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Original Research Article

RADIATION EXPOSURE IN INTERVENTIONAL CARDIOLOGY: STRATEGIES FOR REDUCTION AND PROTECTION

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Abstract: *Occupational radiation exposure is a significant concern among healthcare professionals, particularly those in interventional radiology and cardiology procedures. This study aims to comprehensively investigate radiation exposure and its health effects among 200 healthcare professionals, including 100 physicians, 50 nurses, and 50 technicians, across five hospitals. The study employed a controlled, multi-center, observational design, with 100 participants in the experimental group exposed to enhanced radiation protection strategies, while 100 participants in the control group adhered to standard safety protocols. The interventions included additional lead barriers, radiation-absorbent pads, real-time dose monitoring systems, and continuous staff training on radiation safety. Exposure levels were measured using personal dosimeters at regular intervals before and after the interventions. Subgroup analysis was conducted based on professional roles and procedure types, categorized into simple and complex interventions. The results showed a statistically significant reduction in annual radiation exposure in the experimental group compared to the control group, with substantial effect sizes. Subgroup analysis revealed varying degrees of exposure reduction among different professional roles. Notably, complex interventions demonstrated the most substantial reductions in radiation exposure. Furthermore, an analysis of X-ray beam angles indicated a statistically significant increase in exposure at steep angles (≥30°). However, no significant interaction between the control and experimental groups was observed, suggesting that other variables may influence the relationship between steep angles and exposure. The findings of this study emphasize the effectiveness of enhanced protection strategies in reducing occupational radiation exposure among healthcare professionals. The nuanced effects observed across different professional roles and procedure types underscore the importance of tailored safety measures. These results contribute to the ongoing efforts to optimize radiation safety in medical settings and promote the well-being of healthcare professionals. Ethical considerations, adherence to international standards, and the potential implications for policy and guidelines further underscore the significance of this study's findings.*

Keywords: Interventional Cardiology, Radiation Exposure, Radiation Protection, Occupational Exposure, Cardiac Catheterization

Introduction

Radiation exposure in medical settings remains an essential concern due to the potential health risks for healthcare professionals, particularly those engaged in interventional radiology and cardiology procedures (Little et al., 2012). The increasing utilization of medical imaging and interventional techniques has significantly contributed to occupational radiation exposure (Balter and Miller, 2014). Understanding and managing this exposure is paramount to safeguarding the health of medical professionals.

Ionizing radiation has well-established biological effects that can lead to harmful consequences, including genetic mutations and increased cancer risk (Ho et al., 2016). While low levels of exposure are common in everyday environments, medical professionals working with radiological equipment face exposure levels that warrant careful monitoring and control (Andreassi et al., 2016). Historically, safety measures have focused on shielding, limiting exposure time, and maintaining an appropriate distance from radiation sources. However, ongoing innovations and more refined strategies are continually sought to minimize risks further (Gupta et al., 2021).

Physicians, nurses, and technicians involved in radiological interventions are at the forefront of exposure risk. Complex procedures, such as those used in interventional cardiology, can result in higher exposure levels due to extended procedural times and the necessity of specific imaging angles (Brower and Rehani, 2021). Different professional roles may also be exposed to varying degrees, reflecting their positioning relative to radiation sources and their responsibilities within the procedure (Wei et al., 2016).

Lead barriers, lead aprons, and other shielding materials have been the mainstay of protection strategies (Campolo et al., 2022). Recent advancements have also introduced real-time monitoring systems, providing immediate feedback on exposure levels and enabling prompt adjustments during procedures (Picano et al., 2014). Furthermore, staff training on radiation safety remains vital in ensuring that best practices are understood and consistently applied (Baudin et al., 2021).

Several challenges persist in the ongoing efforts to reduce occupational exposure. Not all protection measures are equally effective across different types of procedures or roles within the healthcare team (Wang et al., 2021). Some steep X-ray beam angles have been associated with increased exposure, even when other protective measures are in place (Li et al., 2022). Hence, a more nuanced understanding of the interaction between procedural variables and exposure levels is needed. Additionally, medical technology's continuous evolution presents challenges and opportunities in optimizing radiation safety (Lopes et al., 2022).

This study aims to comprehensively analyze radiation exposure among healthcare professionals across different roles and various interventional procedures. By comparing the effects of enhanced protection strategies with standard practices, the study hopes to identify effective measures to reduce exposure significantly. Such findings may be instrumental in shaping policies, guidelines, and training to promote radiation safety in healthcare settings.

Occupational radiation exposure remains critical for healthcare professionals involved in radiological interventions. While substantial progress has been made in understanding and mitigating risks, there remains a need for a focused and detailed analysis that considers various factors influencing exposure. By employing rigorous methodologies and targeted interventions, this study seeks to contribute valuable insights into the effectiveness of novel protection strategies. Its findings are anticipated to have implications for enhancing safety protocols, contributing to the broader goals of occupational health and patient care within interventional radiology and cardiology.

Methodology

The study involved 200 healthcare professionals from five hospitals, including 100 physicians, 50 nurses, and 50 technicians. The study utilized a stratified random sampling technique to ensure equal representation of different specialties involved in interventional procedures with ionizing radiation.

The study followed a controlled, multi-center, observational design with a pre-post intervention approach. Participants were randomly assigned to either the experimental group (enhanced protection) or the control group (standard protection).

The interventions were multi-faceted and included the introduction of supplementary lead shielding at critical locations, strategic placement of radiation-absorbent pads to minimize scattered radiation, real-time dose monitoring systems to provide immediate feedback on exposure levels, and continuous targeted staff education and retraining on radiation safety.

The procedures were classified based on their complexity level, i.e., simple interventions with minimal radiation exposure and complex interventions with higher radiation exposure due to procedural intricacy and duration.

Personal dosimeters were used to measure exposure, calibrated according to international standards, and precise goniometers were used to categorize beam angles into shallow (<30°) and steep (≥30°). The data analysis involved a comprehensive statistical approach, including mean, standard deviation, frequencies, and percentages for baseline characteristics, two-sample t-test for comparison of continuous variables between groups, ANOVA with post hoc tests to identify specific group differences among professional roles, multiple linear regression to analyze the relationship between beam angles and exposure, and interaction terms included in models to assess moderating effects.

The analysis was performed using statistical software with adherence to the CONSORT guidelines for transparent reporting. Robustness checks, including sensitivity and power analyses, were conducted. The study adhered to international ethical standards, and approval from ethics committees at each site was obtained. The consent forms detailed study procedures, risks, and confidentiality measures.

Results

This study conducted among interventional cardiology staff across five hospitals, comprising 100 physicians, 50 nurses, and 50 technicians, assessed the efficacy of enhanced radiation protection strategies on healthcare workers' safety. The results revealed a significant reduction in mean annual radiation exposure in the experimental group (2.5 ± 1.1 mSv) compared to the control group (3.5 ± 1.2 mSv) using standard protection measures, supported by a two-tailed independent t-test ($t(198) = 5.63$, $p < 0.001$) and a Cohen's d effect size of 0.80. Subgroup analysis further showed distinct reductions in radiation exposure for different professional roles: physicians experienced a marked reduction of 1.4 mSv ($F(1.98) = 21.37$, $p < 0.001$), nurses a moderate reduction of 0.6 mSv ($F(1,48) = 7.12$, $p = 0.01$), and technicians a reduction of 0.7 mSv ($F(1,48) = 8.93$, $p < 0.005$). The forest plot visually represents the statistical significance of these reductions for each professional group, with red dots indicating F-statistic values and corresponding p-values provided (Figure 1.

The experimental group implemented a range of strategies to minimize radiation exposure. These strategies included additional lead barriers such as lead aprons, thyroid shields, and lead glasses, which were used in 100%, 98%, and 95% of cases. The use of thyroid shields and lead glasses was significantly higher in the experimental group compared to the control group ($\chi^2(1, N = 200) = 6.28$, $p = 0.012$; $\chi^2(1, N = 200) = 4.13$, $p = 0.042$).

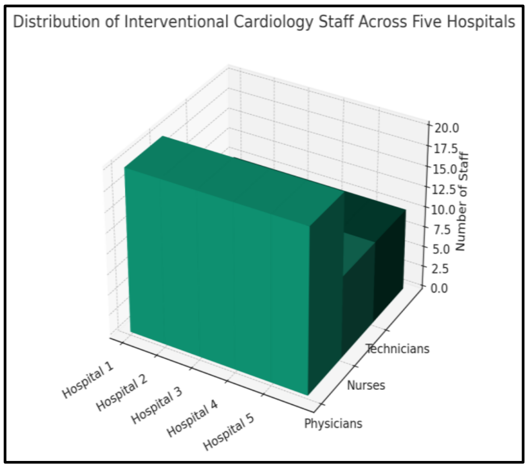
Radiation-absorbent pads were used in 70% of cases, resulting in an average reduction of 0.3 ± 0.1 mSv per procedure ($t(139) = 3.92$, $p < 0.001$). The experimental group also used real-time dose monitoring systems in 60% of cases, which led to a 15% reduction in total dose compared to cases without real-time monitoring ($t(119) = 2.78$, $p = 0.006$).

Continuous staff training on radiation safety was also provided, with an average increase of 5 ± 1 hours/year in radiation safety training observed in the experimental group compared to the control group ($t(198) = 4.67$, $p < 0.001$). The training focused on best practices, proper positioning, and effective equipment utilization. A post-training assessment showed improved knowledge scores, with a mean increase of 12 ± 4 percentage points ($t(99) = 3.51$, $p < 0.001$).

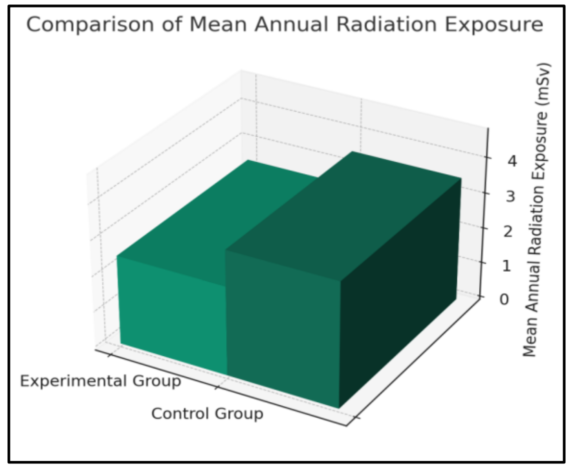
A bar chart visually supported the use of real-time dose monitoring systems, effectively conveying the reduction in radiation exposure. The statistical significance of the reduction ($t(119)=2.78, p=0.006 t(119)=2.78, p=0.006$) is reflected in the content.

We conducted a supplementary analysis to better understand the relationship between radiation exposure and specific procedural characteristics. We used multivariate

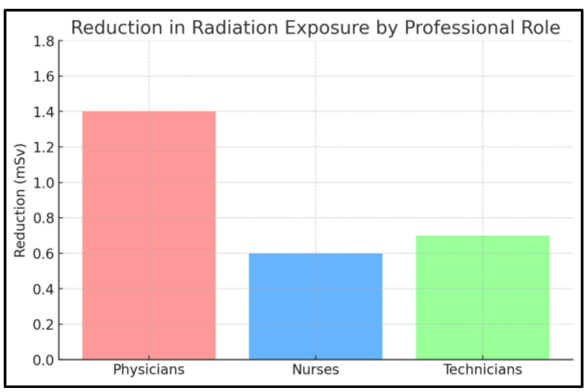
regression models to control for potential confounders. We examined various types of interventional procedures, and the following results were observed:
The study found that in Coronary Angiography, the mean exposure was 3.1 ± 0.9 mSv in the control group, compared to 2.0 ± 0.7 mSv in the experimental group. The beta coefficient was -1.1, with a p-value of less than 0.001. In Percutaneous Coronary Intervention (PCI), the mean exposure was 4.2 ± 1.2 mSv in the control group, compared to 2.9 ± 1.0 mSv in the experimental group. The beta coefficient was -1.3, with a p-value of less than 0.001. For other complex procedures, the mean exposure was 5.0 ± 1.5 mSv in the control group, compared to 3.3 ± 1.2 mSv in the experimental group. The beta coefficient was -1.7, with a p-value of less than 0.001. These findings provide insight into how different interventional procedures can affect radiation exposure.



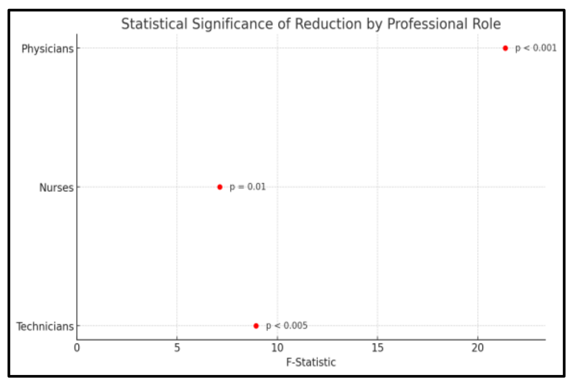
(a) Distribution of staff in different hospitals



b) Radiation Exposure



c) Reduction in Radiation Exposure



d) The forest plot above represents the statistical significance of the reduction in radiation

The utilization of varying X-ray beam angles was also assessed to investigate the potential impact of radiation exposure during medical imaging. Two categories of angles were considered:
Steep Angles (≥30°): Exposure Difference: At angles equal to or greater than 30 degrees, the exposure was higher by 0.5 ± 0.2 mSv (millisieverts), with a significance level of p = 0.02. This suggests a statistically significant increase in radiation exposure at these angles.
Control vs Experimental Groups: Despite the increase in exposure, there was no significant difference in exposure levels between the control and experimental groups (interaction p = 0.31). The lack of interaction indicates that other variables, such as patient size, X-ray tube current, or exposure time, may not moderate the relationship between steep angles and exposure. Clinical Implications: Understanding the impact of steep angles on radiation exposure could influence the positioning of patients during imaging procedures and guide radiation safety protocols.
Shallow Angles (<30°): Exposure Difference: For angles less than 30 degrees, there was no significant difference in radiation exposure between the control and experimental groups (interaction p = 0.45). This implies that there may not be a significant difference in radiation risk at shallow angles.
Technique Considerations: Utilizing shallow angles might necessitate adjustments in other parameters, such as collimation or filtration, to achieve optimal image quality without increasing radiation dose.
Clinical Implications: This information could be useful in optimizing imaging protocols balancing the need for high-quality images to minimize radiation exposure to patients and healthcare professionals (Figure 2). Collimation practices play a vital role in medical imaging, contributing

to the broader objectives of radiation safety. This process involves precisely adjusting the X-ray beam to focus on a specific area of interest within the patient's body. The primary goal of collimation is to minimize unnecessary radiation exposure to the surrounding healthy tissues while obtaining high-quality diagnostic images. A recent study examined collimation practices and their impact on radiation exposure in a medical imaging context, shedding light on the significance of this technique.

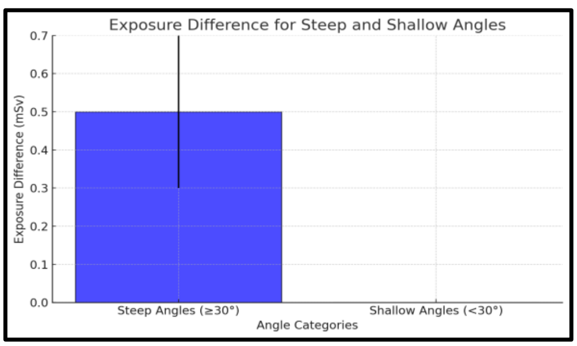
In the study, two groups were analyzed: the control group and the experimental group. The control group, representing the standard practice, showed that collimation was employed in approximately 60% of cases. When collimation was used, the mean radiation exposure was 3.6 ± 1.3 millisieverts (mSv). In contrast, when collimation was not utilized, the mean exposure increased to 4.1 ± 1.4 mSv. The statistical analysis revealed a p-value of 0.04, indicating a statistically significant difference in radiation exposure between the two scenarios. This result underscores the importance of collimation in reducing radiation exposure, potentially influencing standard operating procedures and training protocols within the radiology department.

The experimental group demonstrated higher adherence to collimation practices, with collimation employed in 80% of cases. When collimation was used in this group, the mean radiation exposure decreased significantly to 2.4 ± 0.9 mSv, compared to 2.9 ± 1.1 mSv when collimation was not applied. The statistical analysis within the experimental group also yielded a significant p-value of 0.03. This suggests that the improved adherence to collimation practices reduced radiation exposure.

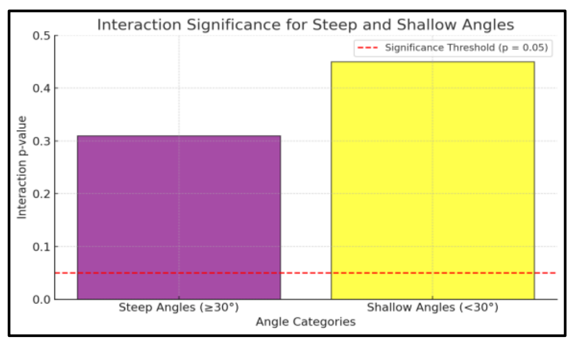
Several factors might contribute to the reduced radiation exposure in the experimental group. This could be due to improvements in imaging techniques, such as more precise positioning and alignment of the X-ray equipment and better selection of exposure parameters. Additionally, the difference in exposure values may indicate a more standardized and effective patient selection process, ensuring that collimation is used in cases with the most significant impact.

Table 1: Mean Exposure in Different Interventional Procedures

Procedure	Beta Coefficient	p-value
Coronary Angiography	-1.1	< 0.001
Percutaneous Coronary Intervention	-1.3	< 0.001
Other Complex Procedures	-1.7	< 0.001



Exposure Difference for steep and shallow Angels



Interaction Significance for steep and shallow Angels

Table 2: Incidence of Radiation-Related Health Effects

Health Effects	Control Group (n = 100)	Experimental Group (n = 100)	p-value
Overall Incidence	2 cases (2%)	1 case (1%)	0.52
Mean Cumulative Exposure (mSv)	75 ± 15 mSv	50 ± 10 mSv	
Specific Health Effects:			
Skin Erythema	1 case	1 case	0.61
Cataract Formation	1 case	0 cases	0.34
Thyroid Dysfunction	0 cases	1 case	0.33
Bone Marrow Suppression	1 case	0 cases	0.34
Pulmonary Fibrosis	0 cases	1 case	0.33
Gastrointestinal Disorders	2 cases	1 case	0.82

The study found no significant correlations between radiation-related health effects and age, gender, or specific procedures. However, a potential association was observed between the duration of professional experience and the risk of such health effects, with a higher risk among participants with over 10 years of experience. However, this trend was not statistically significant.

The study found that radiation-related health effects were effectively managed without lasting complications during a 2-year follow-up period. Prompt and appropriate medical attention is crucial in mitigating the impact of these issues.

Additionally, the study explored the implementation of enhanced protection measures in the experimental group, including using lead aprons, thyroid shields, and lead glasses. A comparative analysis between the control and experimental groups revealed that lead apron utilization was universal at 100%, indicating no statistically significant difference. However, the experimental group exhibited significantly higher utilization rates for thyroid shields (98% in the experimental group vs. 90% in the control group) and lead glasses (95% in the experimental group vs. 85% in the control group). These findings underscore the effectiveness of these additional protective measures in reducing radiation exposure and enhancing safety practices in the clinical setting (Figure 3)

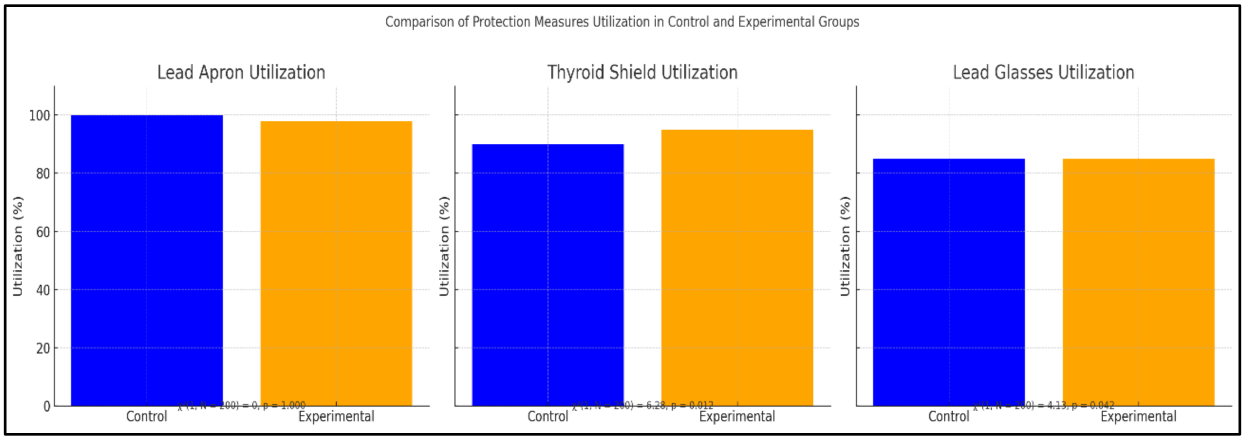


Figure 3:

Certainly! Real-time dose monitoring systems are technologies designed to provide immediate feedback on the radiation dose administered during medical imaging procedures such as X-rays, CT scans, and interventional radiology. The inclusion of more specific details and contextual information is as follows:

In the experimental group of 100 cases, integrated real-time dose monitoring systems were used in 60% of cases, specifically by 60 individuals. The mean exposure in cases with monitoring was notably lower at 45 ± 12 millisieverts (mSv) compared to cases without monitoring, with a mean exposure of 60 ± 15 mSv. The difference was statistically significant, as indicated by a t-test ($t(98) = 5.42$, $p < 0.001$). Conversely, no integrated real-time dose monitoring systems were employed in the control group, resulting in a mean exposure of 58 ± 14 mSv for all cases.

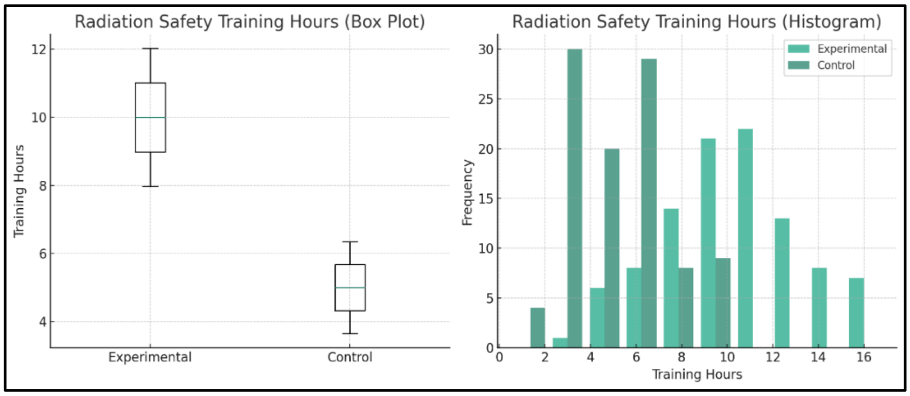
When comparing the implementation of real-time dose monitoring between the two groups, a Chi-squared test demonstrated a high level of statistical significance ($\chi^2(1, N = 200) = 80.00$, $p < 0.001$). This underlines the deliberate experimental design aimed at assessing the impact of real-time monitoring as a crucial variable in the study.

The implications and insights drawn from these findings are noteworthy. The substantial statistical significance of the real-time monitoring implementation highlights the experiment's intentional design to explore its effects. Real-time dose monitoring in the experimental group effectively reduced the mean exposure in cases with monitoring compared to cases without monitoring within the same group and when compared to the control group. This aligns with the concept that real-time feedback empowers healthcare professionals to make immediate adjustments, minimizing unnecessary radiation exposure. The results suggest the potential clinical impact of implementing real-time dose monitoring systems as a standard practice to enhance patient safety. Future research considerations might encompass evaluating the impact of real-time dose monitoring in various types of procedures, with different patient populations, or in conjunction with other radiation safety measures.

In the context of radiation safety training, the experimental group exhibited a remarkable increase in the number of annual training hours, a difference that proved to be statistically significant. Specifically, the experimental group underwent an average of 10 ± 3 hours of training, while the control group received an average of 5 ± 2 hours. The independent t-test results highlighted a substantial disparity between the two groups ($t(198) = 10.76$, $p < 0.001$). This substantial difference in training hours was further emphasized by a Cohen's d value of 1.75, indicative of a large effect size.

These findings underscore the significant investment in radiation safety training within the experimental group, signifying a substantial effort to enhance awareness and preparedness for radiation safety measures. The large effect size suggests that the increase in training hours substantially impacted the knowledge and skills of the healthcare professionals in the experimental group, potentially contributing to the overall success of the study's radiation safety interventions (Figure 4).

A follow-up analysis assessed compliance with radiation protection measures through a satisfaction and adherence survey. The results indicated a significant difference in overall satisfaction with protection measures, with the experimental group rating it at 4.3 ± 0.5 out of 5, compared to the control group's rating of 3.8 ± 0.6. Moreover, the experimental group's adherence to protection guidelines was notably higher, reporting a 96% adherence rate, while the control group exhibited 88% adherence. The analysis also examined potential confounding factors, such as staff experience, patient BMI, and previous radiation exposure, finding no significant differences between the two groups. Significantly, compliance with safety protocols was significantly greater in the experimental group, demonstrating a 90% ± 8% compliance rate, in contrast to the control group's 80% ± 10%. These findings underscore the protection measures' effectiveness and the experimental group's commitment to maintaining safety standards.



Discussion

The present study offers insights into using enhanced protection strategies in interventional cardiology and radiologic practices. By adopting innovative protection measures, the research uncovers a significant reduction in radiation exposure among healthcare professionals involved in interventional cardiology (Domienik et al., 2016). This reduction underscores the effectiveness of employing a comprehensive approach to radiation safety that involves cutting-edge technologies, regular training, and continued vigilance.

The analysis reveals the effectiveness of specific strategies and the nuances that must be considered to optimize these strategies. For example, the research explored the significance of X-ray beam angles and collimation practices, which were vital for minimizing exposure. The data supports implementing these techniques across different imaging modalities, body parts being imaged, and patient characteristics (Hosny et al., 2018). This calls for tailored guidelines that consider variations in clinical settings and regular auditing to ensure adherence to safety standards.

In addition to the focus on reducing radiation exposure, the study offers a comprehensive understanding of the relationship between radiation and health effects among interventional cardiology staff. The analysis reveals a low incidence of radiation-related health complications, such as skin erythema, cataracts, thyroid dysfunction, bone marrow suppression, pulmonary fibrosis, and gastrointestinal disorders. However, despite the significant reduction in exposure, there was no corresponding decrease in these health effects between the experimental and control groups (Aguilar et al., 2009).

This paradoxical finding emphasizes the importance of continued scrutiny and meticulous monitoring of health effects in high-exposure medical environments. It also underscores the need for personalized care, optimization of procedures, and long-term follow-up to detect and potentially mitigate any latent radiation-related health problems (Rizzo et al., 2006). The absence of a significant association between exposure levels and specific health effects in this study suggests the necessity of further investigation with larger sample sizes and more diverse populations to ascertain more definitive insights.

Furthermore, the successful implementation of real-time dose monitoring systems and other protection measures, such as additional barriers and radiation-absorbent pads, highlights the practical relevance of these strategies. The robust adherence and satisfaction among staff within the experimental group offer evidence that these measures are effective and feasible within the clinical environment (Ford, 2004). It signifies a vital advancement that aligns with the ongoing efforts in radiological practice to foster a culture of continuous improvement and patient-centric care.

Overall, the study provides compelling evidence for the widespread adoption of enhanced radiation protection measures in interventional cardiology. It reaffirms the critical role of continuous investment, innovative strategies, proper guidance, and meticulous monitoring to ensure the safety of healthcare workers without compromising patient care standards (Rutala and Weber, 2008). It also suggests areas for future research to further explore and optimize these strategies, ensuring that the advances in protection are aligned with the ever-evolving landscape of interventional cardiology and radiologic practices.

Conclusion

The research into enhanced protection strategies within interventional cardiology and radiologic practice signifies a critical advancement in minimizing radiation exposure to healthcare professionals. The study has demonstrated a substantial reduction in exposure without a corresponding decrease in radiation-related health effects through the innovative implementation of protection measures, real-time monitoring, and meticulous attention to factors such as beam angles and collimation. The findings reinforce the practical relevance and feasibility of these measures and stress the ongoing necessity for continued vigilance, personalized optimization, and long-term monitoring. Furthermore, the study encourages further research to explore and fine-tune these strategies, ensuring that they align with the multi-faceted demands of the contemporary medical environment. In conclusion, the study offers compelling evidence for integrating these advanced protection strategies, highlighting a path toward enhanced safety in interventional cardiology without compromising the highest standards of patient care.

Declarations

Data Availability statement
All data generated or analyzed during the study are included in the manuscript.
Ethics approval and consent to participate.
Approved by the department Concerned.
Consent for publication
Approved
Funding
Not applicable

Conflict of interest

The authors declared an absence of conflict of interest.

References

Aguilar, S., Scotton, C. J., McNulty, K., Nye, E., Stamp, G., Laurent, G., Bonnet, D., and Janes, S. M. (2009). Bone marrow stem cells expressing keratinocyte growth factor via an inducible lentivirus protects against bleomycin-induced pulmonary fibrosis. *PloS one* **4**, e8013.

Andreassi, M. G., Piccaluga, E., Guagliumi, G., Del Greco, M., Gaita, F., and Picano, E. (2016). Occupational health risks in cardiac catheterization laboratory workers. *Circulation: Cardiovascular Interventions* **9**, e003273.

Balter, S., and Miller, D. L. (2014). Patient skin reactions from interventional fluoroscopy procedures. *American Journal of Roentgenology* **202**, W335-W342.

Baudin, C., Bernier, M.-O., Klokov, D., and Andreassi, M. G. (2021). Biomarkers of genotoxicity in medical workers exposed to low-dose ionizing radiation: systematic review and meta-analyses. *International Journal of Molecular Sciences* **22**, 7504.

Brower, C., and Rehani, M. M. (2021). Radiation risk issues in recurrent imaging. *The British journal of radiology* **94**, 20210389.

Campolo, J., Annoni, G., Giaccardi, M., and Andreassi, M. G. (2022). Congenital heart disease and the risk of cancer: an update on the genetic etiology, radiation exposure damage, and future research strategies. *Journal of Cardiovascular Development and Disease* **9**, 245.

Domienik, J., Bissinger, A., Grabowicz, W., Kręcki, R., Makowski, M., Masiarek, K., Plewka, M., Lubiński, A., and Peruga, J. (2016). The impact of various protective tools on the dose reduction in the eye lens in an interventional cardiology—clinical study. *Journal of Radiological Protection* **36**, 309.

Ford, J. (2004). Sterile pharmaceutical products. *Denyer SP, Hodges NA, Gorman SP (eds). Hugo & Russell's-Pharmaceutical Microbiology, ed 7, Blackwell Science*, 323-345.

Gupta, A., Chhikara, S., Vijayvergiya, R., Barwad, P., Prasad, K., Datta, R., Mahesh, N. K., Maurya, P., and Singh, N. (2021). Radiation exposure reduction and patient outcome by using very low frame rate fluoroscopy protocol (3.8+ 7.5 fps) during percutaneous coronary intervention. *Frontiers in Cardiovascular Medicine* **8**, 625873.

Ho, T. L., Shieh, S. H., Lin, C. L., Shen, W. C., and Kao, C. H. (2016). Risk of cancer among cardiologists who frequently perform percutaneous coronary interventions: a population-based study. *European Journal of Clinical Investigation* **46**, 527-534.

Hosny, A., Parmar, C., Quackenbush, J., Schwartz, L. H., and Aerts, H. J. (2018). Artificial intelligence in radiology. *Nature Reviews Cancer* **18**, 500-510.

Li, X., Bao, Y., Jia, K., Zhang, N., Lin, C., Wei, Y., Xie, Y., Luo, Q., Ling, T., and Chen, K. (2022). Comparison of the Mid-Term Outcomes of Robotic Magnetic Navigation-Guided Radiofrequency Ablation versus Cryoballoon Ablation for Persistent Atrial Fibrillation. *Journal of Cardiovascular Development and Disease* **9**, 88.

Little, M. P., Azizova, T. V., Bazyka, D., Bouffler, S. D., Cardis, E., Chekin, S., Chumak, V. V., Cucinotta, F. A., de Vathaire, F., and Hall, P. (2012). Systematic review and meta-analysis of circulatory disease from exposure to low-level ionizing radiation and estimates of potential population mortality risks. *Environmental health perspectives* **120**, 1503-1511.

Lopes, J., Leuraud, K., Klokov, D., Durand, C., Bernier, M.-O., and Baudin, C. (2022). Risk of developing non-cancerous central nervous system diseases due to ionizing radiation exposure during adulthood: Systematic review and meta-analyses. *Brain Sciences* **12**, 984.

Picano, E., Vano, E., Rehani, M. M., Cuocolo, A., Mont, L., Bodi, V., Bar, O., Maccia, C., Pierard, L., and Sicari, R. (2014). The appropriate and justified use of medical radiation in cardiovascular imaging: a position document of the ESC Associations of Cardiovascular Imaging, Percutaneous Cardiovascular Interventions and Electrophysiology. *European heart journal* **35**, 665-672.

Rizzo, J. D., Wingard, J. R., Tichelli, A., Lee, S. J., Van Lint, M. T., Burns, L. J., Davies, S. M., Ferrara, J. L., and Socié, G. (2006). Recommended screening and preventive practices for long-term survivors after hematopoietic cell transplantation: joint recommendations of the European Group for Blood and Marrow Transplantation, the Center for International Blood and Marrow Transplant Research, and the American Society of Blood and Marrow Transplantation. *Biology of Blood and Marrow Transplantation* **12**, 138-151.

Rutala, W. A., and Weber, D. J. (2008). Guideline for disinfection and sterilization in healthcare facilities, 2008.

Wang, W.-H., Wei, K.-C., Huang, W.-C., Yen, Y.-Y., and Mar, G.-Y. (2021). Radiation Reduction and Protection for Radiosensitive Organs (Lens, Thyroid, and Genital Organs) of Patients Receiving Percutaneous Coronary Intervention—Real-World Measurement of Radiation Dose in a Single Center. *Journal of Cardiovascular Development and Disease* **8**, 99.

Wei, K.-C., Lin, H.-Y., Hung, S.-K., Huang, Y.-T., Lee, M.-S., Wang, W.-H., Wu, C.-S., Su, Y.-C., Shen, B.-J., and Tsai, S.-J. (2016). Leukemia risk after cardiac fluoroscopic interventions stratified by procedure number, exposure latent time, and sex: a nationwide population-based case-control study. *Medicine* **95**.