

RADIATION EXPOSURE AND PROTECTIVE PRACTICES IN RADIOLOGY TECHNICIANS: A SYSTEMATIC REVIEW OF OCCUPATIONAL RISKS, DOSE REDUCTION, AND SAFETY STRATEGIES

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Abstract

Background: Radiology technicians and interventional staff are routinely exposed to ionizing radiation, posing risks of cataracts, malignancies, and cumulative occupational hazards. Although protective measures and dose-reduction technologies exist, adherence and implementation vary in clinical settings. This systematic review aimed to evaluate radiation exposure levels and protective strategies among radiology personnel. **Methods:** This review followed PRISMA guidelines. PubMed, Scopus, and Web of Science were searched for randomized controlled trials and prospective comparative studies. Eligible studies assessed protective measures, dose-optimization protocols, or imaging technologies intended to reduce radiation exposure. Outcomes included effective dose, dose-area product, fluoroscopy time, and staff exposure metrics. Ten studies met inclusion criteria. **Results:** in different procedures, including ERCP, cardiac catheterization, atrial fibrillation ablation, orthopedic fixation, spinal surgery, hemodialysis access, and PET-CT, protective drapes, navigation systems, advanced X-ray technologies, and optimized protocols consistently reduced staff radiation exposure, often by 65–99%. Patient exposure varied, with some technologies increasing patient dose while reducing staff exposure. Importantly, dose-reduction strategies did not compromise procedural success or diagnostic accuracy. Variability in adoption in healthcare systems highlights ongoing gaps in protection practices and knowledge. **Conclusion:** Radiology technicians remain at significant occupational risk from ionizing radiation. Evidence supports the efficacy of protective devices, optimized imaging protocols, and advanced technologies in reducing exposure. Consistent implementation, combined with education and adherence to ALARA principles, is critical to safeguard both patients and staff.

Keywords: Radiation Exposure, Radiology Technicians, Fluoroscopy, Occupational Safety, Protective Practices, ALARA, Dose Reduction.

INTRODUCTION

Radiation exposure remains a central occupational hazard for radiology technicians and interventional staff in different clinical settings. Despite technological advances, procedures involving fluoroscopy and interventional radiology continue to subject both patients and healthcare professionals to significant ionizing radiation, raising concerns about long-term safety and protection strategies (Resch et al. 2016).

The biological risks of chronic low-dose radiation exposure among operators have been well-documented, with associations to cancer induction, radiation-induced cataracts, and heightened concerns for pregnant operators (Stahl et al. 2016). Although the stochastic effects of low-level exposure remain controversial, the potential cumulative risk has prompted calls for more rigorous protection practices.

Protective measures such as shielding, dosimetry, and maintaining distance from radiation sources form the cornerstone of radiation safety. However, adherence to these measures remains inconsistent in practice settings, particularly in resource-limited environments (König et al. 2019). Evidence shows that gaps in knowledge and practice contribute to unnecessary exposure for both staff and patients, highlighting the need for standardized education and continuous training programs (Park et al. 2022).

Studies underscore that while advanced imaging technologies, flat-panel detectors, pulsed fluoroscopy, and automated exposure control, reduce radiation dose, they are not uniformly implemented in healthcare systems worldwide (Marengo et al. 2021; Kaatsch et al. 2021). This disparity places certain groups of radiology personnel, especially those in high-volume centers, at greater occupational risk.

Epidemiological findings also emphasize the importance of monitoring cumulative occupational dose. Reports linking interventional cardiologists and radiologists to increased risk of brain cancer and cataracts, although limited by methodological constraints, reinforce the urgency of adopting evidence-based safety protocols (Al-Shakhrah et al. 2000; Arthur et al. 2002).

At the same time, awareness campaigns have proven to mitigate maladaptive fear, which could otherwise deter trainees from pursuing careers in interventional radiology (Stahl et al. 2016).

Recent reviews highlight the principle of ALARA (As Low as Reasonably Achievable) as the guiding framework, yet practice variations suggest that further research is needed to understand barriers to adherence and to develop interventions tailored for different settings (Resch et al. 2016).

These findings indicate the dual challenge: ensuring diagnostic and therapeutic efficacy while safeguarding operators from long-term radiation hazards. This systematic review, therefore, aims to synthesize the available evidence on radiation exposure and protective practices among radiology technicians in different settings, providing a foundation for practice improvements and policy development.

METHODOLOGY

Search Strategy

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A comprehensive literature search was performed in electronic databases including PubMed, Scopus, and Web of Science. The search strategy combined keywords and Medical Subject Headings (MeSH) related to “radiation exposure,” “dose reduction,” “protective measures,” “fluoroscopy,” “interventional cardiology,” “orthopedics,” “endoscopy,” “electrophysiology,” and “spinal surgery.” Boolean operators (AND, OR) were applied to refine results, and references of included studies were manually screened to identify additional eligible articles. Only peer-reviewed articles published in English were considered.

Eligibility Criteria

Study design (Randomized controlled trials or prospective comparative studies). Population: Patients undergoing diagnostic or interventional procedures involving ionizing radiation and healthcare staff exposed during these procedures. Intervention: Any protective measure, imaging protocol, or dose-reduction technology intended to minimize radiation exposure. Outcomes: Quantitative measurement of radiation exposure to patients and/or staff, expressed as effective dose, dose-area product, fluoroscopy time, or equivalent metrics.

Studies were excluded if they were case reports, editorials, reviews, animal studies, simulation-only models, or lacked direct measurement of radiation exposure outcomes.

Study Selection

Two reviewers independently screened titles and abstracts for relevance. Full-text articles were assessed for eligibility, and discrepancies were resolved through discussion or by consulting a third reviewer. A PRISMA flow diagram was used to document the screening and selection process.

Data Extraction

Data were extracted independently by two reviewers using a standardized form. Extracted variables included: author and year, study design, sample size, patient and staff characteristics, type of procedure, intervention or imaging protocol, method of radiation measurement, and reported outcomes. For consistency, all radiation exposure values were recorded in their original reported units (mSv, μ Sv, Gy·cm², fluoroscopy time).

Quality Assessment

The methodological quality and risk of bias of the included randomized controlled trials were assessed using the Cochrane Risk of Bias tool. Domains evaluated included sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessors, incomplete outcome data, selective reporting, and other sources of bias. Each domain was rated as low, high, or unclear risk of bias.

Data Synthesis

Due to heterogeneity in study designs, interventions, and outcome reporting, a narrative synthesis was performed. Results were organized thematically by clinical context: gastrointestinal endoscopy, interventional cardiology, electrophysiology, orthopedic fixation, and spinal surgery. Dose-reduction technologies, protective drapes, navigation systems, and optimized imaging protocols were analyzed in relation to their impact on patient and staff radiation exposure. Quantitative findings such as percentage reduction in radiation dose were highlighted where available.

RESULTS

A total of 10 randomized and prospective studies were included in this review, encompassing different clinical settings such as endoscopy, interventional cardiology, electrophysiology, orthopedics, and spinal surgery. In these studies, a consistent focus was placed on evaluating radiation exposure to patients and healthcare staff and the effectiveness of protective or dose-reduction strategies.

The sample sizes of the included studies ranged from 37 patients in spinal fusion (Bratschitsch et al. 2019) to 1817 patients in PET-CT imaging (Saade et al. 2022). Populations studied included patients undergoing therapeutic ERCP (Muniraj et al. 2015), cardiac catheterization (Patet et al. 2019; Buytaert et al. 2018), atrial fibrillation ablation (Huo et al. 2015), orthopedic fixation for hip fracture (Roukema et al. 2019), and spinal procedures (Hubbe et al. 2015; Bratschitsch et al. 2019). In addition, studies explored dose-reduction strategies in coronary angiography (Park et al. 2020), hemodialysis access interventions (Zhang et al. 2020), and PET-CT imaging (Saade et al. 2022).

Two studies investigated protective drapes during procedures. Muniraj et al. (2015) reported that a radiation-attenuating drape reduced operator and nurse exposure by ~90% during ERCP. Similarly, Patet et al. (2019) demonstrated that the SEPARPROCATH drape achieved an 81% reduction for operators and a 99% reduction for nurses in cardiac catheterization.

Novel imaging systems and navigation technologies were also evaluated. Huo et al. (2015) showed that a fluoroscopy image-integrated electroanatomic mapping system reduced fluoroscopy time by 84% and radiation dose by 73% compared with conventional mapping during atrial fibrillation ablation, without compromising procedural success. In spinal procedures, Hubbe et al. (2015) described a trial protocol comparing conventional fluoroscopy with 3D navigation, while Bratschitsch et al. (2019) found that navigation increased patient exposure but significantly reduced surgeon and staff radiation levels.

Several studies addressed optimized imaging protocols. Roukema et al. (2019) compared direct surgeon-controlled versus technician-operated fluoroscopy during hip fracture fixation and observed shorter adjusted radiation time with indirect acquisition, although no significant differences in dose were found. Buytaert et al. (2018) reported that a new X-ray system with advanced dose-reduction algorithms reduced patient exposure by 67% and staff exposure by 65% during cardiac catheterization. Zhang et al. (2020) showed

that an ultra-low dose protocol reduced radiation exposure for patients, proceduralists, and scrub nurses without loss of image quality in hemodialysis interventions. Park et al. (2020) (ERICA trial) found that a low-dose angiography protocol reduced dose-area product and air kerma compared with conventional dosing while maintaining diagnostic quality.

Saade et al. (2022) demonstrated that weight-based PET-CT protocols lowered effective dose and lifetime attributable cancer risk compared with conventional protocols, without affecting diagnostic accuracy.

Collectively, the evidence highlights substantial variability in radiation exposure depending on procedure type, imaging modality, and protective strategies. Interventions such as radiation-attenuating drapes, advanced imaging systems, navigation techniques, and dose-optimized protocols consistently demonstrated significant reductions in occupational exposure to healthcare staff, with variable effects on patient dose. Importantly, in all studies, radiation reduction strategies did not compromise procedural efficacy, image quality, or patient safety.

Table 1: Summary of Radiation Exposure Studies

Citation	Study Design	Sample Size	Population Characteristics	Method	Study Aim
Muniraj et al. 2015	Double-blind randomized sham-controlled trial	100 ERCP procedures	Patients undergoing therapeutic ERCP; staff included endoscopists and assisting nurse	Radiation-attenuating drape vs sham drape placed around fluoroscopy image intensifier	To assess whether a radiation-attenuating drape reduces radiation exposure to endoscopy staff during ERCP
Roukema et al. 2019	Randomized controlled trial	100 patients (52 direct, 48 indirect)	Patients with hip fracture requiring internal fixation; median age 84 years	Comparison of direct surgeon-controlled fluoroscopy vs indirect technician-operated fluoroscopy	To compare radiation exposure and duration between direct and indirect image acquisition during hip fracture fixation
Huo et al. 2015	Prospective randomized single-blind controlled study	80 patients	Patients with paroxysmal atrial fibrillation undergoing catheter ablation; mean age 63 ± 10 years, 55% men	Randomized to conventional 3D EAM vs novel fluoroscopy-integrated EAM system	To evaluate if the F-EAM system reduces fluoroscopy time and radiation doses during AF ablation
Patet et al. 2019	Prospective randomized pilot comparative study	51 patients	Patients undergoing cardiac catheterization	Comparison of SEPARPROCATH® radiation drape vs	To assess efficacy of SEPARPROCATH® in reducing

				standard shielding	operator and nurse radiation exposure
Hubbe et al. 2015	Randomized controlled trial (study protocol)	40 participants (planned recruitment)	Adults ≥18 years with degenerative lumbar disc disease or instability requiring MIS TLIF	Comparison of conventional fluoroscopy vs 3D fluoroscopy-based navigation in MIS TLIF procedures	To compare radiation exposure of surgeon, staff, and patients during MIS TLIF using different imaging techniques
Bratschitsch et al. 2019	Prospective clinical study	37 patients (19 navigation, 18 fluoroscopy)	Patients undergoing lumbosacral spinal fusion	Measured radiation exposure using dosimeters on patients and OR staff under navigation vs fluoroscopy	To compare radiation exposure of patients and OR staff between navigation and fluoroscopy in spinal surgery
Buytaert et al. 2018	Randomized controlled trial	122 patients	Adult patients undergoing cardiac catheterization	Comparison of reference X-ray system vs new system with advanced dose-reduction technology	To quantify radiation reduction for patients and staff with new X-ray technology in cardiac catheterization
Zhang et al. 2020	Prospective double-blinded randomized controlled trial	80 procedures (40 angioplasties, 40 thrombolysis); 10 proceduralists, 2 radiographers, 11 nurses	Patients undergoing hemodialysis access interventions; medical staff exposed to radiation	Comparison of ultra-low dose protocol (ULDP) vs standard low-dose protocol (LDP)	To assess radiation exposure and image quality under ULDP vs LDP during hemodialysis interventions
Park et al. 2020 (ERICA trial)	Randomized controlled trial (pilot)	103 patients	Patients undergoing invasive coronary angiography	Comparison of low-dose vs conventional-dose protocol during coronary angiography	To evaluate feasibility and effectiveness of low-dose protocol in reducing radiation exposure
Saade et al. 2022	Randomized controlled trial	1817 patients	Patients undergoing FDG PET-CT (full- and half-body)	Weight-based vs conventional CT protocols	To investigate effect of weight-based protocols on radiation dose, image quality, and lifetime attributable risk

Table 2: Demographic Characteristics, Main Findings, and Outcomes

Citation	Demographic Characteristics	Main Findings	Outcomes
Muniraj et al. 2015	Patients undergoing ERCP; endoscopy staff (endoscopists, assisting nurse)	Radiation-attenuating drape reduced radiation by ~90% at endoscopist's eye, neck, and nurse's neck	Estimated annual dose significantly reduced; improved staff safety without affecting procedure
Roukema et al. 2019	100 patients with hip fracture (median age 84 years); randomized to direct vs indirect fluoroscopy	Indirect fluoroscopy showed shorter adjusted radiation duration; no difference in dose or DAP	Indirect technique favored in terms of reduced radiation time but not dose reduction
Huo et al. 2015	80 patients with paroxysmal atrial fibrillation (mean age 63 ± 10 years, 55% men)	Fluoroscopy time reduced by 84% and radiation dose by 73% with F-EAM compared to conventional EAM	Comparable procedural efficacy and recurrence rates; improved radiation safety
Patet et al. 2019	51 patients undergoing cardiac catheterization; operators and nurses assessed	SEPARPROCATH® reduced operator RE by 81% and nurse RE by 99%	Significant radioprotection achieved without affecting DAP or patient safety
Hubbe et al. 2015	Adults ≥18 years with lumbar degenerative disc disease/instability; undergoing MIS TLIF	Protocol study; designed to compare conventional fluoroscopy vs 3D navigation radiation exposures	Expected reduction in staff exposure using 3D navigation while maintaining surgical accuracy
Bratschitsch et al. 2019	37 patients (19 navigation, 18 fluoroscopy) undergoing lumbosacral spinal fusion	Surgeon's radiation higher with fluoroscopy; navigation increased patient dose but reduced staff dose	Navigation safer for staff; trade-off with increased patient radiation exposure
Buytaert et al. 2018	122 adult patients undergoing coronary angiography or PCI	New X-ray system reduced patient dose by 67% and staff leg/C-arm doses by 65%	Improved radiation safety with new technology; no significant collar/chest dose reduction
Zhang et al. 2020	80 hemodialysis access procedures (angioplasty, thrombolysis); 10 proceduralists, 2 radiographers, 11 nurses	Ultra-low dose protocol significantly lowered exposure for patients, proceduralists, and scrub nurses	No compromise in image quality or procedure duration; safer protocol
Park et al. 2020 (ERICA trial)	103 patients undergoing invasive coronary angiography	Low-dose protocol reduced estimated radiation dose (DAP, AK) compared with conventional protocol	Dose reduction achieved without compromising image quality; feasible protocol
Saade et al. 2022	1817 patients undergoing FDG PET-CT (full and half body)	Weight-based protocol reduced mean effective dose and lifetime attributable risk vs conventional protocol	Significant dose reduction without loss of image quality; recommended for PET-CT practice

DISCUSSION

This systematic review highlights that radiation exposure during fluoroscopy-guided procedures remains a significant occupational and patient safety concern. In the included studies, protective devices, optimized imaging protocols, and operator practices consistently demonstrated meaningful reductions in radiation dose, without compromising procedural success or diagnostic accuracy. Findings from the review align with Uradomo et al. (2007), who demonstrated that time-limited fluoroscopy during ERCP reduced

fluoroscopy time by 16.4% after adjusting for confounding factors, emphasizing the role of exposure-time control as a practical protective strategy. Arthur et al. (2002) reported that cardiologist-operated fluoroscopy produced significantly lower radiation doses compared with radiographer-controlled acquisition during coronary angiography, with senior cardiologists achieving the lowest exposure levels. These findings support the importance of operator expertise and careful image acquisition in minimizing unnecessary exposure.

Studies focusing on occupational risks have consistently raised concerns regarding chronic low-level exposure. Stahl et al. (2016) discussed potential long-term hazards such as radiation-induced cataracts and possible cancer risk in interventionalists, underscoring the need for rigorous adherence to protective practices. This is reinforced by Park et al. (2022), who reviewed C-arm use in pain interventions and highlighted scattered radiation as the major source of operator dose, recommending the ALARA principle with emphasis on time, distance, and shielding. The role of personal protective equipment and dosimetry is also central. König et al. (2019) reviewed advancements in radiation protection and highlighted that optimal safety requires combining multiple protective devices, with particular emphasis on shielding the head and eyes, where new lead glasses with integrated dosimeters may significantly reduce cataract risk. Complementary to this, Al-Shakhrah et al. (2000) estimated effective occupational doses during angiographic procedures, reporting mean annual exposures of 2.5 mSv, within international limits but with occasional peaks approaching 16 mSv, stressing the need for consistent dosimetry and dual-monitoring approaches. Broader concerns regarding accidental or unintended exposure were addressed by Marengo et al. (2021), who discussed radiation safety in nuclear medicine. Their work emphasized that even small unintended exposures must be investigated and prevented through stringent quality management, highlighting the universality of radiation protection principles in specialties.

CONCLUSION

This systematic review show that radiation exposure remains a significant occupational hazard for radiology technicians in diverse clinical settings. Evidence from randomized and prospective studies shows that protective drapes, optimized imaging protocols, advanced X-ray technologies, and navigation systems can substantially reduce radiation exposure to healthcare staff, often without compromising procedural efficacy or image quality. Variations in adherence, limited implementation of modern dose-reduction technologies, and inconsistent protective practices continue to place operators at unnecessary risk. Strengthening radiation safety requires not only technological innovation but also standardized protocols, continuous education, and adherence to the ALARA principle.

List of Abbreviations

- AF**, Atrial Fibrillation
- ALARA**, As Low as Reasonably Achievable
- DAP**, Dose-Area Product

EAM, Electroanatomic Mapping

ERICA, Estimated Radiation Exposure Comparison in Angiography (trial)

ERCP, Endoscopic Retrograde Cholangiopancreatography

FDG, Fluorodeoxyglucose

Gy·cm², Gray centimeter squared (dose-area unit)

LDP, Low-Dose Protocol

MIS TLIF, Minimally Invasive Transforaminal Lumbar Interbody Fusion

mSv, Millisievert

PET-CT, Positron Emission Tomography–Computed Tomography

RE, Radiation Exposure

RCT, Randomized Controlled Trial

ULDP, Ultra-Low Dose Protocol

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