occupational radiation exposure during pregnancy.²⁸

Elsewhere, interventional cardiologists and trainees continue CCL work during pregnancy with foetal-dose monitoring and adherence to national limits. International consensus supports an informed choice to continue CCL work when appropriate shielding, monitoring, and ALARA-based practice are available.^{29,30}

This choice depends on reliable safety practices. WIN-APSIC showed that shielding is not universally applied and varies across APAC;⁸ individual case volume, complexity, and available personal and structural protection must therefore be considered.

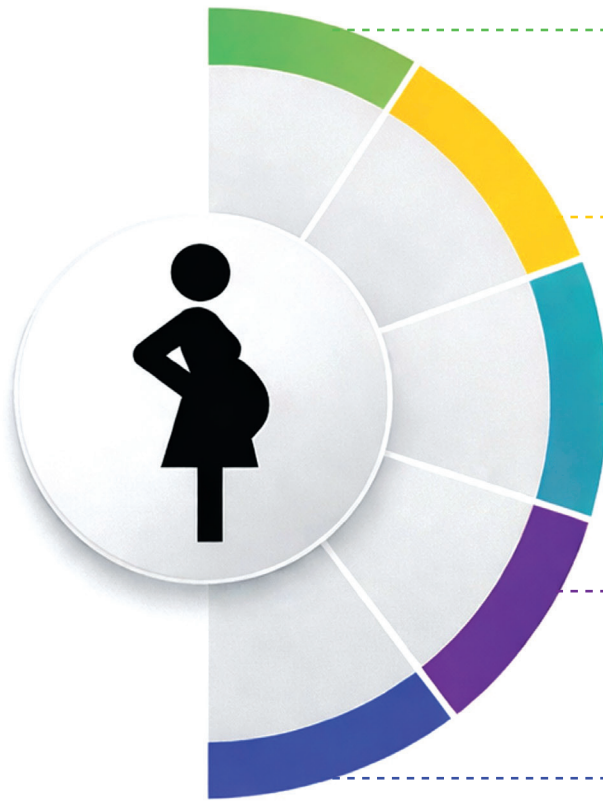
Support for pregnant CCL workers should include the following:

1. Safe and confidential access advice, information, and evidence-based data on radiation safety during pregnancy.
2. Safe and confidential access to tools for more frequent monitoring, ideally with case-by-case feedback on dose (such as the Mirion DMC 3000 electronic radiation dosimeter [Mirion] or similar) or at least monthly monitoring information from standard radiation badge monitoring.
3. A personal protective equipment (PPE) check by a radiation safety officer to assess the integrity of the lead gown(s) in use, ensuring no cracks in the gown that would cause a loss of integrity of garment shielding (often caused by improper storage or folding).
4. Provision of lead gowns with breast shielding (pauldron) and of various sizes allowing crossover at the torso and

Table 3. Comparison of radiation safety practices across the Asia-Pacific, US, and Europe.

Metric	APAC	United States	Europe
Use of personal dosimeter	73.36% wear dosimeters in WIN-APSIC survey	82% use a dosimeter (interventional echocardiographers) ²²	64.4% (EAPCI survey, 2012)
Formal radiation safety training	76.42% in WIN-APSIC survey in APSIC member countries	70% received some radiation training (interventional echocardiographers) ²² ; 82% had formal radiation safety training	~28% of interventional echocardiographers had periodic radioprotection training (EACVI survey) ²¹ ; 77% of radiographers received training (2025)
Awareness of annual dose	7.96% awareness	20% were aware of their annual dose (interventional echocardiographers) ²² ; 19% were aware of their annual dose	20% among interventional imagers (EACVI survey, 2024); 65.9% reviewed data, 7% annually (EAPCI survey, 2012)

APAC: Asia-Pacific; APSIC: Asian Pacific Society of Interventional Cardiology; EACVI: European Association of Cardiovascular Imaging; EAPCI: European Association of Percutaneous Cardiovascular Interventions; WIN-APSIC: Women-in-Asian Pacific Society of Interventional Cardiology



0.09 mSv
Estimated total radiation dose to the foetus of a working pregnant female during the entire gestation

0.3 mSv
Under-lead dose for working pregnant female during the entire gestation

≤1 mSv
Legal dose limit (in lab) for the entire gestation in Australia, Bangladesh, Indonesia, India, Israel, New Zealand, & UK

2.4 mSv
Annual natural background radiation dose worldwide

5 mSv
Legal dose limit (in lab) for the entire gestation in the USA

Figure 1. Foetal radiation exposure in pregnant interventionalists compared with regulatory and natural background limits. Comparison of estimated foetal radiation exposure (0.09 mSv), cumulative under-lead dose (0.3 mSv), occupational radiation dose limits during pregnancy (≤1 mSv in several countries and 5 mSv in the USA), and average annual natural background radiation (2.4 mSv). mSv: millisievert

Table 4. Radiation exposure limit for total pregnancy in different countries based on current policies.

Radiation exposure limit for total pregnancy	Countries
≤ 1 mSv	Australia, India, Bangladesh, Indonesia, Japan, United Kingdom, Israel
4 mSv	Canada
5 mSv	United States
Not allowed	Singapore, Austria, Hungary, Italy, Portugal, Romania

Examples of current national policies governing occupational radiation exposure during pregnancy. Limits refer to the total permitted occupational exposure during pregnancy; some countries prohibit occupational radiation exposure during pregnancy. mSv: millisievert

- abdomen throughout all stages of pregnancy so the benefit of front crossover shielding is not lost because of poor fit.
5. Provision of radiation safety refresher courses to pregnant staff and those working with them to reduce exposure.
 6. Ensuring that decisions made about ongoing work in the lab are led by the person who is pregnant. Informed

decisions to stay in the lab (with appropriate monitoring and shielding) or, alternatively, to self-limit lab time should ultimately be a choice made by the pregnant worker and allowed without career or financial penalty (**Figure 2**).

Recommendations and requirements

OPERATOR TRAINING/EDUCATION

Radiation-safety education should be mandatory for all CCL staff. Training should cover terminology, hazards, ALARA principles, practical dose-reduction techniques, and regular refreshers; structural imagers should be included.^{21,31} CCLs should also provide routine dose reporting, preferably monthly, and formal radiation-safety programmes led by radiation protection officers.^{32,33}

INNOVATIONS IN RADIATION PROTECTION

Novel protection systems can reduce scatter beyond traditional lead PPE. Dedicated architectural shielding is particularly important for IEs, who work close to the radiation source. Current protection systems include the following:

1. Suspended radiation protection systems: individual operator suspended radiation protection systems, such as the Zero-Gravity system, are specifically designed to

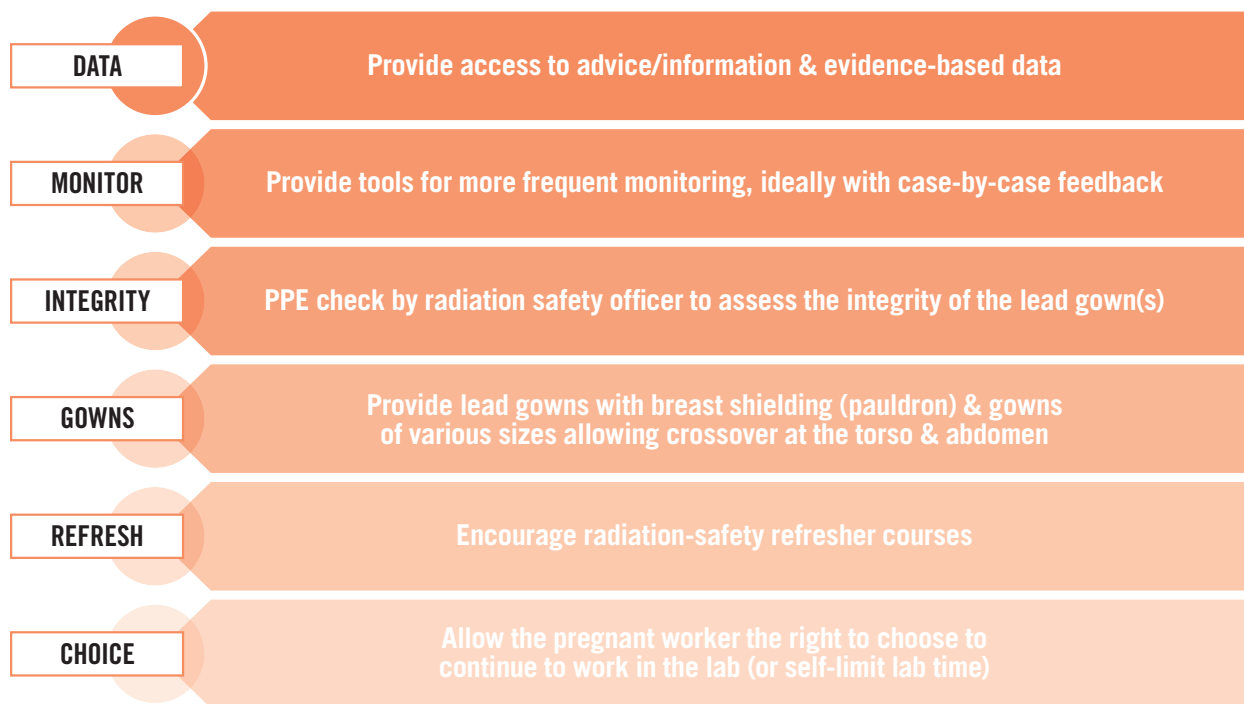


Figure 2. Strategies to enhance radiation safety for pregnant healthcare workers in the cardiac catheterisation laboratory. Key measures include access to evidence-based information, individualised radiation monitoring, regular assessment of protective equipment integrity, provision of appropriately fitted lead gowns with breast shielding, radiation safety refresher training, and informed choice regarding continued laboratory work during pregnancy. PPE: personal protective equipment

enhance radiation protection to the primary operator (interventional cardiologist or electrophysiologist) while eliminating the burden of the lead apron weight.³¹ This system comprises a 1.0 mm suspended lead body shield that magnetically engages with a vest worn by the primary operator, attached to a 0.5 mm lead acrylic face shield. Compared with conventional lead aprons with under-table or ceiling-mounted shields, suspended radiation protection systems have been shown to provide enhanced radiation protection, with a 93.8-94.0% reduction in head-level physician radiation dose.³⁵ Reductions in fatigue and orthopaedic injury are also noted.³⁶ These systems are designed to protect only the first operator, and they do not decrease radiation exposure to other members of the CCL team.

2. Robotic percutaneous systems: robotic-assisted percutaneous coronary intervention (R-PCI), wherein a remote-controlled robotic system is used to undertake PCI with the operator either outside the CCL or at a remote location, has potential for addressing both a reduction in radiation exposure and the mitigation of orthopaedic issues resulting from lead apron use. R-PCI systems include the CorPath 200, the CorPath GRX system (both Corindus/Siemens Healthineers), and the R-One system (Robocath).³⁷ With enhanced improvements, these systems resulted in significantly reduced radiation exposure to the operators (up to 96% reduction),³⁰ with the potential to also undertake more complex lesion subsets, making them particularly useful in peripheral

interventions. A randomised controlled trial³⁸ – the PARTY trial – of a robotic-assisted system has been performed and found patient and operator radiation doses were reduced. However, the system has been withdrawn commercially.

3. Portable radiation-shielding systems: portable radiation-shielding systems, such as the RAMPART ic M1128 (Rampart), provide adjustable radiation protection shield systems, with the intention of offering “lead-free” full-bodied radiation protection for CCL staff (where local radiation policy permits).³¹ Preliminary data suggest that portable radiation-shielding systems may significantly reduce total body radiation exposure compared with traditional lead aprons and shields (LAS), but further independent large-scale research is required. Current early studies suggest reduced radiation exposure to body areas not traditionally protected by LAS, such as the head, and radiation attenuation to all members of the procedural team.³⁶ The potential benefits of lead apron-free work are promising, suggesting reduced pain and fatigue, and the potential to reduce orthopaedic injury. Data showed significant protection for the primary operator (for all dosimeter locations) as well as for the second operator and scrub nurses, with reductions between 50% and 100%.³² One of the limitations of the RAMPART system is that it is not designed to attenuate radiation to the left side of the CCL, thus its utility is limited for staff who work exclusively on the left side of the patient, namely, IEs and anaesthesiologists.³⁶⁻³⁸ Disposable radiation protection shields like RADPAD

Table 5. APSIC recommendations for reducing radiation and ergonomic occupational risk in CCLs.

Level/domain	Recommendation
Operator level – radiation hazard prevention	Educational programmes should start during training years, when habits develop, and continue throughout one's career.
	Adopt safe practices: limit cine runs, wear appropriate radiation protection gear, wear monitoring devices, place protective shields, and create distance from the scatter source (Table 6).
Operator level – ergonomic/ musculoskeletal hazard prevention	Improving awareness of radiation dangers and safe practices through continuous education is a collective responsibility of individual operators, CCL personnel, hospital administration, and societies.
	Use weight-distributing, two-piece pelvic-support apron designs rather than single-piece wraparound aprons.
	Participate in structured core-strengthening/stretching exercise programmes; only 32% of WIN-APSiC respondents currently do so.
Interventional echocardiographer checklist	Take scheduled breaks and rotate operators during long or high-volume procedure days; seek physiotherapy/occupational health review if symptomatic.
	Position self on the image-detector side near the patient's head whenever possible; request advance notice of steep RAO/cranial views.
	Use ceiling-suspended and mobile upright shields consistently; wear thyroid shield, glasses, leaded gloves, and forearm shield.
Institutional level	Wear ≥ 2 body dosimeters plus a finger/extremity dosimeter for every case; review dose data quarterly; favour TTE-first strategies where appropriate.
	Update systems and provide protective gear, with regular checks for cracks, particularly at the seams, as a fundamental institutional requirement.
	Continuous monitoring and regular reporting of exposure to all CCL personnel and operators (including pregnant females) is key to improving individual habits.
	Room layout for novel procedures is important to ensure radiation protection is optimal for all team members, including IEs and the anaesthesia team.
	Provide access to lightweight/composite apron materials and, where feasible, use suspended or robotic systems that remove the apron burden entirely.
Policy level	Consider real-time dosimetry and AI-assisted dose-optimisation/advanced collimation technology at equipment procurement or upgrade, balanced against cost and resource availability (Table 7).
	Societies & authorities should elaborate a practical guide for interventional cardiologists, imagers, anaesthesiologists, and support staff to use during complex interventions:
	Step 1 – mandate the use of dedicated shields (under-table-mounted shield, ceiling-mounted shield, mobile upright or “perforated” shield, examples shown in Figure 3) for the IEs or anaesthesiologists.
	Step 2 – utilise personal wearable protective devices and extremity shields (gloves, forearm/lower-limb shield) where Step 1 protection is inadequate.
	Step 3 – position IEs & anaesthesiologists at the head or right side of the patient whenever possible.
	Step 4 – limit TOE probe or endotracheal tube manipulation or transthoracic scanning during cinefluorography.
	Authorities should provide a central monitoring system that reports exposure doses back to institutions and individuals.
	Authorities/societies could incentivise institutions with safer practices.
	Authorities should require licensure or certification to use fluoroscopy equipment.
	Authorities/societies should formally recognise both radiation-related and ergonomic/musculoskeletal conditions as occupational hazards, given that awareness of this recognition is currently low across the region.

APSiC recommendations for reducing radiation-related and ergonomic/musculoskeletal occupational risk at operator, interventional echocardiographer, institutional, and policy levels. AI: artificial intelligence; APSiC: Asian Pacific Society of Interventional Cardiology; CCL: cardiac catheterisation laboratory; IE: interventional echocardiographer; RAO: right anterior oblique; TOE: transoesophageal echocardiography; TTE: transthoracic echocardiography; WIN-APSiC: Women-in-Asian Pacific Society of Interventional Cardiology

(Worldwide Innovations & Technologies) and SorbX (AngioSystems) are other cost-effective alternatives that can be considered to attenuate scatter radiation. They have the added advantage of being absorbent and easy to use.

- Mobile radiation protection cabins: mobile radiation protection cabins, such as the Cathpax AIR (Lemer Pax), provide shielding of 1.0-2.0 mm of lead equivalence.³⁹ A pilot unrandomised early feasibility study reported first-operator relative radiation exposure reduction of 78% at the chest and 70% at the wrist.³⁹ The effect on the non-physician CCL team has not been examined.

OTHER COMMERCIALY AVAILABLE RADIATION PROTECTION SYSTEMS

Other systems include Protego (Image Diagnostics), a fixed barrier designed for lead apron-free work. A pilot cohort reported an approximately 99% reduction in operator head-and-waist-level doses.⁴⁰ Evidence for several proprietary systems remains largely preliminary or industry-sponsored.

Although novel systems can markedly reduce operator dose, the cost and infrastructure requirements limit their applicability across APAC, particularly in LMICs. Resource-limited CCLs should prioritise lower-cost measures such as radiation-absorbent drapes, optimised conventional shielding,

421 **Table 6. Practical ALARA/ALADA checklist for daily practice – containing the primary beam and scatter radiation.**

422 Category	423 Measure	424 Practical action in daily CCL practice
425 Primary beam/ 426 patient equipment	427 Collimation	428 Collimate tightly to the anatomical region of interest for every acquisition
	429 Frame/pulse rate	430 Use the lowest acceptable fluoroscopy frame rate (e.g. 7.5-15 fps rather than 30 fps) as default
	431 Magnification & angulation	432 Avoid unnecessary magnification; minimise steep RAO/cranial views where an alternative view suffices
	433 Filtration & source distance	434 Maximise tube-to-patient distance; keep detector as close to the patient as possible
435 Scatter/staff 436 protection	437 Cine/acquisition	438 Restrict cine runs to essential acquisitions; use last image hold instead of repeat fluoroscopy
	439 Positioning	440 Stand on the image detector side; maximise distance from the source (inverse square law)
	441 Structural shielding	442 Use ceiling-suspended shields, under-table lead skirts, and mobile barriers for all team members
	443 Personnel	444 Minimise the number of staff within the primary procedural field
445 Monitoring	446 Personal protective equipment	447 Wear lead apron, thyroid shield, radiation glasses; wear extremity/finger dosimeter for high-exposure roles
	448 Dosimetry	449 Wear assigned dosimeter(s) for every case; review individual dose data at least quarterly

450 Practical daily measures to reduce the primary X-ray beam, patient exposure, and scatter radiation to catheterisation laboratory staff, consistent with
451 ALARA/ALADA principles. ALADA: As Low As Diagnostically Acceptable; ALARA: As Low As Reasonably Achievable; CCL: cardiac catheterisation
452 laboratory; fps: frames per second; RAO: right anterior oblique

453 **Table 7. Comparison of novel radiation protection systems, including feasibility in lower-resource (LMIC) Asia-Pacific settings.**

454 System	455 Pros	456 Cons	457 Limitations	458 Cost issues	459 LMIC feasibility
460 Zero-Gravity 461 suspended radiation 462 protection system ^a	463 ~94% reduction in head-level 464 operator radiation; removes 465 weight burden; reduces fatigue/ 466 orthopaedic injury; allows mobility	467 Only protects the 468 primary operator; does 469 not protect other staff	470 Requires compatibility 471 with room layout and 472 ceiling mounting	473 High initial 474 installation cost; 475 infrastructure 476 modifications 477 may be required	
478 Robotic PCI 479 systems	480 Up to ~96% reduction in operator 481 radiation exposure; operator can 482 work outside radiation field; 483 reduces orthopaedic strain; 484 improves procedural precision	485 Learning curve; longer 486 setup time; limited 487 tactile feedback	488 Currently limited 489 availability; not suitable 490 for all lesion types; 491 requires trained staff	492 Very high capital 493 cost (purchase, 494 maintenance, 495 disposables)	
496 RAMPART ic 497 M1128 portable 498 radiation-shielding 499 system ^b	500 Lead-free full-body protection; 501 protects entire procedural team; 502 reduces exposure to areas not 503 covered by aprons; portable and 504 adjustable	505 May interfere with 506 procedural workflow; 507 requires space/ 508 positioning adjustments	509 Does not shield left 510 side of cath lab 511 effectively; limited 512 protection for imagers/ 513 anaesthesiologists on 514 the left side	515 Moderate-high 516 cost; 517 maintenance and 518 space 519 considerations	
520 Protego radiation 521 protection system ^c	522 Up to 99% reduction in operator 523 radiation exposure; eliminates 524 need for heavy lead aprons; 525 comprehensive shielding barrier	526 Non-portable; requires 527 fixed installation	528 Limited evidence, 529 mostly single-centre; 530 may not fit all lab 531 layouts	532 High installation 533 cost and 534 infrastructure 535 modification 536 requirements	
537 Disposable drapes 538 (RADPAD ^d , SorbX ^e) 539 & basic shielding 540 upgrades	541 Low cost; no infrastructure 542 change; immediately deployable; 543 absorbent, easy to use	544 Attenuation less than 545 dedicated barrier 546 systems	547 Single-use/consumable 548 costs accrue over time	549 Low	550 High

551 Comparison of selected contemporary radiation-protection technologies according to their potential benefits, disadvantages, practical limitations, cost
552 considerations, and applicability in lower-resource settings. ^aBy TIDI Products; ^bby Rampart; ^cby Image Diagnostics; ^dby Worldwide Innovations &
553 Technologies; ^eby AngioSystems. CCL: cardiac catheterisation laboratory; LMIC: low- and middle-income countries; PCI: percutaneous coronary
554 intervention

555 and rigorous training and positioning, reserving proprietary
556 systems for settings where resources permit. Regional
557 procurement initiatives may improve affordability.

558 ROOM LAYOUT, PROTECTIVE INITIATIVES, AND THE 559 IMAGING ECHOCARDIOGRAPHER

560 Ceiling-mounted shields with retractable flexible protection
561 can accommodate C-arm rotation and improve bedside
562 protection for imaging and interventional operators.

563 Structural interventions increasingly require IEs positioned
564 close to the patient and radiation source. Transoesophageal
565 echocardiography (TOE) provides essential soft-tissue,
566 flow, and three-dimensional imaging, but frequent probe
567 manipulation increases exposure, while formal radiation-
568 safety training remains limited.⁴¹

569 McNamara et al reported higher per-case exposure for IEs
570 than interventionalists despite a dedicated shield.⁴² Hands
571 and feet may receive substantial exposure during probe

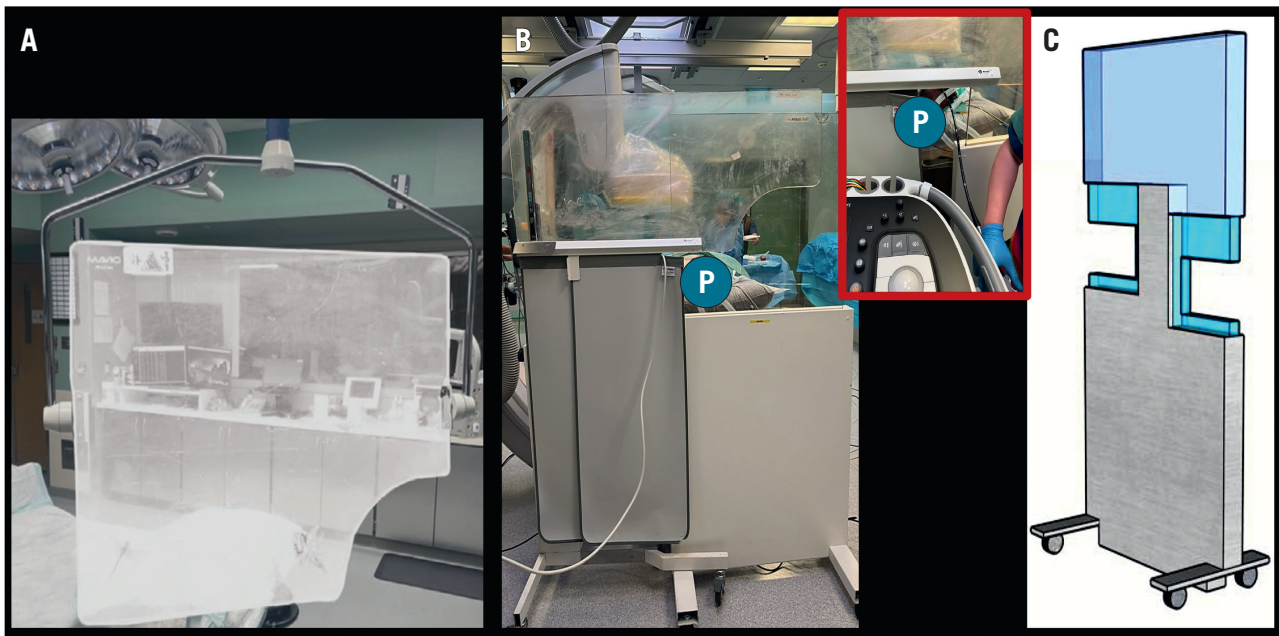


Figure 3. Examples of radiation protection shielding for interventional echocardiographers during transcatheter structural heart interventions. A) Ceiling-suspended transparent radiation shield. B) Mobile radiation protection barrier with transparent upper shielding and lead-lined lower panel, illustrating the protected position (P) behind the barrier. C) Mobile radiation protection shield with adjustable transparent upper panels and a lead-lined lower section.

manipulation. An additional ceiling-suspended lead shield reduced IE exposure by 82% in the study by Crowhurst et al.¹⁴

IE exposure also depends on procedure complexity, fluoroscopy time, and projection. Steep right anterior oblique (RAO) views produce high exposure,⁴³ whereas left anterior oblique views are lower.⁴⁴ Repositioning during steep RAO projections is therefore advisable. TOE guidance has been associated with an approximately threefold higher radiation dose than transthoracic echocardiography (TTE) guidance;⁴⁴ fluoroscopy should also be minimised during TTE scanning.

Anaesthesiologists remain near the patient's head during structural procedures and should be protected by mobile shielding. Although their effective dose may be lower than the interventionalist's, appropriate shielding remains essential.

Radioprotection remains based on time, distance, and shielding. Minimising fluoroscopy, maximising distance, and using echocardiography when appropriate reduce team exposure; longer or remotely controlled ultrasound probes may offer further benefit.

New structural CCLs should incorporate dedicated IE shielding (Table 5, Table 6, Table 7), including table-mounted lower-body skirts and ceiling-mounted or upright mobile shields (Figure 3A). IEs should use appropriate eye, thyroid, and hand/forearm protection, as well as body and extremity dosimetry with regular dose review.

In practice, IE protection requires optimised positioning, advance warning of steep RAO/cranial views, consistent use of ceiling/mobile shields, appropriate PPE, body and extremity dosimetry, regular dose review, and TTE-first guidance when clinically appropriate (Table 5).

Conclusions

Global and WIN-APSIC data demonstrate persistent APAC gaps in training, shielding, dosimetry, policy, and ergonomic protection. The priorities are mandatory training, standardised dose reporting, equitable access to protection, and pregnancy-inclusive policies. Emerging dose-reduction technologies may add benefit but should be implemented according to regional resources. These measures can improve safety and equity across APAC.

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Conflict of interest statement

The authors have no conflicts of interest to declare.

References

1. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Ann ICRP*. 2007;37:1-332.

2. Authors on behalf of ICRP; Stewart FA, Akleyev AV, Hauer-Jensen M, et al. ICRP publication 118: ICRP statement on tissue reactions and early and late effects of radiation in normal tissues and organs--threshold doses for tissue reactions in a radiation protection context. *Ann ICRP*. 2012;41:1-322.
3. Roguin A, Goldstein J, Bar O, Goldstein JA. Brain and neck tumors among physicians performing interventional procedures. *Am J Cardiol*. 2013;111:1368-72.
4. Elmaraezy A, Ebraheem Morra M, Tarek Mohammed A, et al. Risk of cataract among interventional cardiologists and catheterization lab staff: A systematic review and meta-analysis. *Catheter Cardiovasc Interv*. 2017;90:1-9.
5. Abdelhalim MA, Patel A, Moquet J, et al. Higher Incidence of Chromosomal Aberrations in Operators Performing a Large Volume of Endovascular Procedures. *Circulation*. 2022;145:1808-10.
6. Buchanan GL, Chieffo A, Mehili J, et al. The occupational effects of interventional cardiology: results from the WIN for Safety survey. *EuroIntervention*. 2012;8:658-63.
7. Ballatore A, Casella M, Moscoso Costa F, et al. Radiation Awareness and X-Ray Use in Cardiology: An International Independent Web-Based Survey. *J Interv Cardiol*. 2024;2024:2247603.
8. Cader FA, Thamman R, Burgess S, et al. TCT-742 Radiation Hazards and Safety Among Physicians and Allied Health Practitioners (AHP) in Invasive Cardiology Procedures. *J Am Coll Cardiol*. 2024;84:B295-6.
9. Cousins C, Miller DL, Bernardi G, et al. ICRP PUBLICATION 120: Radiological protection in cardiology. *Ann ICRP*. 2013;42:1-125.
10. Gutierrez-Barrios A, Cañadas-Pruaño D, Noval-Morillas I, Gheorghe L, Zayas-Rueda R, Calle-Perez G. Radiation protection for the interventional cardiologist: Practical approach and innovations. *World J Cardiol*. 2022;14:1-12.
11. Hirshfeld JW Jr, Ferrari VA, Bengel FM, et al. 2018 ACC/HRS/NASCI/SCAI/SCCT Expert Consensus Document on Optimal Use of Ionizing Radiation in Cardiovascular Imaging: Best Practices for Safety and Effectiveness: A Report of the American College of Cardiology Task Force on Expert Consensus Decision Pathways. *J Am Coll Cardiol*. 2018;71:e283-351.
12. Ishibashi T, Takei Y, Sakamoto H, et al. [Nationwide Survey of Medical Radiation Exposure on Cardiovascular Examinations in Japan]. *Nihon Hoshasen Gijutsu Gakkai Zasshi*. 2020;76:64-71. Japanese.
13. Crowhurst JA, Whitby M, Thiele D, et al. Radiation dose in coronary angiography and intervention: initial results from the establishment of a multi-centre diagnostic reference level in Queensland public hospitals. *J Med Radiat Sci*. 2014;61:135-41.
14. Crowhurst JA, Scalia GM, Whitby M, et al. Radiation Exposure of Operators Performing Transesophageal Echocardiography During Percutaneous Structural Cardiac Interventions. *J Am Coll Cardiol*. 2018;71:1246-54.
15. Srimahachota S, Krisanachinda A, Roongsangmanoon W, et al. Establishment of national diagnostic reference levels for percutaneous coronary interventions (PCIs) in Thailand. *Phys Med*. 2022;96:46-53.
16. Uthirapathy I, Dorairaj P, Ravi S, Somasundaram S; ACERT group - Associates for Cardiology Education and Research in Tamilnadu. Knowledge and practice of radiation safety in the Catheterization laboratory among Interventional Cardiologists - An online survey. *Indian Heart J*. 2022;74:420-23.
17. Subban V, Amelot S, Victor SM, et al. Radiation doses during cardiac catheterisation procedures in India: a multicentre study: Radiation dose study. *AsiaIntervention*. 2020;6:25-33.
18. Siiskonen T, Ciraj-Bjelac O, Dabin J, et al. Establishing the European diagnostic reference levels for interventional cardiology. *Phys Med*. 2018;54:42-8.
19. Picano E, Vano E. The radiation issue in cardiology: the time for action is now. *Cardiovasc Ultrasound*. 2011;9:35.
20. Ghatan C, Kothary N. Radiation Safety Considerations for the Female Interventionist. *Endovascular Today*. 2016;15:70-72.
21. Galli E, Soliman-Aboumarie H, Gargani L, et al. EACVI survey on radiation exposure in interventional echocardiography. *Eur Heart J Cardiovasc Imaging*. 2024;25:727-34.
22. Wessly P, Garcia-Sayan E, Quader N, Little S, Khalique O, Jain R. Radiation Realities: Radiation Safety Practices and Awareness Among Interventional Echocardiographers in the United States. *Struct Heart*. 2025;10:100785.
23. Mendonça RP, Estrela C, Bueno MR, Carvalho TCASG, Estrela LRA, Chilvarquer I. Principles of radiological protection and application of ALARA, ALADA, and ALADAIP: a critical review. *Braz Oral Res*. 2025;39:e14.
24. Hattori K, Inaba Y, Kato T, et al. Evaluation of a New Real-Time Dosimeter Sensor for Interventional Radiology Staff. *Sensors (Basel)*. 2023;23:512.
25. Shaghghi Z, Javid RN, Alvandi M. Advancements in Cardiac Catheterization Safety: Novel Radiation Protection Approaches Redefining Occupational Health. *Curr Cardiol Rev*. 2025;21:e1573403X304828.
26. Weiss JF, Landauer MR. History and development of radiation-protective agents. *Int J Radiat Biol*. 2009;85:539-73.
27. Sahni S, Chieffo A, Balter S. Radiation safety in the practice of cardiology: what all women should know. Women as One. Radiation safety toolkit. <https://rad.womenasone.org/> (Last accessed 25 Sep 2026).
28. Burgess SN, Alasnag M, Haan LI, et al. Radiation Safety for Women in Cardiology: Myths and Important Messages. *Indian Journal of Cardiovascular Disease in Women*. 2024;9:102-8.
29. Burgess S, Shaw E, Ellenberger K, Thomas L, Grines C, Zaman S. Women in Medicine: Addressing the Gender Gap in Interventional Cardiology. *J Am Coll Cardiol*. 2018;72:2663-7.
30. Manzo-Silberman S, Velázquez M, Burgess S, et al. Radiation protection for healthcare professionals working in catheterisation laboratories during pregnancy: a statement of the European Association of Percutaneous Cardiovascular Interventions (EAPCI) in collaboration with the European Heart Rhythm Association (EHRA), the European Association of Cardiovascular Imaging (EACVI), the ESC Regulatory Affairs Committee and Women as One. *EuroIntervention*. 2023;19:53-62.
31. ICRP IC on RP. ICRP Annual Report 2011. Ottawa: International Commission on Radiological Protection; 2011. <https://www.icrp.org/docs/ICRP%20Annual%20Report%202011.pdf>. 2011.
32. Tamirisa KP, Alasnag M, Calvert P, et al. Radiation Exposure, Training, and Safety in Cardiology. *JACC Adv*. 2024;3:100863.
33. Chambers CE, Fetterly KA, Holzer R, et al. Radiation safety program for the cardiac catheterization laboratory. *Catheter Cardiovasc Interv*. 2011;77:546-56.
34. Anon. BIOTRONIK. Zero-Gravity radiation protection system. BIOTRONIK website. Available at: <https://www.biotronik.com/en-us/products/services/zero-gravity>. Accessed March 17, 2026
35. Salcido-Rios J, McNamara DA, VanOosterhout S, et al. Suspended lead suit and physician radiation doses during coronary angiography. *Catheter Cardiovasc Interv*. 2022;99:981-8.
36. Lisko JC, Shekiladze N, Chamoun J, et al. Radiation Exposure Using Rampart vs Standard Lead Aprons and Shields During Invasive Cardiovascular Procedures. *J Soc Cardiovasc Angiogr Interv*. 2023;3:101184.
37. Durand E, Sabatier R, Smits PC, Verheye S, Pereira B, Fajadet J. Evaluation of the R-One robotic system for percutaneous coronary intervention: the R-EVOLUTION study. *EuroIntervention*. 2023;18:e1339-47.
38. Leung J, French J, Xu J, et al. A randomised clinical trial investigating robotic-assisted percutaneous coronary intervention: the PARTY trial. *AsiaIntervention*. 2026;12:e136-45.
39. Gutierrez-Barrios A, Angulo-Pain E, Noval-Morillas I, et al. The radioprotective effect of the Cathpax® AIR cabin during interventional cardiology procedures. *Catheter Cardiovasc Interv*. 2021;98:E523-30.
40. Image Diagnostics Inc. Protego® Radiation Protection System. <https://get-protego.com/> (Last accessed 25 Sep 2026).
41. Schubert S, Kainz S, Peters B, Berger F, Ewert P. Interventional closure of atrial septal defects without fluoroscopy in adult and pediatric patients. *Clin Res Cardiol*. 2012;101:691-700.
42. McNamara DA, Chopra R, Decker JM, et al. Comparison of Radiation Exposure Among Interventional Echocardiographers, Interventional Cardiologists, and Sonographers During Percutaneous Structural Heart Interventions. *JAMA Netw Open*. 2022;5:e2220597.
43. Yanagawa A, Takata T, Onimaru T, et al. New perforated radiation shield for anesthesiologists: Monte Carlo simulation of effects. *J Radiat Res*. 2023;64:379-86.
44. Olgun Kucuk H, Fetterly KA, Betz JL, Pislaru S V., Rihal CS, Pellikka PA, Wiley BM. Interventional Echocardiographer Radiation Exposure Varies With Procedure Type and Echocardiography Modality. *Journal of the American Society of Echocardiography*. 2024;37:110-112.