Radiation dose assessment on operator during the dental postmortem procedure using handheld radiograph system

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KEYWORDS

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ABSTRACT

Portable handheld radiograph devices are increasingly common in forensic odontology, particularly in postmortem dental examinations. However, concerns remain regarding radiation exposure to operators handling these devices in mortuary settings. This study aimed to assess the radiation dose to the lens of the eye and fingers of the operator that is exposed to radiation from the NOMAD™ Pro handheld Radiograph. The radiation exposure on the operator of a dental portable handheld radiograph device in the dental postmortem procedure was monitored from March 2020 to February 2021. NanoDot™ OSL Dosimeters (Landauer, IL, USA) were positioned near the eyes and fingers of the operator to estimate the radiation dose. The dosimeters were then analysed using the LAUNDER's MicroStar reader and corrected based on the background reading and calibration parameters. Data from 80 procedures were analysed with the equivalent yearly doses for eyes and fingers were estimated and compared to the International Commission on Radiological Protection (ICRP) recommended limits. Results showed that the annual dose estimation for the lens of the eyes was 1.34 (range 0.56-6.57) mSv/yr while the fingers were 1.52 (range 0.40-5.51) mSv/yr. Radiation exposure to the fingers was slightly higher than exposure to the eyes but remained within requirements of the ICRP dose limits. In conclusion, even though portable radiograph equipment is useful in forensic odontology, operators only receive safe and low levels of radiation exposure. The continuous safe use of these devices in postmortem dental examinations is ensured by appropriate monitoring and adherence to safety procedures.

INTRODUCTION

Dental radiograph imaging is an integral part of forensic odontology investigations. A dental radiograph provides crucial information for establishing the facts of such cases, such as in the identification of unknown human remains using dental features.[1]

In forensic human identification, dental radiographs contribute towards building dental profiles and lead to the identification by comparison of the antemortem and postmortem radiographs.[2–5] During the dental postmortem procedure in the mortuary, radiograph acquisition is a common practice and is usually taken in the form of small film radiographs, such as

periapical or bitewing radiographs.[6] INTERPOL recommends taking a series of periapical and bitewing radiographs as part of the dental postmortem procedure in DVI operations, such as in the event of disasters resulting in mass casualties.[7] These radiographs enable forensic odontologists to collect vital information of the distinctive features of dental anatomy and treatment to aid in identifying unknown human remains.

In dental radiography, a portable, handheld radiograph is now widely used by forensic odontologists.[8] An example of a dental portable handheld radiograph device is the Nomad™.[9] The device is designed to be used by the operator by holding the handle with an outstretched hand, away from the patient, parallel to the ground, and activated at the arm's length distance.[9-10] The device resembles a photographic camera or a shotgun and comes with protective features, i.e. primary protective shielding, a fixed beam limiting device, and a backscatter radiation shield.[9–11]

As the portable radiograph works on a battery source, it offers the advantage of being used at any location compared to the conventional wall-mounted radiograph machine or the portable type activated at a distance used in dental clinics. The device can be used in a mortuary, an operational field, or a remote location with no electricity source.[8] Furthermore, the protective design of the Nomad™ portable radiograph device in the form of a lead shield inside and lead-embedded acrylic protective ring externally creates a maximum protective zone or "area of significant occupancy" for the user against backscatter radiation.[9–12] Minimal exposure to radiation may only be yielded if the device is used according to the manufacturer's recommended use in clinical practice with the operator standing within the area of significant occupancy.[9–11,13] In the mortuary, the deceased body on the autopsy table may be positioned in various, and sometimes unpredictable positions depending on the degree of decomposition or manner of death.[14] The operator may not always be in the area of significant occupancy during the radiographic procedure.[15]

Previous studies indicate the level of radiation exposure to the operator from using the dental portable handheld radiograph device either in a temporary mortuary setting or experimental settings is comparatively low and still within the acceptable or recommended occupational radiation level.[16–18] Previous studies indicate a comparatively low level of radiation exposure within the recommended occupational radiation level to the operator using the portable radiograph device, whether in a temporary mortuary setting[15] or a simulated one.[12,19] Similar observations were noted with different positioning of the operator's hand, body, or the device to the radiated subject.[12,20] Nonetheless, radiation exposure to the operator while using a dental portable handheld radiograph device still raises a concern as the prolonged usage of the device may subject the operator to health risks due to cumulative radiation exposure.[21–23] As such, a baseline radiation exposure level helps to monitor, control, and implement the necessary intervention steps to ensure the safety of the operator.[8,24] Currently, there are no known recorded longitudinal radiation exposure levels to the operator based on actual dental postmortem cases in the mortuary. Thus, the objective of this paper was to establish a baseline radiation exposure to the lens of the eye and fingers of the operator from using NOMAD™ portable handheld radiograph in the mortuary based on forensic dental postmortem cases by the Forensic Odontology Unit of Hospital Kuala Lumpur.

MATERIALS AND METHOD

This cross-sectional study was approved by the National Medical Research Register (NMMR-20-2427-57108). The staff of the Forensic Odontology Unit of Hospital Kuala Lumpur was monitored for radiation exposure while operating the NOMAD™ Handheld Radiograph System (NOMAD™ Pro 2, USA) during the dental postmortem procedure. The radiation exposure doses were collected intermittently between March 2020 and February 2021 during dental postmortem cases in various mortuaries under the Ministry of Health Malaysia. All the periapical radiographs taken in this study were indicated for dental postmortem investigations.

The portable dental handheld radiograph device in this study is regularly calibrated and checked for leakage as part of the maintenance regime. When the portable dental handheld radiograph was used in the dental postmortem procedure, the radiation exposure parameters were fixed at 60 kV and 2.5 mA (adjustment of peak potential

and tube current setting is not possible). The operator practised standard protective precautionary steps when taking radiographs for the postmortem procedure. This was carried out by handling the device according to the manufacturer's usage recommendation as much as practically possible, such as standing behind the handheld radiograph device with the installed backscatter shield extended as close as possible to the subject. The operator also wore a lead apron, goggles, and protective collar during the procedure as a standard radiation safety measure. The concept of ALARA (doses should be As Low As Reasonably Achievable) was also applied.

When taking the radiograph(s), the operator was provided with two NanoDot™ Optically Stimulated Luminescence Dosimeters (OSLD) (Landauer, IL, USA) to measure the directly absorbed dose (Figure 1). Before each procedure, the OSLDs were annealed at the Nuclear Medicine Department, Hospital Kuala Lumpur to eliminate any radiation dose stored from previous experiments, radiographic procedures, or from the background radiation of its storage location. Each NanoDot™ OSLD was also pre-analyzed to obtain the background radiation level using LANDAUER's MicroStar InLight® portable reader. Additionally, the portable reader was also calibrated daily to ensure that it produced accurate results.

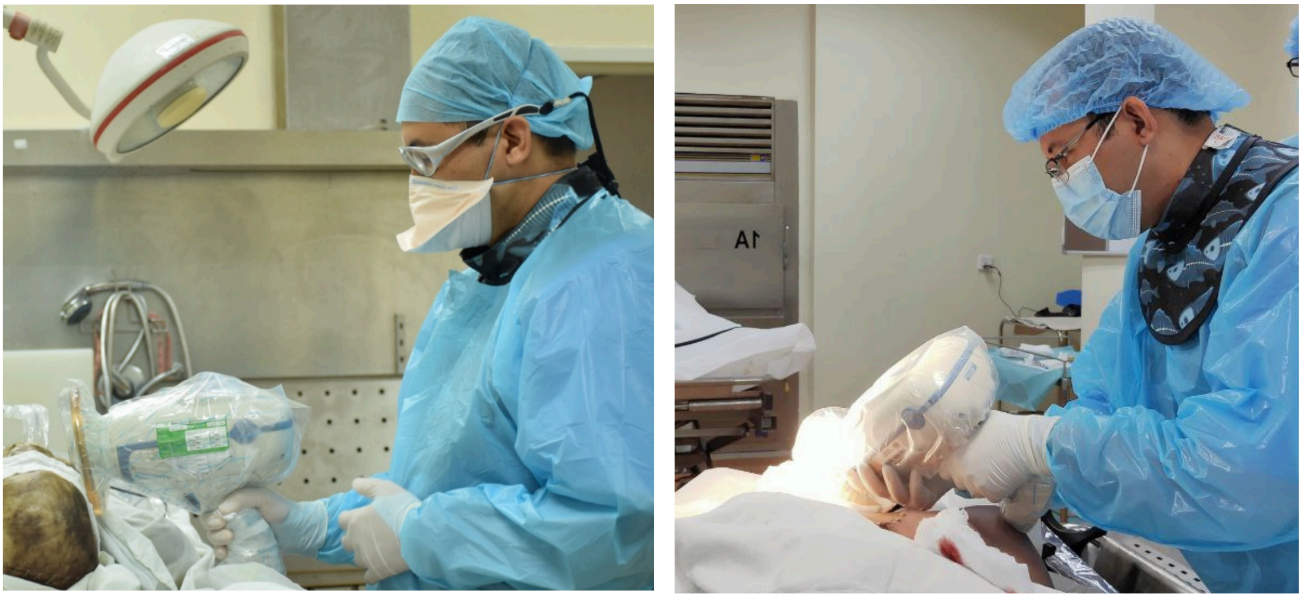
The NanoDot™ OSLDs were customised into a ring by attaching the OSLD to the stationery plastic ring binder (Figure 2). The two customised OSL Dosimeters were provided to the operator to be worn while taking the radiograph; one ring was attached to the eyeglass frame and one to any one of the fingers of the hand handling the portable handheld radiograph machine (Figure 3). The dental portable handheld radiograph device was usually positioned in proximity to the operator with the operator's hands being approximately within 25 cm from the radiation source output while taking radiographs. The operator stood in any positions practically suitable to the operator that were either the position considered typical as recommended by the manufacturer[1] or positions that deviated or were atypical from the recommended position by the manufacturer (Figure 4).[2,3]

Figure 1. NanoDot™ Optically Stimulated Luminescence (OSL) Dosimeters (Landauer, IL, USA)

Figure 2. The NanoDot™ Optically Stimulated Luminescence (OSL) Dosimeters (Landauer, IL, USA) modified into a ring using ring binder.

Figure 3. Location of the OSL dosimeters on the eyes (Left) and fingers (Right) of the operator.

Figure 4. The operator in "typical" (Left) and "atypical" position to the body



For each case (or procedure), the number of exposures and total exposure time per case was recorded using a standard form for every dental postmortem procedure. In this study, the total number of exposures is referred to as the total number of radiographs taken during a single dental postmortem procedure.

The NanoDot™ OSLDs were analysed, and the measured dose was corrected based on the background reading and calibration parameter. The measured dose was recorded as an absorbed dose (mGy). Since radiographs were used as the radiation source, the absorbed dose corresponds to the equivalent dose (mSv) as the radiation weighting factor is 1. Therefore, an absorbed dose of 1 mGy in an organ equals an equivalent dose of 1 mSv to that organ.

Data collected was statistically analysed using IBM SPSS Version 20 (IBM Corporation, Armonk, NY, USA). All data were tested for normality of distribution. The annual dose received by the eye and the fingers was then estimated and compared to the occupational exposure dose limits recommended by the International Commission on Radiological Protection (ICRP) for the respective organs.

RESULTS

A total of 112 dental postmortem procedures were performed using the dental portable handheld radiograph device. However, only 80 procedures were included in this study of dosimetry after the protocol deliberation. The exclusion of the procedures was due to either mislabelling, missing data, or data recording errors.

Table 1 shows the profile of the procedures included in this study. The total time for all exposure in this dosimetry study is 93.450s. The exposure times were relatively short, ranging from 0.07 to 0.16 (mean = 0.10) seconds per exposure. The radiation equivalent dose to the finger ranged from 0.0053 to 0.0623 mSv (mean = 0.0296 ± 0.0148 mSv) which was greater than radiation equivalent doses measured for the lens of the eyes which ranged from 0.0058 to 0.0577 mSv (mean = 0.0267 ± 0.0131 mSv) as shown in Table 2.

Table 1. The profile of the study samples

	Total Procedure	Total Exposure	Total time (s)	Time/ Exposure (s) (range)	Mean of Exposure/ Case (range)
Profile of included case	80	916	93.450	0.1 (0.07-0.16)	12 (3-25)

Table 2. Equivalent dose received by the eye and finger of the operator

	Total Exposure	Total time (s)	Total dose (mSv)	Equivalent Dose (mSv) Mean ± SD	Equivalent Dose (mSv) Range	Equivalent Dose (mSv) Median
Eyes	899	91.59	0.855	0.0267 ± 0.0131	0.0058-0.0577	0.0271
Finger	865	87.31	0.946	0.0296 ± 0.0148	0.0053-0.0623	0.0262

Table 2 shows the profile of the equivalent dose received by the operator. As shown in Table 2, the fingers received 865 exposures with a total equivalent dose of 0.946 mSv while the eyes received slightly fewer exposure and an equivalent dose of 0.946 mSv.

Table 3 & Figure 5 show the slightly higher equivalent dose per exposure for the fingers, ranging from 0.00031 to 0.00426 (median = 0.00117) mSv per exposure. Radiation doses measured for the lens of the eyes ranged from 0.00028 to 0.00508 (median =0.00104) mSv per exposure.

Table 4 and Figure 6 show the slightly higher equivalent dose per unit time of the finger, ranging from 0.0160 to 0.0117 (median= 0.0113) mSv/s. The dose per unit time of the eyes ranges from 0.0025 to 0.0693 (median = 0.0109 mSv/s).

Table 4 and Figure 6 show the slightly higher equivalent dose per unit time of the finger, ranging from 0.0160 to 0.0117 (median= 0.0113) mSv/s. The dose per unit time of the eyes ranges from 0.0025 to 0.0693 (median = 0.0109 mSv/s).

Figure 7 shows the dose distribution for the eye lens and finger versus exposure time. The Spearman correlation showed that there was a low correlation between dose and exposure time. There was a wide variation in the dose received by the operator with most of the exposure times per case recorded between 1 to 3 seconds.

Table 5 shows the estimated annual dose to the operator's eye and finger compared to the ICRP's recommended dose limit for eyes[4] and extremities[5].

Figure 5. The box plot of equivalent dose per exposure for eye lens and finger. Symbol (○) indicates outlier of the samples

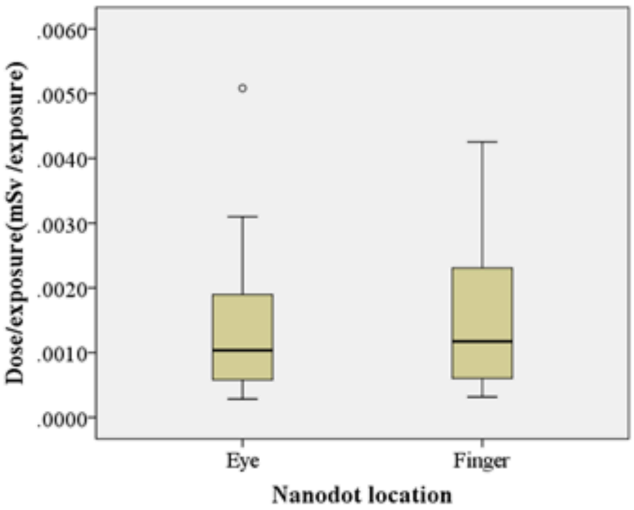


Table 3. Equivalent dose per exposure for the eye and finger

	Equivalent dose/exposure (mSv) Mean ± SD	Equivalent dose/exposure (mSv) Range	Equivalent dose/exposure (mSv) Median
Eyes	0.0014±0.0010	0.0014-0.0010	0.00104
Finger	0.0016±0.0012	0.0016-0.0012	0.00117

Table 4. Equivalent dose per unit time for eyes and finger

	Total time (s)	Dose/time (mSv/s) Mean ± SD	Dose/time (mSv/s) Range	Dose/time (mSv/s) Median
Eyes	91.59	0.0142 ± 0.0130	0.0025-0.0693	0.0109
Finger	87.31	0.0160 ± 0.0117	0.0031-0.0450	0.0113

Figure 6. The box plot of dose per time for eye lens and fingers. Symbol (*) shows outlier of the samples

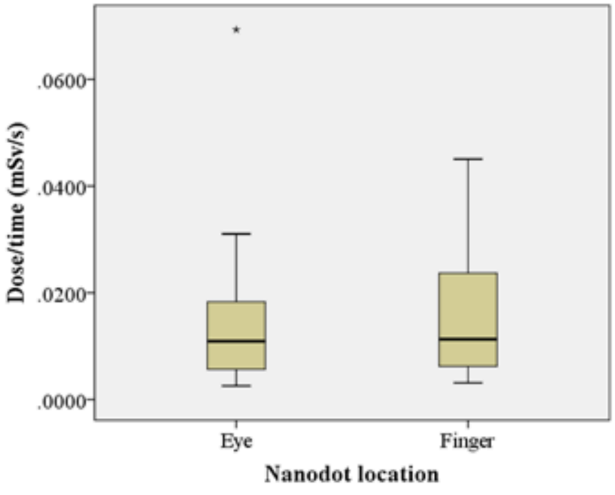


Figure 7. The dose distribution for the eye lens and finger versus exposure time

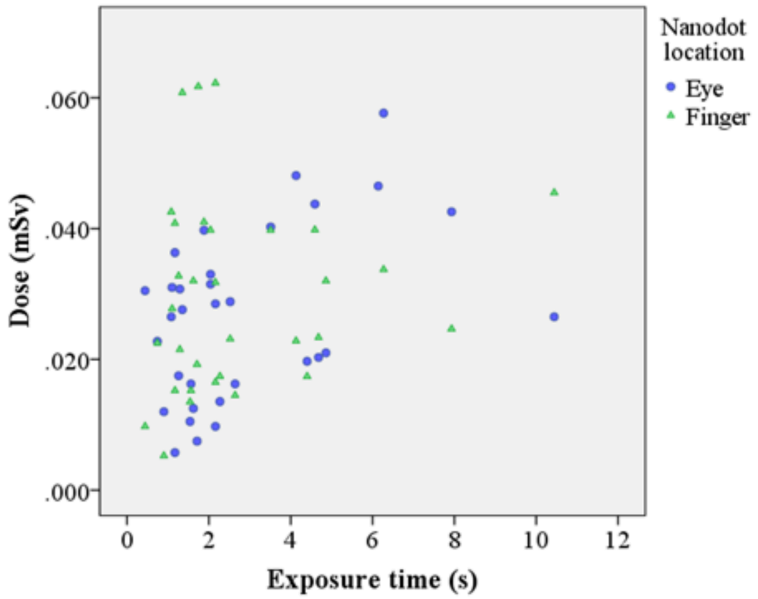


Table 5. Annual dose estimation for the lens of the eyes and finger

	Equivalent dose per year (mSv/yr)	Dose limit occupational exposure
Eyes	1.34 (0.56-6.57)	*20mSv
Finger	1.52 (0.40-5.51)	**500mSv

Recommended dose limit for the lens of the eye; ICRP 118, 2012
****Recommended dose limit for extremities; ICRP 103, 200***

DISCUSSION

This is the first personal dosimetry study analysing radiation dose on an operator handling a portable handheld radiograph device based on a typical Forensic Odontology HKI's postmortem workload. As there were different study designs, the radiation exposures in this study could not be directly compared to the other clinical[25], experimental[12-13,19-20,26] or simulation studies based on the previous exposures in the mortuary.[15] However, the radiation dose in this study was similar to those studies in that the doses to the operator were substantially below the recommended or accepted radiation level either by ICRP or the National Council on Protection & Measurement (NCRP).[18]

According to the exposure profile in this study (3 to 25 exposures, 0.07 to 0.16 seconds per exposure, median 1.036 mSv per case), the same operator will have to perform radiograph acquisition for approximately 1500 dental postmortem procedures within a calendar year to reach the recommended occupational radiation dose limit by ICRP. Presently, it is not necessary to limit the number of procedures per year or the number of radiographs per procedure if adequate radiation protection measures are taken.

One limitation of this study is that it did not compare different positioning techniques with alternative radiographic devices, such as wall-mounted which all require the operator to be in a protected zone or during image acquisition. According to previous research, using a fixed radiographic system reduces operator radiation exposure by increasing distance compared to a handheld radiograph device, which requires close contact with the patient.[27-28]

In this dosimetry study, the limitation included the number of radiation exposures to the finger and lens of the eye was different, with less exposure to the fingers. The difference was due to logistical limitations during the postmortem procedure, of which only the OSLD of either the

eye or fingers was available for analysis. Despite the slight difference in radiation exposure, the results showed the fingers received higher exposure compared to the eyes.

This study showed that the annual radiation dose received by the fingers was slightly higher than the eye, and this may be explained by the different distances between the operator's finger and eye to the device. The difference may also be attributed to the positioning of the radiograph machine, which may affect the different exposures. This finding is similar to the findings in the study by Makdissi et al. and Hermsen et al. [15,20]

One of the other possible sources of radiation could be the leakage from the device itself, as reported by the manufacturer.[10] However, as the radiograph device was periodically maintained, the positioning of the organs to the device contributed the most to the radiation exposure.

In this study, the operator took on various positionings of the operator and the radiograph device to the body on the table. The positions were either a modification of the device-operator positioning recommended by the manufacturer [9-10] or similar positions considered as a deviation[20] or atypical exposure situations[12] from the area of significant occupancy described by the manufacturer, which consequently modifies the area of significant occupancy.[10] As this study stresses the effect of the positioning of the portable hand-held radiograph device on the radiation exposure to the operator, the state of the body on the autopsy table may cause a certain unpredictability in positioning the machine itself. Consequently, it is incumbent for the operator to observe and maintain optimum radiation protection measures.

Radiation doses below the recommended level of exposure by ICRP [16,17] or NCRP [18] do not negate the health risk from the radiation exposure to the operator. The annual radiation from a dental portable handheld radiograph device to the operator is shown to be greater than the typical wall-mounted or portable radiograph device operated from what is considered a protected area due to shielding or appropriate distance.(29) Hence, despite the low radiation levels, the exposure is still considered unnecessary radiation when compared to the possibly near-zero exposure when an operator can be in the protected area during the radiography acquisition.[30] Significantly, cumulative exposure may still have negative health effects even though radiation doses are still below the recommended annual thresholds. Stochastic risks associated with radiation exposure include a modest but apparent rise of the risk of cancer over an extended period. The regular use of handheld radiograph devices over the years and repeated exposure and regular use may accumulate doses that may pose to long-term health hazards.[31]

The authors opine and recommend that the use of dental portable handheld radiographs in the mortuary to always be aware of the stochastic effects on the operator and subsequently adopt every possible and practical protective measure against unnecessary radiation exposure. Principally, ALARA and the radiation protection concepts should be observed while using the portable handheld radiograph during the postmortem dental procedure. The protective measures may include the use of the lead apron, collar, glove and goggles as they can significantly reduce the radiation exposure to the operator.[8,12,32] Most importantly, while operating the dental handheld portable radiograph device, the backscatter shield should always be properly installed as described and recommended by the manufacturer.[8-10,30-33] The backscatter shield is shown to minimise the radiation exposure to the operator with some studies reporting the radiation as almost ten times higher when used without the shield [15] and others reported a 23-32% reduction in radiation dose to the hand and up to 37% reduction to the waist.[32]

The ALARA approach has evolved into ALADA (As Low As Diagnostically Acceptable) in tandem with a rising conversation about radiation safety. ALADA emphasizes the significance of ensuring adequate image quality to achieve diagnostic criteria, whereas ALARA concentrates on reducing radiation exposure. In forensic odontology, in which radiographs can be potentially used as admissible legal evidence it is important. (Jaju 2015) Accordingly, ALADA compliance signifies that radiation amounts are maximized without affecting the quality of postmortem radiographs that are used for forensic odontology cases.[34]

Furthermore, regular training in taking radiographs of the examined bodies in the mortuary is also essential to avoid radiograph errors such as movement[8] or incorrect sensor positioning, which may increase the risk of producing unusable radiographs. This may result in radiograph retakes, thereby potentially

increasing radiation exposure to the operator which is considered unnecessary radiation exposure to the operator. In addition, in the event of mass casualties with multiple bodies requiring examination, such as in DVI, spacing out the period between examinations may be considered a proper measure to minimise cumulative exposure to the operator.

Radiation protection requires continuous operative management. A succeeding study may be required as part of the continuous monitoring of radiation exposure especially when the number of exposures substantially increases from the baseline data recorded in this study. For example, in a DVI operation, it is possible to have continuous exposures or prolonged working hours when multiple bodies need to be examined within a short time.[7,15,35]

The typical dental postmortem procedure in the mortuary may require extra dental personnel to assist the operator during the radiographic procedure.[15] The dose received by the extra personnel will be influenced by the position the assistant stood during radiograph acquisition. Hermsen et al. found that the assistant was exposed the most at the 60° angle from the radiograph primary beam[15] with the least radiation when occupying the area of significant occupancy. [9-10] As such, the assistant or extra personnel during the postmortem procedure is considered to receive significantly low radiation if they are occupying the area of significant occupancy. However, regardless of the position assumed by the extra personnel, adopting similar shielding measures as the operator against radiation exposure should always be considered.

As part of a further radiation protection programme, a visual-spatial mapping may add value for the assistant or extra personnel when occupying the space surrounding the dental portable handheld radiograph in the mortuary. Thus, a further study is underway to map the area of the least radiation exposure based on the radiation doses measured in this study.

This study also highlights the role of medical physicists (radiation protection experts) in radiation protection. Medical physicists can take part in the testing of the device and radiation exposure assessment to minimize unnecessary radiation to the operator. The European Commission proposed in their legislation to involve the medical physicist not only during the acceptance testing of the device but also to test the device throughout its lifetime.[36] In this study, the involvement of the medical physicist assists in the usage compliance of the dental portable handheld radiograph device following the relevant Malaysian radiation regulatory agencies [24] and this practice will likely continue throughout the lifetime of the device. It is noted that current dose limits in the regulations [24] are based on the outdated ICRP [37] recommended dose limit for the eye lens. The authors recommend a revision of the current radiation regulations to be parallel to the global radiation practice such as the revised ICRP recommended limit.[16]

CONCLUSION

To the best of our knowledge, at present, this is the only study that surveys and evaluates the radiation exposure of the operator handling a dental portable handheld radiograph device for the radiograph acquisition based on the typical dental postmortem workload in the mortuary. This study established the baseline dental postmortem procedure profile and correlated radiation profile based on the typical workload for a window of one operation year.

The use of a portable handheld radiograph device NOMAD™ PRO 2 exposes the operator to, albeit low radiation, which is below the accepted or recommended occupational limit. However, despite the substantially low radiation exposure, the exposure still may impose health risks on the operator.

Therefore, there are few recommendations for the operators, such as:

1. Maintaining maximum possible distance from the device by extending the arm.
2. The use of proper radiation protection gear such as lead gloves and goggles.
3. Minimizing the number of repeat exposures by attending proper training.

Meanwhile, for the regulatory bodies and institutions, it is recommended to:

1. Develop standards of operating procedure (SOP) that are specifically intended for the

use of portable handheld radiograph devices and rigorously enforced.
2. Ensure that the portable handheld radiograph devices are well maintained and undergo regular inspections.
3. Monitor radiation exposure data to ensure no unnecessary radiation exposure to the operator.

Consequently, the safe and efficient use of portable handheld radiographs in forensic odontology can be maintained without jeopardizing the health of the operator by integrating careful operator techniques with institutional control and compliance to regulatory standards.

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