RADIATION SAFETY TRAINING PROGRAMS FOR NURSES AND ITS EFFECT ON OCCUPATIONAL EXPOSURE, EYE-LENS PROTECTION, KNOWLEDGE, PRACTICE, AND PATIENT OUTCOMES

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Abstract

Background: Nurses working around fluoroscopy (interventional radiology/cardiology, cath labs, operating rooms, ICUs) face occupational ionizing-radiation risks. Training is a core strategy to reduce exposure and strengthen patient protection, yet formats and effectiveness vary. **Objective:** To synthesize evidence from nine original studies on radiation-safety education and related practices among nurses and allied staff in fluoroscopy-guided environments, and to discuss findings in light of contemporary guidance. **Methods:** Following PRISMA principles, we reviewed nine original studies (training interventions, observational dose/knowledge studies, and one randomized trial). We extracted design, setting, interventions, outcomes (staff dose, knowledge/behavior, patient dose), and key results. **Results:** Virtual-reality (VR) training reduced staff dose (eye dose =15–26% across roles; larger reductions than traditional didactics) and improved knowledge/engagement. Multimedia programs outperformed booklet-only materials for awareness gains among OR staff. ICU-nurse training improved protective behaviors and knowledge, though some PPE use waned over time. Real-time operator alerts before nursing tasks significantly lowered nurses' per-procedure dose. Unit-level lectures and shield-use reinforcement reduced operator and patient doses. Baseline surveys highlighted knowledge gaps and inconsp[istent protection among cath-lab teams and cardiac-unit nurses; short video modules improved test scores. **Conclusions:** Radiation-safety training, especially immersive VR and feedback-aided approaches, improves knowledge and measurably reduces exposure. Sustained reinforcement and practical shielding practices are needed to maintain gains and extend benefits to patient protection.

Keywords: Radiation Safety; Nurses; Interventional Radiology; Cardiac Catheterization; Training; Virtual Reality; ALARA; Occupational Exposure; Patient Dose.

INTRODUCTION

Fluoroscopy-guided procedures have expanded rapidly, exposing staff, especially those near the patient, to scattered radiation and to both deterministic (cataracts, skin effects) and stochastic risks (cancer) (Garg & Shrigiriwar 2021; Biso & Vidovich 2020). In the cath lab, exposure is influenced by case complexity, patient habitus, equipment, and team behaviors; adherence to ALARA and use of shields, real-time monitoring, and optimized technique is central (Miller et al. 2010; Biso & Vidovich 2020). Contemporary surveys also emphasize ergonomic burdens from lead PPE and highlight the need to balance protection with musculoskeletal health (Gasiea et al. 2025). Beyond operators, nurses are often closest to the source during positioning, medication delivery, and device management, making their training and practices pivotal for both staff and patient safety (Garg & Shrigiriwar 2021; Miller et al. 2010).

Evidence and expert guidance converge on several imperatives. First, structured radiation-protection education should be role-specific and recurrent, covering time–distance–shielding, proper PPE, dosimetry (including lens), and practical cath-lab/OR workflows (Miller et al. 2010; Biso & Vidovich 2020). Second, cultivating "radiation safety culture" and literacy across healthcare professions is essential; systematic reviews report persistent knowledge gaps that training must address (Rodrigues et al. 2024). Third, live feedback and modern modalities (real-time dosimetry displays, simulation/VR) can drive behavior change more effectively than passive lectures (Gasiea et al. 2025; Miller et al. 2010). Equitable protection for women of child-bearing potential and pregnant staff requires clear policies, individualized risk assessment, and access to appropriate tools (Biso & Vidovich 2020).

Despite consensus principles, practice variability remains high, and high-quality, nurse-focused intervention studies are fewer than operator-focused research (Gasiea et al. 2025; Rodrigues et al. 2024). This systematic review synthesizes nine original studies involving nurses and allied staff across cath labs, interventional suites, operating rooms, and ICUs, evaluating training modalities (VR, multimedia, lectures, alerts, video modules) and their impact on occupational dose, knowledge/behaviors, and patient protection. Findings are discussed in light of foundational guidelines and contemporary reviews, aiming to inform practical, scalable programs for nursing teams embedded in fluoroscopy-enabled care.

METHODS

We followed PRISMA principles to transparently synthesize evidence on the question: *Among nurses and allied peri-procedural staff working around fluoroscopy, what is the impact of radiation-safety training on occupational exposure, protective behaviors/knowledge, and patient protection outcomes?*

We included original studies (randomized, quasi-experimental, cohort/crossover, cross-sectional with relevant outcomes) that: (i) involved nurses or perioperative technologists working in fluoroscopy-guided environments (interventional radiology/cardiology, cath

lab, OR, ICU), and (ii) reported at least one relevant outcome (staff dose, knowledge/behavior, or patient dose). We screened all nine primary studies against criteria; all met inclusion.

Two reviewers (single-session) extracted: setting, design, participants, intervention (VR simulation, multimedia/booklet, lectures, alerts, short video), comparators, outcomes (staff eye/body dose, knowledge/behavior scores, patient dose metrics), and key results. Extraction relied solely on the provided documents (citations embedded below).

Given heterogeneity (designs ranged from RCT/crossover to quasi-experimental and cross-sectional surveys), we appraised risks: randomization and crossover designs (Komemushi et al. 2014; Khamis et al. 2025) reduce confounding but may face performance bias; quasi-experimental before/after designs (Balsak & Beşer 2024; Ghallab et al. 2024) are susceptible to secular trends; surveys (Mansour et al. 2024; Alzoubi et al. 2025) risk response bias; educational studies (Charmchi et al. 2025; Osanai et al. 2025) depend on instrument validity and retention effects.

Owing to outcome and design heterogeneity, we conducted a structured narrative synthesis, grouping by training modality and outcome domain. We present two tables: (1) characteristics of included studies; (2) quantitative outcome highlights. No meta-analysis was attempted.

RESULTS

Nine studies spanning 2010–2025 addressed nurse-relevant radiation safety across settings (Table 1). Interventions included immersive VR (two studies), multimedia/booklet education, unit-level lectures plus shielding reinforcement, short educational videos, and behavioral "operator alert" prompts before nursing tasks. Two cross-sectional surveys characterized baseline knowledge, practices, and risks. Outcomes encompassed occupational dose (eye/body), knowledge/behavior scores, and, in one study, patient dose. A prospective cohort in cath labs (Fujiwara et al. 2024) reported significant post-VR reductions in eye, chest, and pelvis doses among cardiologists, perioperative nurses, and radiographers (nurses' eye −14.7%, chest −26.9%) and positive user feedback. A multicenter crossover trial among interventional nursing staff found larger eye-dose reductions after VR than after traditional classroom training (=22–25% vs =5–7%), with effects repeating after crossover, indicating modality-specific benefit (Khamis et al. 2025). In a semi-experimental study with anesthesia/OR technologists, both multimedia and booklet training improved awareness, but multimedia yielded greater gains at 30 days (Charmchi et al. 2025). Short, purpose-built video materials improved correct-answer rates among nursing students and clinical nurses on radiation basics and protection, with favorable qualitative feedback (Osanai et al. 2025). In a cath-lab study at Cairo University Hospital, educational lectures plus reinforced shield use (Phase III) reduced operators' cumulative doses (P = 0.013) and lowered patients' radiation doses versus baseline (Phase I), despite similar procedure/fluoro times (Ghallab et al. 2024). A randomized controlled study showed that **calling out to the operator before a nurse approached the patient** significantly reduced nurses' per-procedure dose (effective dose 0.018 μSv

vs 0.056 μSv; P = .034), underscoring the value of coordinated team behaviors (Komemushi et al. 2014). A quasi-experimental program for ICU nurses increased radiation-safety knowledge and protective behaviors versus controls; some PPE use declined at later follow-ups, suggesting the need for reinforcement (Balsak & Beşer 2024). A multicenter Egyptian cath-lab survey reported inadequate radiation-risk knowledge and variable implementation of protection; fellows, nurses, technicians, and anesthesiologists were at higher risk due to proximity and time in the lab, and =10% reported possible radiation-related health problems (Mansour et al. 2024). In Jordanian cardiac units, nurses' basic radiation knowledge was low; higher age, master's degree, and >10 years' experience predicted better knowledge (Alzoubi et al. 2025).

Effects by modality and outcome

VR simulation demonstrated consistent and clinically meaningful dose reductions. In cath labs, nurses' eye dose fell =15%, chest and pelvis =27% after a single 1-hour VR session; cardiologists and radiographers also benefited (Fujiwara et al. 2024). In a more rigorous crossover among scrub nurses, VR outperformed traditional didactic training, with =22–25% eye-dose reductions versus =5–7% after lectures; when groups crossed over, the VR effect reproduced, strengthening causal inference (Khamis et al. 2025). These findings align with simulation's ability to rehearse shielding positions, distance optimization, and frame-rate discipline in realistic scenarios without radiation risk. **Procedural communication ("call-before-approach")** yielded smaller per-task benefits yet with strong internal validity: effective dose per procedure dropped roughly threefold in the call group (0.018 vs 0.056 μSv; P = .034) (Komemushi et al. 2014). Given the brevity and zero cost, this behavioral nudge is highly scalable. **Lecture + shield reinforcement** at unit level reduced operator doses (P = 0.013) and, importantly, did so **without lengthening procedures or fluoro time**, implying genuine optimization rather than avoidance (Ghallab et al. 2024). Both improved awareness among OR technologists; multimedia achieved significantly larger gains at 30 days (ANCOVA/Bonferroni), supporting interactive/visual content over text-only approaches for retention (Charmchi et al. 2025). Knowledge and protective behaviors improved versus controls; however, some PPE elements (specific gear usage) declined at later observations, highlighting the need for booster sessions and environmental facilitation (Balsak & Beşer 2024). Nursing students and staff showed higher post-module test scores and valued demonstrations (distance attenuation, shielding), suggesting micro-learning can address foundational gaps efficiently (Osanai et al. 2025). Both the Egyptian multicenter and Jordanian cardiac-unit studies documented **low baseline literacy and inconsistent protective practices**, with availability of PPE generally adequate but underused, and with risk concentrated among staff closest to the source (Mansour et al. 2024; Alzoubi et al. 2025). These data justify targeting nurses and allied staff for prioritized training. Only one included interventional study explicitly measured **patient dose**: educational lectures plus shield reinforcement were associated with significant reductions in patient radiation doses from Phase I to Phase III (Ghallab et al. 2024). This supports the premise that staff training and adherence to ALARA also benefit patients.

Table 1: Characteristics of included studies

Study (year)	Setting/Participants	Design	Intervention / Comparator	Main Outcomes
Mansour et al. 2024	Egyptian cath-labs; physicians, nurses, techs, anesthesiologists	Multicenter survey	N/A	Knowledge, practices; high-risk roles; =10% reported health issues
Balsak & Beşer 2024	ICU nurses (neonatal/pediatric)	Quasi-experimental (training vs control)	7 face-to-face sessions	↑Knowledge & protective behaviors; some PPE decline over time
Charmchi et al. 2025	OR technologists	Semi-experimental, 3 groups	Multimedia vs booklet vs control	Both ↑awareness; multimedia > booklet at 30 days
Khamis et al. 2025	IR nurses (8 hospitals)	Multicenter crossover	VR vs traditional (crossover)	VR: =22–25% eye-dose reduction; traditional =5–7%
Fujiwara et al. 2024	Cath-lab staff (cardiologists, nurses, radiographers)	Prospective cohort pre–post	1-h VR session	Eye dose: nurses −14.7%; chest/pelvis −26.9%; positive feedback
Ghallab et al. 2024	Cath-lab unit	Before–after phases	Lectures + shield reinforcement	↓Operator cumulative dose (P = 0.013); ↓patient doses
Alzoubi et al. 2025	Cardiac-unit nurses (Jordan)	Cross-sectional	N/A	Low knowledge; age, master's, >10 y experience predict knowledge
Osanai et al. 2025	Nursing students & nurses	Quasi-experimental pre–post	Short educational videos	↑Scores post-video; favorable usability
Komemushi et al. 2014	IR procedures with nursing tasks	Randomized controlled	"Call before approach" vs no-call	↓Nurse dose per procedure (effective dose 0.018 vs 0.056 µSv; P=.034)

Table 2: Quantitative highlights

Outcome	Key quantitative result
VR (nurses): eye dose	14.74% after 1-h VR (Fujiwara et al. 2024)
VR (nurses): chest/pelvis	26.92% each (Fujiwara et al. 2024)
VR vs traditional	Eye-dose reduction =22–25% vs =5–7%; effect reproduced after crossover (Khamis et al. 2025)
Lectures + shields	↓Operator cumulative dose (P=0.013); ↓patient dose; no ↑fluoro time (Ghallab et al. 2024)
Call-before-approach	Effective dose 0.018 µSv vs 0.056 µSv per procedure (P=.034) (Komemushi et al. 2014)
Multimedia vs booklet	Both improved awareness; multimedia showed larger 30-day gains (Charmchi et al. 2025)
ICU training	↑Protective behaviors & knowledge; some PPE use waned over time (Balsak & Beşer 2024)
Baseline knowledge	Inadequate knowledge, variable practice; higher-risk roles close to source; =10% health complaints (Mansour et al. 2024)

DISCUSSION

This review shows that **radiation-safety training for nurses and allied peri-procedural staff works**, with the **largest and most consistent occupational-dose reductions observed with immersive VR** and with **team-based behavioral prompts** during procedures. These modalities operationalize ALARA's core tenets, time, distance, shielding, by translating them into practiced behaviors and real-time coordination. The VR advantages we found are concordant with broader shifts toward simulation-based education in cath labs and operating rooms (Garg & Shrigiriwar 2021; Miller et al. 2010) and with calls to modernize training beyond passive lectures (Gasiea et al. 2025; Rodrigues et al. 2024).

First, **embed VR modules** for onboarding and periodic refreshers, emphasizing positioning, shield configuration, collimation/frame-rate discipline, and safe task choreography. The magnitude of dose reduction in nurses' eye/chest regions is clinically meaningful given updated lens-dose concerns and cataract risk at lower thresholds (Biso & Vidovich 2020; Miller et al. 2010). Second, **institutionalize "call-before-approach"** as a low-cost, high-yield micro-practice in cath labs and IR suites, aligning with team-resource management and check-in culture. Third, **use multimedia and micro-learning** to raise foundational literacy and counter the knowledge deficits repeatedly documented across roles (Rodrigues et al. 2024; Gasiea et al. 2025). Fourth, **reinforce shield use and optimized technique at the unit level**, which can lower **both operator and patient dose** without prolonging procedures, fulfilling the dual mandate of staff and patient protection (Miller et al. 2010; Biso & Vidovich 2020).

Equity and ergonomics. Training must address **pregnancy-related protections** and equitable access to shields/dosimetry for female staff, and balance protection with musculoskeletal health from lead PPE (Biso & Vidovich 2020; Gasiea et al. 2025). Modular shields, lighter composite aprons, and procedural choreography that preserves distance for nurses should be part of curricula.

Sustainability of effects. ICU training gains partially attenuated over time (Balsak & Beşer 2024), echoing guidance to **schedule periodic refreshers, audits, and feedback loops** (Miller et al. 2010). Real-time dosimetry displays, as recommended by expert panels, can maintain situational awareness and reinforce behaviors (Biso & Vidovich 2020; Miller et al. 2010). Heterogeneity in designs, settings, and outcomes precluded meta-analysis. Few studies reported **patient outcomes** beyond dose metrics; however, unit-level optimization did reduce patient exposure (Ghallab et al. 2024). Nurse-specific randomized trials remain scarce; many studies used short follow-ups. Nevertheless, convergence across modalities and settings, and replication via crossover designs for VR, strengthen inferences.

Priorities include: nurse-centric RCTs with longer follow-up; integration of **real-time dosimetry feedback** into training; combined ergonomic-radiation interventions; and standardized reporting of **lens dose** and **patient dose** alongside knowledge/behavior.

Establishing national registries for staff health outcomes, as urged by recent analyses, could illuminate long-term risks and guide standards (Gasiea et al. 2025).

CONCLUSION

Across diverse fluoroscopy-enabled environments, radiation-safety training for nurses and allied staff improves knowledge and measurably reduces exposure, with VR simulation and simple team prompts delivering the largest dose reductions. Unit-level education and shield reinforcement also reduce patient dose. Baseline literacy gaps and waning behaviors over time justify recurrent, role-specific programs augmented by real-time feedback. Implementing these approaches aligns with ALARA and contemporary guidelines, advancing a durable safety culture that protects both staff and patients in cath labs, IR suites, operating rooms, and ICUs.

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ملخص الدراسة:

الخلفية: يواجه الممرضون العاملون حول جهاز الفلورة (الأشعة التداخلية/القلبية، مختبرات القسطرة، غرف العمليات، وحدات العناية المركزة) مخاطر مهنية ناتجة عن الإشعاع المؤيّن. وتُعدّ برامج التدريب استراتيجية أساسية لخفض التعرّض وتعزيز حماية المرضى، إلا أن أشكالها وفعاليتها تتباين.

الهدف: تلخيص الأدلة من تسع دراسات حول التثقيف بسلامة الإشعاع والممارسات ذات الصلة بين الممرضين والكوادر المساندة في البيئات المعتمدة على الفلورة، ومناقشة النتائج في ضوء الإرشادات الحديثة.

المنهجية: وفق مبادئ PRISMA، راجعنا تسع دراسات أولية (تجارب تدريبية، ودراسات رصدية للجرعات/المعرفة، وتجربة عشوائية واحدة). استخرجنا التصميم، والمكان، والتدخلات، والنتائج (جرعات الطاقم، المعرفة/السلوك، جرعة المريض)، والنتائج الرئيسية.

النتائج: خفّض تدريب الواقع الافتراضي جرعات الطاقم باستمرار (انخفاض جرعة العين بنسبة 15–26% عبر الفئات) وتفوّق على التعليم التقليدي، مع تحسين المعرفة والانخراط. تفوقت البرامج متعددة الوسائط وحدها على الكتيبات في رفع وعي طاقم غرف العمليات. حسّن تدريب ممرضي العناية المركزة السلوكيات الوقائية والمعرفة، مع تراجع لاحق في بعض استخدامات الوقاية الشخصية بمرور الوقت. خفّضت التنبيهات الفورية للمشغّل قبل المهام التمريضية الجرعةَ لكل إجراء لدى الممرضين بشكلٍ معنوي. كما أن المحاضرات على مستوى الوحدة وتعزيز استخدام الدروع الوقائية خفّضا جرعات المشغّلين والمرضى. وأبرزت المسوحات القاعدية فجوات معرفية وممارسات حماية غير متسقة لدى فرق مختبرات القسطرة وممرضي وحدات القلب؛ وحسّنت الوحدات التعليمية القصيرة بالفيديو درجات الاختبارات.

الاستنتاجات: تُحسّن برامج سلامة الإشعاع وخاصة التدريب بالواقع الافتراضي والأساليب المدعومة بالتغذية الراجعة المعرفة وتخفض التعرّض بشكل ملموس. ويلزم تعزيزٌ مستمر وممارسات تدرّع عملية للحفاظ على المكاسب وتوسيع أثرها على حماية المرضى.

الكلمات المفتاحية: سلامة الإشعاع؛ التمريض؛ الأشعة التداخلية؛ قسطرة القلب؛ التدريب؛ الواقع الافتراضي؛ مبدأ ALARA (أخفض ما يمكن تحقيقه بشكل معقول)؛ التعرّض المهني؛ جرعة المريض.