ORIGINAL ARTICLE

Protective Shielding Effectiveness for Occupational Radiation Exposure in Coronary Angiography: Evaluating the Eye Lens Safety

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ABSTRACT

Introduction: Coronary angiography is the preferred imaging investigation in assessing acute coronary syndrome yet it involves continuous radiation not only to the patient but also to the catheterisation laboratory (cath lab) personnel. The increasing frequency of cataracts among cath lab personnel is concerning, as the cumulative occupational dose has a stochastic effect, particularly on the eye lens. Besides, the dose limit had been reduced from 150 to 20 mSv/year, thus needing the measurement of the current coronary angiography acquisition protocol to obey the dose limit. Therefore, a phantom study was conducted to measure the effectiveness of lead eyeglasses in reducing the occupational effective dose to the eye lens. **Methodology:** An experimental study was done with an Alderson-Rando (A.R) phantom that stood 35cm to the right of the couch, representing the cardiologist's standpoint. 72 calibrated Lithium-Fluoride-thermoluminescent-dosimeter chips (TLD-100) were sequentially attached to the phantom's bilateral eyes, with a standard 6-view coronary angiography performed using a Philips Azurion 7 B20/15 angiography system. The effectiveness of shielding to the eye lens was measured with shallow dose equivalent, Hp(3), acquired in unshielded versus shielded conditions. **Results:** The experimental coronary angiography acquisition exposed the cardiologist's phantom eye with a 0.0013 mSv occupational dose. However, the same acquisition resulted in a 0.009mSv occupational dose when the eye lens is shielded with lead eyeglasses, a 30% significant dose reduction with a p-value of 0.014. **Conclusion:** Compliance with wearing lead eyeglasses during coronary angiography contributes to the safety of the eye lens.
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Keywords: Occupational effective eye dose, Shallow dose equivalent Hp(3), Coronary angiography, Eye shielding

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INTRODUCTION

Cardiovascular diseases mainly involving the cardiac and coronary vessel morphology are the primary cause of mortality among Malaysians [1]. According to the latest report by the National Cardiovascular Disease Acute Coronary Syndrome (NCVD-ACS) Registry 2018-2019, more than 20,000 new cases have been reported with an increasing trend of 2 to 3% yearly [2-3]. Corresponding to the clinical practice guideline of management of acute cardiac events, the catheterisation intervention approaches were the preferred therapy [4-5]. This practice led to increasing trends of coronary angiography procedures on top of other scheduled elective diagnostic and interventional procedures.

The single or biplane digital C-arm is vital equipment in cardiac catheterisation particularly in angiocardiography and angiocardioplasty procedures. During the procedure, not only the patient will be exposed to continuous radiation, but the cardiac catheterisation laboratory (cath lab) personnel assisting the procedure also continuously receive the scattered radiation [6-7]. Ionising radiation received by radiation workers, and in this case, the cath lab personnel, in the course of occupational imaging activities is known as occupational exposure [7-9]. This exposure is mainly contributed by the scatter radiation resulting from the interaction of the primary beam with the matter. Scatter radiation is harmful as this secondary, low-energy radiation is absorbed by the body as it travels through which cumulation of it might increase the likelihood of stochastic effects over time, especially to the radiosensitive organs including the eye lens [6,7-9]. Several works of literature also reported increased incidence of radiation-induced cataracts and lens opacities among interventionalists working in catheterisation laboratories [10-13]. Considering the workload in the current management of patients with cardiac events as mentioned earlier, the cardiologist could be the most affected personnel.

Considering the need for radiation protection to these radiosensitive organs, personal dose monitoring is essential for measuring occupational exposure. The latest ICRP publication recommended the occupational dose to the eye lens of radiation workers, and in this research context, the cardiologist, be significantly reduced from 150 mSv/year to limited to 20 mSv/year to protect the cardiologist from stochastic effects [9-10]. From the perspective of imaging procedure, the main contributor of occupational dose to cath lab personnel, particularly to the cardiologist, is during angiography and cardiac intervention procedures such as invasive cardiac catheterisation procedures where the cardiologist needs to stand at a short distance from the x-ray tube throughout the examination [8,12-13]. Hence, performing the procedures on multiple patients on the same day could expose the cardiologist to receiving accumulated doses over time. The scatter radiation may reach numerous organs of the cardiologist and may induce an adverse reaction to radiation since any amount of dose that has been received may be harmful and cannot be regarded as safe, even involving a small dose [6-7].

Given that matter, shielding from radiation is one of the fundamental protective measures in minimising scatter radiation exposure since the image intensifier will emit a variable amount of dose exposure at different times needed for each cardiology procedure [14]. Even though it is proven good compliance with wearing the load apron and thyroid shield among cath lab personnel, several survey studies proved significant disobedience, with only 31% to 44% of the respondents wearing lead eyeglasses during catheterisation procedures [15-17]. Amids, the eye lens is of concern since this radiosensitive organ was not fully protected as underutilisation of lead eyeglasses frequently occurs. Besides, limited available literature reported the actual effective dose to the eye lens of the cardiologist exposed to occupational radiation considering the utilisation of lead eyeglasses.

Considering the cardiologist's position near the patient and the x-ray tube in the angiographic suite shows that the cardiologist might encounter approximately 100% scatter radiation, especially when horizontal or oblique beams are used [18-19]. Even though the presence of scattered radiation has lower energy than the primary beam, continuous exposure may cause damage to the eye lens. Therefore, the researcher conducted an experiment to report proof of the effectiveness of lead shielding by justifying the difference in the effective dose received by the unshielded versus shielded eye lens from the cardiologist's standpoint during the coronary angiography procedure.

MATERIALS AND METHODS

Study design

An experimental study was conducted at Hospital Al-Sultan Abdullah (HASA) Puncak Alam's angiography suite which is equipped with Philips Azurion 7 B20/15 operating with a tube voltage range between 40 to 125 kV. This modality is subjected to regular maintenance and quality control schedules. Ethical approval was obtained from the Faculty of Health Sciences (Reference: 500-FSK (PT_23/4) and the Department of Research, Industrial Linkage and Innovation HASA (reference: 500-PJI(18/4/73).

Study settings

The experiment was set to mimic the diagnostic coronary angiography procedure where standard 6 projections of different angulations were needed. As shown in **Figure 1**, an anthropomorphic thorax phantom was laid on the angiographic couch to represent the patient. Next, the Alderson-Rando (A-R) phantom representing a cardiologist stood 35 cm from the right side of the anthropomorphic laid phantom representing the place of the cardiologist standing during the real case. The phantom was placed at a height of 1.64 metres representing the average height of the Malaysian adult male population. This setting is established to ensure accurate measurements are acquired at the eye lens.

Fig. 1: Phantom setting. The Anthropomorphic Thorax Phantom representing the patient was laid on the angiography table, and the Alderson-Rando (A.R.) Phantom, representing the cardiologist, was placed on the trolley table with a height set to meet the average adult. The A.R. phantom stood 35cm to the right of the Anthropomorphic thorax phantom.

Dosimetry to the eye lens measurements

Personal dose equivalent, Hp(d) is an operational quantity for individual occupational dose monitoring. According to International Commission for Radiation Protection (ICRP) Publication 103, shallow dose equivalent, Hp(3) is used to quantify the dose measured at 3 mm from the surface of the eye representing the effective eye dose. The SI unit of Hp(d) is Sievert (Sv) and it is the sufficiently precise assessment for radiological protection purposes of effective dose monitoring to the radiation worker working under a homogeneous X-radiation field such as cathlab [8-9]. To acquire the dose measurement, the calibrated Lithium-Fluoride thermoluminescent dosimeter chips (TLD-100) of 1 cm x 1 cm in size were labelled and attached at the stood A-R phantom representing the cardiologist [19-20]. Two TLD chips were attached, one at the right and left eye, respectively, as shown in **Figure 2**. The acquisitions were made with the exposure protocol set to cater to a standard clinical protocol of adult-average-size patients of diagnostic coronary angiography procedure (source-to-image distance 119 cm, AEC automation, 3.5 mm Al/75kV filtration and 15 frame-per-second). The ceiling-suspended lead-equivalent screens and lead skirting were used as in the normal procedure setting. With the location of both phantoms kept constant, acquisitions were made at RAO30/CRAN30, RAO25/CAUD25, LAO50/CAUD30, LAO40/CRAN10, AP/CRAN10 and RAO40 representing coronary angiography projections as different angulations needed to assess the 3-dimensional vasculature of the coronary vasculature. These acquisition angulation series were the standard protocol performed for diagnostic coronary angiography procedures at the centre under investigation. For each exposure, the TLDs were replaced with a new set to allow accurate quantification of radiation dose received per exposure. For each projection, three exposures were made for each projection to average the values and increase the accuracy of the experiment. These sets of exposures were repeated twice; the first set was an unshielded eye lens (without the utilisation of radiation protection apparatus to the eye lens), then the second set was acquired with a shielded eye lens (the phantom equipped with lead eyeglasses (Infab Corp.) of 0.75mm Plumbum equivalent), as shown in **Figure 3**. The TLD readout was performed by the Malaysian Nuclear Agency using the TLD Reader Harshaw TLD 5500. The dosimetry report was generated of Hp(3) for the eye lens effective dose. All the readings were recorded in units of millisievert (mSv). Therefore, all the readings obtained were indicated as the cardiologist's estimated effective dose of the eye lens received per coronary angiography procedure.

Statistical Analysis

The statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) version 27.0. Kolmogorov-Smirnov and Levene's tests were used to determine the conformity of numeric data to a normal distribution and homogeneity of variance, respectively. $P < 0.05$ was considered statistically significant for numeric data. Furthermore, an independent sample T-test was performed to compare the mean effective dose received by the eye lens of the cardiologist's A-R phantom from unshielded versus unshielded acquisitions.

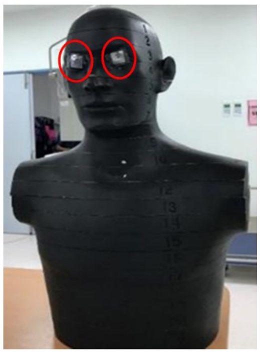

Fig. 2: The TLD placement on the A-R Rhando phantom bilateral eye. The TLD placements (red circle) represent the location of the lens of the eyes where the dose measurement is made.

Fig. 3: The setting of the lead eyeglass shielding on the A-R Rhando phantom. The lead eyeglasses, weighing 76g with a lead equivalent of 0.75 mm Pb, are placed to provide shielding to the lens of the eyes.

RESULTS

A total of 72 TLDs attached to the bilateral eye lens (1 TLD chip per eye len per projection taken three times for averaging purposes) were exposed in six different projections of standard coronary angiography procedures in shielded and unshielded eye lens acquisition conditions. The effective dose received by the eye lens of the cardiologist was extracted from the TLD chips readout at the depth of 0.03mm. The dose distribution for the unshielded and shielded eye lens is presented in **Figure 4**.

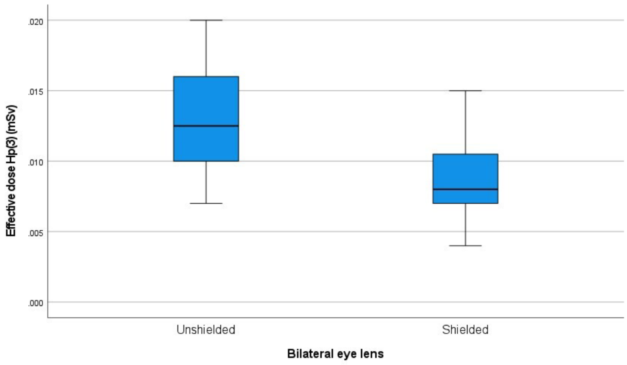

Fig. 4: The mean effective dose, Hp(3) of the eye lens. The graph shown a 30% reduction of mean effective dose with the application of the lead eyeglass shielding.

In analysing the effective dose to the eye lens received from the experimental coronary angiography procedure, the measured shallow dose equivalent to the eye lens, Hp(3) was significantly different with the p-value of 0.014 in unshielded versus shielded acquisitions, as shown in **Table I**. The independent sample T-test proved that the mean cumulative effective dose of the 6 projections in unshielded eye lenses was 0.013mSv. However, when lead eyeglasses were fixed to the phantom, the mean effective dose to the eye lens was reduced by 30% (0.013 ± 0.036mSv versus 0.009 ± 0.003mSv).

Table 1: The effective dose in unshielded versus shielded eye lens.

Part	Mean effective dose ± SD		Mean diff	t-stats	*p-value*
	Unshielded (n = 36)	Shielded (n = 36)	(95%, CI)	(df)	
Eye lens	0.013 mSv ± 0.036	0.009 mSv ± 0.003	0.004 (0.003, 0.006)	5.488	0.0014

Note: mSv = millisievert

DISCUSSION

As the yearly cardiac event increases, the accumulated occupational dose also increases, thus increasing the stochastic effects on the cath lab personnel, especially the cardiologist. Fundamentally, a catheter will be administered through a femoral or radial sheath and advanced to the area of coronary vessels of interest by the cardiologist with the guidance of fluoroscopy mode of angiography. The contrast media is hand-injected by the cardiologist while the acquisition of contrast-filled coronary vessels is acquired in 6 different projections for maximal delineation of coronary vessels with the least structure superimposition [21-22]. In doing so, the position of the cardiologist is the closest to the patient during the procedure, which contradicts the recommended inverse square law of radiation protection principle [6-7]. As a result, the cardiologist received the most scattered radiation throughout the procedure [23]. This study measured the effectiveness of utilising lead eyeglasses using personal dose monitoring using TLD Hp(3) readings to measure the cumulated effective dose to the eye lens.

In analysing the effective dose of the cardiologist's eye lens received from the occupational exposure, findings have shown that an unshielded eye lens will receive the mean dose of 0.013 mSv from standard 6 projections of coronary angiography acquisition protocol implemented in the centre under study. The dosimetry result is concurrent with a study conducted by Alnaaimi et al, which ranged from 0.012 to 0.03 mSv [24]. Agreement of the result is contributed by the fact that the coronary angiography examination is performed by at least 6 acquisitions to study different coronary vessels in respective views. In assessing the left coronary artery, right anterior oblique (RAO) with caudal angulation is performed to visualise the left main stem (LMS) as well as the proximal portion of the left anterior descending (LAD) and circumflex (LCX) artery with the obtuse marginal (OM) artery branches. In contrast, RAO with cranial angulation is performed to visualise the middle portion of the LAD with the diagonal branches and the LCX with OM branches. On the other hand, the left anterior oblique (LAO) with cranial angulation is essential in assessing the middle to the distal segment of the LAD and is best to demonstrate the origin of the diagonal arteries. Contrary, LAO with caudal angulation is key in assessing the LMS, proximal LAD and LCX and is best to demonstrate the ramus intermedius artery. The right coronary artery (RCA) is evaluated in Anteroposterior (AP) with cranial angulation and RAO, demonstrating the ostium to the middle portion of the RCA and the extension of the patent ductus arteriosus branch, respectively [21-22].

Considering the latest report by the NCVD-ACS 2019 registry, 305 registered cardiologists in Malaysia were subjected to approximately 20,000 new acute coronary syndrome cases, on top of daily scheduled elective angiocardiography and angiocardioplasty procedures [2-3]. Estimation of stratification workload of 10 to 15 coronary angiography procedures performed daily, the cardiologist is subjected to receiving approximately 3.9 mSv monthly doses to the eye lens even with the ceiling-suspended lead screen attached to the angiography unit routinely placed. The interpolated yearly effective dose to the unshielded eye lens would easily reach 47 mSv, exceeding the ICRP revised dose limit to the eye lens of 20 mSv/year. Considering the fact that the lens cell is highly radiosensitive yet does not regenerate, and the cardiologist is exposed to daily repeated exposures from multiple procedures, proper eye protection is vital. In conjunction, research from Kidon et al [24] states that cataracts is the stochastic side effect of tissue damage that can be considered chronic occupational exposure to ionising radiation. The literature also reported that cataracts result from the progressive accumulation of exposure over 25 years with a total of 0.5 Gy, exceeding the recommended dose limit from the ICRP. Pieces of literature proved that an average of 10.8 to 15.8 mSv of scatter radiation was produced from 20 to 25 minutes of continuous exposure during the angiography procedure. This nature of occupational exposure contributed to a 40% increase in the significant appearance of lens opacities of the interventional cardiologists as compared to scrub nurses [14,25].

In addition, the present study also reported that there are statistically significant differences in effective dose between unshielded and shielded eye lenses in this experimental coronary angiography procedure. 30% dose reduction is measured with the implementation of lead eyeglasses as personal radiation protection equipment. As a result, the yearly effective dose to the eye lens would be reduced to 32 mSv. As the present study utilised the ceiling-suspended lead protective screen and equipped the phantom with sunglasses-type lead eyeglasses, minimal effectiveness, in terms of dose reduction, is evident. This might be due to the presence of uncovered sides of the eyes which scattered radiation able to reach to the eye lens. This is substantially important considering the fact that the acquisitions were made in 6 different c-arm angulations, scattering the secondary radiation in various directions. Lanzer [21] also suggested that the scattered radiation doses are mostly exposed to the cardiologist when their position is too close to the patient since the scattered radiation may backscatter deflected up to 180 degrees. Besides, the cardiologist needs to turn the head towards the monitor during catheter manipulation throughout the procedure, exposing the sides of the eye kept unprotected. Cheon et al. [26] also supported that the nature of the cardiologist's task during the procedure requires a frequent head turn demanding lateral protection of the eyes from the scattered radiation.

The present study had several limitations. The experiment was conducted using the anthropomorphic and Alderson Rando phantoms as the subject of the study instead of using the real patient and cardiologist in the clinical setting. The setting only mimics the tissue as they do not fully represent the presence of a cardiologist. Besides, the amount of scattered radiation, the main contributor of the occupation dose to the cardiologist, emitted from the phantom may not be as exact as the real human tissue and radiation interaction. Future studies of actual clinical procedural settings might best serve the solution for the limitations. Apart from that, the chosen acquisition of coronary angiography is a diagnostic procedure which generally takes 10 to 15 minutes of total radiation activation duration. Extending the current research to consider longer and more complicated angiocardioplasty procedures might amplify the amount of cumulated occupational effective dose and depict a more significant dose received by the cardiologist.

CONCLUSION

In summary, the practice of applying radiation protection apparatus to protect the eye lens is essential during the catheterisation procedure. The present study proved quantitatively that the compliance of wearing lead eyeglasses during coronary angiography procedures contributes to positive benefits in terms of reducing the cumulative occupational effective dose to the eye lens. Therefore, as the occurrence of scatter radiation in the angiography procedure could not be prevented, huge efforts in the implementation of lead eyeglasses and other radiation protection equipment must be taken among cardiologists and all cath lab personnel to protect the radiosensitive organs from stochastic effects. Nevertheless, the present study does not measure the cumulative occupational effective dose in the assisting nurse and radiographer who also participate actively during the catheterisation procedure. Measuring the cumulative occupational dose during actual coronary angiography procedure also might portray the accurate occupational effective dose received by the cath lab personnel.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

ETHICAL CLEARANCE

We obtained approval from the Faculty of Health Sciences (Reference: 500-FSK (PT_23/4) and the Department of Research, Industrial Linkage and Innovation HASA (reference: 500-PJI(18/4/73).

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