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EVALUATING OCCUPATIONAL RADIATION EXPOSURE IN INTERVENTIONAL CARDIOLOGY: AN INVESTIGATION INTO ESTIMATING EFFECTIVE DOSE

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ABSTRACT

To safeguard the safety and well-being of interventional cardiology healthcare workers, monitoring their occupational radiation exposure is crucial. This study evaluates the radiation dose of interventional cardiologists using the Swiss Ordinance for personal dosimetry approach. Its primary aim is to estimate the radiation dose for each operator engaged in interventional cardiology procedures to protect from dangerous levels of radiation. Additionally, this study assesses the correlation between under-apron and over-apron dosimeters. Notably, no previous studies in Sri Lanka have specifically assessed radiation dose in this context, making this research vital in shedding light on radiation exposure in an interventional cardiology environment. Two cardiologists conducted a total of 108 interventional cardiology procedures, including coronary angiograms and percutaneous coronary interventions for a month at the cardiac catheterization laboratory of Sri Jayewardenepura General Hospital, Sri Lanka. Active dosimeters were utilized to measure dose values using a two-dosimeter approach where one dosimeter was positioned above the thyroid collar and the other beneath the lead apron on the left side of the waist. The effective doses (E) were determined using the Swiss Ordinance algorithm. Furthermore, this study also examined the relationship between under and over-apron dose values. The Swiss Ordinance algorithm estimated the mean annual E values for each cardiologist, resulting in 3.0397 mSv/year and 0.9697 mSv/year, respectively showing that the estimated annual occupational doses remained well below the annual dose limit (20 mSv/year). The accuracy of the algorithm in interventional ionising radiation scenarios was also highlighted. A strong positive correlation (R^2 = 0.9500) was observed between over-apron and under-apron dose values. Applying the Swiss Ordinance for personal dosimetry and studying the link between over and under-apron dosimeters in interventional cardiology improve our grasp of radiation dosimetry. Emphasizing precise dose estimation for the safety of cardiologists, this study enhances the radiation safety practices in interventional cardiology.

KEYWORDS: *Effective Dose, Double Dosimetric Algorithm, Interventional Cardiology, Occupational Exposure, Radiation Protection, Swiss Ordinance for Personal Dosimetry*

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1. INTRODUCTION

Fluoroscopy-guided interventional cardiology is a rapidly developing medical field focused on diagnosing and treating cardiovascular diseases. Within this field, procedures involving fluoroscopy-guided cardiac catheterization have proven highly advantageous for patients. However, a significant concern arises around potential radiation risks for medical professionals involved in these procedures. This concern is particularly relevant to interventional cardiologists, who work in close proximity to patients within radiation fields that can be irregular and scattered. Prolonged and close exposure to such conditions can result in higher cumulative radiation doses for medical staff over time. Consequently, it is imperative to implement adequate measures to safeguard the health of healthcare workers. To minimize radiation exposure, protective equipment like lead aprons and thyroid shields play a pivotal role in interventional cardiology. Lead aprons offer protection to critical organs such as the lungs and reproductive organs, while thyroid shields are designed to shield the neck and thyroid gland. Beyond relying solely on protective gear, cardiologists should adopt safe radiation practices. This involves limiting their time spent in radiation-prone areas, maintaining distance from radiation sources, and utilizing shielding methods (Balter, 1993; Biso and Vidovich, 2020; Valentin, 2006; Ramanathan, Almeida and Fernando, 2021).

An essential tool for ensuring radiation safety is determining the effective dose (E), which quantifies the absorbed radiation energy in the body, accounting for the type and sensitivity of exposed tissues and organs. This measurement helps to evaluate potential health risks and the necessity for additional protective measures. Typically, E is calculated and reported when significant radiation exposure occurs. The International Commission on Radiological Protection (ICRP) recommends whole-body dose limits of 20 mSv/year averaged over a defined 5-year period. It is emphasized that the E should not exceed 50 mSv in any single year for healthcare workers with occupational exposure, aiming to prevent adverse health effects. Regular monitoring of radiation levels and individual doses assists in identifying areas requiring heightened protection and assessing the effectiveness of current safety protocols (López *et al.,* 2018).

To estimate radiation dose accurately, the operational quantity Hp(10) is employed, representing the dose at a 10 mm depth in soft tissue. Dosimeters, coupled with protective equipment, are vital for precise monitoring and reducing exposure levels. For interventional cardiology units with high radiation doses, the ICRP advises the use of two dosimeters. One dosimeter is placed beneath the lead apron to measure the absorbed dose, while the other is positioned above the apron to gauge ambient radiation levels. This approach provides a reliable estimation of the E (Vano *et al.,* 1998). However, it is important to acknowledge that dosimeters positioned beneath lead shielding can sometimes miscalculate the E due to the protective effect of the shielding. Placing a dosimeter in front of the lead garment can lead to an overestimation of the dose. To address this issue, a common strategy involves using a single dosimeter reading adjusted by a correction factor. Nevertheless, for greater accuracy, a method involving two dosimeters is preferred. One dosimeter is positioned beneath the shielding garment, and the other is placed above it. This dual dosimetry approach enhances the accuracy of energy determination by combining both measurements in a linear manner (Von Boetticher, Lachmund and Hoffmann, 2010; Kuipers *et al.,* 2008). Despite these benefits, some concerns have been raised regarding the use of two dosimeters, including the potential for them to be swapped or forgotten by medical professionals. Acknowledging the real-world limitations of using only a single dosimeter in certain interventional cardiology units, this study focuses on evaluating the correlation between dosimeter measurements taken directly above the apron and those obtained beneath the apron. This assessment aims to provide valuable insights into radiation exposure and safety within the field.

In Sri Lanka, the regulatory bodies responsible for radiation protection have adopted a method for calculating the E in interventional cardiology procedures, as proposed by the National Council on Radiation Protection and Measurements (NCRP). However, this method has certain limitations. It does not account for protective measures like lead thyroid shields, and it does not take into consideration the specific energy spectrum of the radiation being measured. In response to these shortcomings, the current study has turned to the Swiss Ordinance Personnel dosimetric method to address these issues more effectively (Abdelrahman *et al.,* 2020; Baechler *et al.,* 2006). The Swiss Ordinance method offers a more comprehensive solution by addressing the concerns mentioned above. It proposes a dual dosimetric approach that provides a more accurate estimation of the E. Among the various algorithms available for double dosimetry in radiation measurement, the decision to use the Swiss Ordinance method was based on its ability to yield accurate and thorough results, especially when only Hp(10) dosimeters are available in cardiology departments. By implementing the Swiss Ordinance dosimetric method, the aim of this study is to overcome the limitations posed by the NCRP double dosimetric method. The goal is to ensure a more comprehensive and accurate assessment of radiation exposure for international cardiologists working in interventional cardiology settings. It is worth noting that the accuracy of this algorithm has been validated by various studies, confirming its performance within the recommended uncertainty ranges.

This study focuses on assessing the annual occupational radiation exposure of interventional cardiologists using the Swiss Ordinance method for personal dosimetry. The main objective is to estimate the radiation dose that interventional cardiologists are exposed to over a year and to evaluate the correlation between dosimeters positioned below and above the protective apron in order to determine the reliability of utilizing a single dosimeter. This approach is being investigated for its effectiveness in estimating radiation dose levels. The purpose of this estimation is to ensure that these medical professionals are not subjected to hazardous levels of radiation during their work and use. Given the absence of prior research in Sri Lanka concerning the evaluation of radiation dose specifically for interventional cardiologists, this study aims to fill this knowledge gap. It aims to shed light on the extent of radiation exposure in the unique working environment of interventional cardiology. By gaining a more comprehensive understanding of radiation levels, the research intends to pave the way for implementing appropriate measures that will effectively safeguard the health and well-being of these healthcare workers.

2. METHODOLOGY

In this study, a total of 108 interventional cardiology procedures were performed during a month. These procedures included 78 Coronary Angiograms (CA), and 30 Percutaneous Coronary Intervention (PCI) procedures. However, no cardiac implantation and electrophysiology procedures were included due to the limited number of procedures conducted during the data collection period. The research project received approval from the institutional ethics committee, ensuring that it met ethical guidelines. All participants involved in the study provided their informed consent, indicating their full understanding and agreement to take part. The procedures were conducted by two cardiologists identified as operators A and B. All procedures in Cath Lab were performed using ceiling-mounted Philips Allura FD 10 C-arm (Philips Medical Systems, Best, the Netherlands) equipped with a 1024x1024 matrix, 1250 mA at 80 kV, standard Fluro, and cine acquisition frame rate with 7.5 and 15 frames/sec, respectively for CAs and PCIs. This study excluded procedures that deviated from the standard acquisition protocol in terms of magnifications and frame rates in order to prevent any potential bias in the results caused by non-standard acquisitions. Both operators used wraparound lead aprons with an overall lead equivalence of 0.25 mm at 50-110 kVp during all interventional cardiology procedures. The wrap-around apron had an overlay due to which the real lead apron thickness in front is 0.5 mm lead equivalent. Both operators wore 0.5 mm Pb neck collars. Operator A used 0.5 mm Pb equivalent eye goggles during their procedures. The Cath Lab had 0.5 mm ceiling-mounted Pb shields for additional protection.

In this study, active dosimeters were utilised to measure the estimated E values. Two Hp(10) active dosimeters, specifically the PM1610 model from Polimaster in Austria, were employed to gather dose measurements. The PM1610 dosimeter employs a Geiger-Muller tube to detect radiation. Calibration of the PM1610 device was conducted using ^{137}Cs sources and a plane parallel PMMA phantom measuring 30x30x15 cm. The measurement range for the dose equivalent rate (DER) varied from 0.1 µSv/h to 10 Sv/h. The calibration of the device assembly is accurate within ± 6% at a confidence probability of 0.95. For continuous photon radiation, the measured DE range was 0.05 µSv to 10.0 Sv, while for pulsed photon radiation; it was 10 µSv to 10.0 Sv. The accuracy of DE measurement was ± 20%, and the detector's energy range was 0.02 to 10.0 MeV.

Figure 01: Hp(10) dosimeter positioned above the thyroid collar.

For the double dosimetric approach, dose measurements were obtained using two Hp(10) dosimeters. One dosimeter was positioned above the thyroid collar on the left side of the neck (Figure 01),

Figure 02: Hp(10) dosimeter positioned under the lead apron

while the second dosimeter was placed underneath the lead apron on the left side of the waist (Figure 02). Before obtaining the actual dosimeter measurements, the background radiation dose was consistently measured. The E was estimated using double dosimetric algorithms suggested by Swiss ordinance on personal dosimetry where a thyroid shield was used.

$$H_{total(10)} = H_{under(10)} + \alpha * H_{over(10)} \quad (01)$$

where $H_{under(10)}$ is the equivalent dose reading of the under-apron and $H_{over(10)}$ is the equivalent dose reading of the over-apron dosemeter. The value of the weighting parameter α = 0.05 when a thyroid shield is used. The recorded background doses were subtracted from the measurements of the over and under-apron doses. E per CA and PCI procedure for each operator was also estimated.

To contrast the doses measured above and below the apron, given the availability of just one Hp(10) dosimeter in the cardiology unit, a basic linear regression analysis was carried out. The Wilcoxon ranked test was used to analyse the difference between over and under-apron doses. All statistical computations were performed using the software Statistical Package for the Social Sciences (SPSS) version 26.0. The significance threshold was established at a value of $p < 0.05$.

3. RESULTS

The number of procedures performed over a month by the A and B operators was 65 and 43, respectively. Operator A performed 40 CAs and 25 PCIs. Operator B performed 35 CAs and 8 PCIs.

Table 01 shows the mean, standard error of the mean, median, standard deviation, minimum, maximum, and sum of the estimated E per year for all the procedures, annual estimated E per procedure of CA, and annual estimated E per procedure of PCI. Figures 03 and 04 visually illustrate the distribution of annual estimated E values, as well as the estimated E values per individual CA and PCI procedure.

These figures provide a graphical representation of how these values are spread across the two operators being studied.

Table 1: Mean, standard error of the mean, median, standard deviation, minimum, maximum, and sum of the estimated E (mSv) per year for all the procedures, annual estimated E (mSv) per procedure of CA, and annual estimated E (mSv) per procedure of PCI.

Estimated E per Year (mSv)						
	Mean	**Std. Error of Mean**	**Median**	**Std. Deviation**	**Minimum**	**Maximum**
A	3.0397	0.6086	1.3932	4.5543	0.2171	22.1774
B	0.9697	0.1717	0.4282	1.2499	0.0714	6.8958
Estimated E per CA per Year (mSv)						
	Mean	**Std. Error of Mean**	**Median**	**Std. Deviation**	**Minimum**	**Maximum**
A	0.3675	0.0388	0.3200	0.2363	0.0340	0.9678
B	0.1754	0.0207	0.1378	0.1344	0.0181	0.5814
Estimated E per PCI per Year (mSv)						
	Mean	**Std. Error of Mean**	**Median**	**Std. Deviation**	**Minimum**	**Maximum**
A	2.4148	0.4953	1.5191	2.1591	0.0866	8.8724
B	0.7511	0.1375	0.6761	0.4560	0.2553	1.7508

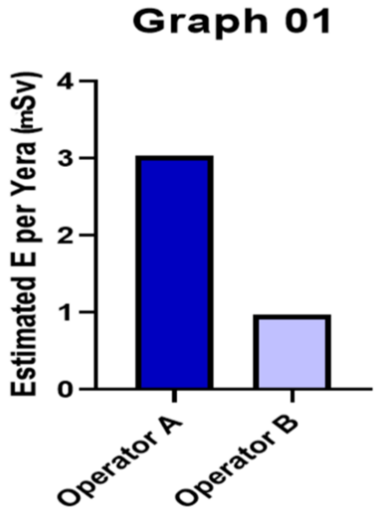

Figure 03: Distribution of the annual estimated effective doses (E) for operators A and B

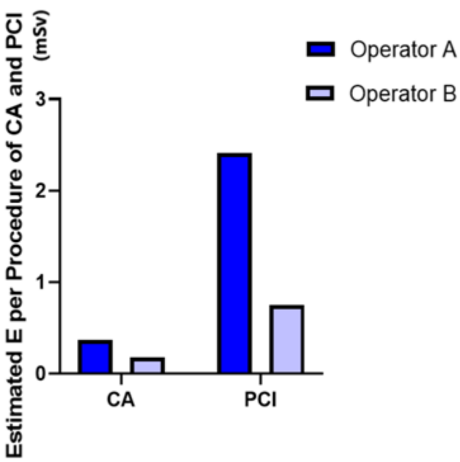

Figure 04: Distribution of estimated effective doses (E) for the procedure of CA and PCI for operators A and B

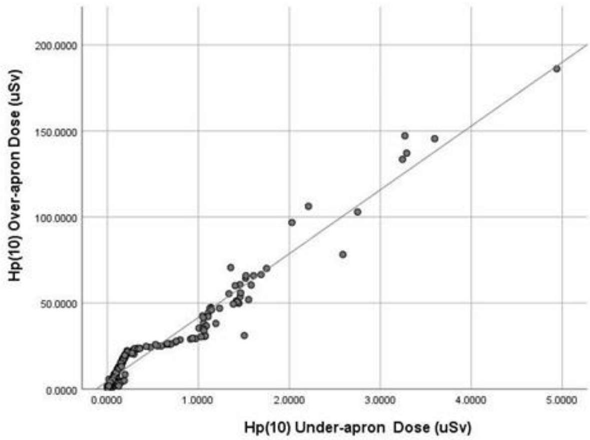

Figure 05: The relationship between the estimated effective doses (E) (μSv) obtained from the over and under-apron doses obtained within a one-month duration.

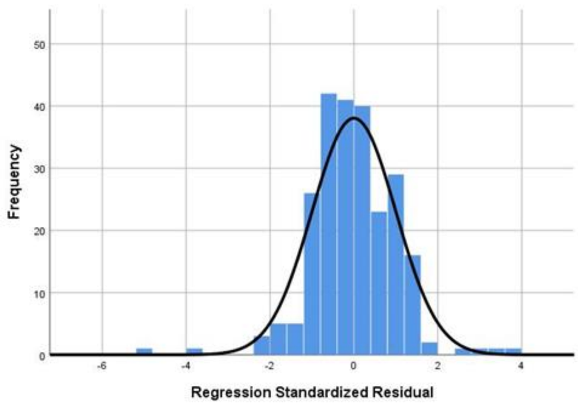

Figure 06: The distribution of standardized residuals from the linear regression.

Upon evaluating the relationship between dose values taken above and below the apron, the regression analysis revealed robust and positively inclined linear connections ($p < 0.001$, ANOVA) ($R^2 = 0.9500$). Figures 05 and 06 visually depict the connection between the dose measurements obtained from over and under the apron, alongside the distribution of standardized residuals from the linear regression, respectively. The Wilcoxon signed-rank test was employed to investigate the statistical significance in the comparison of recorded shielded and unshielded dose readings.The results of the test validated a statistically notable distinction between these two measurements ($p < 0.05$, Wilcoxon ranked test).

4. DISCUSSION

The utilization of the double dosimetric algorithm proposed by the Swiss ordinance on personal dosimetry, as demonstrated by several studies (Baechler *et al.*, 2006; Jossen *et al.*, 2003), has proven to be a reliable approach for assessing radiation exposure. The current findings of the study, which indicate that the calculated dose values remain well below the stipulated annual dose limit of 20 mSv/year, highlight the effectiveness of this algorithm in accurately estimating radiation doses. Moreover, the congruence observed between the estimated E values obtained from the Swiss ordinance on the personal dosimetry algorithm and the outcome of our study reinforces the robustness of this approach. This alignment between theoretical estimations and empirical data further substantiates the algorithm's credibility in practical radiation exposure assessments. The endorsement of the Swiss Ordinance algorithm by Järvinen *et al.* (2008), following a meticulous evaluation of various double dosimetry algorithms, underscores its superior accuracy in predicting effective doses, particularly in scenarios involving interventional ionizing radiation. The ability of the algorithm to mitigate both overestimation and potential underestimation, particularly when relying solely on Hp(10) dosimeters, adds to its utility and reliability in diverse radiation exposure scenarios. In essence, the empirical evidence and expert validation provided in this study collectively affirm the efficacy of the Swiss ordinance on personal dosimetry algorithm, thereby establishing it as a valuable tool for accurate radiation dose assessment across a spectrum of practical applications.

Operator A obtained the highest annual estimated E values from the algorithm, most likely because they carried out the greatest number of cases, specifically 65 procedures. Likewise, it is evident that Operator A encountered higher radiation doses during each individual CA and PCI procedure. These procedures encompassed both fluoroscopic imaging and Cine imaging. Notably, Cine imaging emits approximately

10 times more radiation than fluoroscopy (McKetty, 1996). Consequently, the variance in annual estimated E values between Operator A and Operator B could be attributed to multiple factors. These factors encompass the number of procedures conducted, the intricacy of said procedures, discrepancies in operational methods, and variations in expertise and proficiency among operators. In essence, a higher radiation exposure of operator A is likely a result of a combination of these variables (Kicken *et al.*, 1999; McKetty, 1996; Vano *et al.*, 1998).

The study uncovered strong connections between the readings of dosimeters placed in an unshielded manner (without any protective covering) and those placed with shielding (protected by a lead covering) ($R^2 = 0.9500$). This finding suggests that a single dosimeter positioned above the thyroid collar can effectively provide an accurate measurement of radiation exposure for medical personnel working with interventional cardiology. This eliminates the need for an additional dosimeter placed under the lead apron, which is typically used for shielding against radiation. Similar research conducted by Kuipers et al. (2008), Dalah et al. (2018), and Moladoust et al. (2015) also yielded comparable results, reinforcing the idea that a single dosimeter placed above the protective thyroid collar is sufficient for accurate dose assessment in fluoroscopy scenarios. However, an important finding emerged from the Wilcoxon signed-rank test, which highlighted significant differences between the direct readings of dosimeters placed with shielding and those placed without. This indicates that these two measurements are not interchangeable. In other words, the protective barrier of the lead apron does influence the radiation dose recorded by the dosimeter underneath it. The research by Moladoust et al. (2015) cautioned against swapping measurements between shielded and unshielded positions based on this significant difference. This underscores the importance of maintaining consistency in the approach to radiation dose assessment. Such consistency is crucial to prevent potential health risks for medical personnel who are routinely exposed to radiation, as inaccuracies in dose measurement could have negative consequences for their well-being.

The annual estimated radiation exposure for each operator was calculated considering the medical procedures they performed within the current hospital setting. It is worth noting that both operators involved in this study have the potential to carry out a greater number of CAs and PCIs in their private practices. In light of this possibility, it becomes necessary to account for the radiation doses they would receive during these additional procedures performed in their private practices. Therefore, for a comprehensive and accurate assessment of the annual radiation exposure for each operator, it is essential to include the dose values received by both operators during their private practice procedures as well.

5. CONCLUSION

The integration of the Swiss Ordinance for personal dosimetry brings about significant consequences in the field of radiation dosimetry, marking a substantial advancement in our comprehension of this complex discipline. This regulatory framework goes beyond merely highlighting its importance; it emphasizes the utmost importance of meticulously selecting methods to achieve accurate and reliable estimations of radiation doses, particularly in the context of Sri Lanka.

The study brought attention to the dependability of using a single dosimeter positioned above the thyroid collar for the purpose of estimating radiation dose. The finding underscores the trustworthiness of this approach in accurately gauging radiation exposure. Nonetheless, it is worth noting that the study also revealed noteworthy disparities between the measurements of radiation dose taken when a shielding barrier was in place and when it was not. In other words, the presence or absence of shielding, such as a protective apron, had a discernible impact on the recorded dose measurements. The results obtained from the study provide validation for the practice of utilizing dosimeters positioned beneath lead aprons when conducting measurements, even though there are inherent challenges associated with employing two dosimeters simultaneously. The findings of the study offer substantial evidence to justify the continued use of dosimeters under lead aprons for accurate measurements, even considering the difficulties posed by the use of two dosimeters in such scenarios.

To sum up, the adoption of the Swiss Ordinance for personal dosimetry as a double dosimetric approach has far-reaching implications for the field of radiation dosimetry. Its primary focus on precisely estimating radiation doses not only underscores its significance but also establishes a fundamental basis for refining safety protocols. This, in turn, cultivates a culture centred around precision and well-informed decision-making. Through the implementation of this regulatory framework, the field takes a significant stride forward, not only in enhancing our theoretical knowledge but also in ensuring practical applications that prioritize the health of individuals and the broader environment.

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