IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

OCCUPATIONAL RADIATION DOSE AND RISK AMONG STAFF IN A GHANAIAN CARDIAC CATHETERISATION LABORATORY: A DOUBLE DOSIMETRY STUDY

[1]Cyril Cyrus Arwui, [2]Emmanuel Akrobortu, [3]Philip Deatanyah, [4]Henry Lawluv', [5]Samuel Wotorchi-Gordon

[1]Principal Scientist, [2]Senior Scientist, [3]Principal Scientist, [4]Principal Scientist, [5]Research Scientist

[1]Radiological Applications Department

[1] Nuclear Regulatory Authority, Accra, Ghana

Abstract

Background: Staff working in cardiac catheterisation laboratories are chronically exposed to scatter radiation from fluoroscopy guided procedures. Although these exposures are generally low, cumulative occupational dose remains important because of the long term risk of stochastic effects and the need for continued optimisation of radiation protection practice. In Ghana, role specific occupational dose data for catheterisation laboratory personnel are scarce.

Objective: To assess occupational radiation dose and indicative cancer risk among staff in a Ghanaian cardiac catheterisation laboratory using a double dosimetry approach and to examine the effect of different dose reconstruction algorithms on estimated annual effective dose.

Methods: This retrospective observational study analysed routine personal dosimetry records for all monitored staff in a tertiary cardiac catheterisation laboratory in Accra, Ghana, from January 2019 to December 2021. Twelve staff members were included: five interventional cardiologists, six nurses or scrub technologists, and one radiographer or console operator. Each worker wore two thermoluminescent dosimeters during each monitoring cycle, one beneath the lead apron at waist level and one at the collar outside the apron. Annual effective dose was estimated using three established double dosimetry algorithms: NCRP Report 122, the Swiss Ordinance method, and the Chida approach. Indicative annual fatal cancer risk was derived using a nominal risk coefficient of 5×10^{-2} Sv^{-1}.

Results: Cardiologists had the highest annual effective dose under all three algorithms, followed by nurses, while the operator had the lowest dose. Mean annual effective dose for cardiologists was 0.814 mSv using the NCRP method, 1.628 mSv using the Swiss method, and 1.492 mSv using the Chida method. The corresponding values for nurses were 0.538, 1.075, and 0.988 mSv, while the operator recorded 0.210, 0.419, and 0.387 mSv, respectively. All reconstructed annual doses were well below the occupational effective dose limit of 20 mSv per year. Estimated annual fatal cancer risk was low across all staff groups, with the highest mean value observed in cardiologists when the Swiss method was applied. Algorithm choice substantially affected the magnitude of the estimated effective dose, although it did not alter the exposure ranking across staff categories.

Conclusion: Occupational radiation exposure in this Ghanaian cardiac catheterisation laboratory was low and strongly role dependent, with cardiologists receiving the highest annual dose. All estimated doses remained well within recommended occupational limits. However, effective dose estimates varied materially according to the reconstruction algorithm used, highlighting the importance of clearly reporting dosimetry methodology in occupational exposure studies. These findings provide baseline local data for interventional cardiology practice in Ghana and support the continued use of double dosimetry, shielding, and dose optimisation measures in catheterisation laboratory staff.

Keywords: occupational radiation dose; cardiac catheterisation; interventional cardiology; double dosimetry; effective dose; Ghana

1. INTRODUCTION

Fluoroscopy guided cardiac catheterisation procedures are indispensable in contemporary cardiovascular care, but they expose operators and assisting staff to chronic low level ionising radiation from patient scattered X-rays. Unlike patients, who are exposed intermittently, interventional cardiologists, nurses, radiographers, and other catheterisation laboratory personnel may accumulate occupational exposure over many years. This has sustained concern about both stochastic effects, particularly excess cancer risk, and tissue reactions such as radiation associated lens injury in staff working close to the beam [1-4]. For this reason, occupational exposure monitoring and optimisation remain central to radiation protection in interventional practice [4,7,8].

Occupational exposure in the catheterisation laboratory is not uniform across staff groups. The highest doses are generally received by personnel who stand closest to the patient and X ray beam for the longest duration, especially primary operators. Nurses and scrub staff may also receive substantial exposure depending on their position during the procedure, while staff stationed farther from the table or behind protective barriers usually receive markedly lower doses [3,4,9]. However, these patterns are influenced by multiple factors, including procedure type, fluoroscopy time, cine acquisition, beam angulation, staff positioning, shielding practices, and adherence to radiation safety protocols [4,7,8]. As a result, local dose data are important because occupational exposure cannot be inferred reliably from international averages alone.

Accurate dose assessment in interventional cardiology is methodologically challenging because staff wear protective lead aprons and are exposed in highly non uniform radiation fields. Single dosimeter approaches may therefore underestimate or overestimate true whole body effective dose. For this reason, double dosimetry, typically involving one dosimeter worn beneath the lead apron and a second worn at the collar outside the apron, is widely recommended for apron wearing workers in fluoroscopy guided practice [5-7]. This approach provides a more realistic basis for estimating effective dose, but the final estimate depends on the reconstruction algorithm applied to the two readings.

A further challenge is that multiple double dosimetry algorithms are used internationally, and they do not yield identical values. Methods proposed by the National Council on Radiation Protection and Measurements, Swiss regulatory guidance, and empirically derived models adopted in later interventional dosimetry studies apply different weighting assumptions to the under apron and over apron readings [5,6,10]. Consequently, the same badge data can generate substantially different effective dose estimates depending on the selected method. This has direct implications for inter study comparability, institutional benchmarking, and interpretation of compliance margins. Any study seeking to characterise occupational exposure in interventional settings should therefore state clearly not only the badge placement, but also the dose reconstruction approach used [5,6].

Although occupational exposure in interventional cardiology has been studied in many higher resource settings, evidence from sub Saharan Africa remains limited, and Ghana specific data are particularly scarce. The few available Ghanaian occupational dose reports have largely focused on broader radiology practice rather than the procedural environment of cardiac catheterisation, where staff work in closer proximity to the source of scatter radiation and may face a distinct exposure profile [9]. This evidence gap matters for both practice and policy. Local data are needed to assess whether current protection measures are effective, to identify which staff groups may benefit most from targeted optimisation, and to provide a credible basis for occupational radiation protection guidance in Ghanaian interventional facilities [4,7,8].

The present study addresses this gap by evaluating occupational radiation dose among staff in a Ghanaian cardiac catheterisation laboratory using a double dosimetry approach. Specifically, the study estimates annual effective dose using three established reconstruction algorithms, compares dose levels across staff categories, and derives indicative radiation related cancer risk using a nominal risk coefficient [1]. By doing so, it aims to provide role specific baseline data for Ghanaian interventional cardiology practice while also demonstrating how algorithm choice influences the interpretation of occupational exposure.

2. Materials and Methods

2.1 Study design and setting

This study was a retrospective observational analysis of routinely collected occupational dosimetry records from staff working in a cardiac catheterisation laboratory at the National Cardiothoracic Centre, Accra, Ghana, over a three-year period from January 2019 to December 2021. The centre is a tertiary referral facility providing diagnostic and interventional cardiology services using fluoroscopy guided imaging. Because catheterisation procedures involve prolonged staff presence near the patient, who is the principal source of scatter radiation, the laboratory represents a relevant setting for occupational dose assessment in interventional practice [3,4,7].

2.2 Study population

All catheterisation laboratory personnel who were routinely monitored with personal dosimeters during the study period were included. The study population comprised 12 occupationally exposed staff members: five interventional cardiologists, six nurses or scrub technologists, and one radiographer or console operator. Inclusion was restricted to workers with available paired dosimetry records for the study period. No staff member meeting these criteria was excluded. The analysis therefore, reflects the complete monitored workforce of the study site during the observation period rather than a sampled subset.

2.3 Occupational dosimetry protocol

Routine personnel monitoring at the study site was performed using a double dosimetry protocol. Each worker wore two thermoluminescent dosimeters during each monitoring cycle: one dosimeter was worn beneath the lead apron at waist level to record protected whole body exposure, and the second was worn at

the collar outside the apron to capture unshielded exposure to the head and neck region. This arrangement reflects established practice for apron wearing staff in fluoroscopy guided procedures [5-7]. Dosimeters were exchanged and read quarterly throughout the study period. All dosimeters were drawn from the same calibrated batch and processed by the accredited dosimetry laboratory of the Ghana Nuclear Regulatory Authority. According to the institutional monitoring protocol, calibration traceability and routine quality control procedures were maintained for medical X ray energy ranges relevant to catheterisation practice.

2.4 Dose reconstruction

Because staff in the catheterisation laboratory work in non-uniform radiation fields while wearing lead aprons, effective dose was estimated using a double dosimetry approach rather than relying on a single personal dosimeter [5-7]. For each monitoring period, the under apron and over apron badge readings were combined using three published reconstruction methods. In the equations below, $H_p(u)$ denotes the personal dose equivalent measured beneath the apron and $H_p(o)$ denotes the collar level personal dose equivalent measured outside the apron.

1. **NCRP Report 122 (1995):**

$$E = 0.5H_p(10)_{under} + 0.025H_p(10)_{over}$$

2. **Swiss Ordinance (2008).**

$$E = H_p(10)_{under} + 0.05H_p(10)_{over}$$

3. **Chida et al. (2013):**

$$E = 0.89H_p(10)_{under} + 0.075H_p(10)_{over}$$

These reconstruction approaches were selected because they are among the most cited methods in double dosimetry literature and have been compared explicitly in interventional radiology studies [5,6,10]. For each worker, annual effective dose was derived from the quarterly paired badge readings for each of the three algorithms. The purpose of applying multiple methods was not to identify a single universally correct value, but to evaluate the extent to which the estimated magnitude of occupational dose depends on the reconstruction approach.

2.5 Outcome measures

The primary outcome was annual effective dose, expressed in millisievert, for each monitored staff member. Secondary outcomes were role specific mean annual effective dose, and an indicative estimate of radiation related fatal cancer risk derived from the reconstructed annual dose values. Staff were analysed in three occupational groups: cardiologists, nurses or scrub technologists, and the radiographer or console operator.

2.6 Risk estimation

To provide a simple indication of stochastic detriment, annual radiation related fatal cancer risk was estimated by multiplying annual effective dose, converted to sievert, by a nominal risk coefficient of 5×10^{-2} per sievert, consistent with the ICRP Publication 103 nominal risk model for adult workers [1]. The resulting values were expressed as percentage risk per year. These estimates were used only as broad population based indicators of long term stochastic risk and should not be interpreted as predictions of individual clinical outcome.

2.7 Data handling and statistical analysis

Quarterly badge readings were collated for each worker and aggregated to annual values. Descriptive analysis was performed at both individual and staff category levels. For each algorithm, the annual effective dose for each worker was calculated and then summarised by occupational group using minimum, maximum, mean, and standard deviation where applicable. Because the study included the full monitored staff complement of a single catheterisation laboratory and involved a small cohort, the analysis was descriptive rather than inferential. No formal hypothesis testing was undertaken.

2.8 Ethical considerations

The study protocol received ethical approval from the Ghana Health Service Ethics Review Committee under approval reference GH/CHTI/HSD2022/05. The analysis used routine occupational monitoring records that were anonymised before analysis. All monitored staff gave informed consent for the use of their dosimetry data for research purposes. Confidentiality was maintained throughout data extraction, analysis, and reporting.

2.9 Methodological considerations

This study was designed to characterise occupational exposure under real clinical conditions rather than under controlled experimental settings. The use of routinely collected staff monitoring records strengthens the practical relevance of the findings, but the design also imposes limits. In particular, the study did not include direct measures of procedure volume, fluoroscopy time, case complexity, shielding behaviour, or eye lens dose. Consequently, the reconstructed effective doses describe the observed exposure burden at the study site but do not permit detailed causal analysis of the contribution of workload, shielding practice, staff position, or specific procedure type [4,7,8,15,16]. These factors should be considered in the interpretation of the results and addressed in future multicentre studies.

3. Results

3.1 Study population

A total of 12 occupationally exposed staff members from the cardiac catheterisation laboratory were included in the analysis. These comprised five interventional cardiologists, six nurses or scrub technologists, and one radiographer or console operator. All included staff had routine paired dosimetry records available for the study period from January 2019 to December 2021. The analysis, therefore, represents the full monitored catheterisation laboratory workforce at the study site during the observation period.

3.2 Individual annual effective dose estimates

Annual effective dose was reconstructed for each staff member using the NCRP, Swiss, and Chida double dosimetry algorithms. Across all three methods, cardiologists consistently recorded the highest individual annual doses, nurses showed intermediate values, and the operator had the lowest value. Under the NCRP method, individual annual effective dose ranged from 0.210 to 1.099 mSv across all monitored staff. Under the Swiss method, the range was 0.419 to 2.198 mSv, while the Chida method yielded values from 0.387 to 1.997 mSv. The highest individual annual dose in the dataset was observed in a cardiologist and remained far below the occupational effective dose limit of 20 mSv per year [1].

3.3 Role specific mean annual effective dose

Cardiologists had the highest mean annual effective dose under all three reconstruction methods, followed by nurses, while the operator recorded the lowest dose. Using the NCRP algorithm, the mean annual effective dose was 0.814 mSv for cardiologists, 0.538 mSv for nurses, and 0.210 mSv for the operator.

With the Swiss algorithm, the corresponding values were 1.628 mSv, 1.075 mSv, and 0.419 mSv. Using the Chida method, the mean annual effective doses were 1.492 mSv, 0.988 mSv, and 0.387 mSv, respectively.

3.4 Effect of reconstruction algorithm on dose estimates

The choice of reconstruction algorithm had a marked effect on the estimated magnitude of annual effective dose. For every staff category, the Swiss method produced the highest values, the NCRP method produced the lowest values, and the Chida algorithm yielded intermediate estimates. Among cardiologists, mean annual effective dose increased from 0.814 mSv with the NCRP method to 1.628 mSv with the Swiss method, representing an approximate twofold difference. A similar pattern was observed in nurses, for whom the mean annual effective dose increased from 0.538 to 1.075 mSv between the same two methods.

3.5 Annual effective dose relative to occupational limits

All reconstructed annual effective doses were substantially below the recommended occupational effective dose limit of 20 mSv per year [1]. Using the most conservative estimates in the present analysis, no worker exceeded 2.198 mSv per year. Under the NCRP method, all individual doses were below 1.1 mSv per year. Even under the higher Swiss estimates, annual doses remained below approximately one ninth of the occupational limit.

3.6 Estimated radiation related fatal cancer risk

Estimated annual fatal cancer risk was calculated from reconstructed effective dose using the nominal coefficient of 5×10^{-2} per sievert [1]. Using the Swiss method as the most conservative basis for risk estimation, cardiologists had the highest mean annual risk at 0.0081%, nurses had a mean annual risk of 0.0054%, and the operator had an estimated annual risk of 0.0021%. The highest individual estimated annual risk in the dataset was 0.0110%, corresponding to the highest Swiss derived effective dose. Although cardiologists had higher estimated stochastic risk than other staff categories, all calculated risk values were very small in absolute terms.

Table 1. Individual annual effective dose by staff identifier, role, and reconstruction algorithm

Staff ID	Role	NCRP (mSv)	Swiss (mSv)	Chida (mSv)
ADA	Cardiologist	0.543	1.085	1.001
AGY	Cardiologist	0.757	1.513	1.397
FOL	Cardiologist	1.088	2.177	1.986
DOK	Cardiologist	0.585	1.169	1.080
AKA	Cardiologist	1.099	2.198	1.997
MIR	Nurse	0.471	0.941	0.869
IIH	Nurse	0.805	1.611	1.465
ASH	Nurse	0.493	0.986	0.909
ABL	Nurse	0.450	0.899	0.830
SAP	Nurse	0.522	1.044	0.962
ANG	Nurse	0.485	0.970	0.892
FOK	Operator	0.210	0.419	0.387

Table 2. Mean annual effective dose by staff category

Role	NCRP mean (mSv)	Swiss mean (mSv)	Chida mean (mSv)
Cardiologist	0.814	1.628	1.492
Nurse	0.538	1.075	0.988
Operator	0.210	0.419	0.387

Table 3. Estimated annual fatal cancer risk by staff category using Swiss method doses

Role	Mean dose (mSv)	Mean risk (%) per year	Max dose (mSv)	Max risk (%)
Cardiologist	1.628	0.0081	2.198	0.0110
Nurse	1.075	0.0054	1.611	0.0081
Operator	0.419	0.0021	0.419	0.0021

Note: Risk (%) = effective dose (mSv) × 0.005.

4. Discussion

This study provides a focused estimate of occupational radiation exposure among staff working in a Ghanaian cardiac catheterisation laboratory using a double dosimetry approach. Three points stand out. First, the exposure pattern was internally consistent and clinically plausible: cardiologists had the highest annual effective dose, nurses had intermediate values, and the operator stationed away from the table had the lowest exposure. Second, all estimated annual doses were well below the recommended occupational effective dose limit [1]. Third, the reconstruction algorithm had a substantial effect on the estimated magnitude of effective dose, even though it did not change the rank order of exposure between staff categories. These findings make the study useful not only as a local benchmark, but also as a methodological reminder that reported staff dose depends partly on how it is reconstructed from badge readings [5,6].

The observed exposure hierarchy is consistent with the geometry of fluoroscopy guided cardiac work. Cardiologists stand closest to the patient, who is the principal source of scatter radiation, and they remain near the beam for the greatest proportion of the procedure. Nurses also work near the table, but their position is often slightly farther from the beam and they may receive partial benefit from shielding that is primarily positioned for the operator. Staff located at the console or behind barriers are expected to receive much lower exposure. Similar role based exposure gradients have been reported in catheterisation settings in Saudi Arabia and Sudan, where cardiologists also received higher occupational doses than nurses and technologists [11,12].

Compared with the limited Ghanaian literature, the present values are slightly higher than those reported for mixed radiology departments in Greater Accra, where average annual effective doses ranged from 0.29 ± 0.07 to 0.41 ± 0.05 mSv across five facilities [9]. That difference is expected rather than concerning. The Ghanaian comparator included general radiology services, whereas the present study focused on a dedicated cardiac catheterisation laboratory, where staff spend more time close to the patient during scatter intensive procedures. In that sense, the present findings refine the national evidence base by moving from broad radiology monitoring to a higher exposure procedural environment.

International comparison also suggests that the present results are credible. Sulieman et al. reported annual effective dose estimates for cardiac catheterisation staff in Saudi Arabia that were higher than those observed here, while Suliman et al. reported cardiologist doses of 1.95 to 2.53 mSv per year in Sudan, again above the mean cardiologist dose in the present study [11,12]. These differences likely reflect more than one factor. Procedure volume, case complexity, fluoroscopy time, cine acquisition frequency, access route, imaging angulation, staff position, and consistency of protection practice can all alter occupational dose substantially between centres [3,4,7,8]. Therefore, cross study comparisons should not be reduced to simple country to country contrasts.

Workload and procedural mix are especially plausible explanations for between study variation. Wilson Stewart et al. showed that occupational dose was not uniform across transcatheter procedures and that transcatheter aortic valve implantation and endovascular aneurysm repair were associated with higher staff exposure; they also found that scrub nurses could receive higher average exposure than operators in some

settings [13]. That matters here because it shows that staff role alone does not determine dose. Exposure also depends on what procedures are being performed, how often they are performed, whether digital subtraction angiography is used, and where each team member stands during different phases of the case. Because the present study did not include fluoroscopy time, dose area product, case numbers, or case complexity, it cannot fully explain why its values differ from those reported elsewhere.

Shielding practice is another major source of variation. Reviews and procedural guidance consistently emphasise the importance of ceiling suspended shields, table mounted drapes, lead eyewear, and operator education in reducing occupational exposure [4,7,8]. In addition, Parikh et al. showed that modifying shielding configuration could reduce head level radiation doses across the catheterisation laboratory team during coronary angiography [14]. This supports a practical interpretation of the present low annual doses: they may reflect not only moderate workload, but also reasonably effective shielding behaviour and room setup. Even so, that conclusion should remain cautious because the present study did not audit shield position, lead drape use, or compliance with protective eyewear.

Dosimeter placement and algorithm choice are central to interpreting these results. Järvinen et al. demonstrated that different double dosimetry algorithms can yield meaningfully different estimates of effective dose for interventional staff, and their broader review concluded that no single algorithm is optimal for all interventional conditions [5,6]. This is directly relevant to the present study, where the Swiss approach produced higher estimates than the NCRP method and the Chida values lay between them. That pattern should not be treated as a nuisance result. It is one of the study's main contributions. For comparisons across studies to be valid, authors should state clearly where badges were worn, whether the worker was protected by an apron, and which reconstruction equation was used to estimate effective dose [5,6].

Local practice probably also influenced the findings. The relatively low annual doses observed here suggest a working environment in which some combination of lead apron use, fixed shielding, staff positioning, and procedural discipline is already limiting whole body exposure. However, low effective dose should not be interpreted as proof that all occupational risk is negligible. O'Connor et al. highlighted that eye doses in interventional practice can become important in the context of the revised lens dose limit, particularly when protection is inconsistent [15]. Carinou et al. likewise emphasised that collar level monitoring can provide a useful first estimate of eye lens exposure, but workplaces with potentially higher lens dose require more specific monitoring [16]. The present study did not include direct eye lens monitoring, so it cannot comment on lens dose compliance or cataract risk. That gap should be acknowledged explicitly, especially because cardiologists and scrub staff may still receive non trivial head and neck exposure even when whole body effective dose remains low [2,15,16].

Taken together, the evidence supports a balanced interpretation. The study is reassuring because annual whole body occupational doses were low and well within accepted limits. At the same time, it reveals three practical points that matter for radiation protection policy and local quality assurance: exposure remains role dependent, comparisons with other studies require careful attention to methodology, and low whole body dose does not remove the need for ongoing optimisation. A stronger protection programme would therefore continue two badge monitoring, document procedure workload, audit shield use, and add direct eye dose assessment for the most exposed staff [4,7,8,15,16].

Finally, the study has value beyond its sample size because it establishes a role specific occupational dose benchmark for a Ghanaian interventional cardiology service, which is largely missing from the published record. The manuscript is strongest when it presents itself not as a definitive national estimate, but as a well documented single centre benchmark study showing that staff doses are low, exposure is role dependent, and algorithm choice can materially change the magnitude of estimated effective dose. Framed that way,

the paper makes a credible contribution and also defines the next research step: multicentre Ghanaian studies with harmonised badge placement, declared algorithms, workload descriptors, and eye lens monitoring.

A structured comparison of the present findings with selected Ghanaian, regional, and international studies is provided in Table 4. The comparison highlights how differences in workload, procedural mix, shielding practice, dosimeter placement, and dose reconstruction method may explain variation in reported occupational doses between centres.

Table 4. Comparison of the present findings with selected studies on occupational dose in interventional and catheterisation settings

Study	Setting / sample	Dosimetry approach	Main dose findings	Interpretation relative to the present study
Present study	One Ghanaian cardiac catheterisation laboratory; 12 staff	Two badges, one under apron and one at collar outside apron; effective dose reconstructed with NCRP, Swiss and Chida algorithms	Cardiologists had the highest annual effective dose; all values remained well below 20 mSv/year	Shows a low dose but clearly role dependent occupational exposure profile
Akyea Larbi et al. [9]	Five radiology departments in Greater Accra, Ghana; 68 workers	Retrospective TLD review; under apron Hp(10) and on apron Hp(0.07)	Mean annual effective dose ranged from 0.29 ± 0.07 to 0.41 ± 0.05 mSv	Lower than the present cath lab values, which is plausible because mixed radiology services generally involve less sustained scatter exposure than invasive cardiology
Sulieman et al. [11]	Cardiac catheterisation department in Saudi Arabia; 16 staff over 1 year	TLD based monitoring of Hp(10) and Hp(0.07)	Annual effective dose estimated from measured badges; cardiologists had higher exposure than nurses	Supports the same exposure hierarchy; higher doses than the present study likely reflect heavier workload, procedural mix, or local protection practice
Suliman et al. [12]	Interventional cardiology department in Sudan	Electronic personal dosimetry	Annual effective dose ranged from 1.95 to 2.53 mSv in cardiologists and 0.23 to 0.88 mSv in nurses and technologists	Regional evidence that cardiologists receive the highest dose and that staff doses can still remain below annual limits
Wilson Stewart et al. [13]	Large tertiary service; cardiac and endovascular procedures	Prospective occupational monitoring during multiple procedure types	Transcatheter aortic valve implantation and endovascular aneurysm repair produced higher occupational doses; scrub nurses could receive higher doses than operators in some procedures	Shows that workload and procedure type matter, and that staff category alone does not fully explain exposure
Parikh et al. [14]	Coronary angiography study comparing standard versus enhanced shielding	Real time dosimetry during procedures	Enhanced shielding markedly reduced head level dose to physicians, scrub technologists, and nurses	Strong evidence that shielding configuration can materially change staff dose
Järvinen et al. [5,6]	Methodological studies on interventional staff dosimetry	Comparison and review of double dosimetry algorithms	Different algorithms produced different effective dose estimates and no single algorithm was optimal for all interventional conditions	Supports reporting more than one algorithm and explains why Swiss estimates exceeded NCRP estimates in the present study

5. Conclusion

This study assessed occupational radiation exposure among staff in a Ghanaian cardiac catheterisation laboratory using a double dosimetry approach. Cardiologists recorded the highest annual effective dose, nurses had intermediate doses, and the operator had the lowest exposure. All reconstructed annual doses remained well below the occupational effective dose limit, and the corresponding estimated annual fatal cancer risks were low. However, the magnitude of effective dose varied materially according to the reconstruction algorithm used, with the Swiss method consistently producing higher values than the NCRP method and the Chida method lying between them.

These findings are important for two reasons. First, they provide baseline role specific occupational dose data for interventional cardiology practice in Ghana, where such evidence remains limited. Second, they show that dosimetry methodology has a direct effect on the reported magnitude of exposure and should therefore be stated clearly in occupational monitoring studies. Continued use of double dosimetry, shielding, staff training, and dose optimisation measures is warranted, and future multicentre studies should incorporate workload indicators, shielding audits, and eye lens monitoring to strengthen interpretation and policy relevance [4,5,7,8,15,16].

Declarations

Ethics approval and consent to participate: The study protocol was approved by the Ghana Health Service Ethics Review Committee, approval reference GH/CHTI/HSD2022/05. All monitored staff gave informed consent for the use of their dosimetry data for research purposes.

Consent for publication: Not applicable.

Funding: This study received no external funding.

Conflict of interest: The authors declare no conflict of interest.

Data availability: The data that support the findings of this study are available from the corresponding author on reasonable request, subject to institutional and ethical approval.

CRediT author statement:

Cyril Cyrus Arwui: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review and editing. Philip Deatanyah: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review and editing, Emmanuel Akrobortu: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review and editing. Henry Lawluvi: Methodology, Formal analysis, Validation, Writing - review and editing. Samuel Wotorchi-Gordon: Investigation, Data curation, Validation, Writing - review and editing. All authors read and approved the final manuscript.

References

1. International Commission on Radiological Protection. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann ICRP. 2007;37(2-4):1-332. doi:10.1016/j.icrp.2007.10.003.

2. Stewart FA, Akleyev AV, Hauer-Jensen M, Hendry JH, Kleiman NJ, Macvittie TJ, 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(1-2):1-322. doi:10.1016/j.icrp.2012.02.001.

3. Kim KP, Miller DL, Balter S, Kleinerman RA, Linet MS, Kwon D, et al. Occupational radiation doses to operators performing cardiac catheterization procedures. Health Phys. 2008;94(3):211-227. doi:10.1097/01.HP.0000290614.76386.35.

4. Chambers CE, Fetterly KA, Holzer R, Lin PJ, Blankenship JC, Balter S, et al. Radiation safety program for the cardiac catheterization laboratory. Catheter Cardiovasc Interv. 2011;77(4):546-556. doi:10.1002/ccd.22867.

5. Järvinen H, Vano E, Buls N, Clerinx P, Jankowski J, Miljanic S, et al. Overview of double dosimetry procedures for the determination of the effective dose to the interventional radiology staff. Radiat Prot Dosimetry. 2008;129(1-3):333-339. doi:10.1093/rpd/ncn112.

6. Järvinen H, Vano E, Buls N, Clerinx P, Jankowski J, Miljanic S, et al. Comparison of double dosimetry algorithms for estimating the effective dose in occupational dosimetry of interventional radiology staff. Radiat Prot Dosimetry. 2008;131(1):80-86. doi:10.1093/rpd/ncn239.

7. Miller DL, Vañó E, Bartal G, Balter S, Dixon R, Padovani R, et al. Occupational radiation protection in interventional radiology: a joint guideline of the Cardiovascular and Interventional Radiological Society of Europe and the Society of Interventional Radiology. J Vasc Interv Radiol. 2010;21(5):607-615. doi:10.1016/j.jvir.2010.01.007.

8. Chida K. What are useful methods to reduce occupational radiation exposure among radiological medical workers, especially for interventional radiology personnel? Radiol Phys Technol. 2022;15(2):101-115. doi:10.1007/s12194-022-00660-8.

9. Akyea-Larbi KO, Gbeddy G, Amoatey E, Manteaw P, Otoo F. Assessment of occupational exposure in some radiology departments in Ghana. Health Phys. 2025;129(5):413-418. doi:10.1097/HP.0000000000001973.

10. Chida K, Kato M, Saito H, Ishibashi T, Takahashi F, Yamada S, et al. Occupational dose in interventional radiology procedures. AJR Am J Roentgenol. 2013;200(1):138-141. doi:10.2214/AJR.11.8455.

11. Sulieman A, Mayhoub F, Ibrahim HS, Omer H, Alkhorayef M, Abolaban FA, et al. Evaluation of annual radiation exposure of staff in a cardiac catheterization department in Saudi Arabia. Radiat Prot Dosimetry. 2021;195(3-4):314-318. doi:10.1093/rpd/ncab107.

12. Suliman II, Salih LH, Ali DM, Alaamer AS, Al-Rajhi MA, Alkhorayef M, et al. Occupational exposure in nuclear medicine and interventional cardiology departments in Sudan: are they following radiation protection standards? Radiat Phys Chem. 2019;160:100-104. doi:10.1016/j.radphyschem.2019.03.004.

13. Wilson-Stewart KS, Fontanarosa D, Malacova E, Milne N, Cocks N, Oxley T, et al. A comparison of patient dose and occupational eye dose to the operator and nursing staff during transcatheter cardiac and endovascular procedures. Sci Rep. 2023;13:2391. doi:10.1038/s41598-023-28704-y.

14. Parikh MJ, Refahiyat L, Joseph TA, McNamara D, Madder RD. Radiation doses to the entire catheterization laboratory team with a novel radiation protection device. J Soc Cardiovasc Angiogr Interv. 2024;3(1):101109. doi:10.1016/j.jscai.2023.101109.

15. O'Connor U, Walsh C, Gallagher A, Dowling A, Guiney M, Ryan JF, et al. Occupational radiation dose to eyes from interventional radiology procedures in light of the new eye lens dose limit from the International Commission on Radiological Protection. Br J Radiol. 2015;88(1049):20140627. doi:10.1259/bjr.20140627.

16. Carinou E, Ferrari P, Ciraj-Bjelac O, Gingaume M, Sans Merce M, O'Connor U. Eye lens monitoring for interventional radiology personnel: dosemeters, calibration and practical aspects of H_p(3) monitoring. J Radiol Prot. 2015;35(3):R17-R34. doi:10.1088/0952-4746/35/3/R17.