

Occupational radiation exposure to nursing staff during cardiovascular fluoroscopic procedures: A review of the literature

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Abstract

Fluoroscopy is a method used to provide real time x-ray imaging of the body during medical procedures to assist with medical diagnosis and treatment. Recent technological advances have seen an increase in the number of fluoroscopic examinations being performed. Nurses are an integral part of the team conducting fluoroscopic investigations and are often located close to the patient resulting in an occupational exposure to radiation. The purpose of this review was to examine recent literature which investigates occupational exposure received by nursing staff during cardiovascular fluoroscopic procedures. Articles published between 2011 and 2017 have been searched and comprehensively reviewed on the referenced medical search engines. Twenty-four relevant studies were identified among which seventeen investigated nursing dose comparative to operator dose. Seven researched the effectiveness of interventions in reducing occupational exposure to nursing staff. While doctors remain at the highest risk of exposure during procedures, evidence suggests that nursing staff may be at risk of exceeding recommended dose limits in some circumstances. There is also evidence of inconsistent use of personal protection such as lead glasses and skull caps by nursing staff to minimize radiation exposure. Conclusions: The review has highlighted a lack of published literature focussing on dose to nurses. There is a need for future research in this area to inform nursing staff of factors which may contribute to high occupational doses and of methods for minimizing the risk of exposure, particularly regarding the importance of utilizing radiation protective equipment.

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Abbreviations: ALARA, as low as reasonably achievable; CV, cardiovascular; DAP, Dose Area Product; DSA, digital subtraction angiography; EP, electrophysiology; EVAR, endovascular aneurysm repair; $H_p(0.07)$, calibration of a dose meter to detect the personal dose equivalent at 0.07 mm depth in tissue; $H_p(3)$, calibration of a dose meter to detect the personal dose equivalent at 3 mm depth in tissue; $H_p(10)$, calibration of a dose meter to detect the personal dose equivalent at 10 mm depth in tissue; IC, interventional cardiology; ICRP, International Commission on Radiological Protection; INR, interventional neuro-radiology; IR, interventional radiology; KAP, kerma area product; mSv, milliSievert; NR, neuroradiology; PDM, personal dose meter

KEY WORDS

fluoroscopy, nursing, occupational exposure, radiation exposure, systematic review

1 | INTRODUCTION

Fluoroscopy is a method used to provide real time imaging of the body during medical procedures. It utilizes x-rays which pass through the patient to visualize internal structures. Historically x-ray fluoroscopy was primarily used for diagnosis, but recent advances in both imaging and procedural equipment have led to considerable growth in the range of fluoroscopically guided procedures, particularly in the field of interventional cardiology, (IC) and vascular intervention.^{1–3} Interventional cardiovascular (CV) cases are often less costly than surgery and allow medical intervention to be conducted in a minimally invasive way, reducing the risk to the patient.⁴

Although very useful for imaging, ionizing radiation may result in several detrimental effects to those exposed, including cellular damage, malignancies, and cataracts.^{5–8} The greatest risk of occupational exposure occurs when the primary x-ray beam strikes the patient's skin and scatters, a portion of the x-ray photons are absorbed and scatter in the patient's body.⁹ Scattered radiation levels near the patient can be relatively high, even under routine working conditions, and staff are subsequently exposed while conducting CV procedures.^{1,10}

There has been justifiable concern over the dose received by the physicians operating in this environment, but data detailing exposure to supporting staff during fluoroscopic procedures are scarce.^{1,11,12} The fundamental premise is to keep exposure to ionizing radiation as low as reasonably achievable (ALARA)^{6,13} and organizations such as the International Commission on Radiological Protection (ICRP) recommend dose limits to those that are occupationally exposed.¹⁴ Staff radiation monitoring is performed as locally legislated to ensure that departments are complying with regulatory occupational dose limits, but problems with effective monitoring have been highlighted partly due to the attitude and radiation safety culture of staff.¹⁵ Poor adherence to the ICRP recommendation to conduct measurements using two dosimeters, one worn above and the other underneath the lead apron, as well as irregular use of personal dosimeters and has been emphasized,¹⁶ and it has been reported that appropriate dosimetry is essential to provide reasonable estimations of dose to the lens of the eye.^{17–19}

There has been increasing concern over recent epidemiological evidence suggesting that radiation-induced cataracts can occur at much lower doses than previously assumed.^{20–22} Staff involved in fluoroscopic CV procedures have demonstrated an elevated incidence of radiation-associated lens changes.^{16,21,23–26} In response, in 2011 the ICRP recommended reducing the occupational dose limit for the eye from 150 mSv (millisievert) to 20 mSv per year.²⁷ This has resulted in numerous studies investigating the lens dose received by fluoroscopic operators, but there is very little research evaluating the risk of occupational eye exposure for nursing and allied health staff.^{1,11,19}

Nurses are an integral part of the team conducting CV procedures, and many cases require staff to stand adjacent to the patient resulting in inadvertent exposure to radiation. To minimize the risk of exposure, it is vital that occupational dose to individuals is monitored and quantified. To date, the occupational exposure to nurses within the CV setting is widely unexplored.

1.A | Review objective

The purpose of this review is to provide a current account of research specifically examining occupational dose to nursing staff during x-ray guided CV procedures. It will compare results of publications within procedural contexts, critically review the findings, and assess areas in which further research would be beneficial.

2 | MATERIALS AND METHODS

A search for relevant literature published between 2011 and 2017 was undertaken between November 2016 and June 2017 to retrieve articles related to occupational radiation dose to nursing staff present during fluoroscopically guided CV procedures. A combination of keywords was used correlated to occupational radiation dose to nurses, i.e.: “nurse occupational dose”, “nursing fluoroscopy”, “staff fluoroscopy dose”, and “occupational fluoroscopy dose”. Search terms were purposefully general to ensure that articles which did not explicitly articulate ‘cardiovascular’ terminology were included in the initial screening for suitability for inclusion in the review. Due to the relatively small number of identified studies, reference lists of located manuscripts were also used to detect additional articles. Due to the rapid advancements in both imaging and procedural equipment in the last decade, searches were limited to those published after 2010 to ensure relevance to current operating practices.

A total of thirty potentially relevant articles were identified and of these six articles were excluded from the review as the investigated radiation doses to nurses were not directly related to the imaging of the CV system as illustrated in Fig. 1. The literature was subsequently reviewed, analyzed, and compared. A summary of selected articles is provided in Table 1.

2.A | Radiation dose monitoring

It has been demonstrated that the dose to nursing staff during fluoroscopic procedures can be similar or higher than that received by the physician^{28–30} with evidence of an increasing trend toward higher dose levels to nurses working in this environment.²⁸ It is therefore important to quantify the radiation exposure to individuals working within fluoroscopic departments.^{31–33}

Typically, the devices used to evaluate the individual cumulative radiation exposure are personal dosimeters, which are usually badges worn by occupationally exposed staff during procedures. The ICRP recommends the proper use of personal monitoring badges in interventional fluoroscopic laboratories to monitor and audit occupational radiation dose.¹⁴ There was a variety of styles, anatomical positioning, and calibration of dosimeters utilized in the reviewed literature (Table 2). Active dosimetry systems, such as DoseAware (Philips Medical Systems, Amsterdam, The Netherlands) provide real time visualization of radiation dose rate. It consists of a personal dosimeter worn by staff [Fig. 2(a)], a wireless base station which displays live radiation exposure information transmitted from individual dosimeters [Fig. 2(b)], a download cradle [Fig. 2(c)], and computer software which downloads badge data for analysis [Fig. 2(d)]. Several studies evaluated the effectiveness of immediate exposure information on staff behavior by monitoring dose received by DoseAware^{31,34–38} or other real time systems.³⁹ The blinded, or closed phase measurements were downloaded from badges worn when staff were not able to view the base station display. During the unblinded, or open phase staff could visualize the real time dose rate information on the base station and modify behavior.

Baumann et al. report the overall mean staff dose per fluoroscopic minute was 42.79 vs 19.81 $\mu\text{Sv}/\text{min}$ ($P < 0.05$) comparing the closed and open phases,³⁶ and Racadio et al. also demonstrate that the dose to staff was higher in the closed phase with a median of

3.01 $\mu\text{Sv}/\text{min}$ than in the open phase 0.56 $\mu\text{Sv}/\text{min}$.³⁵ Similarly, Butcher et al. reports a mean personal percentage dose reduction for scrub nurses from 0.065% (SD, 0.12) in the closed phase to 0.03% (SD, 0.034) in the open phase, while scout nurses decreased from 0.06% (SD, 0.11) measured during the closed phase, to 0.009% (SD, 0.01).³⁹ None of these reductions were reported as statistically significant with one cited explanation the possibility that the nurses had a restricted view of the readout monitor during cases, but it is acknowledged that real time dose feedback can be effective in dose reduction.^{35–39}

2.B | The effect of equipment and staff location

Radiation scatter is the primary mechanism of operator and staff exposure, and understanding the factors that can affect its magnitude and distribution is essential.⁴⁰ As X-ray scatter from the patient is the primary source of radiation dose to in-room personnel,⁴¹ staff location within the fluoroscopy room influences the level of occupational exposure.^{1,19,42} In x-ray guided CV procedures, the area of greatest scatter alters as the geometry of the x-ray tube changes (Fig. 3).⁴³ Nursing staff may undertake several roles within fluoroscopic suites, and the in-room location of the nurse may vary during procedures. In many of the reviewed articles, the role of the nurse was not well-defined and it was unclear whether staff were performing the scrub or scout role^{12,32,35,44–46} and consequently reported data may represent an average of the dose of both duties.

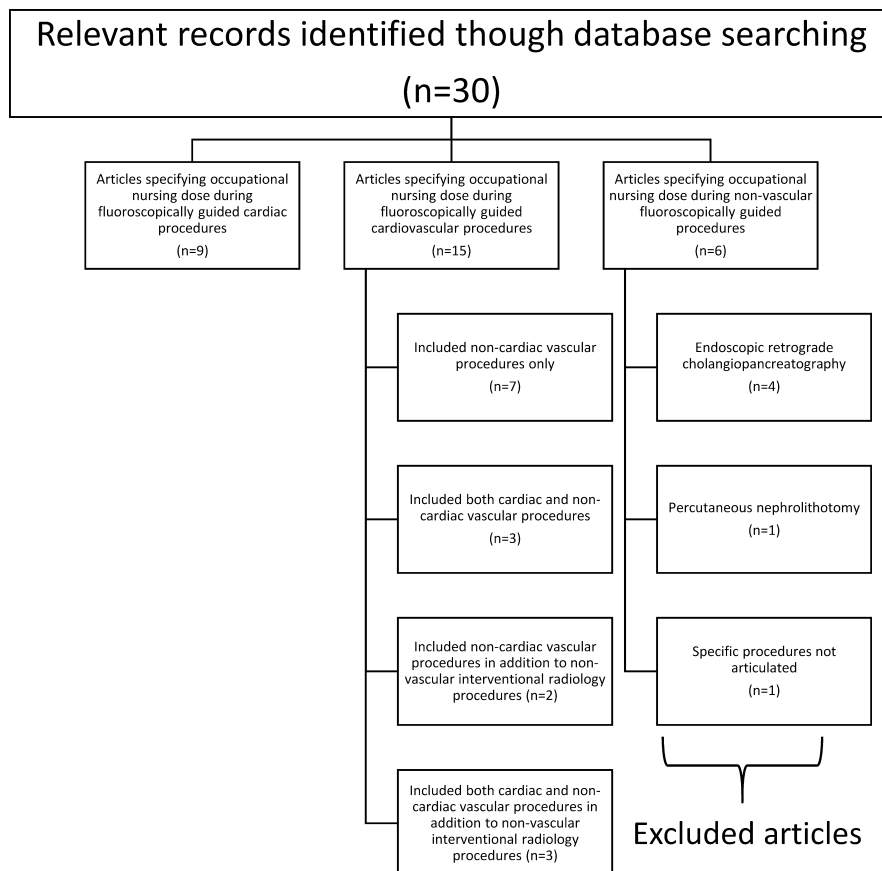


FIG. 1. Flow diagram of study selection and exclusion process.

TABLE 1 Summary of reviewed literature.

| First author; year; location | Studied population | Cases | Collection period | Phantom measurements | Clinical | Intervention |
|--|--|--|--|--|----------|---|
| Domienik, J. (2012) Poland ¹ | Cardiologist* Nurse* | Vas IC (D + I) (n = 79) RFA (n = 11) PPM/ICD (n = 20) CRT/CRT-D (n = 11) | * | y- for calibration of dosimeters Hp(0.07) | y | n |
| Chohan, M. (2015) United States of America ¹¹ | Patient (n = 24) Radiologist (n = 1) Scout nurse* | Vas NR D (n = 18) I (n = 6) | July 2011 to Dec. 2011 | n | y | n |
| Chida, K. (2013) Japan ¹² | IR physician (n = 18) nurse (n = 7) Radiographer (n = 8) | Vas IC D (n = 5280) I (n = 1326) | During 2009 | n | y | n |
| Antic, V (2012) Serbia ¹⁹ | Primary operator (n = 13) Secondary operator (n = 8) Scrub nurse (n = 18) Radiographer (n = 12) | Vas IC (D + I) (n = 106) | * | n | y | n |
| Sailer, A. (2015) * ²⁵ | Primary operator* Second operator* Scrub nurse* Scout nurse* Radiographer* Anaesthesiologist* | EVAR (n = 22) TEVAR (n = 11) FEVAR (n = 11) | Sept. 2013–Jan. 2014 | n | y | n |
| Nuraeni, N. (2016) Indonesia ²⁹ | Radiologist (n = 1) Scrub nurse (n = 1) Scout nurse (n = 1) Radiographer (n = 1) | Vas NR (D + I) (n = 8) | * | n | y | n |
| Mohapatra, A. (2013) * ³¹ | Primary operator Secondary operator Total (n = 101) Scrub nurse * Radiographer * | FEVAR (n = 39) | Oct. 2011–Feb. 2012 | n | y | n |
| Korir, G. (2012) Kenya ³² | Physician* Nurse* Radiographer* Neurologists* Clinical staff* Total (n = 216) | Vas INR Vas IC (D + I) (n = 54) | Nov. 2007–end time * | n | y | n |
| Omar, A. (2017) Sweden ³⁴ | IR and IC physician (n varied per room) Scrub nurse Scout nurse Anaesthetist Anaesthetic nurse | Vas IR, IC and INR NVas IR R1 (n = 200) R2 (n = 55) R3 (n = 80) R4 (n = 10) | R1 (hybrid IR OR)—11 months R2 (IR)—2 months R3 (IC)—3 months R4 (INR)—3 months | n | y | n |
| Racadio, J (2014) ³⁵ | IR physician (n = 4) IR fellow (n = 4) Nurse ^ (n = 3) Radiographer (n = 7) Anaesthetist * | Vas IR (n = 38) NonVas IR (n = 207) CP (n = 97) OP (n = 148) | CP—12 weeks OP—17 weeks | n | y | CP—blinded OP—unblinded |
| Baumann, F. (2015) * ³⁶ | IR physician and fellows* Scout nurse ^ * Radiographer * Anaesthetist * | Vas and NonVas IR (D + I) CP (n = 88) LP (n = 50) OP (n = 114) | CP—6 weeks LP—6 weeks OP—10 weeks year * | n | y | CP—blinded LP—unblinded, not evaluated OP—unblinded and evaluated |
| Sandblom, V. (2013) Sweden ³⁷ | Cardiologist (n = 3) Nurse (n = 10) | Vas IC (D + I) CP (n = 80) OP (n = 81) | CP—1 month OP—1 month | n | y | CP—blinded OP—unblinded |

(Continues)

TABLE 1 (Continued)

| First author; year; location | Studied population | Cases | Collection period | Phantom measurements | Clinical | Intervention |
|---|---|--|--------------------------------------|-------------------------|----------|---|
| James, R. (2015) United States of America ³⁸ | Radiologist (n = 2) Scrub nurse* Scout nurse* Total (n = 25) | Vas NR (D) CP (n = 60) OP (n = 60) | Apr. 2012–Aug. 2013 | n | y | CP—blinded OP—unblinded |
| Butcher, R. (2015) Australia ³⁹ | Scrub nurse* Scout nurse* Total (n = 10) | Vas IR (D + I) CP (n = 28) OP (n = 28) | * | n | y | CP—blinded OP—unblinded |
| Haga, Y. (2017) Japan ⁴⁴ | Cardiologist (n = 12) Nurse (n = 11) | Vas IC (D) (n = 1707) Vas IC (I) (n = 902) | Sept. 2015–Feb. 2016 | n | y | n |
| Gilligan, P. (2015) * ⁴⁵ | Cardiologist (n = 14) Nurse ^ * Cardiac Technicians * Radiographer * | IC (total n*) | 3 times within 7 months | n | y | P1—standard shield P2—larger shield with lamellae and femoral cutout + additional flexible shield |
| McLean, D. (2016) * ⁴⁶ | Cardiologist * IC nurse ^ * IR operator (n = 6) IR nurse ^ (n = 9) IR radiographer (n = 2) ERCP operator * ERCP nurse ^ * | Vas IR (n = 93) IC (n = 192) ERCP (n = 34) | 1 month per location | n | y | n |
| Efstathopoloulos, E. (2011) Greece ⁴⁷ | Cardiologist (n = 5) Radiologist (n = 5) Nurse (n = 3) | IC (D) (n = 6) PPM (n = 1) Vas IR (D + I) (n = 11) | Oct. 2008—Jan. 2009 | n | y | n |
| Omar, A. (2015) Sweden ⁴⁸ | Cardiologist (n = 1) Nurse (n = 3) | IC * | 1 month | y | y | n |
| Rigatelli, G. (2016) Italy ⁴⁹ | Physician (n = 4) Nurse (n = 9) Radiographer (n = 7) | IC (D + I) (n = 2130) Vas peripheral (D + I) (n = 440) INR (n = 60) | 12 months (2014) | y | y | n |
| Principi, S. (2015) Spain ⁵² | P1—cardiologist (n = 9) P1—nurse ^ (n = 6) P2—cardiologist (n = 3) P2—nurse ^ (n = 1) | Vas IC (D + I) * | P1—2 weeks P2—7 weeks | n | y | n |
| Urboniene, A. (2015) Lithuania ⁵³ | IC physician (n = 114) IC nurse (n = 137) | Vas IC (n*) Non Vas IC (n*) | 2012–2013 1 month for the eyes | n | y | n |
| Komemushi, A. (2014) * ⁶³ | IR physician (n = 3) Nurse (n = 5) ED physician (n = 1) | Vas IR Non Vas IR CG (n = 50) NCG (n = 43) | Mar.—May 2012 | n | y | CG—nurse alerted operator before approaching patient NCG—no alert |
| Mori, H. (2015) Japan ⁶⁴ | IR nurse (n = 27) IC nurse (n = 42) | Vas IR (n*) Vas IC (n*) | * | n | y | P1—change dosimeters P2—staff education P3—additional portable lead shields P4—reducing radiation parameters |

Summary of review literature. RFA: radiofrequency ablation; PPM: permanent pacemaker; ICD: implantable cardioverter defibrillator; CRT: cardiac resynchronization therapy; EVAR: endovascular aortic repair; TEVAR: thoracic aortic repair; FEVAR: fenestrated aortic repair; INR: interventional neuroradiology; NR: neuroradiology; IC: interventional cardiology; Vas: vascular; D: diagnostic; I: interventional; CP: closed phase; OP: open phase; LP: learning phase; R: room; OR: operating room; P1: Phase 1; P2: Phase 2; P3: Phase 3; P4: Phase 4; ERCP: endoscopic retrograde cholangio-pancreatography; CG: call group; NCG: no call group; ^: role not articulated; *: not articulated.

TABLE 2 Location, calibration, and dose values of dosimeters.

| Reference: First author (year) | Cases | Monitored staff-1 | Monitored staff-2 | Dosimeter type | Monitored staff-3 | Monitored staff-1 | Dosimeter type | Monitored staff-2 | Monitored staff-3 |
|---------------------------------------|---|--|---|-------------------|--|--|---|---|---|
| Domenik, J. (2012) ¹ | Vas IC | Nurse (n = 1) | Cardiologist * | TLD | 1-FH (E) 2-RF L 3-RF R 4-W L 5-W R 6-K L 7-K R 8-An L 9-An R | MD/case# 1-15.7 μSv 2-26 μSv 3-24.3 μSv 4-24.6 μSv 5-23.7 μSv 6-14.5 μSv 7-13 μSv 8 & 9-33.3 μSv | TLD | MD/case# 1-67.6 μSv 2-203 μSv 3-205 μSv 4-133 μSv 5-115 μSv 6-72.8 μSv 7-43.1 μSv 8 & 9-108 μSv | Monitored staff dose-3 |
| | Non Vas IC | | | | 2-RF L 3-RF R 4-W L 5-W R 6-K L 7-K R 8-An L 9-An R | | | | |
| Chohan, M. (2015) ¹¹ | Vas INR | Scout nurse (n = 1) | Radiologist (n = 1) | ED | 1-eye L (E) 2-eye L (U) | 1-MD/case 30 + /- 60 μSv | TLD | 1-MD/case 80 + /- 190 μSv 2-MD/case 5 + /- 16 μSv | cranial entrance MD/case 220270 + /-221170 μSv |
| | | | | | | | | | |
| Chida, K. (2013) ¹² | Vas IC | Nurse ^ (n = 7) | Physician (n = 18) | PGD | 1-Ch (U) 2-Co (E) | Hp(10) | 1-Ch (U) 2-Co (E) | Hp(10) | annual MD equiv./year 19840 +/- 12450 μSv |
| | | | | | | | | | |
| Anlic, V. (2013) ¹⁹ | Vas IC | Scrub nurse (n = 18) second physician (n = 8) | Cardiologist (n = 8) | APD | 1-eye L (E) | Hp(3) | 1-eye L (E) | Hp(3) | MD/case 1-121 μSv |
| | | | | | | | | | |
| Sailer, A. (2015) ²⁵ | EVARS (angio) | Scrub nurse (n = 1) | Radiologist (n = 1) Cardiologist (n = 1) Gastroenterologist (n = 1) | APD | 1-Ch (E) | Hp(10) | 1-Co (E) | Hp(10) | MD/case 17 μSv |
| | | | | | | | | | |
| Nuraeni, N. (2016) ²⁹ | Vas INR | Nurse (n = 2) A & B | Radiologist (n = 1) | TLD | 1-eye side * 2-Ch (U) 3-Co (E) 4-Co (U) 5-G (E) 6-G (U) 7-F (E) | 1-Hp(3) 2-6 Hp(10) 7-Hp(0.07) | 1-eye side * 2-Ch (U) 3-Co (E) 4-Co (U) 5-G (E) 6-G (U) 7-F (E) | 1-Hp(3) 2 to 6-Hp(10) 7-Hp(0.07) | Highest dose 2-1 μSv |
| | | | | | | | | | |
| Mohapatra, A. (2013) ³¹ | EVARS | Scrub nurse (n = 1) | Primary & Assistant surgeons (n = 101) | APD | 1-Co (E) | Hp(10) | 1-on anaesthetic equipment | Hp(10) | MD/case 26 μSv |
| | | | | | | | | | |
| Konir, G. (2012) ³² | Vas IC | Nurse ^ (n = 1) | Cardiologist (n = 1) Radiologist (n = 1) | TLD | 1-Co (E) | * | 1-Co (E) | * | MD/case-270 μSv |
| | Vas IR | | | | | | | | |
| Omar, A. (2017) ³⁴ | Vas IC | Scrub nurse (n = 1) | Radiologist (n > 14) | APD | 1-Ch (E) | Hp(10) | 1-Ch (E) | Hp(10) | equiv. eye dose/case calculated from T APD# R1-60 μSv R2-190 μSv R3-66 μSv R4-8.6 μSv |
| | Non Vas IC R1 & 2 Vas IC R3 Vas INR R4 | | Cardiologist (n = 6) | | | | | | |

(Continues)

TABLE 2 (Continued)

| Reference: First author (year) | Cases | Monitored staff-1 | Badge location | Calibration | Dosimeter type | Monitored staff-2 | Badge location | Calibration | Dosimeter type | Monitored staff-3 | Badge location | Calibration | Dosimeter type | Monitored staff dose-1 | Monitored staff dose-2 | Monitored staff dose-3 |
|--------------------------------------|----------------------|--|-------------------------|-----------------------|-------------------|---|---|----------------------------------|-------------------------|---|----------------|----------------|-------------------|---|---|---|
| Racadio, J (2014) ³⁵ | Vas IR Non Vas IR | Nurse ^a (n = 3) | 1—Ch (E) | Hp(10) | APD | Radiologist (n = 4) N or F from pt | 1—Ch (E) | Hp(10) | APD | IR (ellow (n = 4)) | 1—Ch (E) | Hp(10) | APD | CP median— N—0.15 μSv/min F—4.14 μSv/min OP median— N—0.02 μSv/min F—4.12 μSv/min | CP median— N—0.15 μSv/min F—4.14 μSv/min OP median— N—0.02 μSv/min F—4.12 μSv/min | CP median— N—0.01 μSv/min OP median— N—0.01 μSv/min |
| Baumann, F. (2015) ³⁶ | Vas IR Non Vas IR | Nurse ^a (n = 1) Non Vas IR | 1—Co (E) | Hp(10) | APD | Radiologist (n = 1) | 1—Co (E) | Hp(10) | APD | Anaesthetist (n = 1) | 1—Co (E) | Hp(10) | APD | Avg. of all staff (dts, nurse, primary physician, fellow, radi- CP—42.79 μSv/min OP—19.81 μSv/min | anaesthetist— CP—16.9 μSv/min OP—8.9 μSv/min | |
| Sandblom, V. (2013) ³⁷ | Vas IC | Scrub nurse (n = 10) CP—69 cases OP—73 cases | 1—Ch (E) | Hp(10) | APD | Cardiologist (n = 3) | 1—Ch (E) | Hp(10) | APD | | | | | median/case CP—9.9 μSv OP—8.5 μSv | median/case CP—9.9 μSv OP—8.5 μSv | |
| James, R. (2015) ³⁸ | Vas INR | scrub nurse (n = 26) CP—60 cases OP—60 cases | 1—Ch (E) 2—Ch (E) | 1— 2—Hp(10) | 1—TLD 2—APD | Radiologist (n = 2) A & B OP—30 cases each CP—30 cases each | 1—Ch (E) 2—Ch (E) | 1— 2—Hp(10) | 1—TLD 2—APD | Scrub nurse (n = 26) CP—60 cases OP—60 cases | 1—TLD 2—APD | 1— 2—Hp(10) | 1—TLD 2—APD | CP MD—0.045 μSv/Gy-cm2 A-OP MD—0.051 μSv/Gy-cm2 B-OP MD—0.051 μSv/Gy-cm2 dose divided by DAP | A-CP MD—0.028 μSv/Gy-cm2 B-OP MD—0.015 μSv/Gy-cm2 dose divided by DAP | B-CP MD—0.033 μSv/Gy-cm2 B-OP MD—0.015 μSv/Gy-cm2 dose divided by DAP |
| Butcher, R. (2015) ³⁹ | Vas IR | Scrub nurse (n = 10) CP—14 cases OP—14 cases | 1—Ch (U) | * | SM | | | | | Scrub nurse (n = 10) CP—12 cases OP—12 cases | | | | MD/case CP—3.25 μSv OP—0.009 μSv | MD/case CP—3.25 μSv OP—0.009 μSv | |
| Hajra, Y. (2017) ⁴⁴ | Vas IC | Nurse ^a (n = 11) | 1—eye L (E) 2—Co (E) | 1—Hp(3) 2—Hp(0.07) | 1—TLD 2—PGD | Cardiologist A—with LG (n = 9) B—without LG (n = 3) | 1—eye L (E) 2—eye L (U) A only 3—Co (E) | 1—Hp(3) 2—Hp(3) 3—Hp(0.07) | 1—TLD 2—TLD 3—PGD | | | | | est. annual dose 1—15800 ± 6600 μSv 2—4200 ± 2600 μSv 3—22800 ± 12800 μSv est. annual dose B 1—12600 ± 10200 μSv 3—10000 ± 5200 μSv | est. annual dose A 1—15800 ± 6600 μSv 2—4200 ± 2600 μSv 3—22800 ± 12800 μSv est. annual dose B 1—12600 ± 10200 μSv 3—10000 ± 5200 μSv | |
| Gilligan, P. (2015) ⁴⁵ | Vas IC Non Vas IC | Scrub nurse (n = 14) P1—Standard shield P2—larger shield + pt drape | 1—Co (E) | Hp(10) | EPD | Cardiologist (n = 14) P1—standard shield P2—larger shield + pt drape | 1—Co (E) | Hp(10) | EPD | rad (n = 14) P1—standard shield P2—larger shield + pt drape | 1—Co (E) | Hp(10) | EPD | median P1—15.4 μSv P2—7.3 μSv | median P1—15.4 μSv P2—7.3 μSv | median P1—4.2 μSv P2—2.5 μSv |
| McLean, D. (2016) ⁴⁶ | Vas IR IC ERCP | Nurse A—Cardiology (n = 6) B—Angiography (n = 9) C—ERCP cases (n = 9) | 1—eye L (E) | Hp(3) | TLD | A—cardiologist (n = 6) B—radiologist (n = 6) C—gastroenterologist (n = 9) | 1—eye L (E) | Hp(3) | TLD | | | | | median eye dose! A—340 μSv B—930 μSv C—1510 μSv | median eye dose! A—340 μSv B—930 μSv C—1510 μSv | |

(Continues)

TABLE 2 (Continued)

| Reference: First author (year) | Cases | Monitored staff-1 | Monitored staff-2 | Dosimeter type | Monitored staff-3 | Dosimeter type | Monitored staff-1 | Monitored staff-2 | Monitored staff-3 |
|--|----------------------|--|--|--|---|---|---|---|---|
| Efathiopoulou, E. (2011), ⁴⁷ | IC PPM Vas IR | Nurse ^a (n = 3) tail (n = 6) | Cardiologist (n = 5) tail (n = 5) | TLD H _p (0.07) | 1—eye L (E) 2—central FH (E) 3—MF L hand (E) 4—L W (E) 5—MF R hand (E) 6—W R (E) 7—leg L (E) 8—leg R (E) | 1—eye R & L (E) 2—Ch (E) 3—central FH (E) | 1—eye L (E) 2—central FH (E) 3—MF L hand (E) 4—L W (E) 5—MF R hand (E) 6—W R (E) 7—leg L (E) 8—leg R (E) | MD/case 1—37 μSv 2—64 μSv 3—324 μSv 4—485 μSv 5—88 μSv 6—108 μSv 7—124 μSv 8—103 μSv | MD/case 1—1 μSv 2—4 μSv 3—4 μSv 4—26 μSv 5—2 μSv 6—26 μSv 7—15 μSv 8—19 μSv |
| Omar, A. (2015), ⁴⁸ | Vas IC | Nurse ^a (n = 3) tail (n = 3) | Cardiologist (n = 1) tail (n = 2) B: physician >165 cm tail (n = 2) | 1—TLD 2—APD 3—APD H _p (10) | 1—eye R & L (E) 2—Ch (E) 3—central FH (E) | 1—eye R & L (E) 2—Ch (E) 3—central FH (E) | quantitative measurements ^a Annual mean for all staff A—4550 ± 4000 μSv B—1950 ± 1000 μSv | quantitative measurements ^a Annual mean for all staff A—4550 ± 4000 μSv B—1950 ± 1000 μSv | |
| Rigatelli, G. (2016), ⁴⁹ | IC Vas IR INR | A: nurse <165 cm tail (n = 6) B: nurse >165 cm tail (n = 3) | A: physician <165 cm tail (n = 2) B: physician >165 cm tail (n = 2) | TLD H _p (10) | 1—Ch (E) 2—Ch (E) 3—central FH (E) | 1—Ch (E) 2—Ch (E) 3—central FH (E) | TLD A: rad <165 cm tail (n = 4) B: rad >165 cm tail (n = 3) | TLD A: rad <165 cm tail (n = 4) B: rad >165 cm tail (n = 3) | |
| Principi, S. (2015), ⁵² | Vas IC | Nurse ^a P1 (n = 6) P2 (n = 1) | Cardiologist P1 (n = 9) P2 A (n = 2) B (n = 1) | TLD H _p (10) | 1—eye L (E) 2—Ch (E) P2B—eye L (E & U) | 1—eye L (E) 2—Ch (E) P2B—eye L (E & U) | nurse MD/case# P1—17 μSv P2—13 ± 1.5 μSv P2B—mean UJE—3.5 | nurse MD/case# P1—114 μSv P2—97 μSv P2B—mean UJE—3.5 | |
| Urbaniene, A. (2015), ⁵³ | Vas IC Non Vas IC | Nurse ^a 1 & 2 (n = 137) 3 (n = 8) | Physician 1 & 2 (n = 114) 3 (n = 42) | TLD H _p (10) | 1—T (U) 2—Co (E) 3—eye (E) | 1—T (U) 2—Co (E) 3—eye (E) | Avg. annual dose# 2—1490 μSv (Avg. over 9 hospitals) est. eye dose/year# 3—2300 μSv/yr (Avg. over 18 physicians) | Avg. annual dose# 2—14500 μSv (Avg. over 9 hospitals) est. eye dose/year# 3—2300 μSv/yr (Avg. over 18 physicians) | |
| Konemushi, A. (2014), ⁵⁴ | Vas IR Non Vas IR | Scout nurse (n = 5) A—No CG B—CG | Radiologist (n = 4) A—No CG B—CG | PDM H _p (10) | 1—Ch (E) 2—T (U) | 1—Ch (E) 2—T (U) | MD/case 1A—0.51 ± 1.17 μSv (A) 1B—0.16 ± 0.41 μSv (B) 2A & B—below detectable limit (A & B) | MD/case 1A—8.70 ± 12.70 μSv 1B—8.88 ± 13.38 μSv 2A—0.65 ± 1.45 μSv 2B—0.48 ± 1.03 μSv | |
| Mori, H. (2015), ⁶⁴ | Vas IC Vas IR | Vascular IR nurse (n = 69) | Vascular IR nurse (n = 69) | PGD H _p (10) | 1—T (U) 2—Co (E) | 1—T (U) 2—Co (E) | a reduction of annual effective dose to approx 1/3 or baseline dose after education, and a reduction to 2/5 of baseline after reduction in pulse rates | a reduction of annual effective dose to approx 1/3 or baseline dose after education, and a reduction to 2/5 of baseline after reduction in pulse rates | |

Vas: vascular; Non Vas – non vascular radiology procedures; IC: interventional cardiology; IR: interventional radiology; INR: interventional neuro-radiology; EVAR: endovascular aortic repair; Ch: chest; Co: collar; T: trunk; W: wrist; K: knee; F: finger; RF: ring finger; MF: middle finger; G: gonad; FH: forehead; An: ankle; L: left; R: right; P: phase; E: external to protective equipment; (U): under protective equipment; APD: active personal dosimeter; ED: electronic dosimeter; EPD: electronic personal dosimeter; PDM: personal dosimeter; PGD: phosphate glass dose meter; SM: survey meter; TLD: thermoluminescent dosimeter; CP: closed phase; OP: open phase; LP: learning phase; LG: lead glasses; CG: call group; NCG: no call group; rad: radiographer; pt: patient; dr: doctor; Avg.: average; MD: mean dose; DAP : dose area product; μSv: microsievert; Gy.cm2 : gray-centimetres squared; N: near; F: far; #: not articulated; ±: role not articulated; #: average calculated from data; ±: normalized with fluoroscopy time; i: dose normalized by cumulative KAP; equiv.: equivalent; est.: estimated.

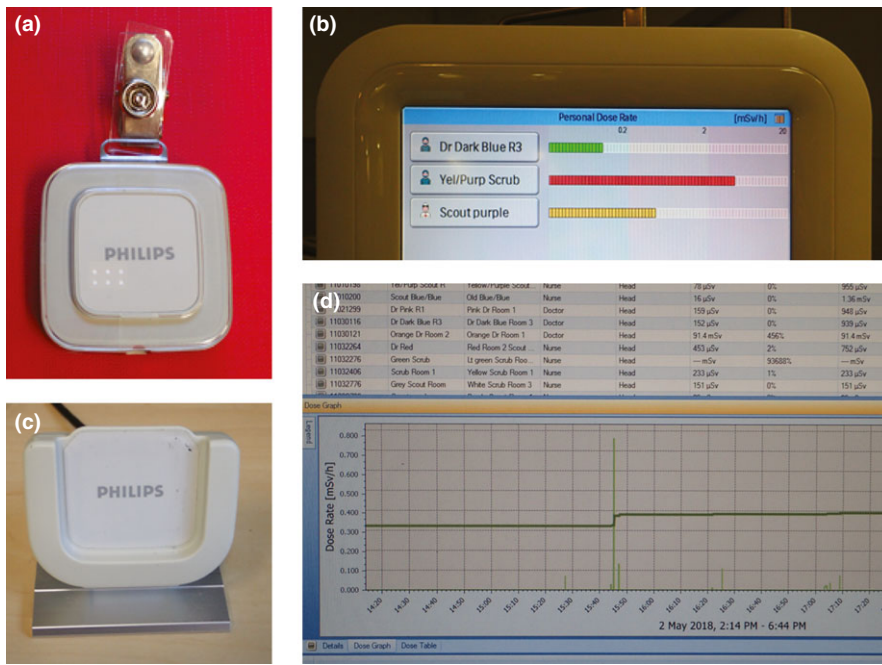


FIG. 2. Components of a real time feedback monitoring system. (a) personal dosimeter. (b) base station. (c) download cradle. (d) dose manager software.

Mohapatra et al. investigated several staff roles and found that there was surprising variation in doses to different personnel present during the same procedure.³¹ The authors also identified that personal behavior within the fluoroscopic suite alters dose considerably. Depending on their responsibilities during the procedure nurses may have greater opportunity of deliberately increasing their distance from the patient resulting in a decrease in dose.^{1,25,29,39}

Some authors investigated dose in relation to proximity to the x-ray tube.^{25,34,38,47–49} Explanatory diagrammatic representation of the position of staff was provided in several articles^{25,38,47–49} which allows comparison by dosimetric location rather than assigned role. Specific articulation of staff distances from the x-ray tube or table^{31,47,49} was constructive when comparing occupational doses.

2.C | Lead shielding

Lead shielding refers to the use of lead, or lead equivalent products to shield staff from radiation. Variations in accessibility and utilization of lead shielding devices by staff in fluoroscopic suites have been well documented^{50,51} and this has been reflected in reported use of personal protection in the reviewed studies

(Table 3). Thyroid shields were either not worn^{12,44} or inconsistently worn by staff at some centers.⁵² Only one reviewed article specifically articulated the use of a lead skull cap during fluoroscopic procedures and was utilized by the operator only.¹¹ Lead glasses also had varying degrees of use with several studies reporting that while doctors routinely used lead eye protection, nursing staff did not.^{11,19,44,47,53}

Consideration should also be given to the location of lead protection. This may include items such as ceiling mounted lead glass, table mounted, or stand-alone lead shields (Fig. 4). This equipment provides a barrier between the scattered radiation from the patient and the staff member, but correct positioning is vital for effective dose minimization.⁵⁴

The importance of careful positioning of the movable ceiling mounted lead shield has been previously reported⁵⁵ especially when using biplane equipment,⁵⁶ and this was echoed in the reviewed literature.^{1,11,19,25,31,32,34,35,46,48,52,53} Several authors declared the absence of ceiling^{25,44,46} and table-mounted lead shields²⁵ when no other additional lead protection such as lead glasses or skull caps were worn by staff.^{25,44} It has been highlighted previously that some fluoroscopic staff have access to a ceiling mounted lead shield but

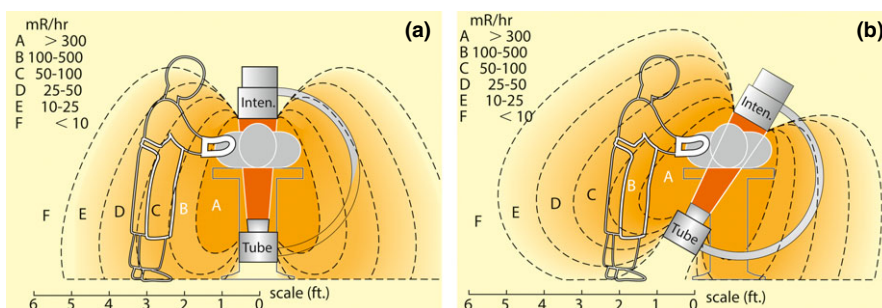


FIG. 3. Exposure levels during fluoroscopy. (a): straight under table tube orientation. (b): central ray 30° from vertical. Reprinted with permission from Personnel exposure during fluoroscopy procedures, Postgraduate Radiology 8:162–173, 1988. 1 millirem (mR) is equivalent to 0.01 millisievert (mSv).

TABLE 3 Protective equipment utilized by staff.

| Reference: First author (year) | Lead coat | Thyroid shield | Lead glasses | Table mounted lead drape | Ceiling mounted lead shield | Lead cap | Lead gloves | Additional shielding | X-ray tube orientation |
|------------------------------------|-----------|----------------|--------------------------------|--|--|-------------------|-------------|---|---------------------------|
| Domienik, J. (2012) ¹ | Y | * | *—nurses Y—drs (use varied) | R1—Y R2—Y R3—use varied R4—use varied R5—n R6—Y | R1—Y R2—use varied R3—use varied R4—n R5—n R6—n | n | * | * | OT (R5) UT (R1-4;6) |
| Chohan, M. (2015) ¹¹ | Y | Y | Y | Y | Y | n—nurses Y—drs | n | Additional lead shield on anaesthetic side | Biplane |
| Chida, K. (2013) ¹² | Y | n | * | Y | Y | n | * | * | UT |
| Antic, V (2012) ¹⁹ | Y | Y | 0%—nurses 46%—doctors | Y | Y | n | n | nil | UT (x2) |
| Sailer, A. (2015) ²⁵ | Y | Y | n | n | n | n | n | nil | UT |
| Nuraeni, N. (2016) ²⁹ | Y | Y | * | Y | Y | * | * | * | biplane |
| Mohapatra, A. (2013) ³¹ | Y | Y | Y—use varied | Y | Y (2) | n | * | Floor shield for anaesthetic team (infrequently used) | UT |
| Korir, G. (2012) ³² | * | * | * | * | * | n | * | * | * |
| Omar, A. (2017) ³⁴ | Y | * | * | R1—Y (x2) R2—Y R3—Y R4—Y | R1 (hybrid IR OR)—Y (x2) R2 (IR)—Y (x2) R3 (IC)—Y (large) R4 (IR)—Y | * | * | Mobile full body radiation protection shield available in R1, 3 and 4 | UT (R1-3) biplane (R4) |
| Racadio, J (2014) ³⁵ | Y | * | * | Y—use varied | Y—use varied | * | * | * | UT |
| Baumann, F. (2015) ³⁶ | Y | Y | n | * | * | n | n | * | * |
| Sandblom, V. (2013) ³⁷ | Y | * | * | * | Y | * | * | * | * |
| James, R. (2015) ³⁸ | * | * | * | * | Y | * | * | Standing stationary full body length leaded acrylic barrier | Biplane |
| Butcher, R. (2015) ³⁹ | Y | * | * | * | * | * | * | * | UT |
| Haga, Y. (2017) ⁴⁴ | Y | n | 0%—nurses 75%—drs | * | n | n | n | Nil | UT |
| Gilligan, P. (2015) ⁴⁵ | * | * | n—nurses Y—drs (use varied) | * | Y | n | * | * | UT |

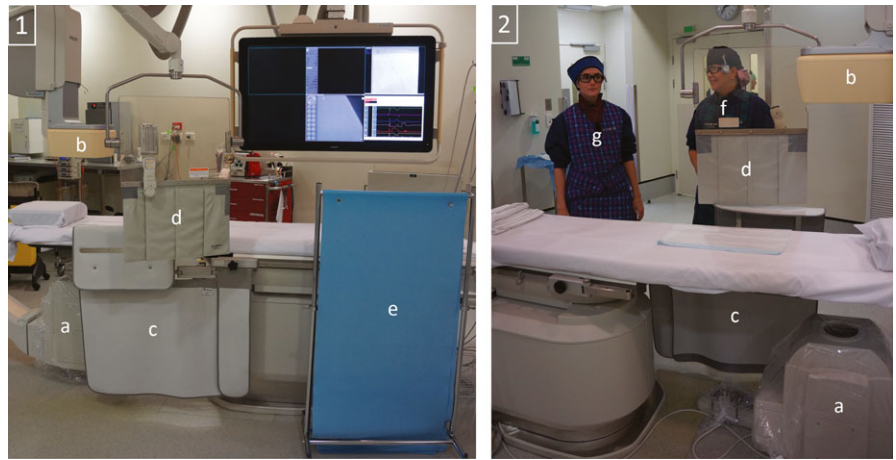
(Continues)

TABLE 3 (Continued)

| Reference: First author (year) | Lead coat | Thyroid shield | Lead glasses | Table mounted lead drape | Ceiling mounted lead shield | Lead cap | Lead gloves | Additional shielding | X-ray tube orientation |
|---|-----------|------------------------|--|-----------------------------|---|----------|---------------------------|--|---------------------------|
| McLean, D. (2016) ⁴⁶ | * | * | 50%—IC staff 30%—Vas IR staff 0%—ERCP staff | * | y—IC y—IR Angiography n—ERCP | n | n | * | UT |
| Efstathopoulos, E. (2011) ⁴⁷ | y | y | 0%—nurses 71%—radiologists 83%—cardiologists | y | y | n | Available but not used | Mobile floor screen 78%—IR 14%—IC | UT |
| Omar, A. (2015) ⁴⁸ | y | * | y! | * | y | y | * | * | UT |
| Rigatelli, G. (2016) ⁴⁹ | y | * | * | * | Phantom measurements taken with and without CML | * | * | * | UT |
| Principi, S. (2015) ⁵² | y | 17%—nurses 100%—drs | 0%—nurses 11%—drs | y | y—78% | n | n | nil | UT |
| Urboniene, A. (2015) ⁵³ | y | y | 50%—IR staff | * | y—use varied ~76% of workers were protected with lead screens or glasses | n | * | * | * |
| Komemushi, A. (2014) ⁶³ | y | * | * | y | y | n | * | * | UT |
| Mori, H. (2015) ⁶⁴ | y | * | * | y | * | * | * | Portable radiation shielding screens | UT |

Vas: vascular; R: room; CML: Ceiling mounted lead; IC: interventional cardiology; IR: interventional radiology; ERCP: endoscopic retrograde cholangiopancreatography; drs: doctors; UT: undertable; OT: overtable; OR: operating room; !: 'protective glasses' unclear whether this is lead or plastic; *: not articulated; y: yes; n: no.

FIG. 4. Lead protection and staff position: 1:View from operating side; 2: View from non-operating side; (a) x-ray tube; (b) x-ray detector; (c) Table mounted lead drapes with extension panel; (d) Movable ceiling mounted lead glass shield with lead drapes; (e) Moveable stand-alone shield; (f) Common location for fluoroscopic operator; (g) Common location for scrub nurse.



choose not to utilize it⁵⁰ and this was also found to be the case in a number of reviewed manuscripts.^{1,34,35,52,53}

2.D | Eye dose

While many dosimeters are worn underneath protective lead aprons, it is important to monitor dose for the unprotected areas of the body exposed to radiation.¹⁹ Ideally a dedicated dosimeter should be worn adjacent to the eye closest to the x-ray tube and monitor lens dose using the operational quantity personal dose equivalent $H_p(3)$ ^{18,56,57} which means it is designed to detect dose to the lens at a depth of 3 mm. Dosimeters are also available in $H_p(10)$ and $H_p(0.07)$ which estimate values for dose of deep organs and skin dose, respectively. Several of the reviewed manuscripts recorded eye dose at the level of the eye^{1,11,19,29,44,46–48,53,58} and some utilized multiple dosimeters around the face or head (Table 2).^{1,11,47,48,52}

Several studies positioned dosimeters external to protective lenses^{19,44,46–48} which gives an approximation of the unprotected dose to the eyes, but not the actual dose incident on the lens of the monitored staff member.^{19,46,48} To assess the benefit of protective lead glasses Haga et al. measured doses both inside and outside the lead eye ware and found the shielding effect was approximately 60% reduction in measured radiation dose in a clinical IC setting.⁴⁴

Several of the reviewed research investigated whether eye dose to personnel would exceed the recommended ICRP dose limits. A number of authors found that staff eye doses were within acceptable limits, but it is observed that some of these findings relate to the pre-2012 ICRP recommended limit of 150 mSv per year, not the revised limit of 20 mSv per year. With the new eye limits applied, nurses in Korir et al. study, with a mean dose of 270 μ Sv per case, and physicians in Domienik et al. and Efstathopoulos et al., with procedural eye doses of 67.6 and 64 μ Sv, respectively, may be at risk of exceeding the current recommendations. Domienik et al. goes on to report an annual estimated eye dose for one operator of 247 mSv, which not only exceeds the new limit of 20 mSv, but definitively exceeded the old limit of 150 mSv. Multiple reviewed studies highlighted the fact that this new eye dose limit could be exceeded by the operator when bad practices are followed, radiation protection

tools are not used appropriately,^{34,47} or when protective eyeglasses are not worn.^{11,19,34,44,46,52,53,59,60}

With a recommended equivalent dose limit of 500 mSv in a year for the hands and feet, even the highest recorded average extremity dose of 485 μ Sv at the left wrist of a physician⁴⁷ would require participation in over 1000 fluoroscopic cases within a year to be at risk of exceeding the recommended limit.

Chohan et al. demonstrated that scout nurses would receive 39 mSv of cumulative exposure per year and were at risk of exceeding the recommended ICRP eye limit¹¹ and Antic et al. noted that a scrub nurse could exceed the limit if over 600 procedures per year were performed in this role.¹⁹ McLean et al.⁴⁶ identified that the nursing staff received three of the highest six doses in the angiographic suite and noted that, while not routinely the closest to the patient, nurses were present during a large number of procedures. Chida et al. established that individual nurses were present for over double the number of coronary cases as interventionalists (average 754 ± 352 times vs 293 ± 145 times, respectively).¹² Nuraeni et al. reported that a single monitored nurse, due to her proximity to the x-ray tube and her habit of bowing her head during procedures, resulted in a similar eye exposure as the operator.²⁹ If findings of nursing dose measured of 0.27 mSv per case at the collar in Korir et al.³² study were extrapolated, nurses would exceed the eye dose after only 75 cases.

2.E | Imaging parameters

Mohapatra et al. found that digital subtraction angiography (DSA) acquisition runs, as opposed to fluoroscopy accounted for “a large fraction of individuals’ doses”³¹ (p. 702) which has been highlighted by other researchers.^{61,62} James et al. reported changes in behavior regarding the use of DSA in cerebral angiography as a result of real time feedback from the scrub nurse’s dosimeter which monitored a difference in the mean dose of 0.045 μ Sv/Gy-cm² during the closed phase, to 0.02 μ Sv/Gy-cm² during the open phase.³⁸

It was demonstrated that reducing staff proximity to the x-ray tube during fluoroscopic activation can be achieved by better communication between the operator and the nurse,^{38,63} limiting DSA

acquisitions³¹ and increasing staff distance during acquisitions especially when using large tube angles.^{31,38} Adequate staff training and education were also seen as essential, and this was successfully supplemented by using real time feedback monitors.^{34,37}

2.F | Staff education

Mori investigated nursing doses before and after staff were provided with practical education.⁶⁴ This resulted in a decrease in annual effective dose from 1.33 to 0.47 mSv, which corresponds to similar studies.^{65,66} Several authors articulated the need for appropriate training to heighten staff awareness to ideally result in the active participation of staff in optimizing occupational exposure.^{32,34,35,48,52,67}

3 | DISCUSSION

While lead aprons were universally worn, it was concerning to note the irregular use of other radiation protection (Table 3). The use of lead glasses is especially important in the absence of a ceiling mounted lead shield and provides protection from the formation of radiation-induced subcapsular cataracts.³³ Although the reviewed literature was unconvincing in demonstrating a staff commitment to utilizing eye protection, a vast number of authors acknowledged the advantage of lead glasses,^{1,11,19,32,34,35,44,46,48,53} and hopefully, this signals a trend toward greater compliance. Haga et al. report the mean \pm the standard deviation for dosimeter measurements external to, and inside of protective lead glasses as being 7.9 ± 3.3 mSv and 3.1 ± 1.3 mSv/6 months, respectively, concluding the shielding effect was approximately 60%.⁴⁴ The reviewed publications almost universally recommend the diligent use of appropriately positioned lead shielding and protective eyewear during fluoroscopic procedures.

Due to cardiac motion, DSA is infrequently used in cardiology procedures which may result in lower occupational doses as demonstrated by McLean et al.⁴⁶ in reported lower extrapolated annual eye dose to nurses involved in fluoroscopic cardiac procedures (1.32 mGy) compared to vascular interventions (6.06 mGy). Authors investigating endovascular aortic repairs which, in theory, should expose staff to increased levels of radiation due to the proximity of staff to the irradiated area, the thickness of the imaged body part, and the use of DSA report mean nursing doses of 17 μ Sv (measured at the chest)²⁵ and 26 μ Sv (measured at collar level).³¹ Omar et al. (2017) report a higher equivalent eye dose received by nurses assisting during interventional neuroradiology procedures compared with the physician (11 vs 8.6 μ Sv).³⁴

Ideally DSA runs should be limited where possible,^{5,31,35,36,68} magnification should be increased,³¹ and the pressure injector should be utilized to allow staff to stand further away from the patient during acquisitions.^{31,38} James et al.³⁸ reported modification of staff behavior during cerebral DSA due to real time monitoring. One physician substituted fluoro-save where possible for

visualization of the femoral artery, which has been shown to reduce dose by 95%.⁶² The pressure injector was more consistently used, as opposed to injecting by hand, thus allowing personnel to step back during DSA acquisitions which may have contributed to the significant decrease in mean dose for physician B from 0.243 μ Sv/Gy-cm² during the closed phase, to 0.069 μ Sv/Gy-cm² during the open phase. It was also reported that during the open phase the scrub nurses utilized the operating physician as a personal shield by stepping behind them to reduce exposure.³⁸ Physicians should also let other in-room staff know of an impending DSA acquisition so that the staff know to not approach the patient and stay behind shielding if possible.^{38,63}

Research indicates a considerable number of parameters which can cause a significant variation in resultant dose levels during fluoroscopic cases, even within the same type of procedures.¹ The Optimization of RAdiation protection for MEDical (ORAMED) staff study also revealing a large variability of practices between cases and workplaces.⁵⁶ Given the variation in procedure type, operator, tube geometry, and staff position, correlation of dose conditions within differing procedures proved difficult. This was exacerbated by the different reporting values used by the authors.

The ICRP notes that radiation training may be lacking which may result in a radiation safety issue for staff as well as patients⁶⁹ and recommends that departments implement an effective optimization program through training and raising consciousness of radiology protection in individuals.⁷⁰ The effectiveness in dose reduction to staff following radiation education has been highlighted^{65,66,71} as has the need for radiation training of occupationally exposed nursing staff.⁷²

Several authors noted that nursing staff are at risk of exceeding recommended dose levels if radiation protection tools are not properly used. Given the variables that exist for nursing staff during fluoroscopic procedures, dose minimization is not as simple as increasing distance from the source of the scattered radiation. Given the invisible nature of radiation, staff should be provided with appropriate information and training to highlight factors which influence dose allowing them to become conscious contributors to personal dose minimization.

3.A | Limitations of current evidence

Several limitations have been identified in the current literature. Many of the articles reviewed had relatively small sample sizes either due to the number of staff or procedures, or a relatively short data collection period. Evaluation of occupational nursing dose during fluoroscopic procedures is vital, and it is recommended that monitoring of nurse doses should be implemented as part of a robust quality assurance program. This review has highlighted the need for additional research to evaluate radiation exposure to nurses during fluoroscopic procedures. It would be constructive for future investigations to specifically articulate the location of the nurse during procedures and divide the monitoring per position as well as monitoring the dose to the individual. Having multiple dosimeters evaluating eye and extremity dose would also be beneficial.

3.B | Strengths and limitations of the review

To the author's knowledge, this is the first review to examine literature reporting dose to nursing staff during fluoroscopic CV procedures. One limitation of the review is the difficulty in making direct comparisons of nursing dose in the reviewed studies due to the variability of staff role and position, the wide variety of procedures, the type, calibration, and location of the dosimeters and the differing parameters in the reporting of dose.

4 | CONCLUSION

This literature review was undertaken to highlight research specifically investigating the occupational dose received by nursing staff within fluoroscopic examinations and to critically review the findings. Nursing staff should be aware of the effect that x-ray tube angle, orientation, and acquisition type has on potential exposure and use this knowledge to position themselves and lead shielding correctly to minimize risk. Appropriate education and training should be provided to inform nursing staff working within CV fluoroscopic suites of dose reduction techniques and the importance of utilizing protective equipment. Departments should also provide adequate shielding options for personnel to ensure that occupational radiation dose is kept as low as reasonably achievable.

Of all the reviewed literature, only three authors looked purely at dose to nurses during fluoroscopic procedures^{39,63,64} indicating that more studies are needed focussing on the occupational dose to nursing staff during x-ray guided CV procedures.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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