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Radiation Exposure Monitoring of Operating Room and Endoscopy Nurses at a Singapore Public Hospital

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ABSTRACT

Background: Healthcare workers' radiation safety during fluoroscopy-guided procedures remains a critical occupational health concern, particularly for nursing staff with intermittent exposure. With evolving healthcare practices, increasing procedural volumes, and technological advancements in fluoroscopic equipment, there is a need to evaluate whether continuous personal radiation dose monitoring is necessary for occasionally exposed nursing staff in operating rooms and endoscopy suites.

Materials and Methods: A prospective observational study was conducted at a Singapore public hospital from July to December 2024. Eighty nurses from operating theatre and endoscopy departments were equipped with a personal dosimeter to record their dose exposure. A secure digital platform with QR code integration enabled immediate exposure logging via participants' mobile phones, capturing 1,512 exposure data from various procedures. Radiation doses were measured bimonthly by Singapore's National Environment Agency.

Results and Discussion: Analysis revealed significant variations in the median of total exposure time across specialties, with participants specializing in vascular having the highest median exposure (4.4 hours), followed by endoscopy (2.8 hours), urology (0.3 hours), and orthopedics (0.2 hours). Despite these variations, total effective doses remained consistently low across participants from all specialties below the study period threshold of 1 mSv. The absence of a strong correlation between exposure time and effective dose suggests the effectiveness of current radiation protection measures. Cost-benefit analysis indicated potential savings of approximately $60,000 annually through reduced subscription fees, in addition to administrative man-hour savings, which would have been required for dosimeter management and dose reporting for a cohort of 315 staff.

Conclusion: This study demonstrates that occasional participation in fluoroscopy-guided procedures results in minimal radiation exposure for nursing staff, supporting the discontinuation of routine radiation monitoring while maintaining periodic reviews. The findings demonstrate that current radiation protection protocols effectively maintain exposure levels well within safety limits.

Keywords: Radiation Safety, Occupational Exposure, Fluoroscopy, Nursing Staff, Dose Monitoring

Technical Note

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Introduction

Healthcare workers' radiation safety during fluoroscopy-guided procedures remains a critical occupational health concern, particularly for staff with intermittent exposure

[1–5]. Modern fluoroscopic equipment incorporates advanced radiation protection features, and healthcare facilities have implemented comprehensive shielding measures including protective barriers, lead aprons, and thyroid shields [6]. These improvements, combined with strict adherence to radiation safety protocols and the As Low As Reasonably Achievable (ALARA) principles, have significantly reduced occupational exposure risks.

With these enhanced protection measures in place, there is a need to evaluate whether continuous personal radiation dose monitoring remains necessary for occasionally exposed nursing staff in operating rooms (ORs) and endoscopy suites. While previous studies have investigated radiation exposure among healthcare workers in various clinical settings [7, 8], limited data exists on the specific exposure patterns of nursing staff who assist intermittently in fluoroscopy-guided procedures across different specialties.

This study evaluated radiation exposure levels among OR and endoscopy nurses with periodic radiation exposure in a Singapore public hospital. The objectives were to quantify radiation exposure levels among nurses working in radiation-exposed environments, assess whether cumulative doses exceeded International Commission on Radiological Protection (ICRP) recommended limits for non-occupational radiation workers [9] and develop evidence-based recommendations for optimizing radiation monitoring practices.

Materials and Methods

1. Study Design and Study Population

This prospective observational study was conducted at a Singapore public hospital from July to December 2024. From a target population of 315 nursing staff who occasionally assist in fluoroscopy-guided procedures, 80 participants were enrolled, representing approximately 25% of the target population. The participants consisted of 28 Endoscopy nurses and 52 OR nurses (16 vascular, 10 urology, and 26 orthopedics) across various designations as shown in Fig. 1. Before the study began, all participants attended a comprehensive briefing session covering study objectives, proper thermoluminescent dosimeters (TLDs) wearing protocols, radiation safety practices, and exposure time documentation procedures.

From the initial cohort of 80 participants, 70 completed the study period, while 10 were excluded from the final analysis due to various reasons, including lost TLDs, prolonged leave, or staff resignation. These 70 participants were deployed across four main specialties: endoscopy (n = 26), orthopedics (n = 21), urology (n = 9), and vascular (n = 14). The study captured data from 1,512 radiation exposure individual records, with the majority occurring in endoscopy (46%, n = 694), followed by orthopedic (25%, n = 373), vascular (14%, n = 211), and urologic procedures (14%, n = 221), with a small proportion from general surgery (1%, n = 13) as shown in Fig. 2.

Median radiation exposure times varied significantly across specialties, as shown in Fig. 3. Vascular procedures showed the highest median exposure times due to the continuous fluoroscopic imaging required for real-time visualization during complex interventions such as angiography, stent placements, and endovascular repairs. Similarly, endoscopic procedures demonstrated substantial exposure times due to the need for fluoroscopic guidance during catheter navigation and therapeutic interventions. In contrast, orthopedic and

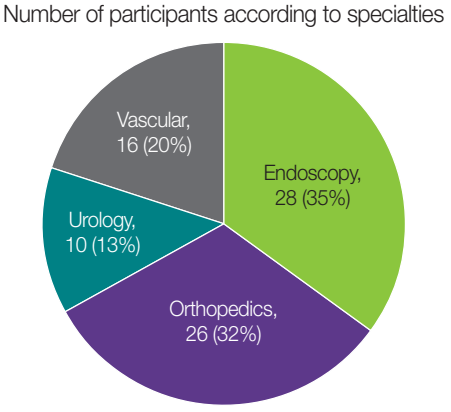

Fig. 1. Participant breakdown according to specialties.

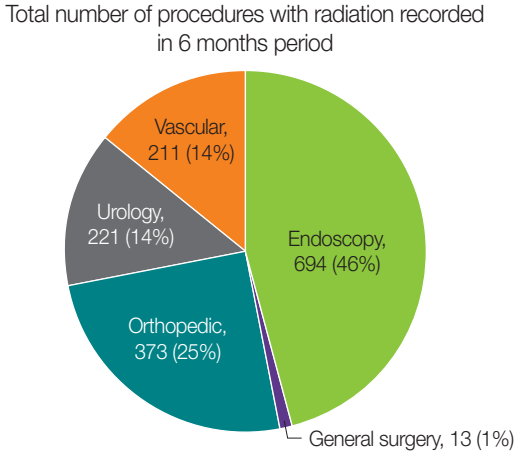

Fig. 2. Distribution of procedures involving radiation exposure across specialties.

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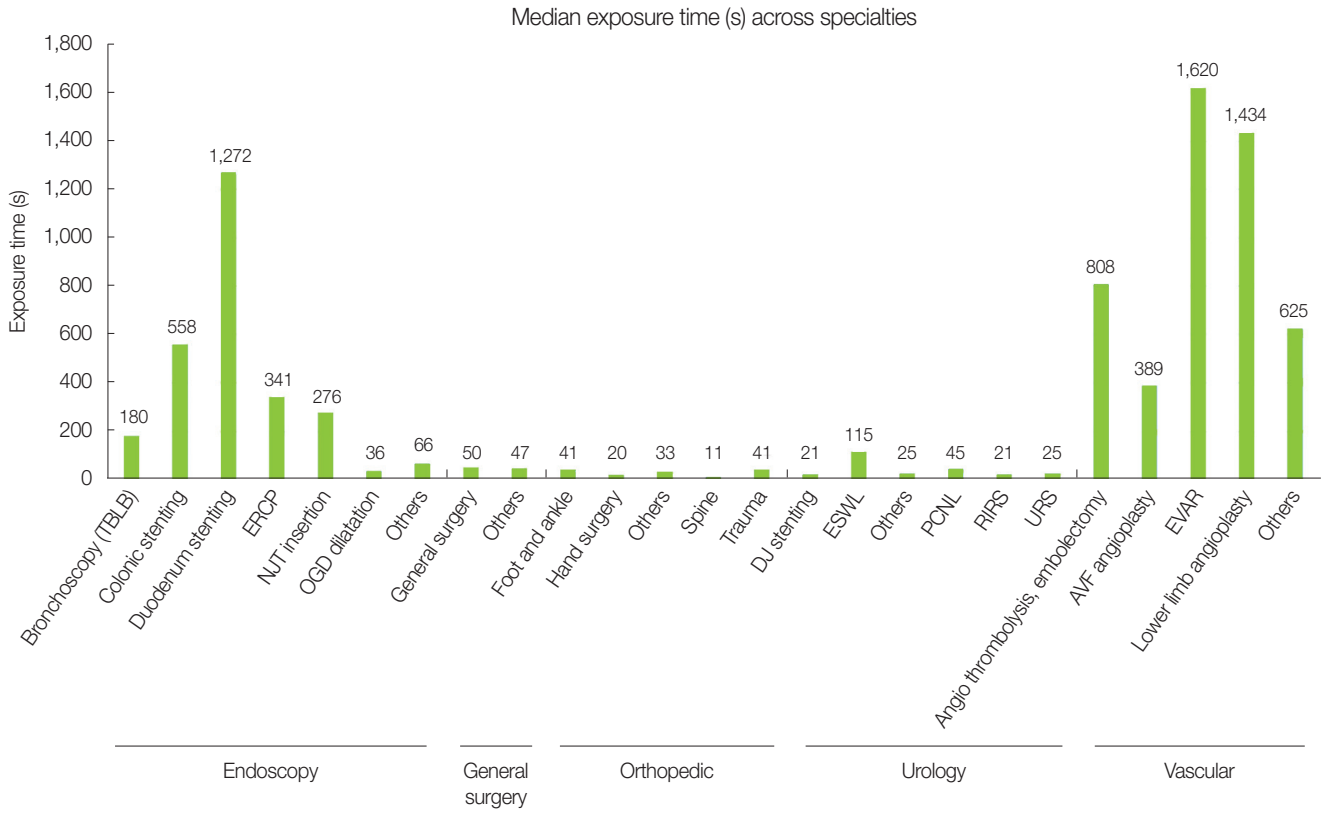

Fig. 3. Median of total exposure time (seconds) across specialties. TBLB, transbronchial lung biopsy; ERCP, endoscopic retrograde cholangiopancreatography; NJT, naso-jejunal tube; OGD, oesophago-gastro-duodenoscopy; DJ Stent, double-J (DJ) stent; ESWL, extracorporeal shock wave lithotripsy; PCNL, percutaneous nephrolithotomy; RIRS, retrograde intrarenal surgery; URS, ureteroscopy; AVF, arteriovenous fistula; EVAR, endovascular aneurysm repair.

urological procedures showed notably lower exposure times, reflecting their intermittent use of fluoroscopy.

2. Equipment and Radiation Monitoring

All participants wore TLDs for the 6-month study period, with bimonthly readings conducted by Singapore's National Environment Agency (NEA). The bimonthly TLD reading intervals were determined by the NEA's subscription-based radiation monitoring service, which provides standardized dose measurements on a 2-monthly cycle for all subscribers.

TLDs were chosen over electronic personal dosimeters (EPDs) as they offered several advantages for this study. EPDs would have required additional staff time to record both exposure time and EPD readings for each procedure, potentially affecting recording efficiency and potentially introducing additional error. Furthermore, TLDs offered a more cost-effective solution through NEA's subscription-based dose monitoring model, compared to the significant upfront investment required for EPDs which would become redundant after the study period. This subscription-based service was particularly suitable for this short-term study involving 80 participants.

The radiation exposure assessment was conducted in actual clinical settings where staff movements and positions are dynamic throughout procedures. Staff frequently change positions based on procedural needs, patient care requirements, and team coordination. For example, during a single fluoroscopy-guided procedure, a nurse may move between equipment trolleys, patient monitoring stations, and assisting positions, making it impractical to maintain consistent distance and orientation measurements.

The TLDs were worn consistently on the chest or front body area of the staff, following standard radiation monitoring protocols. This approach, though not capturing granular spatial data, reflects the actual occupational exposure experienced by nursing staff during their regular duties. To address radiation safety, all staff followed standard radiation protection principles, including maintaining maximum practical distance from the radiation source and minimizing time in high-exposure zones when possible.

Table 1. Distribution of Procedures, Exposure Time, and Effective Dose of Participants across Specialties

Specialty	No. of participants	Procedures count	Exposure time (hr)	Effective dose (mSv)
Overall	70	19 (0–79)	1.1 (0–26.2)	0.68 (0.58–0.99)
Endoscopy	26	23 (1–79)	2.8 (0.2–10.5)	0.66 (0.58–0.99)
Orthopedics	21	17 (0–45)	0.2 (0–0.5)	0.70 (0.60–0.85)
Urology	9	21 (0–50)	0.3 (0–2.0)	0.67 (0.63–0.85)
Vascular	14	12 (1–66)	4.4 (0.2–26.2)	0.72 (0.63–0.93)

Values are presented as median (range).

Fluoroscopic imaging systems included both mobile and static C-arms in OR and endoscopy center. All equipment underwent regular quality assurance testing and preventive maintenance to ensure optimal performance and radiation safety.

3. Data Collection Protocol

A secure digital platform with QR code integration enabled efficient documentation of radiation exposure details by individual participant. Each record submission includes individual staff identifier, procedure specifications, role during the procedure (scrub nurse, rotating nurse, or anesthesia unit support), and duration of radiation exposure. The digital documentation system with mandatory fields improved data accuracy and eliminated transcription errors.

4. Radiation Dose Assessment

The nurses in this study are not classified as radiation workers as their primary role is patient care, with radiation exposure being incidental to their duties during fluoroscopy-guided procedures. As their radiation exposure is occasional rather than routine and they do not handle or operate the irradiating equipment, they are categorized as members of the general public for radiation protection purposes. Hence, their exposure levels were evaluated against general public dose limits.

Natural background radiation exposure in Singapore averages to 1 mSv/yr as estimated from ambient radiation measurements conducted by the NEA [10]. Following the ICRP recommendations, a dose limit of 1 mSv/yr was established for non-occupational radiation workers, in addition to natural background levels [9]. Therefore, the applicable dose limit for this 6-month study period was set at 1 mSv, representing half of the total annual limit (2 mSv).

5. Statistical Analysis

Statistical analysis was performed using Microsoft Excel version 16.33. Descriptive statistics were performed for radiation exposure times and effective doses of participants across different specialties. The effective dose results were presented as median values as the data showed a non-normal distribution with the presence of outliers, and some specialty groups had relatively small sample sizes. Given the wide range of exposure times across different specialties, median values provided a more robust measure of central tendency. This approach better represents the typical exposure levels experienced by nursing staff, particularly in datasets with skewed distributions. Correlation analysis examined the relationship between exposure times and effective doses. Cost-benefit analysis was also performed to evaluate the financial implications of continuous radiation monitoring practices.

Results and Discussion

1. Radiation Exposure and Dose Patterns Analysis

Analysis of procedure participation rate, radiation exposure times, and effective doses are presented as median (minimum–maximum) in Table 1. Participants attended a median of 19 procedures (range, 0–79) during the study period. By specialty, endoscopy staff recorded the highest median procedure count (23 procedures; range, 1–79), followed by urology (21 procedures; range, 0–50), orthopedics (17 procedures; range, 0–45), and vascular (12 procedures; range, 1–66).

Cumulative exposure times showed significant variations across specialties. Vascular staff accumulated the highest median duration (4.4 hours; range, 0.2–26.2 hours), followed by endoscopy (2.8 hours; range, 0.2–10.5 hours), while urology (0.3 hours; range, 0–2.0 hours) and orthopedics (0.2 hours; range, 0–0.5 hours) recorded notably lower exposures. These variations reflect both the inherent differences in procedure complexity and the frequency of fluoroscopy-guided procedures across specialties. Nevertheless, despite these substantial differences in procedure counts and cumulative exposure times, total effective doses remained consistently low across

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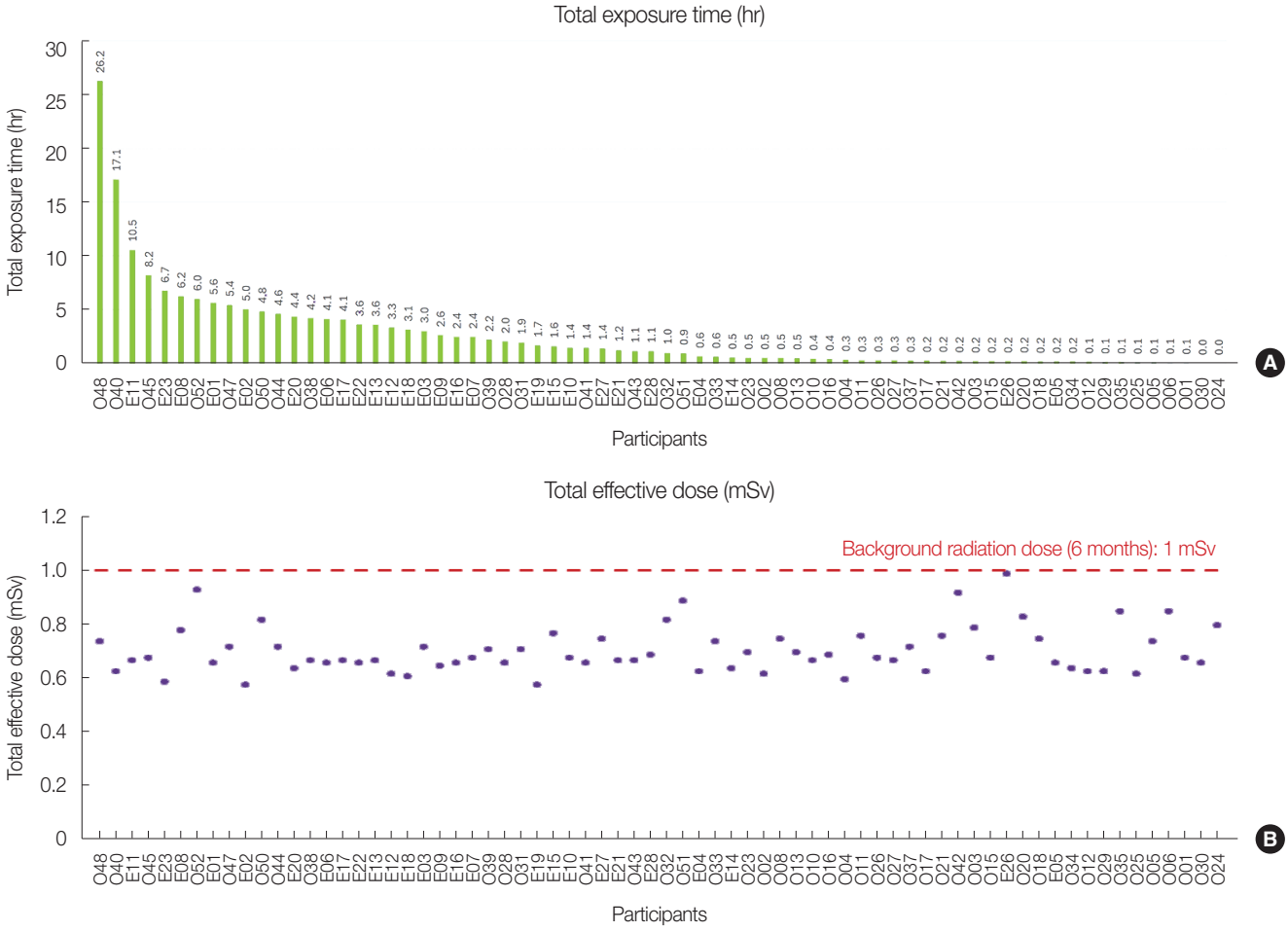

Fig. 4. Total exposure time (A) and total effective dose (B). Data are arranged from longest exposure (left) to shortest (right).

all specialties, below the study period threshold of 1 mSv.

Median effective doses showed remarkable consistency (0.68 mSv; range, 0.66–0.72 mSv) across specialties, with vascular procedures recording a median of 0.72 mSv, followed by orthopedic (0.70 mSv), urologic (0.67 mSv), and endoscopy procedures (0.66 mSv). As observed in Fig. 4, no strong correlation was found between exposure time and effective dose ($r = -0.09$, $p < 0.05$), suggesting that current radiation protection measures are effective in minimizing staff exposure regardless of the procedure duration. This finding aligns with the outcome of a similar study conducted internally within the same hospital back in 2019, which emphasized the importance of proper radiation protection practices over procedure duration in determining staff dose.

Further analysis identified two outliers where participants recorded relatively higher doses despite having minimal procedure participation. A participant who worked in vascular recorded a total dose of 0.92 mSv while having participated in only one procedure (0.22 hours) in October 2024, with bimonthly TLD readings showing higher doses for July–August (0.38 mSv) and November–December (0.32 mSv) as compared to September–October (0.22 mSv) when the procedure occurred. Similarly, another participant who worked in endoscopy recorded a total dose of 0.99 mSv despite having only assisted in two procedures (0.19 hours) in July 2024, with consistent bimonthly TLD readings throughout the study period (July–August, 0.37 mSv; September–October, 0.29 mSv; November–December, 0.33 mSv).

Based on the analysis, the higher readings were determined to be likely due to natural background radiation rather than occupational exposure. The outlier cases showed uniform bimonthly TLD readings (ranging, 0.29–0.38 mSv) even during periods without procedure participation, suggesting background radiation influence rather than occupational exposure. Additionally, these participants recorded relatively high total doses (0.92–0.99 mSv) despite minimal procedure par-

ticipation (only 0.19–0.22 hours), which is inconsistent with the expected dose-time relationship from occupational exposure. The finding of no strong correlation between exposure time and effective dose ($r = -0.09$, $p < 0.05$) across all participants further supports that factors beyond occupational exposure influenced the readings.

2. Economic Implications

The cost-benefit analysis revealed potential savings of $17,000 in initial TLD costs ($54.60 per unit) and $60,000 in annual subscription fees ($15.75 per TLD per staff monthly) for the 315 nursing staff. In addition, there will be savings through administrative manhours, which would have been required for the management of regular TLD exchanges. Transitioning from continuous monitoring to periodic assessment after every few years would maintain safety standards while significantly reducing operational costs. However, these financial benefits must be weighed against the need for maintaining robust radiation safety protocols and periodic validation of exposure levels.

3. Limitations

This study provides valuable insights while acknowledging certain methodological limitations. The 6-month study period, while providing robust initial data, may not capture potential seasonal variations in procedure volumes or long-term exposure patterns. A longer study duration would be beneficial to understand annual exposure trends and validate the consistency of our findings.

While we acknowledge the importance of backscattering radiation in occupational exposure, measuring ambient dose rates would have presented significant challenges due to multiple variables such as procedure types, patient sizes, staff positioning, equipment settings, and room layouts. These variables would make it difficult to establish meaningful correlations with actual staff exposure. Instead, TLD measurements provided more reliable data by capturing both direct and scattered radiation exposure in real working conditions, offering a more accurate representation of total occupational radiation dose during routine duties.

As this was a single-center study at a Singapore public hospital, the findings may not fully represent practices at other institutions with different fluoroscopy protocols or radiation safety measures. Variations in equipment, procedure volumes, and local regulations could influence exposure patterns. Nevertheless, our findings provide valuable benchmarking data for healthcare institutions with similar radiation protection protocols, particularly in the Asia-Pacific region.

The self-reporting nature of our digital documentation system, despite having QR code integration and mandatory fields, could introduce reporting bias in exposure time accuracy. While our digital platform improved data collection efficiency, the accuracy depends on staff compliance and timely documentation. Future studies could benefit from automated exposure time tracking systems for higher exposure time accuracy.

Background radiation exposure, a common factor in all radiation monitoring studies, was noted to influence individual dosimeter readings as observed in the outlier analysis. However, the consistency of such findings across participants and specialties supports the reliability of our study's conclusions. These limitations do not significantly impact our primary finding that radiation exposure levels remained consistently low across all specialties.

4. Implementation Considerations

The findings support modifying radiation monitoring protocols for occasionally exposed nursing staff. While exposure levels were consistently low, maintaining periodic reviews and spot checks remains crucial for quality assurance. Staff education and adherence to radiation protection protocols continue to be crucial, given the effectiveness demonstrated by the low correlation between exposure time and effective dose.

Conclusion

This study demonstrates that occasional participation in fluoroscopy-guided procedures results in minimal radiation exposure for nursing staff in OR and endoscopy settings, with all measured doses remaining well below recommended limits. The lack of correlation between exposure time and effective dose validates the effectiveness of current radiation protection protocols. These findings support the discontinuation of routine radiation monitoring for occasionally exposed nursing staff while maintaining periodic reviews, which potentially generates significant cost savings while maintaining safety standards. The study provides valuable benchmarking data for healthcare institutions and confirms that current radiation protection protocols effectively maintain exposure levels well within safety limits.

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Conflict of Interest

The authors declare no conflict of interest. The authors alone are responsible for the content and writing of this paper.

Ethical Statement

This study was reviewed and qualified as a quality assurance and service improvement project and was therefore deemed exempt by our Institutional Review Board.

Data Availability

No new datasets were generated for this study. All data analyzed are already included within the figures and descriptions presented in the manuscript, and no additional data files are available.

Author Contribution

Conceptualization: Arlany L. Methodology: Arlany L. Data curation: Arlany L. Formal analysis: Arlany L. Supervision: Arlany L, Tan W, Cillo JC Jr, Tugade LDV, Loy YH, Mohd Nor NB. Funding acquisition: Ng SP. Project administration: Arlany L, Tan W, Cillo JC Jr, Tugade LDV, Loy YH, Mohd Nor NB. Investigation: Arlany L, Tan W. Visualization: Arlany L. Resources: Ng SP. Validation: Arlany L, Tan W. Writing - original draft: Arlany L. Writing - review & editing: Tan W, Cillo JC Jr, Tugade LDV, Loy YH, Mohd Nor NB, Ng SP. Approval of final manuscript: all authors.

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