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Assessment of occupational radiation exposure among various medical professions in interventional cardiology: A five-year study (2018–2022)

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Abstract – Occupational radiation exposure in medical settings is a growing concern, especially in interventional cardiology. This study aims to assess the occupational radiation exposure among medical personnel in interventional cardiology from 2018 to 2022. We conducted a retrospective analysis of the annual mean effective doses (AMED) and the average over a five-year period (MED-5y) among various medical professionals, including anesthesiologists, cardiologists, nurses, radiologists, and radiologic technologists. The effective doses were estimated using thermoluminescent dosimeters and analyzed to compute the AMED and MED-5y. Statistical significance was determined using *T*-tests and ANOVA, with subsequent Tukey Post-Hoc Tests for specific group comparisons. The AMED varied significantly among professions, with cardiologists experiencing the highest exposure (3.469 ± 7.81 mSv in 2022). An overall increase in AMED doses was observed from 2018 to 2022. The results of the *T*-Test showed a significant difference in the radiation exposure across the years under study ($p < .001$). The MED-5y were anesthesiologists (0.62 ± 0.30), cardiologists (3.23 ± 7.37), nurses (1.17 ± 0.56), radiologic technologists (1.13 ± 0.38), and radiologists (0.86 ± 0.26). The study also found significant differences in MED-5y across professions ($F = 14.8$, $p < .001$). Gender-based analysis indicated significant differences in MED-5y, particularly among nurses and radiologists. The results of this study revealed that the annual effective dose received by anesthesiologists, cardiologists, nurses, radiologists, and radiologic technologists was below the recommended occupational dose limits, as stipulated by both national and international standards.

Keywords: occupational exposure / medical professionals / interventional cardiology / radiation safety

1 Introduction

Interventional cardiology, a critical branch within cardiology, has seen a substantial increase in its role due to the growing prevalence of cardiovascular diseases. Leveraging advanced X-ray imaging modalities such as angiography and fluoroscopy, interventional cardiology facilitates the diagnosis and treatment of various cardiovascular conditions (Buccheri *et al.*, 2017). The World Health Organization (WHO) emphasizes the alarming surge in cardiovascular diseases, which have emerged as the leading cause of mortality globally, accounting for 17.5 million deaths annually in 2012. This figure increased to 17.9 million in 2016 and is projected to reach 22.2 million by 2030 (Şahin *et al.*, 2022). This upsurge has consequently led to an increase in the volume of procedures in interventional cardiology, thereby amplifying the exposure of medical personnel to radiation (Moreira *et al.*, 2023).

Medical staff in interventional cardiology, especially cardiologists, face higher radiation exposure compared to other medical fields. Techniques central to this specialty, namely angiography and fluoroscopy, significantly contribute to this elevated exposure. A study by revealed that medical personnel in interventional cardiology, particularly cardiologists, experience radiation exposure about ten times higher than their counterparts in diagnostic radiology (Picano *et al.*, 2013; Moreira *et al.*, 2023). The cumulative doses over a 30-year career can range between 50 to 200 mSv, leading to a notable excess cancer risk (Picano *et al.*, 2013; Moreira *et al.*, 2023). Recent observations have raised concerns over the increasing incidence of cataracts and brain cancers among

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long-serving personnel in interventional cardiology (Ciraj-Bjelac *et al.*, 2010). Despite this, studies have shown that interventionists in high-volume catheterization labs often exceed these limits (Kwon *et al.*, 2011).

Ensuring radiation safety is crucial for individuals working in environments with radiation exposure. The daily exposure to radiation experienced by medical personnel in interventional cardiology raises health concerns if proper protective measures are not implemented. It is essential to monitor radiation doses and employ protective strategies to maintain occupational exposure within safe limits, preventing deterministic effects and minimizing stochastic risks associated with ionizing radiation, as recommended by the International Atomic Energy Agency (IAEA, 2014). Occupational dose monitoring is typically conducted using personal radiation monitoring devices like thermoluminescent dosimeters (TLDs). For the purposes of radiological protection, the assessment of occupational exposure is primarily based on the measurement of effective and equivalent doses, as outlined by the IAEA and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2010; IAEA, 2006).

The purpose of this study was to assess the occupational radiation exposure among medical personnel in interventional cardiology and to determine if the exposure levels are within the recommended occupational dose limits set by regulatory bodies. The International Commission on Radiological Protection (ICRP) has set the occupational radiation dose limits at 20 mSv per year, with a five-year cumulative limit of 100 mSv and no single year exceeding 50 mSv, to safeguard medical staff (ICRP, 2007). Therefore, monitoring and analyzing the annual mean effective doses (AMED) and the five-year average doses (MED-5y) is crucial for ensuring compliance with these regulatory limits and for identifying any trends or differences in exposure levels across medical professions and gender that may warrant further investigation or intervention. We hypothesize that the occupational radiation exposure among medical personnel in interventional cardiology will be within the recommended dose limits, but may vary significantly across professions and gender groups. The results of this study will provide valuable insights into the current state of radiation safety in interventional cardiology and may inform future strategies for minimizing occupational radiation exposure.

2 Methods and materials

2.1 Study design and period

This study was conducted to assess occupational radiation exposure among medical personnel in interventional cardiology clinics in the western region in Saudi Arabia. The investigation encompassed a period of five years, extending from 2018 to 2022. The study population included various professional groups actively engaged in these settings, namely anesthesiologists, cardiologists, radiologists, nurses, and radiologic technologists. Approval from the Institutional Review Board (IRB) was obtained, and participant confidentiality was maintained.

2.2 Dosimetry monitoring and effective dose estimation

TLDs were employed as the tool for monitoring personal radiation doses. These devices were distributed and subsequently collected on a quarterly basis by the Ministry of Health (MOH) radiation protection offices located in each region. Each worker was assigned a personal bar-coded TLD, which contained individualized data such as the worker's name, sex, date of birth, department, and historical radiation exposure records. To ensure an accurate assessment of whole-body radiation dose, workers were instructed to wear their TLDs at chest level. It is crucial to note that the placement of TLDs, whether worn inside or outside personal protective equipment, can significantly influence the dose measurements. In our protocol, TLDs were worn outside any protective gear to standardize exposure assessments across all personnel, acknowledging that this placement provides a conservative estimate of actual body dose. The effective dose received by each worker was estimated by equating it to the measured Hp(10). This approach is generally considered a conservative method for assessing effective dose, particularly under the assumption of uniform whole-body exposure (ICRP, 2007). Thus, the effective dose in this study was estimated by setting it as equal to the measured Hp(10).

2.3 Specifications and calibration

The TLDs utilized in this research (TLD-100 chip; Thermo Fisher Scientific, Massachusetts, United States) were constructed from lithium fluoride (Li natural) LiF:Mg.Ti materials. The dosimetric readings were obtained using a Harshaw Model 6600 Plus Automated Reader Instrument (Thermo Electron Corporation, Ohio, USA), capable of detecting doses ranging from 10 μGy to 1 Gy. The calibration of this instrument is critically important to the accuracy of our measurements and is performed annually using a 137Cs source under free-air exposure conditions to a standardized dose of 0.5 mSv. This calibration process ensures that the reader's sensitivity and accuracy remain within the required standards for precise dose measurement. Furthermore, to address variability in thermoluminescence efficiency across different TLD chips, which can affect the accuracy of dose readings, the reader's built-in internal irradiator (90Sr/90Y) is utilized to generate element correction coefficients (ECCs). These ECCs are essential for calibrating each TLD to ensure that all devices respond uniformly to identical radiation doses. Control TLDs are also employed to measure and account for background radiation, ensuring that the reported doses are net exposures after subtracting any ambient radiation influences.

2.4 Statistical analysis

To analyze the dosimetry data, the Statistical Package for the Social Sciences (SPSS version 20, IBM Inc., Chicago, IL, USA) was used to obtain descriptive and inferential statistics. Analysis of the effective doses, Hp(10), were presented as the annual mean effective dose (AMED) and the averaged over the 5-year study period (MED-5y). Further statistical examination

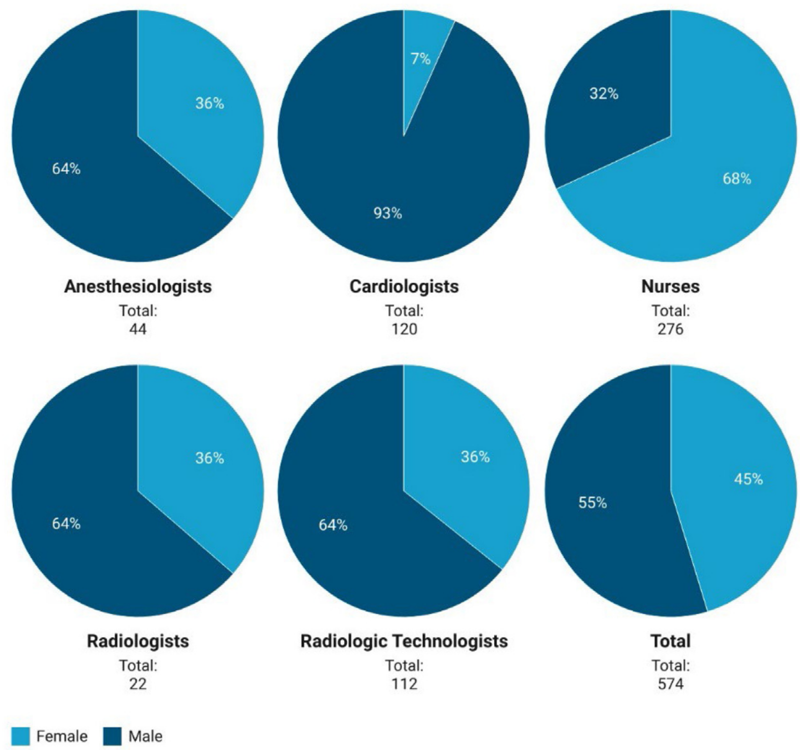

Fig. 1. Gender distribution across various medical occupations.

Table 1. Annual radiation exposure trends in medical professions (2018–2022): Mean Dose ± SD in mSv.

Year		Anesthesiologists	Cardiologists	Nurses	Radiologists	Radiologic technologists
2022	Mean ± SD	0.72 ± 0.41	3.47 ± 7.81	1.43 ± 0.94	0.89 ± 0.44	1.61 ± 0.84
	Minimum – Maximum	0.42 –1.84	0.23 – 48.68	0.07 – 7.44	0.48 – 1.67	0.42 – 6.03
2021	Mean ± SD	0.66 ± 0.49	2.01 ± 1.76	1.31 ± 0.75	1.10 ± 0.29	1.13 ± 0.54
	Minimum – Maximum	0.12 – 1.99	0.18 – 12.16	0.14 – 5.02	0.55 – 1.48	0.34 – 2.44
2020	Mean ± SD	0.87 ± 0.36	1.66 ± 1.26	0.92 ± 0.72	0.66 ± 0.35	0.90 ± 0.30
	Minimum – Maximum	0.36 – 1.16	0.60 – 6.02	0.16 – 7.40	0.17 – 1.05	0.47 – 1.83
2019	Mean ± SD	1.13 ± 0.26	2.02 ± 3.08	0.86 ± 0.33	0.56 ± 0.27	0.90 ± 0.33
	Minimum – Maximum	0.89 – 1.41	0.40 – 18.90	0.10 – 1.53	0.21 – 0.90	0.17 – 1.83
2018	Mean ± SD	0.94 ± 0.16	2.59 ± 4.86	0.82 ± 0.38	0.53 ± 0.33	0.95 ± 0.61
	Minimum – Maximum	0.78 – 1.10	0.39 – 24.90	0.16 – 1.82	0.14 – 0.92	0.36 – 3.66

was conducted using a one-way analysis of variance (ANOVA) and the Tukey honestly significant difference (HSD) *post hoc* test to compare the MED-5y across different medical professions. Independent Samples *T*-Test comparing mean radiation exposure by gender. A p-value <0.05 was considered statistically significant.

3 Results

In this study, a total of 574 medical personnel included in this study, comprising anaesthesiologists ($n = 44$), cardiologists ($n = 120$), radiologic technologists ($n = 112$), nurses ($n = 276$), and radiologists ($n = 22$). Across the assessed professions, males formed a majority with 54.68% ($n = 314$) compared to 45.32% ($n = 260$) females (Fig. 1).

Table 1 shows the AMED across various medical occupations was analyzed from 2018 to 2022. In 2018, anesthesiologists had a mean dose of 0.94 ± 0.16 mSv, cardiologists 2.59 ± 4.86 mSv, nurses 0.82 ± 0.38 mSv, radiologists 0.53 ± 0.33 mSv, and radiologic technologists 0.95 ± 0.61 mSv. By 2019, the mean dose for anesthesiologists increased to 1.13 ± 0.26 mSv, while cardiologists experienced considerable exposure variability (0.40–18.90 mSv). In 2020, all professions except cardiologists reported reduced mean doses, notably nurses at 0.92 ± 0.72 mSv and radiologic technologists at 0.90 ± 0.30 mSv. The year 2021 saw a general decrease in mean doses for most professions, with radiologists noting an increase to 1.10 ± 0.29 mSv. By 2022, anesthesiologists recorded a mean dose of 0.72 ± 0.41 mSv, cardiologists 3.47 ± 7.81 mSv, nurses 1.43 ± 0.94 mSv, radiologists

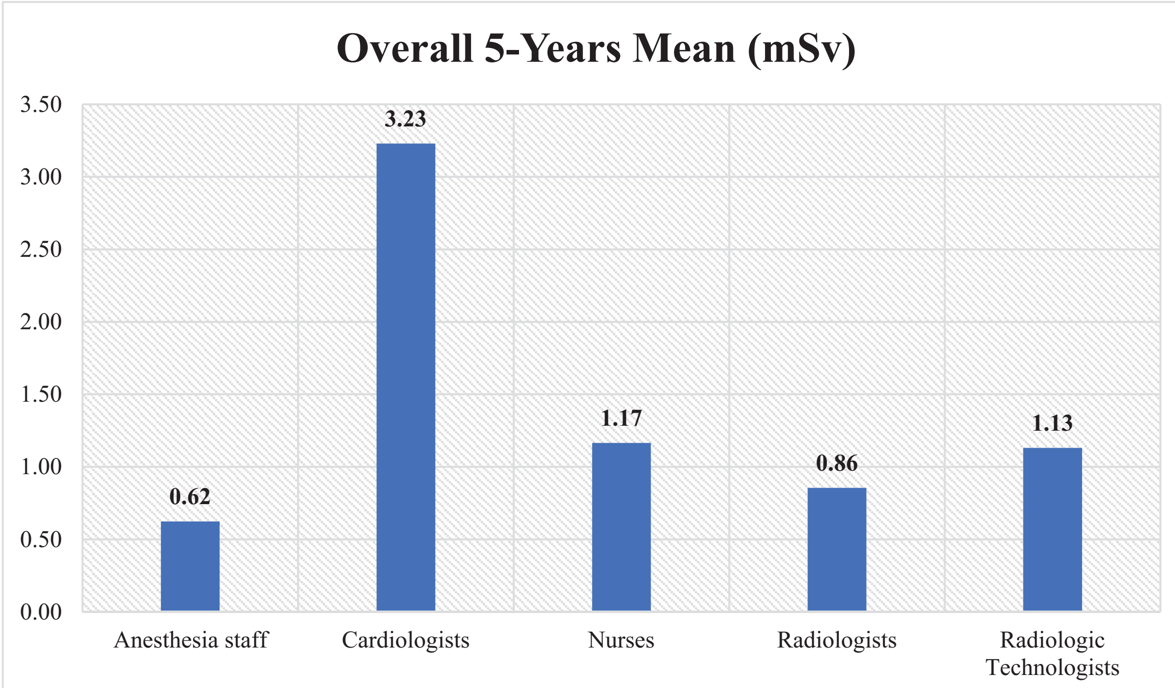

Fig. 2. Overall five-year mean radiation exposure across medical professions (2018–2022).

0.89 ± 0.44 mSv, and radiologic technologists 1.61 ± 0.84 mSv. The results of the *T*-Test showed a significant difference in the radiation exposure across the years under study ($p < .001$). It is important to note that the calculated AMED values represent the mean dose exposure across professionals within each group and do not account for individual variations. Therefore, while the AMED values are below the occupational limit of 20 mSv, these averages do not reflect individual monitoring thresholds, which apply to personal exposure. This distinction underscores the necessity of individualized monitoring to identify outliers and ensure compliance with regulatory limits. There were three cases in 2022 where the AMEDs exceeded the occupational dose limit of 20 mSv per year among cardiologists, with individual doses recorded at 48.68 mSv, 32.41 mSv, and 24.38 mSv. However, these instances involved different individuals and remained under the 50 mSv exception permitted for a single year within the 5-year period.

The overall MED-5Y across various medical professions from 2018 to 2022 was analyzed and presented in Figure 2. The data revealed that anesthesiologists experienced an average radiation exposure of 0.62 ± 0.30 mSv, showing a lower level of exposure compared to other roles. Cardiologists recorded the highest mean exposure at 3.23 ± 7.37 mSv, reflecting the significant radiation exposure inherent in their procedures. Nurses had a mean exposure of 1.17 ± 0.56 mSv, and radiologic technologists showed a mean exposure of 1.13 ± 0.38 mSv. Radiologists experienced a relatively lower level of exposure, with a mean of 0.86 ± 0.26 mSv.

The ANOVA results indicated significant differences in MED-5Y among the professions ($F = 14.8$, $p < .001$). Subsequent Tukey Post-Hoc Tests revealed specific contrasts between the groups. There was a significant mean difference in exposure between anesthesiologists and cardiologists (−2.61 mSv, $p = 0.019$). Similarly, cardiologists showed significantly higher exposure compared to nurses (2.06 mSv, $p = 0.001$) and radiologic technologists (2.1 mSv, $p = 0.009$). However, the differences between anesthesiologists and nurses, radiologists, and radiologic technologists were not statistically significant, with *p*-values exceeding 0.05. The comparisons involving nurses, radiologists, and radiologic technologists also yielded non-significant differences.

The overall MED-5Y across various medical professions was analyzed by gender, as illustrated in Figure 3. The results revealed distinct gender-based variations in exposure levels. In anesthesiologists, females exhibited a higher mean radiation exposure of 0.75 ± 0.41 mSv compared to 0.55 ± 0.20 mSv in males, but this difference was not statistically significant ($p = 0.525$). Cardiologists showed a more pronounced disparity, with female cardiologists experiencing a lower mean exposure of 1.3 ± 0.26 mSv, substantially less than their male counterparts at 3.37 ± 7.61 mSv, though this difference also lacked statistical significance ($p = 0.45$). In the nursing field, female nurses reported a slightly higher mean exposure of 1.25 ± 0.60 mSv than male nurses, who recorded 0.98 ± 0.42 mSv, with this difference being statistically significant ($p = 0.002$). Radiologists presented a similar pattern, with female radiologists experiencing a mean exposure of 1.09 ± 0.16 mSv, higher than the 0.72 ± 0.20 mSv observed in males, and this difference was also statistically significant ($p = 0.024$). Conversely, in Radiologic Technologists, males had a slightly higher mean exposure of 1.18 ± 0.27 mSv compared to females at 1.04 ± 0.52 mSv, but this difference was not statistically significant ($p = 0.193$).

4 Discussion

The present study aimed to analyze the radiation exposure across various medical professions over a five-year period from 2018 to 2022. These results underline the importance of

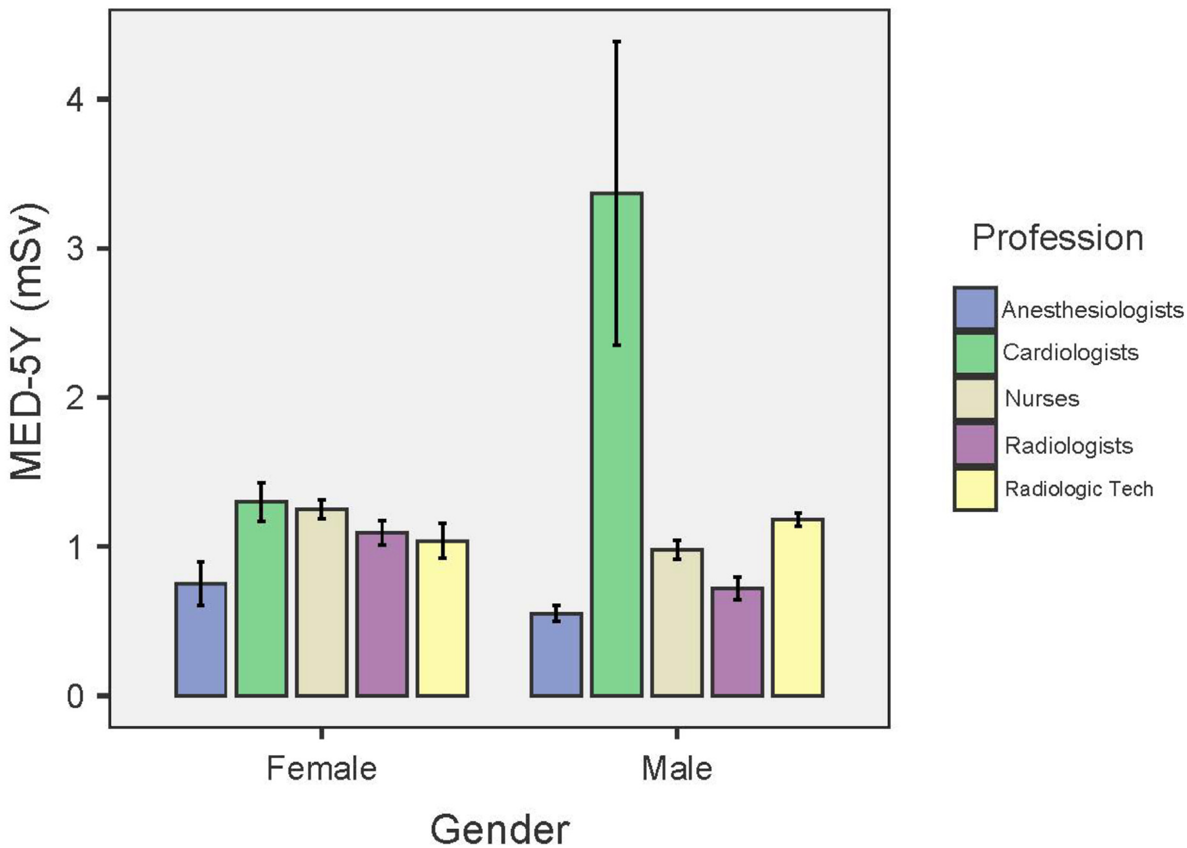

Fig. 3. Gender-based comparison of five-year mean radiation exposure across medical professions.

Table 2. Comparative analysis of five-year mean radiation exposure across medical professions: Tukey Post-Hoc test results.

		Anesthesiologists	Cardiologists	Nurses	Radiologists	Radiologic technologists
Anesthesiologists	Mean difference	—	−2.61*	−0.54	−0.23	−0.51
Cardiologists	Mean difference		—	2.06**	2.37	2.1**
Nurses	Mean difference			—	0.31	0.03
Radiologists	Mean difference				—	−0.28
Radiologic Technologists	Mean difference					—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$.

occupational safety measures and individualized monitoring, given the significant variability in exposure among different roles. The findings revealed variations in AMEDs among different medical professions, with cardiologists consistently recording the highest levels of exposure. These results align with previous research indicating that cardiologists are exposed to higher levels of radiation due to the nature of their work (Kim *et al.*, 2008; Venneri *et al.*, 2009). However, all AMEDs across the different medical professions were below the occupational annual limit of 20 mSv, and no individual exceeded the single year limit of 50 mSv during the five-year period.

Statistical analysis revealed significant differences in the five-year mean radiation exposure levels between medical professions. Specifically, cardiologists (3.23 ± 7.37 mSv) had significantly higher exposure levels compared to anesthesiologists (0.62 ± 0.30), nurses (1.17 ± 0.56 mSv), and radiologic technologists (1.13 ± 0.38 mSv). Instances where cardiologists exceeded the annual occupational dose limit of 20 mSv, such as the maximum values observed in 2018 (24.90 mSv) and 2022 (48.68 mSv), raise concerns about potential systemic factors. These exceedances may reflect high procedural workloads, prolonged fluoroscopy times, or suboptimal use of protective measures. Addressing these issues through targeted training, workload management, and enhanced radiation protection protocols is critical to mitigating such risks. Additionally, regular audits of individual dose records can help identify trends and ensure that deviations are promptly addressed. This is consistent with previous studies that have called for improved radiation safety protocols and training for cardiologists (Chambers *et al.*, 2011; Durán *et al.*, 2013). Anesthesiologists experienced the lowest average exposure (0.62 ± 0.30 mSv), reflecting their relatively limited direct involvement in high-radiation procedures. Nurses and radiologic technologists, radiologists (0.86 ± 0.26 mSv) may benefit from increased protective measures and distance from radiation sources, as noted in previous studies (Boice *et al.*, 2020; Shubayr *et al.*, 2021).

Comparing the radiation doses across various medical professions in our study with those documented in the existing literature offers a broader context for understanding occupational radiation exposure. This trend aligns with the findings of Dalah *et al.* (2018) and Borrego *et al.* (2020), who reported that interventional cardiologists often face doses approaching or exceeding ICRP recommended limits, indicating a high-risk profile for this group (Borrego *et al.*, 2020; Dalah *et al.*, 2018). Kartikasari *et al.* reported even lower mean effective doses for medical staff in Indonesia, with values of 0.047 ± 0.031 mSv, 0.048 ± 0.064 mSv, and 0.043 ± 0.034 mSv for radiologic technologists, nurses, and doctors, respectively (Kartikasari *et al.*, 2020). Elshami *et al.* also highlighted cardiologists' higher mean and maximum effective doses in a UAE study, with AMED ranging from 0.38 to 0.62 mSv per worker (Elshami *et al.*, 2020). These findings collectively reinforce the critical need for enhanced radiation protection strategies, especially in high-exposure roles like interventional cardiology.

Chronic radiation exposure affects cancer risk differently in males and females. Sex-specific differences in radiation-induced cancer risks are influenced by a variety of biological, genetic, and hormonal factors (Narendran *et al.*, 2019; Ozasa, 2016). Females generally have a higher baseline risk for certain cancers, such as breast and thyroid cancer, which can be exacerbated by radiation exposure. Genetic predispositions, like mutations in BRCA1 and BRCA2, and hormonal influences, such as estrogen, contribute to this increased risk. Additionally, differences in DNA repair mechanisms and lifestyle and environmental factors, like smoking rates and occupational hazards, also play a role (Narendran *et al.*, 2019; Ozasa, 2016). Studies have consistently shown that females have a higher risk of developing certain cancers, such as breast, thyroid, and lung cancer, following radiation exposure, indicating a complex interplay of factors that result in differing cancer risks between males and females (Khoramian *et al.*, 2024; Boice *et al.*, 2022; Rodman *et al.*, 2022). Additionally, research on medical diagnostic X-ray workers in Jiangsu, China, revealed that occupational radiation exposure was associated with a significantly increased risk of breast and esophageal cancer, particularly in females (Wang *et al.*, 2015).

The study also revealed gender-based variations in MED-5Y across the medical professions. female nurses and radiologists reported higher MED-5Y than their male counterparts, with statistically significant differences. This finding suggests potential variations in occupational roles or working conditions between genders, which warrants further investigation. Previous research has also reported gender disparities in radiation exposure, although the reasons for these differences remain unclear (Shore *et al.*, 2018; Mettler *et al.*, 2009). On the contrary, male radiologic technologists experienced slightly higher exposure than females, though this difference was not significant. The results for cardiologists were particularly intriguing, with female cardiologists experiencing lower mean exposure than males. This outcome could be reflective of differing workloads, procedural roles, or adherence to safety protocols, highlighting an area for further investigation.

This study underlines the need for tailored safety protocols and monitoring systems across medical professions, considering the significant variability in radiation exposure. The observed gender-based differences also call for a deeper exploration into the factors contributing to these disparities. Future research should focus on expanding the scope of investigation to include more diverse roles within the medical field, and potentially exploring the impact of technological advancements and changing procedural practices on occupational radiation exposure.

5 Conclusion

This study provides valuable insights into the patterns of radiation exposure across different medical professions over a five-year period. The AMEDs for most medical professions remained under the established annual occupational dose limit of 20 mSv. However, this limit was exceeded by three cardiologists, although none exceeded the 50 mSv limit for a single year during the five-year period, emphasizing the need for continuous monitoring and the implementation of effective radiation protection measures. The observed gender-based variations in radiation exposure also suggest the need for further research to understand the underlying causes of these differences and to ensure equitable working conditions for all medical professionals. Further information on the age distribution across sexes could also provide an interesting avenue for understanding the observed differences in exposure to ionizing radiation.

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Conflicts of interest

The authors declares that he has no conflicts of interest in relation to this article.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics approval

All ethical considerations were adhered to, including obtaining institutional review board approval. Confidentiality and anonymity were strictly maintained.

Informed consent

This study did not require informed consent.

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