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Effects of Ionizing Radiation Exposure on Cataract among Radiation Workers of Interventional Cardiology in Indonesia

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Abstract

Purpose The aim of this study was to determine the prevalence of radiation-induced cataracts and its correlation with radiation exposure dose and radiation protection equipment use among radiation workers of interventional cardiology.

Methods This is a cross-sectional and retrospective case–control study. We included 180 subjects. The prevalence of radiation-induced cataracts was assessed using Scheimpflug analysis on the Pentacam-Oculus device. Individual cumulative radiation exposure dose and radiation protection equipment use were identified from questionnaires and personal dosimeters.

Results The prevalence of radiation-induced cataracts was 16.7%. The median cumulative radiation dose was 0.8 (0.1–35.6) Gy. A positive correlation was found between cumulative radiation dose and lens density (R Spearman = 0.64). We found 83.9% of subjects used ceiling-suspended shields in 71 to 100% of their working period. However, most subjects (40.6%) did not wear protective eyewear. There was a statistically significant increasing risk of radiation-induced cataracts and unresponsive use of radiation protection equipment. Subjects using ceiling-suspended shield in only 31 to 50% of their working period increased their cataract risk by 10.8 times (95% confidence interval [CI]: 1.05–111.49, $p = 0.044$). Meanwhile, subjects using protective eyewear in only 51 to 70% of their working period increased their cataract risk by 8.64 times ($p = 0.001$). Subjects who did not wear protective eyewear had an odd ratio of 164.3 (95% CI: 19.81–1363) compared to those who did.

Conclusion Radiation-induced cataracts among radiation workers of interventional cardiology depended on the radiation exposure dose and the use of radiation protection equipment.

Keywords
- radiation workers
- interventional cardiology
- radiation-induced cataract

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Introduction

A cataract is haziness of the lens structure with multifactorial etiology, including age, diabetes mellitus, genetics, trauma, use of steroid drugs, radiation exposure, and free radicals.[1] Lens is described as one of most radiosensitive tissues in the human body. Lens structure can be disrupted due to radiation exposure, especially ionizing radiation.[2–4] Cataract is classified as a deterministic effect of radiation, which only appears when the radiation exposure dose limit is exceeded. Thus, radiation cataractogenesis can be prevented by dose monitoring and responsive use of radiation protection equipment.[5]

Radiation workers of interventional cardiology are among the most frequent users of fluoroscopy in the medical profession. Consequently, they are vulnerable to radiation-induced cataracts.[6]

The International Atomic Energy Agency (IAEA) has conducted RELID (Retrospective Evaluation of Lens Injuries and Dose) studies in several countries to measure the prevalence of radiation-induced cataracts. These studies showed the prevalence of posterior subcapsular cataracts (PSC) in 40 to 50% of interventional cardiologists and 20 to 40% of nurses and technicians exposed to radiation.[3]

International regulations have set radiation dose limit values that are considered safe for interventional cardiology procedures. The International Council on Radiation Protection (ICRP) recommendation 2011 determined the annual occupational eye dose limit, which is 20 mSv per year for a 5-year period, without exceeding 50 mSv per year.[7]

In Indonesia, Peraturan Kepala (Perka) Badan Pengawas Tenaga Nuklir (BAPETEN) number 8 in 2011 became a national guideline for determining radiation dose limit for radiation workers.[8] No study has been conducted in Indonesia about radiation exposure dose and protection equipment usage among radiation workers of interventional cardiology.

The radiation protection equipment is crucial during interventional cardiology procedures. By using it correctly, the excessive recommendation dose could be prevented. Nevertheless, awareness of its use is still lacking.[8,9] Radiation dose monitoring is usually defined using a personal dosimeter.[9] However, radiation workers' compliance in its use is still relatively low. Therefore, the occupational radiation dose to the lens was estimated from the information on the workload provided through a validated questionnaire. Although the dose calculation cannot be perfectly accurate, this retrospective method can provide an estimated cumulative dose received by the radiation workers.[10,11]

This study aims to determine the prevalence of radiation-induced cataracts among radiation workers of interventional cardiology in Indonesia. In addition, this study also explores the relationship between the dose of radiation exposure and the use of radiation protection on the occurrence of cataracts.

Materials and Methods

This study was divided into two stages: cross-sectional prevalence study and nested case–control study. It was performed at the ISICAM (Indonesian Society of Interventional Cardiology Annual Meeting) seminar, Jakarta, and the National Cardiovascular Center Harapan Kita (NCCHK) Hospital, November 2018 to January 2019. Radiation workers of interventional cardiology who were exposed to fluoroscopy more than or equal to 5 years and never underwent lens extraction surgery were included. Exclusion criteria were subjects with history of ocular surface disease that causes difficulty in assessing the lens structure, history of diabetes mellitus, long-term steroid use, uveitis, eye trauma, and not following full examinations.

The subjects were chosen by consecutive sampling method. Minimum number of samples was determined based on calculation to estimate the proportion of a population, which was 96 subjects. For the nested case–control study, the sample size calculation was performed based on a case: control ratio of 1: 2, which were 28 and 56 subjects, respectively. Subject allocation for case and control groups was selected by random sampling method. All procedures performed in this study followed the ethical standards of the research committee of the Faculty of Medicine, Universitas Indonesia (No: 1167/UN2. F1/ ETIK/2018) and the National Cardiac Center Harapan Kita Hospital (No: LB.02.01/VII/312/KEP.002/2019).

In this study, after signing the informed consent, subjects filled out a detailed written questionnaire on ophthalmological conditions, history of the disease, in particular those that can cause PSC, and radiation dose assessment. Estimated cumulative radiation dose assessment was collected from two different resources, which were the RELID questionnaire and BAPETEN data. The BAPETEN data was supposed to be more objective since it was obtained from each subject's personal dosimeter. Nevertheless, 22.2% of all subjects showed an estimated radiation dose of 0 Gy. It was because those subjects did not use personal dosimeter. Based on this consideration, RELID questionnaire method was being used as the modality to measure estimated cumulative radiation dose in this study.

Ophthalmology examinations performed on subjects consisted of best corrected visual acuity, comprehensive dilated slit lamp examination, and lens density examination with Pentacam-Oculus. Scheimpflug analysis on the Pentacam-Oculus was used as cataract assessment method in this study. This technique was applied to measure light scattering to obtain light scattering intensity.[12,13]

Slit lamp examination was performed by the ophthalmologist after giving tropicamide drop 0.5% to subjects' eye until the pupil fully dilated. Subsequently, the posterior area of the lens was measured using three-dimensional mode in Pentacam-Oculus. It was carried out by dragging an area of 3 mm (horizontal) x 0.5 mm (vertical) in the posterior part of the lens (►**Fig. 1**). After the area was selected, the program in Pentacam showed lens opacity average in that area. This data would be collected from each subject and being analyzed as lens density of posterior subcapsular area.

Results

A total of 351 radiation workers participated in cataract examinations. After adjusting for inclusion and exclusion

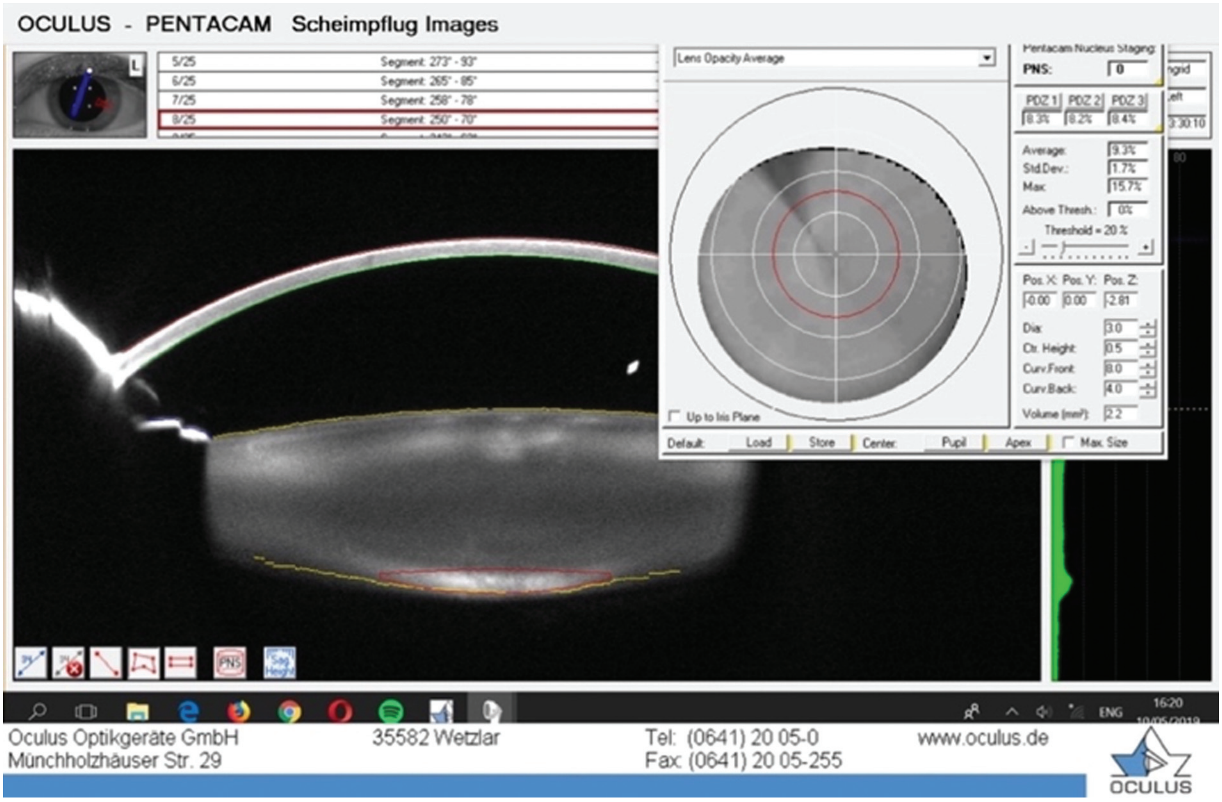

Fig. 1 Lens density measurement using Pentacam-Oculus three-dimensional mode.

criteria, 180 subjects were included in the prevalence study. The nested case–control study consisted of 30 subjects in the case group and 60 subjects in the control group.

A. Prevalence Study

The initial phase of this research was carried out with a prevalence study design.

Characteristics of research subjects are shown in ►**Table 1**.

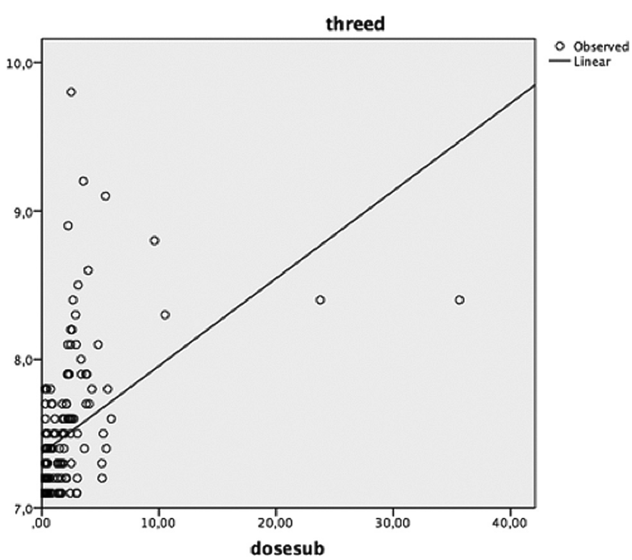

Fig. 2 Correlation between estimated cumulative radiation dose and lens density.

Table 1 Subject characteristics ($n = 180$)

Characteristics	Total
Gender, *n* (%)	
Male	114 (63.3)
Female	66 (36.7)
Age (years)	43.6 ± 9.9
Age group (years)	
≤ 40 years	79 (43.9)
> 40 years	101 (56.1)
Profession, *n* (%)	
Cardiologist	65 (36.1)
Nurse	101 (56.1)
Radiographer dan technician	14 (7.8)
Duration of occupational exposure (years)	9 (5–38)
Ceiling-suspended shield use, *n* (%)	
< 31%	0 (0.0)
31–50%	6 (3.3)
51–70%	23 (12.8)
71–100%	151 (83.9)
Protective eyewear use, *n* (%)	
Not at all	73 (40.6)
< 31%	28 (15.6)
31–50%	29 (16.1)
51–70%	9 (5.0)
71–100%	41 (22.7)
Estimated cumulated radiation dose from RELID questionnaire (Gy)	0.8 (0.1–35.6)
Smoking habit, *n* (%)	
Yes	22 (12.2)
No	158 (87.8)
Alcohol consumption habit, *n* (%)	
Yes	8 (4.4)
No	172 (95.6)

Abbreviation: RELID, Retrospective Evaluation of Lens Injuries and Dose.

Table 2 Prevalence rate of radiation-induced cataract

Radiation-induced cataract	Frequency	Percentage (%)	95% CI
Yes No	30 150	16.7 83.3	13.9–19.5%
Total	180	100.0	

Abbreviation: CI, confidence interval.

This study showed the radiation-induced cataracts prevalence of 16.7% (95% confidence interval [CI]: 13.9–19.5%) among radiation workers of interventional cardiology (►**Table 2**).

B. Nested Case–Control Study

The next stage of this research was a nested case–control study. Ninety subjects were included. The subjects that have PSC were included in the case group, while the subjects that did not have PSC were included in control group. Among the subjects, responsive use of ceiling-suspended shield and protective eyewear can significantly reduce the prevalence of radiation-induced cataract (►**Table 3**).

Table 3 Risk factors of subject between study groups ($n = 90$)

Risk factors	Radiation-induced cataract		*p*-Value
	Case (%)	Control (%)	
Gender Male Female	 20 (32.8) 10 (34.5)	 41 (67.2) 19 (65.5)	 0.873
Age group (years) ≤ 40 years > 40 years	 11 (31.4) 19 (34.5)	 24 (68.6) 36 (65.5)	 0.760
Profession Cardiologist Nurse Radiographer and technician	 10 (29.4) 19 (35.2) 1 (50.0)	 24 (70.6) 35 (64.8) 1 (50.0)	 0.753
Duration of occupational exposure (years)	13 (5–38)	8 (5–30)	0.004
Ceiling-suspended shield use 31–50% 51–70% 71–100%	 3 (75.0) 12 (70.6) 15 (21.7)	 1 (25.0) 5 (29.4) 54 (78.3)	 <0.001
Protective eyewear use No Yes	 29 (76.3) 1 (1.9)	 9 (23.7) 51 (98.1)	 <0.001
Smoking habit Yes No	 2 (18.2) 28 (35.4)	 9 (81.8) 51 (64.6)	 0.324[a]
Alcohol consumption habit Yes No	 1 (25.0) 29 (33.7)	 3 (75.0) 57 (66.3)	 >0.999[a]

[a]Fisher's exact test.

Table 4 Correlation between estimated cumulative radiation dose and radiation-induced cataract

Estimated radiation dose	Radiation-induced cataract		*p*-Value
	Case (%)	Control (%)	
RELID questionnaire	3.03 (2.20–35.64)	0.45 (0.23–8.64)	<0.001[a]

Abbreviation: RELID, Retrospective Evaluation of Lens Injuries and Dose.
[a]Mann–Whitney U test.

Correlation analysis was determined between estimated cumulative radiation dose and radiation-induced cataract. Correlation analysis between two groups showed that median cumulative radiation dose in case group was significantly higher than control group, 3.03 (2.20–35.64) Gy and 0.45 (0.23–8.64) Gy, respectively. Statistical analysis using Mann-Whitney U test resulted *p*-value less than 0.001 (►**Table 4**).

Furthermore, this study also analyzed the correlation between estimated radiation dose and lens density. A positive correlation was also found (R Spearman = 0.64), as seen in ►**Fig. 2**. It confirmed that the lens density became higher along with the higher cumulative radiation dose.

The effect of radiation protection equipment usage on cataracts is also reported in ►**Table 5**. Worse compliance with radiation protection usage leads to an increasing risk of radiation-induced cataracts. It was shown that each radiation protection equipment of the eye, which is a ceiling-suspended shield and protective eyewear, has crucial role in radiation-induced cataracts.

►**Table 6** explains that ceiling-suspended shield and protective eyewear also significantly affected lens density. The median lens density in the group of subjects with better compliance with radiation protection usage was lower ($p < 0.001$).

Discussion

This study resulted in the prevalence rate of radiation-induced cataracts among radiation workers of interventional cardiology that was 16.7% (95% CI: 13.9–19.5%). Compared to the prevalence of cataracts in the Indonesian population, the prevalence of radiation-induced cataracts was much higher. Riset Kesehatan Dasar (Riskesdas) in 2013 showed cataract prevalence between 0.9 and 3.7% in various provinces in Indonesia, while data on Survey Kesehatan Indera Penglihatan in 2009 to 2014 reported a cataract prevalence of 1.8% in Indonesia.[14] Morphology of radiation-induced cataracts is dominated by PSC.[2] The Singapore Epidemiology of Eye Diseases Study mentions PSC as a major risk factor for cataract surgery related to visual impairment due to its location in the central visual axis.[15] Thus, radiation workers of interventional cardiology are the susceptible population to cataracts. Nevertheless, compared to previous similar studies about radiation-induced cataracts, the prevalence rate in this study is relatively lower. RELID studies performed in several countries under the coordination of IAEA showed prevalence rate varies between 31 and 86%.[2,3,6,16] Elmaraezy

Table 5 Correlation between radiation protection usage and radiation-induced cataract

Radiation protection usage	Radiation-induced cataract		*p*-Value	OR	95% CI
	Case	Control			
Ceiling-suspended shield[a]					
31–50%	3	1	0.044	10.80	1.05–111.49
51–70%	12	5	0.001	8.64	2.63–28.40
71–100%	15	54			
Protective eyewear					
No	29	9	0.001	164.3	19.81–1363
Yes	1	51			

Abbreviations: CI, confidence interval; OR, odds ratio.
[a]Fisher's exact test.

Table 6 Correlation between radiation protection usage and lens density

Radiation protection usage	Lens density		*p*-Value
	Median	(Range)	
Ceiling-suspended shield[a]			
31–50%	5.75	(0.98–26.61)	<0.001
51–70%	2.26	(0.26–35.64)	
71–100%	0.49	(0.07–35.64)	
Protective eyewear[b]			
No	2.20	(0.08–26.61)	<0.001
Yes	0.44	(0.07–35.64)	

[a]Kruskal–Wallis test.
[b]Mann–Whitney U test.

et al also mentioned as many as 33.4% of PSC among health professionals with radiation exposure. The risk was increased by 3.21 times compared with health professionals without radiation exposure.[17] The lower prevalence rate of radiation-induced cataract in this study could be caused by differences in the characteristics of subjects, the number of samples, the radiation exposure dose, and the cataract assessment method.

All previous RELID studies used a retrospective cohort design by comparing two groups: the radiation exposure group and the nonradiation exposure group. Those previous study samples also included health professionals who were not exposed to radiation.[2,3,6,16] Therefore, the number of samples in this study was greater than in previous studies.

The radiation dose in this study was calculated from a validated questionnaire. This method gathered information on the workload of radiation workers to produce an estimated cumulative radiation dose. It was developed by IAEA in 2008. The same questionnaire was also used in the previous RELID studies. However, the estimated cumulative radiation dose in this study was lower than the previous RELID studies. The average lens density of the subjects was $7.5 \pm 0.5\%$. All previous RELID studies used modified Merriam-Focht scoring in cataract assessment.[2,3,6,16] The difference in cataract assessment method could affect the prevalence of radiation-induced cataracts.

Furthermore, the results of this study indicated that radiation exposure dose and radiation protection equipment usage have crucial role in development of cataract as one of deterministic effect of radiation.

Correlation analysis between cumulative radiation doses and radiation-induced cataracts in this study showed significant results. The median estimated cumulative radiation dose for the case group was 3.03 (2.20–35.64) Gy, significantly higher than the control group that was 0.45 (0.23–8.64) Gy. ICRP Publication 118 in 2011 explained that radiation cataractogenesis began at a dose of 0.5 Gy. This value has decreased from previous threshold that was 2 to 8 Gy.[8] Nevertheless, the pathogenesis of radiation-induced cataract is still unclear. Thome et al mentioned that previous studies have not been able to show conclusive data that 0.5 Gy radiation exposure will increase the risk of cataract formation.[18]

A positive correlation was also found between cumulative radiation dose and lens density (R Spearman = 0.64). Thus, the lens density was getting higher along with the high dose of estimated cumulative radiation.

The RELID studies divided the use of radiation protection into several categories: not at all, rarely (<30%), sometimes (31–50%), often (51–70%), and always (71–100%).[16] The use of radiation protection in the subjects was varied. The compliance of ceiling-suspended shield usage in this study varied between categories sometimes to always. As many as 83.9% of subjects used ceiling-suspended shield during 71 to 100% of their working period. However, the compliance of protective eyewear usage was relatively lower than ceiling-suspended shield. Only 22.7% of all subjects wore protective eyewear during 71 to 100% of their working period. There were barriers to compliance with the use of protective eyewear, due to not comfortable to use in conjunction with refraction glasses, forget to wear, and not available. Worse compliance of radiation protection equipment usage was leading to increasing risk of radiation-induced cataracts. This was indicated by the greater odds ratio (OR) value. Vano et al mentioned that exposure of radiation to the eye can be reduced by 98% with ceiling-suspended shield usage.[16] Zett-Lobos et al also explained that the use of protective eyewear with 0.25 mm Pb thickness reduced radiation scattering by 50%.[19] This can be achieved by good compliance and well position use of radiation protection equipment.[16,20] In this study, despite the compliance of radiation protection equipment usage was still not in accordance with national recommendation; however, it was relatively better than previous studies. Ciraj-Bjelac et al reported that 59% subjects used ceiling-suspended shield routinely, while only 6% subjects used protective eyewear routinely.[4] It could lead to a lower prevalence of radiation-induced cataracts in this study.

In line with the prevalence of radiation-induced cataracts, the result of this study also showed significantly lower lens density with better use of radiation protection. Thus, responsive use of radiation protection is very important in preventing radiation-induced cataracts.

This study is the first research of radiation-induced cataract using Scheimpflug analysis with Pentacam-Oculus as cataract assessment method. Therefore, minimal changes in the lens structure can be identified by using it. Nevertheless, this study also has several limitations. As it is a cross-sectional study, the causal relationship between risk factors and radiation-induced cataracts cannot be exactly determined. Further prospective research is needed to better analyze the causality relationship. Moreover, the modality that is used in this study to determine cumulative radiation dose was a questionnaire. Although it has already been validated and used in several previous studies, the most objective method to measure radiation exposure dose is personal dosimeter. Hence, the compliance of its usage should be improved.

Conclusion

The prevalence of radiation-induced cataract among radiation worker of interventional cardiology in this study was 16.7%. A significant relationship was identified between the estimated cumulative radiation dose, the risk of radiation-induced cataract, and lens density. The increased cumulative radiation dose is associated with the increasing risk of radiation-induced cataracts and lens density. A significant relationship was also found between the use of radiation protection, the risk of radiation-induced cataracts, and lens density. Responsive use of ceiling-suspended shields and protective eyewear will lead to decreasing the risk of radiation-induced cataracts and lens density.

Ethical approval

All procedures performed in this study were following the ethical standards of the research committee of the Faculty of Medicine, Universitas Indonesia (No: 1167/UN2.F1/ETIK/2018) and the National Cardiac Center Harapan Kita Hospital (No: LB.02.01/VII/312/KEP.002/2019).

Conflict of Interest

None declared.

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