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Technical note

Eye lens dose of medical personnel involved in fluoroscopy and interventional procedures at a Malaysian Hospital

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ABSTRACT

Objective: This study measured the radiation exposure of the eye lens of medical personnel performing fluoroscopy and interventional procedures at the Sarawak General Hospital in Kuching, Sarawak, Malaysia. This study was the first in Malaysia to utilise *in vivo* radiation measurement relatively near the eye lens.
Methods: 41 medical personnel performing 79 procedures were monitored for their eye lens exposure using the NanoDot™ optically-stimulated luminescence dosimeters (OSLD) taped to the outer canthus of their eyes. The air-kerma area product (KAP), fluoroscopy time (FT) and number of procedure runs were also recorded.
Results: KAP, FT and number of runs were strongly correlated. However, only weak to moderate correlations were observed between these parameters with the measured eye lens doses. The average median equivalent eye lens dose was 0.052 mSv (ranging from 0.0155 to 0.672 mSv). The eye lens doses of primary operators were found to be significantly higher than their assistants due to the closer proximity to the patient and X-ray tube. The left eye lens of the operators received the highest amount of radiation due to their habitual positioning towards the radiation source.
Conclusion: KAP and FT were not useful in predicting the equivalent eye lens dose exposure in interventional radiological procedures. Direct *in vivo* measurements were needed to provide a better estimate of the eye lens doses received by medical personnel during these procedures.

This study highlights the importance of using direct measurement, such as OSLDs, instead of just indirect factors to monitor dose in the eye lens in radiological procedures.

1. Introduction

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has reported that around 3.6 billion radiological procedures are performed worldwide annually [1]. In diagnostic imaging, interventional radiological procedures, which are increasing in frequency and complexity incurs the highest radiation dose. Occupational exposure is defined as the radiation received in the course of work, except exposures excluded from the International Atomic Energy Agency (IAEA) Basic Safety Standard (BSS), and from practices or sources stated in the BSS.

Many studies on radiological exposure and its risk to health had been performed among radiology personnel and patients [2–4]. Recently, the occupational dose and the risk it posed to cardiologists had been highlighted [5]. These studies showed increased concern on the health effects for those exposed to radiation at work, particularly while performing complex procedures that might incur a higher dose [6,7]. In Malaysia, an occupational exposure study in 2001 found that medical personnel received an average of 0.45 mSv [8] per year while performing procedures. Most studies used personal dosimeters to monitor body exposure, but few had focused solely on radiosensitive organs, such as the eyes and gonads [6–12].

In 2011, the International Commission on Radiological Protection (ICRP) revised its threshold dose for radiation-induced cataract formation to 0.5 Gy based on new epidemiology findings [13]. This led the commission to recommend that the annual equivalent dose limit for eye lens be reduced from 150 mSv to 20 mSv a year, averaged over a defined period of five years, with no single year exceeding 50 mSv.

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Following this revision, the IAEA had published a new safety guidelines for radiological procedures. The safety assessments included identifying ways that eye exposure could occur, determining the magnitude and likelihood of exposure in normal operations, and assessing potential exposures to a reasonable and practical extent [14].

We aim to determine the typical occupational dose on medical personnel, in particular the eye lens doses as they performed interventional procedures in the largest government hospital in Sarawak, Malaysia. To the best of the authors' knowledge, this is the first publication documenting occupational dose in the country, with emphasis on the eye.

2. Materials & methods

A total of 41 radiological personnel, comprising 14 interventional radiologists, 20 medical officers, five staff nurses and two radiographers, were recruited in this study as they performed 79 procedures from October 2014 to January 2018 at the Sarawak General Hospital in Kuching, Sarawak, Malaysia. Data collection was performed intermittently over four years.

A total of 37 diagnostic angiography and 42 therapeutic procedures were evaluated. Therapeutic procedures included embolization (4 cases), fistuloplasty (12 cases), venoplasty (6 cases), transcatheter arterial chemoembolisation (TACE) (14 cases), percutaneous transhepatic biliary drainage (PTBD) (3 cases), and others (3 cases).

All radiological procedures were performed on a single-plane Toshiba Infinix VC-I angiography unit (Toshiba Medical Systems, USA) installed with an integrated KAP ionisation chamber. The total KAP, FT and number of runs were recorded from the angiographic console in each case. In every procedure, two operators were monitored for radiation dose exposure of the eyes. The primary operator was often the interventional radiologist, who would be standing nearest to the X-ray tube, while the assistant would stand beside him/her (Fig. 1). The assistant could either be a medical officer, nurse or radiographer. The primary operator and assistant wore lead aprons and worked from behind the radiation protection couch drapes and ceiling suspended lead screens. While most of the operators wore lead goggles, not all did.

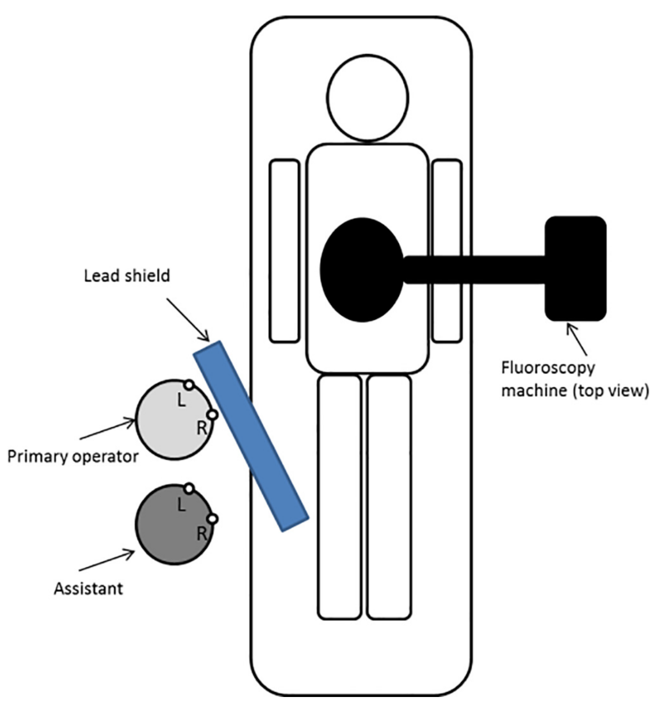

Fig. 1. Position of the primary operator and his/her assistant, and their eyes during interventional radiology procedures.

A simple direct-absorbed dose measurement was obtained from the medical personnel using the NanoDot™ OSLD (Landauer, IL, USA). A pair of NanoDot™ OSLDs was attached on each side of the operators' eyes (left and right outer canthus) using surgical tapes. For the operators that wore lead goggles, the OSLDs were taped to the outer side of the lead goggles. Although some studies proposed wearing a personal dosimeter outside the protective apron, placing the OSLDs nearer to the eyes would detect a more anatomically-accurate dose exposure [6,15–17].

The OSLDs were collected, bleached and read out at the Department of Biomedical Imaging, Faculty of Medicine, University of Malaya. The equivalent eye lens dose was estimated by applying a radiation weighting factor of 1 to the measured dose (mGy).

While arguably the recommended operational quantity for eye lens monitoring was the equivalent dose $H_p(3)$, the use of this operational quantity required the dosimeters to be type-tested and calibrated using specially-designed phantoms irradiated with calibrated beams. In the absence of such dosimeters, IAEA stated that alternative dosimeters calibrated according to $H_p(0.07)$ could be used to assess the eye dose from photon radiation [14,18,19].

Statistical analysis was performed using IBM SPSS Version 22 (IBM Corporation, Armonk, NY, USA). All data were tested for normality of distribution using the Shapiro-Wilk test. Non-parametric statistical tests were used because the data were not normally distributed (Shapiro-Wilk test, $p < 0.001$). The Kruskal-Wallis test with post-hoc correction and Wilcoxon Signed Rank test were used to compare the parameters. Association between factors was determined using the Spearman correlation test. Statistical significance was declared at $p \leq 0.05$.

During the analysis, the radiological interventions were divided into diagnostic and therapeutic procedures. However, it should be noted that therapeutic procedures included an initial diagnostic angiographic examination before the intervention was carried out. The interventional procedures were further categorized into nine groups, comprising of cerebral digital subtraction angiography (DSA), embolization, fistulogram, fistuloplasty, PTBD, TACE, venogram, venoplasty and others. The cases were also classified into sub-categories based on the site of intervention (head & neck, chest & abdomen, and extremities).

3. Results

Fig. 2 shows the boxplots of KAP in different interventional procedures. KAP, FT and number of runs were found to be different across the interventional procedures. Therapeutic procedures, such as

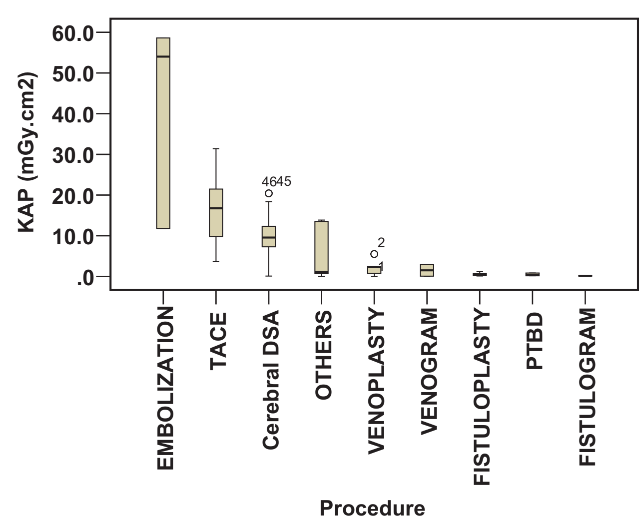

Fig. 2. The box plots of KAP in different interventional procedures. The symbols (°) represents the outlier cases that were ≥ 2 SD of the mean. The numerical numbers beside the symbols shows the respective case identification number.

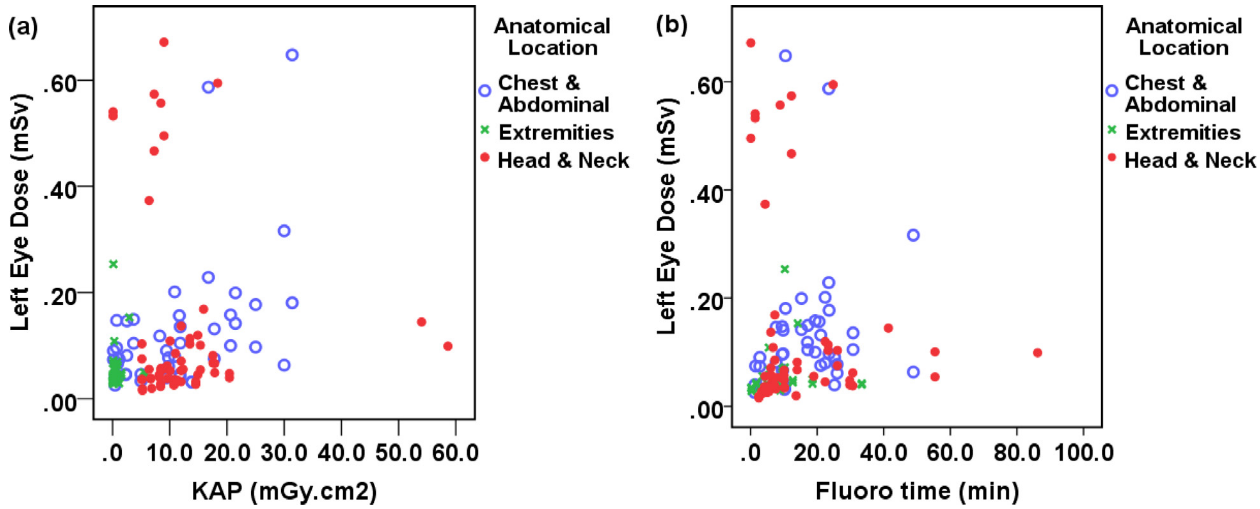

Fig. 3. Scatter plots of the left eye lens dose as a function of (a) KAP and (b) fluoroscopy time.

arteriovenous malformation (AVM) embolization and TACE, incurred higher radiation exposure.

Therapeutic head and neck procedures showed the highest median for KAP, FT and number of runs. However, the median and interquartile range for the 79 procedures were 8.19 (0.8–12.16) mGy cm^2, 9.6 (5.1–19.4) min, 8 (6–13) runs, for KAP, FT and number of runs, respectively. There was wide variations in the machine recorded exposure parameters. KAP per procedure varied between 0.02 and 58.61 mGy cm^2, while FT varied between 0.10 and 86.20 min. Spearman correlation showed correlations between all three parameters.

Fig. 3 shows the scatter plot of the left eye lens dose as a function of KAP and fluoroscopy time identified by different anatomical sites. Spearman test showed weak to moderate correlations between the equivalent eye lens doses with KAP and FT. There exist wide variations in the measured eye lens doses.

Fig. 4 shows the median eye lens doses of the primary operator and his/her assistant. The average median eye lens dose of the operators was 0.052 ± 0.001 mSv. The doses ranged from 0.016 to 0.672 mSv. The median eye lens dose of the primary operator was higher than the assistant. The eye lens doses of the primary operator was correlated with those of his/her assistant's eye lens dose.

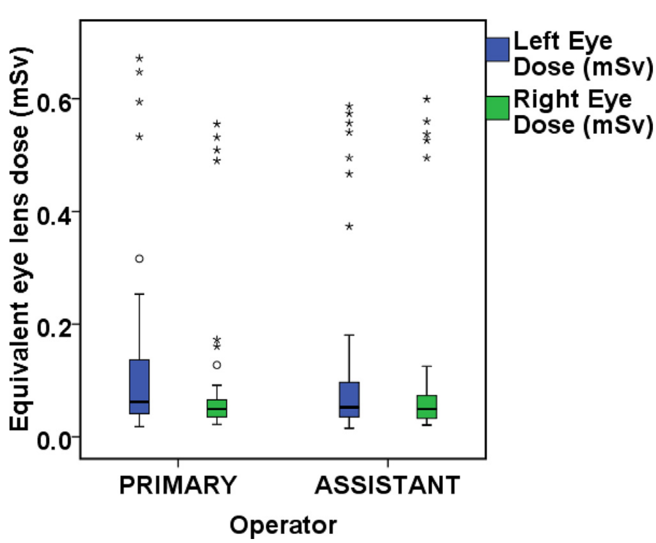

Fig. 4. The box plots of eye lens dose exposure on primary and assistant operators. The symbols (° and *) indicates cases that lies ≥2 SD and ≥3 SD of the mean.

Table 1 shows the median, the 75 percentile and the maximum values of the operators' right and left equivalent eye lens doses, and the projected number of radiological procedures to reach the annual dose limits of the eye lens as specified by ICRU. In this study, the 75th percentile equivalent eye lens doses were 0.137 mSv for the left and 0.069 mSv for the right eye lenses of the primary operator. For the assistant, the 75th percentile equivalent eye lens doses were 0.097 mSv for the left and 0.075 mSv for the right.

A total of 74% of the operators also received significantly higher radiation dose on their left eye compared to the right. We also found a positive correlation between the left and the right eye lens dose.

4. Discussion

Our study found that exposure parameters that were recorded by the fluoroscopy unit console, such as KAP, FT and number of runs, showed moderate to strong correlation with each other. Wide ranges of the KAP and FT resulted in no significant differences between the so called "diagnostic" or "therapeutic" procedures, with exception of specific procedures, such as embolization and TACE procedures showing significantly higher KAP and FT (Fig. 2). Eye lens doses of operators were correlated with anatomical sites. Extremity-related procedures, such as fistulogram, fistuloplasty and venoplasty, had significantly lower exposure of KAP and shorter time (shorter FT and fewer runs) compared to other anatomical locations (Fig. 3).

Studies have found conflicting results in correlating indirect measurements, such as KAP and FT to eye lens dose [9–11]. We found that only KAP and FT showed weak to moderate correlations to operators' equivalent eye lens doses. We reckoned that although theoretically, a higher radiation exposure to patients should result in more radiation being scattered on the eye lenses of the operators, the anatomical site of intervention should be factored into consideration, too (Fig. 3). However, attempts to predict equivalent eye lens dose from these parameters would yield poor results. This means that machine recorded exposure parameters were poor indicators or predictors of operators' eye lens dose exposure. Hence, this studies supported the importance of *in vivo* measurement using suitable dosimeters in determining the expected magnitude of eye lens dose.

The eye lens doses measured were comparable with the occupational-equivalent dose of those reported by other studies (Table 2) [11,15]. It is evident that the increased complexity of cardiac interventional procedures resulted in higher equivalent eye lens dose [9–11]. One caveat is that various groups used different operational quantity to estimate equivalent eye lens dose. Antic et al. (2013) and Zagorska et al. (2015) used $H_p(3)$, Omar et al. (2017) used $H_p(10)$ and

Table 1
Projection of the number of radiological interventional procedures to reach the annual dose limits by International Commission on Radiation Units (ICRU).

		Left eye dose (mSv)	No. of procedures before exceeding 20 mSv	Right eye dose (mSv)	No. of procedures before exceeding 20 mSv
Primary	Median	0.062	324	0.050	402
	Percentile 75	0.137	146	0.069	292
	Maximum	0.672	30	0.580	35
Assistant	Median	0.053	380	0.051	394
	Percentile 75	0.097	206	0.075	268
	Maximum	0.587	34	0.639	31

our study used $H_p(0.07)$ [9–11]. Hence, there may be a limit in the effective comparison across different studies.

The equivalent eye lens doses of the assistant operators in our study appeared to chart slightly higher than most other studies. We postulated that this variation might be highly sensitive to the proximity of the so-called assistant operators to the patient and X-ray tube. In our study, 83% of the assistant operators were either interventional radiologist or medical officers, hence, they tend to stand closer to the patient, assisting in the medical procedures. The different role played by the assistant operators, whether they are medical officers, radiographer or interventional suite nurses, would also impact on their habitual position within the interventional suite. Increased distance from the X-ray tube would result in significant reduction of scattered radiation to assistant operators [11,12].

While this study was limited by the sample size, our findings could still be used to project the number of procedures that operators could perform before the annual dose limits to the eye lens (20 mSv) would likely be exceeded (Table 1). An interventional specialist, who often takes the role of a primary operator, might easily exceed the annual dose limits to his eye lens after 30 procedures at maximum exposure. On the other hand, at a median dose of 0.06 mSv per procedure, the operator could perform up to 324 procedures before the limit was exceeded.

Primary operators receive higher radiation doses to their eye lenses, particularly in the left eye (Fig. 4). This was because they usually stood closer to the patient and the X-ray tube, with the relative position of the operators' left eye being the nearest to the X-ray source (Fig. 1). Omar et al. (2017) also mentioned that during neurovascular procedures, the operators were often in a position where scattered radiation from the patient would mainly hit the left side of their body, including the left eye [11]. This means that although the radiation dose distribution might be non-uniform on the operators' body, due to habitual positioning of the operators during the interventional procedure, the left eye lens would still receive the highest dose compared to the right. Our study also showed that a higher dose to the left eye also inferred a higher radiation dose to the right eye (Fig. 4).

There were a few caveats in this study. Although data collection was carried out intermittently over four years, the complex distance and operational logistics of OSLD readout had limited the sample size. No corrections were made for the attenuation of radiation dose due to wearing of protection goggles. Hence, the dose levels measured in this study would better represent the unprotected eye lens doses. Hu et al. (2016) reported that wearing a 0.5 mm Pb equivalent lead goggle reduced eye lens doses by a factor 4.0 to 6.2 [20]. The measured equivalent eye lens dose did not consider the natural background radiation (NBR), which might not be insignificant at this level of radiation. As part of the monitoring of the NBR, a control OSLD chip was kept along with selected batches of the OSLDs that were mailed to the measurement site. On average, NBR of 0.6 μSv/day with the root mean square error (RMSE) of 5.2 μSv/day was recorded. The large uncertainty, expressed as the RMSE in the NBR record may be due to the limitation of the OSLD system in accurate measurements of such low dose levels. Individual subtraction of the NBR would result in unrealistically large uncertainty that is not related with the interventional procedures. Medici et al. (2017) found in their study the combined uncertainty of OSLD detector used at such low dose levels could be as high as 40% (for a coverage factor of k = 2)[12].

Other parameters, such as the orientation of the X-ray tube, the relative distance of the X-ray tube to operator, collimation and proper/sub-optimal use of radiation protection goggles and lead screens might also affect dose measurements. These parameters were not recorded, which limited further analysis on the possible causes of the variations observed. However, despite the limitations, we had demonstrated the feasibility of using a customized OSLD system to measure equivalent eye lens dose exposure for medical personnel performing interventional radiological procedures.

5. Conclusion

Direct *in vivo* measurement of eye lens dose is important to provide better estimates of the equivalent eye lens dose. The eye lenses of the primary operator received a significantly higher dose than the assistant operators due to the closer proximity of the operator to the patient and X-ray tube. Habitual positioning of the operators resulted in a

Table 2
Comparison of the eye lens doses reported by selected studies. The values were rounded to 3 significant figures in the units of mSv.

Author (year)	Interventional procedures	KAP (min – max)	FT (min) (min – max)	Equivalent eye lens dose (*m*Sv) mean (min – max)
Antic et al. (2013) [9]	Cardiology	7.2–600 Gy cm^2	1–82	Primary = 0.121 (0.005–0.370) Assistant = 0.033 (0.004–0.138)
Zagorska et al. (2015) [10]	Endoscopic retrograde Cholangiopancreatography (ERCP)	–	1–28.8	Primary = 0.016 (0.002–0.047) Assistant = 0.007 (0.001–0.018)
Omar et al. (2017) [11]*	Interventional radiology	–	–	Primary = (0.035–0.500) Assistant = (0.002–0.057)
	Cardiology			Primary = 0.066 Assistant = 0.006
	Neuroradiology			Primary = (0.005–0.015) Assistant = (0.002–0.022)
*3rd quartile values				
This study	Interventional radiology	0.02–58.6	0.1–86.2	Primary = 0.056 (0.019–0.672) Assistant = 0.052 (0.016–0.639)

significantly higher dose to the left eye lens of the primary operators.

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