Research Square

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Occupational ionizing radiation exposure among medical workers rose during the COVID-19 pandemic: a retrospective study

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Abstract

Background

Medical staff constitute the largest cohort exposed to artificial occupational ionizing radiation. This study aimed to analyze the trends in radiation exposure among medical workers from 2008 to 2024, identify potential risk factors, and compare occupational ionizing radiation exposure levels for medical workers before, during, and after the COVID-19 pandemic.

Methods

Retrospective quantitative trend analyses were performed under different conditions, and multivariate logistic regression was utilized to assess potential risk factors associated with radiation exposure. The Kruskal-Wallis H test and one-way ANOVA test were applied to compare radiation exposure doses across subgroups before, during, and after the COVID-19 pandemic.

Results

Basic information analyses indicated that being male, aged 40–50 years, possession of a doctoral degree, working in interventional medicine, and holding the profession of doctor were independent risk factors for average annual exposure doses among the entire population, which was different from those in nonzero exposure group and multivariate logistic regression analyses. Trend analyses revealed that most subgroups experienced insignificant changes in exposure doses, regardless of whether they belonged to the entire population or the nonzero exposure group. Further comparisons showed that the average exposure doses of most workers significantly increased during the COVID-19 pandemic. However, these doses significantly declined following the lifting of lockdown measures.

Conclusion

Our results could be served as a valuable reference for sustainable developments in the future. Most critically, despite the fact that the majority of annual doses remain below the limits established by the International Commission on Radiological Protection, heightened attention ought to be accorded to occupational ionizing radiation exposure among medical workers during pandemics like COVID − 19.

Trial registration:

No trial registration was required for this observational study.

1 Background

Medical applications of ionizing radiation, such as diagnostic imaging (CT, X-ray), interventional procedures, and radiotherapy, have become essential in modern healthcare, making medical workers to be the largest group for artificial radiation exposure[1]. Chronic low-dose exposure has been shown to be linked to thyroid disorders, lens opacities, hematologic abnormalities, and a probably elevated risk of cancer, including brain cancer, breast cancer, and melanoma[2–5]. Consequently, occupational exposure continues to be a significant occupational health concern, especially in high-volume departments such as radiology and nuclear medicine. The International Commission on Radiological Protection recommends that the average annual occupational radiation exposure should not exceed 20 mSv over any five-year period, with the stipulation that exposure in a single year must remain below 50 mSv[1].

At the begin of 2020, the COVID-19 pandemic broke out, and China underwent a three-year period of lockdown. During this time, numerous medical practices underwent significant changes, with radiation exposure among healthcare workers becoming an important concern, particularly for those involved in radiological diagnosis and treatment[6–8].

This study aims to conduct retrospective quantitative trend analyses focusing on occupational ionizing radiation exposure among medical workers in our institution from 2008 to 2024. It also seeks to examine whether these trends have been altered during the COVID-19 pandemic and to further investigate potential risk factors influencing personal ionizing radiation exposure.

2 Methods

2.1 Study design and participants

This study recruited all medical workers involved in radiation-related tasks from the Second Hospital of Chongqing Medical University from 2008 to 2024 (including 2024). Comprehensive data on radiation exposure were collected from the hospital's radiation safety monitoring records. These records documented the radiation doses received by individuals through personal whole-body dosimeters (Hp(10)), which the workers wore during their work shifts. Personnel engaged in the fields of X ray imaging diagnosis and radiotherapy were required to wear a dosimeter at the collar position corresponding to the left chest or clavicle. In addition, personnel working in the fields of nuclear medicine and interventional radiology should wear an additional dosimeter on the trunk within the lead apron. The cadence of badge exchange was set at 90 days. Then, radiation exposure levels for these individuals were assessed and calibrated by an independent third-party institute. The study was approved by the Institutional Review Board of the Second Hospital of Chongqing Medical University (No. 360, 2025).

2.2 Inclusion and Exclusion Criteria

A total of 511 medical workers, representing 3,692 individual records of adults aged 18 years or older, were included in the analysis. The detection limit of the dosimeter for a single quarter was established at 0.01 mSv. In accordance with measurement protocols, exposure doses below this threshold would be

systematically recorded as 0.005 mSv in documentation (Specifications for individual monitoring of occupational external exposure, GBZ 128–2019). The cumulative annual radiation exposure for each worker was calculated by aggregating quarterly data within a single year and subsequently regarded as one record. Consequently, in our study, any record equivalent to 0.02 mSv was considered as zero for analyses. For retired or dismissed employees, records from 2008 to 2024 were incorporated into the analysis to ensure comprehensive data coverage. To minimize potential biases, records with fewer than four quarters of data in any given year were excluded from the dataset.

2.3 Statistical analyses

Basic information, including gender, age (based on the records every year), the highest educational degree, department, and profession, was systematically collected. Statistical software (R version 4.4.1) was utilized for data analysis. A retrospective quantitative trend analysis focusing on occupational ionizing radiation exposure among medical workers in our institution from 2008 to 2024 was conducted using linear regression test. To compare average radiation doses across participant subgroups and temporal intervals (pre-pandemic: 2017–2019, pandemic: 2020–2022, and post-pandemic: 2023–2024), both the Kruskal-Wallis H test (for non-normal distributions) and one-way ANOVA (for parametric assumptions) were applied to assess statistically significant differences between groups. Furthermore, a multivariate logistic regression analysis was also performed to evaluate the effects of potential risk factors influencing radiation exposure. A p-value less than 0.05 was considered statistically significant.

3 Results

3.1 Average radiation exposure based on basic information

A total of 288 males with 2,185 records and 223 females with 1,507 records were included in the analysis. The mean age of all participants (up to January 2025) was 42 ± 13.1 years (males: 43.4 ± 13.4 years, females: 40.7 ± 12.5 years, p = 0.016). The retirement rate was 3.72%, and the dismissal rate was 4.89%. The nonzero radiation exposure rate was 97.5% at the individual level (males: 96.9%, females: 98.2%) and 77.8% at the record level (males: 80.2%, females: 74.2%). The average accumulated radiation exposure dose for individuals during the period from 2008 to 2024 was 2.307 ± 3.523 mSv [mean ± standard deviation (SD)] for the entire population and 2.426 ± 3.574 mSv for the nonzero-exposure population. The distribution of radiation exposure was presented in Figure 1.

The average annual radiation exposure dose in the entire population was 0.319 ± 0.703 mSv (median 0.180 mSv, Interquartile range (IQR) 0.110 - 0.370 mSv), which was significantly higher in males (0.355 ± 0.751 mSv) than in females (0.268 ± 0.628 mSv; p < 0.001). After excluding zero-exposure records, the average dose increased to 0.411 ± 0.774 mSv (median 0.220 mSv, IQR 0.130 - 0.450 mSv), with males still exhibiting higher exposure (0.443 ± 0.815 mSv vs. 0.364 ± 0.709 mSv; p < 0.001).

In addition, we categorized these workers into four subgroups based on age. The subgroup aged 40-50 years exhibited the highest annual exposure dose significantly (p < 0.001). However, although the >50

years subgroup demonstrated the highest exposure dose among nonzero records (0.516 ± 0.998 mSv), this difference was not statistically significant (p = 0.131). When stratified by educational level, workers with a doctoral degree showed the highest proportion of nonzero exposure rates and the highest annual exposure dose, both for the entire population and the nonzero-exposure population (p < 0.001).

What's more, the radiation exposure of medical workers from different departments was also compared. In this analysis, departments with fewer than 15 workers, including gynaecology, obstetrics, stomatology, geriatrics, departments of infectious diseases, emergency, and public health, and physical examination center, were categorized into an "other" group for simplification. Subgroup comparisons revealed that workers in the interventional medicine department had the highest average annual exposure dose (0.461 ± 0.956 mSv, p < 0.001). However, among those with nonzero exposure, the highest individual doses were observed in the cardiology (0.586 ± 1.401 mSv) and surgery (0.582 ± 0.621 mSv) groups (p < 0.001).

By profession, doctors exhibited the highest average annual exposure doses among both the entire population (0.348 ± 0.776 mSv, p < 0.001) and the nonzero-exposure subgroup (0.449 ± 0.856 mSv, p < 0.001). Other professions included engineer, pharmacist and administrator. (Table 1)

3.2 Multivariate logistic regression analysis of potential risk factors

To identify independent predictors of occupational ionizing radiation exposure, we performed a multivariate logistic regression analysis adjusting for potential risk factors. In the entire population, post-pandemic emerged as a significant protective factor. Clinical departments also demonstrated differential risks, with interventional medicine, cardiology, and surgery showing increased odds compared to the reference radiology department. Subgroup analysis of the nonzero cohort demonstrated comparable significant findings, with the exception that the period during the pandemic emerged as a significant risk factor. (All models were adjusted for the reference categories of pre-pandemic, male gender, age <30 years, bachelor's degree, radiology department, and physician occupation) (Table 2)

3.3 Trend analyses of radiation exposure from 2008 to 2024

For all participants, the average annual exposure doses exhibited insignificant fluctuations across the entire cohort [β(95% CI): -0.009 (-0.029 - 0.011), R^2: 0.066, p = 0.317] and the nonzero cohort [β(95% CI): -0.020 (-0.040 - 0.011), R^2: 0.105, p = 0.202] over time. Further analyses revealed that radiation exposure in intervention medicine department and profession of "other" from 2008 to 2024 significantly increased in the entire cohort [β(95% CI): 0.031 (0.005 - 0.054), R^2: 0.311, p = 0.021, and β(95% CI): 0.008 (0.002 - 0.014), R^2: 0.415, p = 0.005, respectively]. While surgery department experienced a significantly decrease [β(95% CI): -0.068 (-0.116 - -0.021), R^2: 0.388, p = 0.007]. Similar trends were also observed in the nonzero subgroup. (Figure 2 and Table 3)

3.4 Comparisons of radiation exposure across COVID -19 pandemic

What's more, we compared the radiation exposure doses among different subgroups pre-, during, and post- the COVID-19 pandemic. The pooled data revealed that there was a significant increase in radiation exposure doses for both males and females during the pandemic, regardless of whether the analysis included the entire population or only those with nonzero exposure. Similar significant increases were observed across all populations, all age subgroup, educational subgroups, and all department subgroups, with the exception of nuclear medicine (H: 0.977, p = 0.614) in the entire population. All nonzero subgroups of the population exhibited a significant increase. Additionally, participants from all professional groups, except "other" profession in the entire population, demonstrated significantly increasing radiation exposure in the entire population and the nonzero subgroup during the COVID-19 pandemic. (Table 3)

During the three years of the COVID-19 pandemic, exposures in 2021 were found to be significantly higher than those in 2020 and 2022 across most subgroups. (Table 4)

4 Discussion

Medical staff constitute the largest cohort exposed to artificial ionizing radiation, making it crucial to prioritize the safety of this population. In our institute, all employees shall be mandated to wear identification badges in strict compliance with regulations. They must strictly adhere to the shift scheduling system to guarantee service continuity and rational personnel allocation. Simultaneously, strict implementation of access control regulations is necessary to prevent unauthorized individuals from entering sensitive areas or accessing sensitive information. Regarding high risk services such as interventional procedures, targeted intervention measures, such as enhancing pre-operative risk assessment, standardizing operational protocols, intensifying emergency drills, and conducting regular skill evaluations, should be carried out.

By integrating available data from our institute's records, we uncovered critical insights into the patterns of radiation exposure among medical workers in relation to hospital development and throughout the COVID-19 pandemic. These findings were valuable for exploring potential strategies to optimize radiation protection in clinical practice.

Our study revealed a nonzero exposure rate of 77.8% among the entire population, which was approximately threefold higher than the 27% reported by Baudin et al.[1]. This discrepancy can be primarily attributed to differences in the methodological criteria used for exposure assessment. When applying the same 0.05 mSv threshold, the rate would decrease to approximately 51%. Baudin et al. conducted a longitudinal analysis (2009–2019) of occupational ionizing radiation exposure among French medical personnel, identifying nuclear medicine physicians and technologists as the most exposed subgroup and demonstrating statistically significant decreasing trends in annual radiation doses over the decade [1].

Similarly, Sharkey et al. assessed doctors' occupational exposure over a 25-year period and found a significantly reduced overall exposure to ionizing radiation, despite an increase in the utilization of diagnostic imaging[9]. However, in our study, these decreasing trends were not statistically significant for most subgroups of the total population and the non-zero subgroup. This finding was consistent with studies focusing on the nuclear medicine department conducted by Villoing et al.[10, 11]. These results implied that greater attention should be paid to occupational exposure to ionizing radiation, even though the use of imaging techniques has also increased in our institution.

In the multivariate logistic regression analysis, we initially identified several significant risk factors, including age, educational level, department, and professional role. In 2020, Adliene et al. conducted a retrospective dose assessment of nuclear medicine and radiology workers, reporting that radiology technologists and radiology nurses received the highest radiation doses[12]. A similar study by Osei et al. also indicated that nuclear medicine technologists, diagnostic imaging radiologists, and diagnostic cardiologists were among the highest-exposed subgroups[13]. However, neither of these studies performed a multivariate logistic regression analysis based on stratification factors.

Our research indicated that the majority of annual doses among three periods were below the thresholds established by the International Commission on Radiological Protection. Though the relationship between low-dose radiation exposure and cancer risk had remained controversial[14–16], increased radiation exposure among the general public during the COVID-19 pandemic had been observed[17, 18]. In a study by Shi et al., trends in inpatient radiology imaging utilization and workload during the pandemic were assessed, revealing a significant increase in inpatient radiology workload as advanced imaging modalities replaced lower-cost alternatives[19, 20]. Sahebi et al. warned that physicians, pulmonologists, and infectious disease specialists should avoid unnecessary and repeated requests for chest high-resolution computed tomography during the pandemic due to the elevated risk of breast cancer[21]. Concerns had also been raised regarding other types of cancer due to the increased use of imaging during the pandemic[22–26].

However, occupational radiation exposure among medical workers during the COVID-19 pandemic has not been previously documented to our knowledge. The average radiation doses in our study were significantly higher, whether the entire population or only those with measurable exposure were considered. This increase was especially evident in 2020 and 2021, suggesting that radiation-related procedures did not decrease and may have increased due to a surge in lung examinations[27] driven by public anxiety[28–30]. However, these elevated exposure levels began to decline after 2022, indicating that both the general population and medical workers had gradually adapted to the challenges posed by the pandemic and associated recovery measures.

Apart from diagnostic departments, some therapeutic departments, such as cardiology, surgery, and the anesthesia center, also exhibited similar trends. These findings might be attributed to the following factors: 1) Emergency and therapeutic services in large medical centers might have increased during the

COVID-19 pandemic due to a reduction in primary healthcare services [31–33]. 2) The simultaneous long-term use of infectious disease isolation gowns and lead protective suits was not comfortable. 3) The management of occupational ionizing radiation exposure for healthcare workers during this period was potentially overlooked.

Finally, several limitations of this study should be acknowledged. First, the study was conducted using single-center data, which may introduce selection bias and reduce the level of evidence. Second, the relationship between radiation exposure and health outcomes was not investigated in this study and will be explored in future research. Third, due to incomplete data, the exposure doses prior to 2008 and from other dosimeters, such as crystalline lenses, were not analyzed. Fourth, certain contextual covariates, such as annual departmental procedure volumes, fluoroscopy minutes, and CT counts per worker, were not incorporated into the analysis, which could potentially result in inaccuracy. Further studies with larger sample sizes and more comprehensive datasets are necessary to validate the findings of this study.

5 Conclusions

Although affected by the reduction in radiation dose in 2022, our research demonstrated that the COVID − 19 pandemic was associated with an elevation in radiation exposure among medical workers when compared to the pre-pandemic period (mean difference (MD): 0.021 mSv, 95% CI: − 0.056–0.099, increment rate: 5.7%, $p = 0.591$ for the entire population; and MD: 0.014 mSv, 95% CI: − 0.083–0.011, increment rate: 2.8%, $p = 0.784$ for the nonzero subgroup) and the post-pandemic period (MD: 0.221 mSv, 95% CI: 0.179–0.261, increment rate: 124.3%, $p < 0.001$ for the entire population; and MD: 0.257 mSv, 95% CI: 0.209–0.306, increment rate: 108.9%, $p < 0.001$ for the nonzero subgroup). Despite the disparities observed across different subgroups in both trend and comparative analyses, certain consistent patterns emerged regarding the management of occupational ionizing radiation exposure during the pandemic, which could offer valuable perspectives for future investigations. Although new protective measures were duly implemented, and the majority of annual doses remained well below the limits, it is essential to further focus on alleviating occupational ionizing radiation exposure among medical workers and improving radiation protection standards in the context of public health emergencies.

Declarations

6.1 Ethics approval and consent to participate

The study was approved by the Institutional Review Board of the Second Hospital of Chongqing Medical University (No. 360, 2025). For retrospective analysis of mandated occupational monitoring, individual consent is usually waivable. The whole study follows the principles of Helsinki declaration.

6.2 Consent for publication

Not Applicable.

6.3 Availability of data and materials

The individual-level maternal and clinical data generated and/or analysed during the current study are not publicly available due to ethical and privacy restrictions but are available from the corresponding author on reasonable request.

6.4 Competing interests

The authors declare that they have no competing interests.

6.5 Funding

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6.6 Authors' contributions

Y.W. and L.G. conceived the concept of this study and modified the manuscript.

Z.L., Q.S., C.L. and Q.J. were responsible for data collection.

Y.W., G.W. and L.G. analyzed the data.

Y.W., Z.L. and L.G. coordinated and drafted the manuscript.

All authors have read and agreed to the published version of the manuscript.

6.7 Acknowledgements

Not Applicable.

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Tables

Tables 1 to 4 are available in the supplementary files section

Figures

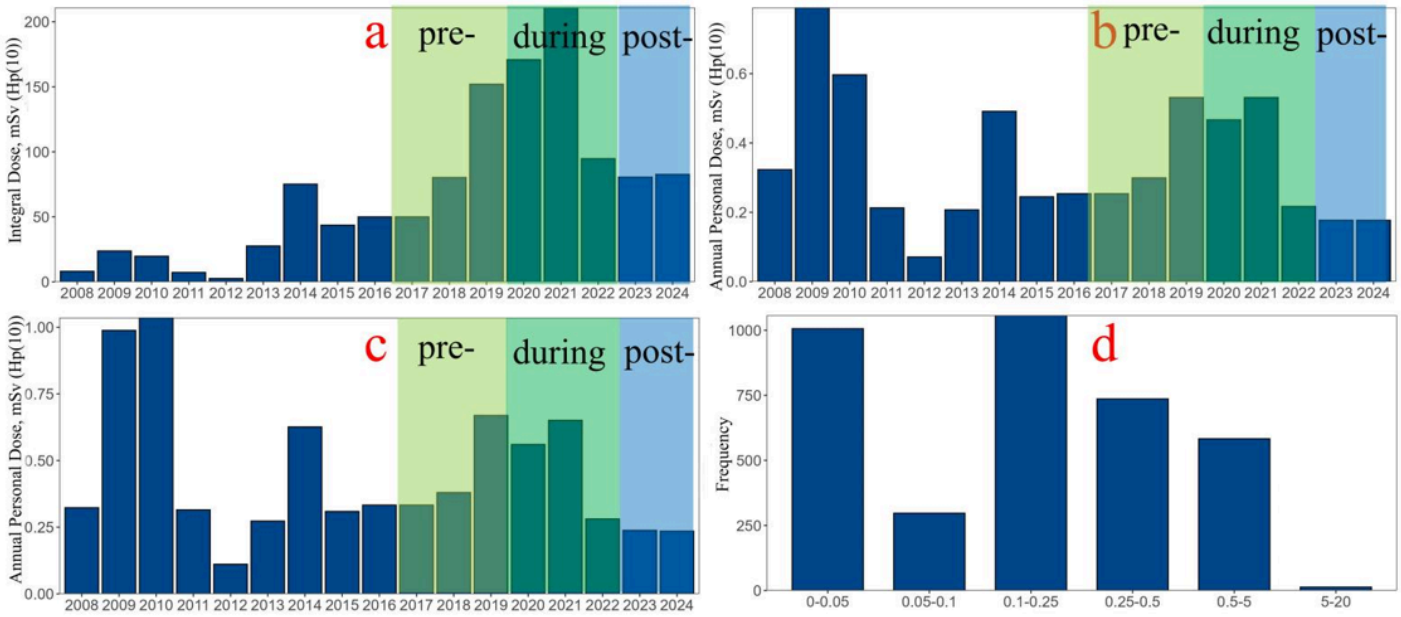

Figure 1

Characteristics of population distribution for occupational ionizing radiation exposure among medical workers in our institute from 2008 to 2024. Neither the annual accumulated dose in the entire population (a), average annual personal dose in the entire population (b), average annual personal dose in the nonzero subgroup (c), nor the aggregated average annual dose (d) followed a normal distribution. The colorized background represents the three distinct phases: pre-pandemic (2017–2019), during the pandemic (2020–2022), and post-pandemic (2023–2024).

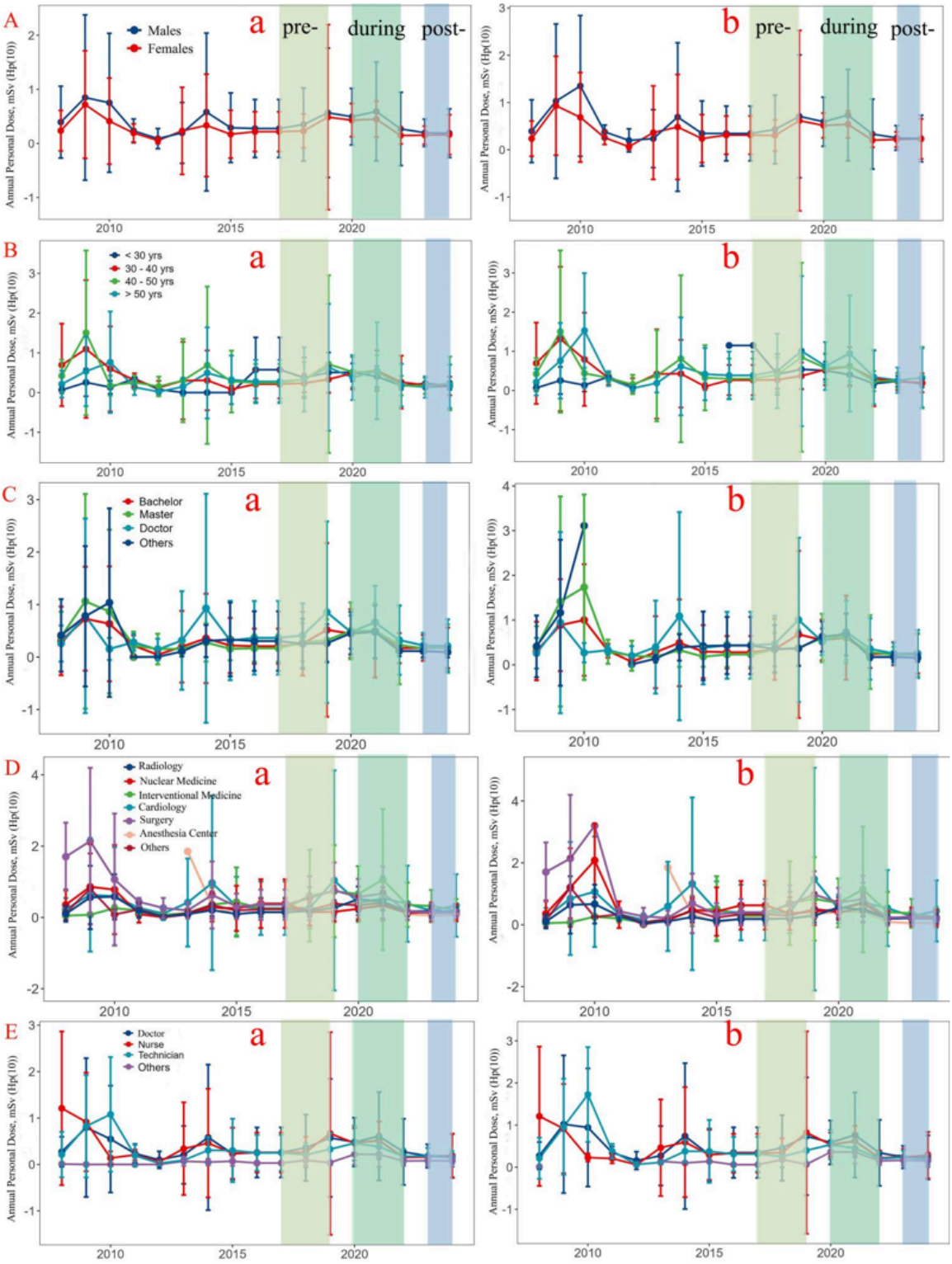

Figure 2

Trend analyses of average annual occupational ionizing radiation exposure by gender (A), age group (B), educational level (C), department (D), and profession (E) in the entire population (a) and the nonzero subgroup (b) from 2008 to 2024. The colorized background represents the three distinct phases: pre-pandemic (2017–2019), during the pandemic (2020–2022), and post-pandemic (2023–2024). The age was based on the records each year. The mean and standard deviation (SD) of each

subgroup were utilized for plotting, and the results of the median and inter - quartile range (IQR) were presented in Table 1.

Supplementary Files

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- tables.doc