ORIGINAL ARTICLE

Evaluation of Occupational Radiation Exposure to Undergraduate Students During Clinical Training in Radiology Department

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ABSTRACT

Introduction: Assessing radiation exposure is a vital step in determining the potential health risks associated with radiation and identifying the necessity for protective measures. The study assesses the occupational radiation dose encountered by undergraduate students specializing in diagnostic imaging and radiotherapy (DIR) during their clinical training in the radiology department. **Materials and methods:** An analysis was conducted to compare individual exposure doses with the dose limits established by the International Commission on Radiological Protection (ICRP), concurrently assessing the variations in mean effective doses among distinct student cohorts. Optically stimulated luminescence dosimeters (OSLD) were employed to monitor 143 students across five cohorts from 2017 to 2022. The electronic Secondary Standard Dosimetry Laboratory (e-SSDL) information security management system tracked the deep (Hp(10)) and shallow (Hp(0.07)) dose equivalents of DIR students. **Results:** The mean values for accumulated Hp(10) and Hp(0.07) were found to be 0.51 and 0.50 mSv, respectively, averaged over 800 hours of clinical training. The highest recorded exposure was 1.30 mSv, signifying that the radiation exposure experienced by DIR students was well below the threshold. The mean annual effective radiation dose per student amounted to 0.17 mSv. Small but significant difference ($p < 0.001$) in the radiation exposure between five cohorts was observed with increments over a 5-year period. **Conclusion:** The students' radiation dose was notably below the ICRP dose limit of 6 mSv/year designated for trainees. These results indicate the efficacy of the existing radiation protection measures during clinical training, reducing the likelihood of overexposure.
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Keywords: Radiation exposure, Clinical training, Undergraduate students, Diagnostic imaging, Optically stimulated luminescence dosimeter

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INTRODUCTION

The term "occupational exposures" refers to the exposure of workers to ionizing radiation resulting from both natural and man-made sources in the course of workplace activities, excluding exposures from practices or sources exempted by standards. With the increasing integration of technological advancements in diagnostic radiology, the occupational exposure of health professionals to ionizing radiation in the medical field is on the rise. Consequently, it becomes crucial for health institutions to monitor the radiation dose of healthcare professionals (1-4). The monitoring of radiation doses for radiography undergraduate students during clinical training becomes imperative to underscore the challenges associated with radiation protection and instill an understanding of safe practices that will be applied throughout their professional careers. The International Commission on Radiological Protection (ICRP) has outlined three fundamental principles for radiation protection: justification, optimization (ALARA), and dose limitation (5). ALARA, representing "As Low As Reasonably Achievable," encapsulates the principle of minimizing radiation exposure in radiation protection practices.

Radiation safety regulations (6,7) require healthcare providers in radiology departments to use dose-monitoring badges. The optically stimulated luminescence dosimeter (OSLD) has gained popularity for various applications in monitoring personal radiation doses (8-10). Its application in occupational exposure is essential for assessing whether the received dose aligns with the permissible limits set by national and international radiological protection regulations. The ICRP quantifies occupational radiation dose in terms of effective dose and equivalent dose (11). The effective dose, serving as a risk-weighted measure of radiation exposure, is considered a reliable indicator of radiological risk as it accounts for uniform, whole-body exposure. Personal's occupational effective dose is measured in the personal dose equivalent of Hp(10) for deep skin dose, representing a 10 mm depth of soft tissue, and Hp(0.07) for surface skin dose, representing a 0.07 mm depth of soft tissue.

Healthcare personnel in diagnostic radiology, especially those involved in interventional procedures, may face heightened exposure to scattered radiation from patients. This raises concerns about stochastic effects that may manifest many years later during the latent period (12-14), where the severity is independent of the initially received dose. The ICRP and the Atomic Energy Licensing Board (AELB) have advocated safety measures to safeguard the health of both workers and the public from the hazards of ionizing radiation. In this regard, they have established an occupational dose limit of 1 mSv/year for the public, 20 mSv/year averaged over 5 years, with an annual cap not exceeding 50 mSv for radiation workers, while apprentices have a 6 mSv annual dose limit. However, the issue of exposure among radiography undergraduate students has not received the same level of attention compared to professional radiographers (15), likely due to the limited time spent handling various x-ray modalities during clinical training. The current study aims to assess the occupational radiation exposure experienced by undergraduate students during their clinical training across multiple radiology departments as part of their mandatory clinical courses.

MATERIALS AND METHODS

Study population

The dose evaluation covered the period from 2017 to 2022 and encompassed Diagnostic Imaging and Radiotherapy (DIR) undergraduate students from the Universiti Kebangsaan Malaysia (UKM), constituting five cohorts, with ages ranging from 19 to 24 years. Following the completion of various key courses integrating theoretical and practical approaches, DIR students were allocated to public or private clinics and hospitals across Peninsular and East Malaysia. The commencement of diagnostic imaging clinical practices (DICP) took place in the second year of their four-year academic program, requiring students to fulfill all clinical training ranging from diagnostic imaging clinical practice I (DICP I) to VI (DICP VI). Each clinical training student spent 8 hours per day, for a total of 40 clinical hours per week, practicing various diagnostic modalities in clinics, radiology departments, emergency departments, and operating theatres. Inclusion criteria for DIR students involved (1) successful completion of all clinical training (DICP I, II, III, IV, V, and VI) and (2) achievement of the specified minimum number of cases detailed in the program logbook. Conversely, exclusion criteria for this study encompassed students undergoing semester deferral in their course of study.

Ethical Approval

This study was approved by Research Ethics Committee, Faculty of Medicine, Universiti Kebangsaan Malaysia (JEP-2023-161).

Personal Dosimetry system

Aluminum oxide-based optically stimulated luminescent dosimeters, specifically, InLight Dosimeters from Landauer Inc (Glenwood, IL USA), were employed in the study. These dosimeters are disk-shaped detectors with a thickness of 0.2 mm and a diameter of 5 mm, encased in a light-tight plastic jacket measuring 10 mm × 10 mm × 2 mm. Each dosimeter card includes identification information for students in both text and barcode formats. To safeguard the element from contaminants, a thin retaining layer of Teflon covers the front and back sides. All DIR students were equipped with OSLDs provided by the Malaysian Nuclear Agency (MNA) to monitor radiation doses during clinical training in the radiology department. Subsequently, the dosimeters were registered by scanning the provided barcode and entered into the electronic Secondary Standard Dosimetry Laboratory (e-SSDL) information security management system.

During each clinical training, all students receive OSLD to determine their Hp(10) and Hp(0.07). The OSLD is worn on the most exposed part of the body, high on the frontal part of the trunk (torso). In situations where students are wearing protective clothing such as lead aprons, which provide significant attenuation of incident radiation on some parts of the body, the dosimeter is placed on the torso beneath the lead apron. Upon completion of the clinical month, the dosimeters were returned to MNA for monthly dose analysis. The International Commission on Radiation Units and Measurement recommends reporting the whole-body exposure as Hp(10), or personal dose equivalent. The Hp(10) calculates the effective dose for photon energy employed in radiology that are incident on the front of the body. The dosimeters were read using the microStar Reader Version, a data collection and analysis software provided manufacturer.

Data Extraction and Analysis

This study obtained DIR students' occupational radiation doses from 2017 to 2022 directly through the e-SSDL system. In Malaysia, the MNA acted as the radiation surveillance authority (16), with a certified officer reviewing all reported doses. The dose report, owned by the department of DIR UKM, was accessible on the e-SSDL website via a specific username and password provided to the department for reference. Each student's dose was recorded with a unique identification number specifying their university, and measurements were documented in Hp(10) and Hp(0.07). Occupational dose monitoring employs the personal dose equivalent Hp(10). The effective dose of occupational exposure, denoted as E, can be calculated from operational quantities using the following formula:

$$E \cong H_p(10) + E(50)$$

where Hp(10) and E(50) are the personal dose equivalent from external exposure and committed effective dose from internal exposure, respectively. The committed dose is a dose metric that quantifies the stochastic health risk resulting from the ingestion or inhalation of radioactive material into the human body.

Occupational exposure data were segregated and subjected to descriptive analysis, employing frequency and percentage calculations. The spreadsheet categorized students based on their clinical year, duration of clinical training, and assigned hospital. Differences in mean occupational exposures for each cohort were quantified using the Statistical Package for the Social Sciences (SPSS) version 28.0. Quantitative variables were presented as mean, standard deviation, and a variance test (one-way ANOVA) was conducted to ascertain statistically significant differences in mean effective doses of each cohort, followed by Bonferroni's post-hoc comparison testing.

RESULTS

OSLD data from 858 dosimeters belonging to 143 students was analyzed. The readings were collected from students during six rotations of clinical training. Figure 1 illustrates the trend of the average personal equivalent dose received by DIR students over the course of six subsequent clinical training sessions in the radiology department, with a total of 800 clinical hours spent. The dose exposure is minimal (<0.1 mSv) from DICP I to III, commencing at 0.02 mSv and gradually increasing to 0.07 mSv. As students develop confidence and begin to participate more actively in diagnostic examinations, their exposure to radiation increases. A significant rise is seen, with the dose peaking at around 0.3 mSv for DICP IV. However, the dose exposure begins to decrease as DICP V progresses to VI.

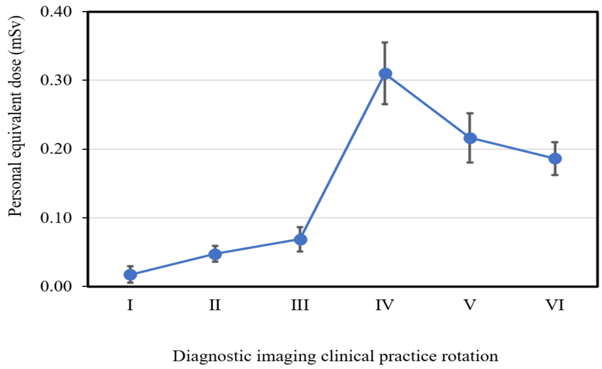

Figure 1: Radiation dose received by DIR undergraduate students across six cycles of clinical practice.

Figure 2 and Figure 3 illustrate the distribution of accumulated OSLD measurements for the whole-body dose Hp(10) and the skin dose Hp(0.07) for all undergraduate students. The recorded Hp(10) ranged from 0.05 to 1.30 mSv, while Hp(0.07) ranged from 0.06 to 1.29 mSv. The mean values for Hp(10) and Hp(0.07) were found to be 0.50 and 0.51 mSv, respectively, accumulated over 800 hours of clinical training. Table I show the average personal equivalent dose received by the students during clinical training with different diagnostic imaging modalities. Students with an active dose below the minimum dose limit (MDL) of 0.03 mSv were categorized as non-exposed and registered as zero in the reporting database.

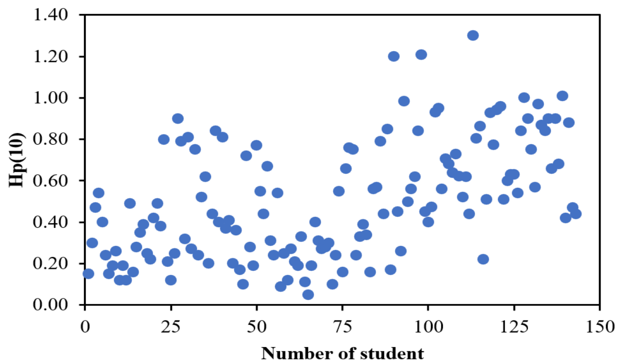

Figure 2: The distribution of accumulated whole-body dose Hp(10) of 143 DIR students.

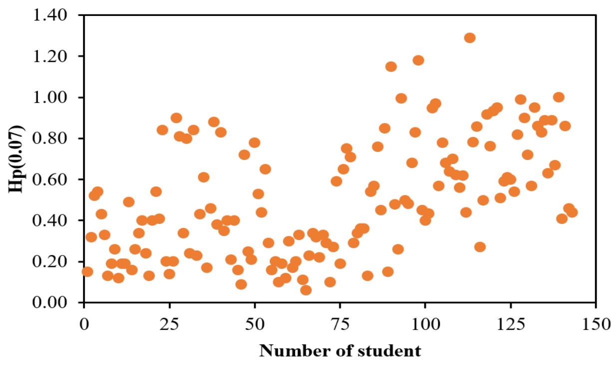

Figure 3: The distribution of accumulated skin dose Hp(0.07) of 143 DIR students.

Table I: Students' average personal equivalent dose received while undergoing clinical training with several diagnostic imaging modalities.

DICP	Location	Radiography modalities	*Clinical hours	Equivalent dose (mSv)
I	Clinic and emergency department	General/ Mobile	80	0.018
II	Radiology Department	General	40	0.048
		Mobile/ Dental	40	
III	Radiology department and operation theatre (OT) room	General/ Mobile/ Dental	40	0.069
		Fluoroscopy	40	
		Mobile C-arm	40	
IV	Radiology department and operation theatre (OT) room	General/ Mobile/ Dental	20	0.310
		Fluoroscopy/ Mammography	50	
		Mobile C-arm/ Mammography	50	
V	Radiology department	Angiography	40	0.216
		Computed Tomography (CT)	40	
		Magnetic Resonance Imaging (MRI)	40	
		Radionuclide imaging/ Ultrasound	40	
		General/ Mobile/ Fluoroscopy	40	

Table I: Students' average personal equivalent dose received while undergoing clinical training with several diagnostic imaging modalities. (CONT.)

DICP	Location	Radiography modalities	*Clinical hours	Equivalent dose (mSv)
VI	Radiology department	Angiography	30	0.186
		Computed Tomography (CT)	30	
		Magnetic Resonance Imaging (MRI)	60	
		Radionuclide imaging/ Ultrasound	60	
		General/ Mobile/ Fluoroscopy	20	

* The clinical hours are set to each modality depending on the number of cases required in the logbook, but the actual time spent on subsequent clinical training is determined by the clinical cases collected previously.

Figure 4 shows the frequency distribution of DIR students' doses of Hp(10) and Hp(0.07), respectively. The histogram reveals that the highest frequency of Hp(10) falls within the range of 0.21 to 0.40 mSv, with 38 students and 4 students recording accumulated Hp(10) exceeding 1.00 mSv. Conversely, Hp(0.07) recorded 35 students within the radiation exposure dose range of 0.21 to 0.40 mSv, with 3 measurements exceeding 1.00 mSv. Overall, the majority (> 97%) of DIR undergraduate students received less than 1 mSv of radiation exposure during 800 hours of diagnostic imaging clinical practice, well below the annual limits of 6 mSv per year as recommended by the ICRP (5) and AELB (7) and for trainees.

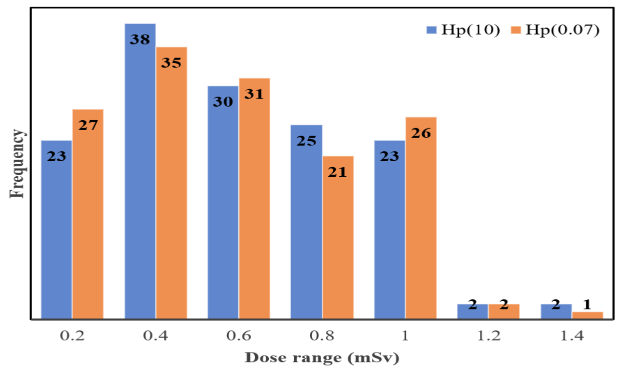

Figure 4: Histogram of accumulated whole body dose Hp(10) and skin doses Hp(0.07).

The box plots in Figure 5 and Figure 6 illustrate the comparison of the mean accumulated radiation dose during diagnostic imaging clinical practice among five cohorts of DIR students. Cohorts 15, 16, and 19 have fewer than 30 members, while both cohorts 17 and 18 consist of 31 members each. The box plot indicates a noticeable trend of gradual increases in the mean accumulated Hp(10) and Hp(0.07) from 2017 to 2022. Across all cohorts, the mean values for Hp(10) and Hp(0.07) varied between 0.31 to 0.77 mSv and 0.31 to 0.73 mSv, respectively. This study highlights a significant disparity in mean effective dose among the various cohorts. Analysis of variance (ANOVA) demonstrates a significant difference ($P < 0.001$) in the mean effective dose among the five cohorts. Further statistical analysis using the Bonferroni post hoc test reveals differences in Hp(10) and Hp(0.07) between each cohort and at least two other cohorts.

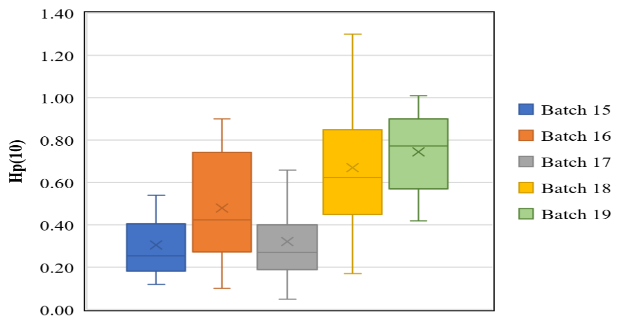

Figure 5: The distribution of effective dose Hp(10) in each cohort. The box plot includes markers (×) representing the mean value of the accumulated Hp(10).

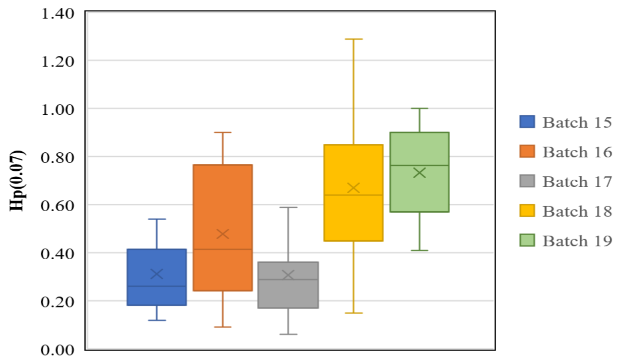

Figure 6: The distribution of skin dose Hp(0.07) in each cohort. The box plot includes markers (×) representing the mean value of the accumulated Hp(0.07).

DISCUSSION

Radiation Exposure

The low doses in first two clinical trainings (DICP I and II) reflect minimal exposure, most likely due to the students' learning stages and limited direct involvement in radiological procedures. During these initial training sessions, the students performed basic plain radiography procedures. The peak dose in DICP IV represents a period of intense, hands-on training during which students are exposed to greater radiation as a result of carrying out more complex tasks such as real-time fluoroscopy examinations, with a total of 120 clinical hours spent. In contrast to the previous one, the dose was lower despite students spending more time in higher-level clinical training (DICP V and VI). This suggests that the time spent training in non-ionizing modalities, like magnetic resonance imaging (MRI) and ultrasound, has an impact on the dose (4, 12), and that students are probably well-versed in minimizing their radiation exposure through strategic positioning, optimal use of shielding equipment, and efficient workflow. The trend reflects a learning curve, where initial low doses are followed by a peak as students become more actively involved, and then a decline as they apply radiation safety techniques more effectively.

An interesting discovery is the increasing pattern observed in the mean effective dose from cohort 15 to 19. However, both Hp(10) and Hp(0.07) for cohort 17 deviate from this trend, with a notably low dose compared to the preceding cohort 16. Upon comparing the doses between these cohorts, the lower mean dose reading for cohort 17 can be attributed to the suspension of clinical training rotations (DICP V and VI) for this group of students. This situation occurred due to the onset of the global outbreak of the Coronavirus disease (COVID-19) pandemic in early 2020, which worsened until 2021 (17-19). Consequently, students were unable to proceed with clinical training in radiology departments (20,21), as many hospitals were utilized for managing COVID-19 patients. The suspension of diagnostic imaging clinical training lasted for a year, impacting a 50-day clinical training period. During this time, the students did not allocate the remaining 400 hours for clinical training; instead, they engaged in equivalent online clinical module competency tasks as a replacement, a practice adopted by higher education institutions worldwide (22,23).

In general, both Hp(10) and Hp(0.07) doses have been gradually increasing over the years, attributed to the evolving sensitivity of OSLD. Advances in InLight OSLD technology have resulted in increased sensitivity, with manufacturers continuously refining dopant distribution homogeneity and optimizing dosimeter designs (24). These enhancements aim to improve the detector's capability to monitor radiation doses more reliably and precisely across a broader dose range (25). Furthermore, the MNA's SSDL utilizes screen OSLD, enabling more accurate dose estimations, particularly when detecting low doses or subtle dose changes. This feature aids in identifying minor external influences on dosimeter measurements, ensuring that the measured dose primarily reflects an individual's external radiation exposure. InLight OSLD offers operational advantages due to its extensive reanalysis capabilities and higher wear frequency (26,27), making it the preferred dosimeter for personal monitoring devices.

Recommendations

Maintaining accurate records of doses is essential for identifying variations in occupational exposure among students. This practice not only provides reassurance but also yields data that can be valuable in reviewing optimization radiation protection programs (28). According to the Atomic Energy Licensing Act of 1984, licensees are obligated to notify workers and trainees in writing of their personal monitoring results and radiation exposure status within fourteen days of obtaining the results. Adhering to this standard operating procedure ensures that employees are promptly informed of their monthly dose reports, enabling them to monitor their radiation exposure levels. However, a significant number of students were not aware of and lost track of their radiation dose exposure, as they were required to meet the officer in charge to obtain this information. An electronically-based dose recording system appears to be a viable solution for current practices (29), allowing students to access their dose reports at any time and from anywhere. This approach not only simplifies the process but also fosters students' interest in monitoring their radiation protection performance.

Moreover, there must be systematic plans in place to address instances of both under and over-exposures, taking into account the likelihood of occurrence and the potential severity of consequences. These plans should encompass the subsequent management of students and the potential health ramifications they might face. Instances of higher dose reports, where students may be at risk of overexposure, whether intentional or unintentional, necessitate appropriate responses, such as dose optimization or modifications to training procedures to mitigate risks (30,31). In cases where exposure exceeds prescribed dose limits or is suspected to have occurred, the licensee is required to conduct an investigation to ascertain the circumstances leading to the exposure and assess its consequences. A report detailing the investigation findings must be submitted to the relevant authority (7). The radiation protection officer is responsible for analyzing the presented issue to ensure that any potential hazards arising from the occurrence are promptly brought under control.

CONCLUSION

This study marks the effort to evaluate the effective radiation dose experienced by DIR undergraduate students in the course of their diagnostic imaging clinical practice. The mean annual effective dose averaged throughout the training period, stood at 0.17 mSv, with no annual dose recordings surpassing the limits stipulated by national and international regulatory bodies. The correlation between clinical time spent and dose received suggests that while increased time in clinical training initially leads to higher doses, effective safety practices, and efficiency improvements can significantly mitigate this exposure over time. This result suggests that the implemented radiation protective measures, coupled with the educational and training curriculum, have played a role in fostering commendable radiation protection practices in clinical radiography. Additionally, these efforts contribute to establishing a secure workplace environment.

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