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THE RELATIONSHIP OF INDIVIDUAL CHARACTERISTICS AND RADIATION EXPOSURE DOSE ON HAEMOGLOBIN LEVELS AMONG WORKERS

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Abstract

Radiation safety aims to protect workers, the public, and the environment from the harmful effects of ionizing radiation. This study aimed to analyze the effect of individual characteristics and radiation exposure dose on hemoglobin levels among radiation workers at a hospital in Surabaya. This study used an analytic observational design with a cross-sectional approach and secondary data from 2019–2020 involving 71 radiology workers. The independent variables were age, gender, length of service, workload, and radiation dose, while the dependent variables were hemoglobin, hematocrit, and erythrocyte levels. Data were analyzed using Chi-square test to determine the association between variables. The results showed that age (p=0.089), length of service (p=0.165), and workload (p=0.720) did not have a significant effect on hemoglobin levels. Gender also did not significantly affect hemoglobin (p=0.053), but had a significant effect on hematocrit (p=0.009). There was no significant relationship between all independent variables and erythrocyte levels (p>0.05).

Keywords: hemoglobin; radiation safety; radiation exposure

Introduction

Radiation safety includes measures to protect against radiation hazards that can ionize the media through which it passes, while radiation protection is an effort to reduce the damaging effects of radiation exposure which can lead to the potential occurrence of work accidents (1). Radiation safety involves various measures to protect the environment, population, and workers from the negative effects of ionizing radiation. Due to the significant hazards of X-ray radiation in its use, safety factors become very important to minimize occupational risks in radiology units and the impact of radiation on workers exposed to radiation (2). Radiofrequency radiation raises concerns for human health, leading to the establishment of safe electromagnetic radiation thresholds to limit excessive exposure, as radiation can cause sleep disturbances, diseases that include brain tumours, Alzheimer's, fatigue, headaches, and psychological impacts such as stress and discomfort (3) . Radiation occupational hazards have three categories: safety hazards, health hazards, and environmental hazards. Health hazards arise from workers’ activities that can cause illness due to radiation exposure to the body. Radiology is one of the health care facilities provided by hospitals, where workers are continuously exposed to ionizing radiation. Ionizing radiation can damage biological tissues and DNA, leading to acute effects such as tissue injury and long-term risks such as cancer .(4,5)

Provisions regarding safety of use are regulated in Government Regulation No. 63 of 2000 concerning Safety and Health in the Utilization of Ionizing Radiation, which refers to the provisions of the International Atomic Energy Agency (IAEA) and recommendations from the International Commission on Radiological Protection (ICRP) (5).

Hospitals are places used to provide health services, including promotive, preventive, curative, and rehabilitative, as recommended by the government to the public to get adequate services (6). Occupational Safety and Health in hospitals is one of the efforts to improve the quality of hospital services in terms of safety and health of hospital human resources, patients, and visitors or patient companions. According to Law Number 44 of 2009, a hospital is a health institution that provides comprehensive individual health care and serves inpatient, outpatient, and emergency care. Hospitals are health facilities that provide services to maintain and improve health, as well as restore individual health through adequate medical care (7). Hospitals are facilities that provide various health services needed by the community, including one of which is the radiology unit, which provides quick and accurate disease diagnosis services. Radiology examinations are one of the medical services in hospitals, where these examinations use X-ray machines for diagnostic and interventional radiology purposes. The use of radiology rooms has a high radiation impact, as X-ray treatment is the second-largest contributor to radiation received by the body. Besides providing health benefits, radiation exposure can also pose dangers to radiation workers, the public, and the surrounding environment if it does not comply with government regulations (8).

The potential radiation hazards for in the radiology unit workers are very high, so that they must prioritize high safety factors to minimize and reduce the risk of occupational diseases and accidents due to radiation exposure (2). Radiation is the emission of energy in the form of heat, particles, or electromagnetic waves/light. Radiation is the transfer of energy through substances or space using particles, heat, or electromagnetic waves (photons) from an energy source (9). Natural radiation has existed in nature without human intervention, while artificial radiation comes from human activities intentionally made for military, medical, power generation, and other purposes (10). Ionizing radiation is any radiation that forms ions through interaction with cells in the human body (11). Ionizing radiation is a type of radiation that can ionize the atoms or materials it passes through, the ionization process forms positive and negative ions. Types of ionizing radiation include alpha particles, beta particles, gamma rays, X-rays, and neutrons (12).

According to the Government Regulation of the Republic of Indonesia Number 33 of 2007 concerning ionizing radiation safety and the security of radioactive sources, which aims to ensure the safety of workers and community members, protection of the environment, and security of radioactive sources. Government Regulation of the Republic of Indonesia Number 29 of 2008 concerning the licensing of the utilization of ionizing radiation sources and nuclear materials requires more stringent, transparent, clear, firm, and fair licensing requirements and procedures by considering the risk of radiation hazards and the security of radioactive sources and nuclear materials that are able to guarantee the safety of workers, community members, and protection of the environment.

The threshold limit value (TLV) for radiation workers must not exceed an effective dose of 20 millisieverts (mSv) per year over five consecutive years, an effective dose of 50 mSv in any single year, an equivalent dose to the eye lens of 20 mSv per year for five consecutive years, an equivalent dose to the eye lens of 50 mSv in any single year, and an equivalent dose to the hands and feet, or skin of 500 mSv in any single year. In the Regulation of the Head of the Nuclear Energy Regulatory Agency Number 8 of 2011 concerning radiation safety in the use of diagnostic and interventional radiology X-ray machines, ionizing radiation safety in the medical field is an action taken to protect patients, workers, community members, and the environment from radiation hazards.

According to the data from the International Labour Organization (ILO), every year ≥ 250 million workers suffer from work accidents, ≥ 160 million workers suffer from occupational diseases, and ≥ 1.2 million workers die due to work accidents and/or occupational diseases (13). In Indonesia, in 2010, there were 2,191 deaths and 2,550 disabilities due to work accidents. In Riau, in 2014, there were 3,127 work accidents and 3,398 occupational diseases (14). Based on the report on radiation worker dose monitoring in 2018, the highest dose was 0.65 mSv and the lowest dose was 0.01 mSv. This indicates that in 2018 there were no radiation workers who exceeded the TLV of 20 mSv per year (15,16) .

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Radiation workers are considered to have hazardous jobs with a high risk of exposure to radiation that can result in chronic diseases and even death. One way to prevent and minimize the impact of radiation received by workers is by using personal protective equipment such as protective clothing, protective hats / safety caps, safety shoes, protective gloves, and protective glasses. The use of personal protective equipment in radiation rooms is very important as it is an effort to control potential radiation hazards in the radiology room (1). The impact of radiation can affect hemoglobin levels. Hemoglobin is a protein in red blood cells that plays a role in carrying oxygen from the lungs to all parts of the body. Radiation can affect the reduction of hemoglobin levels in the body, as it causes anemia, which is a disease caused by a lack of red blood cells (17).

Anemia can be classified into two types based on its causes: the first is duet o a decrease in hemoglobin levels in the blood, which disrupts the formation of red blood cells in the body (18). A significant reduction in red blood cells can be caused by bleeding or excessive destruction of blood cells. The cause of anemia is duet o damage to red blood cells in the body caused by prolonged radiation exposure in the radiation rooms. According to (19), the second cause occurs due to interference with hemoglobin production in the blood caused by the significant effects of radiation, toxins, and infections occurring in the radiation room. Red blood cells become damaged due to radiation exposure and result in an increased number of damaged erythrocytes, leading to anemia. Damage to red blood cells results in damage to the DNA of red blood cells in the body, which can lead to blood cell death or disruption of normal red blood cell formation. Damage occurring in red blood cells can cause difficulties in binding oxygen to distribute it throughout the body. Symptoms of anemia usually include severe fatigue, dizziness, weakness, difficulty breathing, and paleness (20).

Radiation safety management systems are implemented to reduce occupational risks; however, radiology units remain high-risk environments due to continuous exposure to ionizing radiation. This exposure can affect hematological parameters such as hemoglobin, hematocrit, and erythrocytes, which are important indicators of workers' health. Evidence shows that environmental exposures causing hypoxia can increase erythrocyte production and hematocrit levels (20), and similar biological effects may occur due to radiation exposure. The urgency of this issue is supported by recent studies indicating that even low-dose radiation exposure can cause oxidative stress and alterations in blood parameters (21,22). In addition, workload is closely related to exposure duration and frequency, potentially influencing cumulative radiation dose. Variations in individual characteristics and workload may therefore affect hematological outcomes (23). Based on these considerations, this study aims to analyze the relationship of individual characteristics and radiation exposure dose on hemoglobin, hematocrit, and erythrocyte levels among radiology workers (25).

Methodology

This study used an analytic observational study with a cross-sectional design to examine the hematological profile of radiology unit workers at X Hospital, in Surabaya, East Java, which was conducted on August 10, 2020, from 08:00 to 10:00 WIB. Data were obtained from a secondary data analysis approach in 2019-2020, involving all 71 radiology unit workers as samples at X Hospital. All radiology with radiation exposure dose ≤20 mSv. The variables studied included age, gender, length of service, and workload, as well as hematological parameters such as hemoglobin, hematocrit, and erythrocytes. Age and gender were obtained from the respondent's identity cards, length of service was calculated from the start of working as a radiographer, workload was calculated from the total annual working hours, and radiation exposure dose was obtained from the monthly dose calculation, measured from an external measuring device. Hematological parameters consisting of hemoglobin, hematocrit, and erythrocyte levels were obtained from the results of the annual routine Medical Check-Up (MCU) conducted by X Hospital. Hematology levels were measured using a Sysmex XN-550 device with EDTA blood samples. This study has received ethical approval from the Research Ethics Committee of Universitas Airlangga Hospital with number "165/KEP/2020".

In this research, statistical data processing was carried out using SPSS. The analysis process consisted of inputting data into statistical software, followed by carrying out statistical tests such as descriptive tests, homogeneity tests, linearity tests, and chi square test. which allows researchers to gain a deep understanding of the data obtained.

Results

The results showed that out of 71 radiology unit workers at X Hospital, the majority were adults (26-45 years old) as many as 60 people (84.5%), followed by adolescents young adulthood (18-25 years old) as many as 7 people (9.9%), and elderly (46-65 years old) as many as 4 people (5.6%). Most of the respondents were female (66%), and the rest were male (34%), with length of service divided into beginner (< 6 years) as many as 23 people (32.4%), intermediate (6-10 years) with as many as 18 people (25.4%), and advanced (> 10 years) with as many as 30 people (42.2%). The characteristics of the respondents are shown in Table 1.

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Table 1. Characteristics of Respondents Based on Age, Gender, Length of Service, Workload, and Radiation Exposure Dose of Radiology Unit Workers at X Hospital in 2020

Variable	Category	Frequency	
		n	%
Age	Young adulthood	7	9.9
	Adults	60	84.5
	Elderly	4	5.6
Gender	Male	24	34.0
	Female	47	66.0
Length of service	Beginner	23	32.4
	Intermediate	18	25.4
	Advanced	30	42.2
Workload	<1,850 hours	41	58.0
	≥1,850 hours	30	42.0
Radiation Exposure Dose	>20 mSv	0	0.0
	≤20 mSv	71	100.0

Table 2. Identification of Hemoglobin, Hematocrit, and Erythrocyte Levels of Radiology at X Hospital Unit Workers in 2020

Variable	Category	Frequency			
		2019		2020	
		n	%	n	%
Hemoglobin	Abnormal	22	30.9	29	40.9
	Normal	49	69.1	42	59.1
Hematocrit	Abnormal	20	28.2	30	42.2
	Normal	51	71.8	41	57.8
Erythrocytes	Abnormal	25	35.2	20	28.2
	Normal	46	64.8	51	71.8

From the data obtained in 2019 and 2020 data analysis from Table 2 at X Hospital, there are variations in hemoglobin, hematocrit, and erythrocyte levels among radiology workers. In 2019, out of 71 respondents, in 2019 out of 49 respondents (69.1% respondents) had normal hemoglobin, 51 respondents (71.8% respondents) had normal hematocrit, & 46 respondents (64.8% respondents) had normal erythrocytes. In 2020 out of 42 respondents (59.1% respondents) had normal hemoglobin, 41 respondents (57.8% respondents) had normal hematocrit, and 51 respondents (71.8% respondents) had normal erythrocytes.

Table 3. Cross Tabulation between Characteristics of Respondents to Hemoglobin Profile of Radiology Unit Workers with Radiation Exposure Dose ≤20 mSv at X Hospital in 2020

Characteristics of Respondents	Hemoglobin				Total		p-value
	Normal		Abnormal				
	n	%	n	%	n	%	
			Age				
18 – 25	3	42.9	4	57.1	7	100.0	0.089
26 – 45	35	58.3	25	41.7	60	100.0	
46 – 65	4	100.0	0	0.0	4	100.0	
			Gender				

Male	18	75	6	25	24	100.0	0.053
Female	24	51.1	23	48.9	47	100.0	
Length of Service							
<5 Years	16	69.6	7	30.4	23	100.0	0.165
5 – 19 Years	21	56.8	16	43.2	37	100.0	
>20 Years	5	45.5	6	54.5	11	100.0	
Workload							
<1,850 hours	17	56.7	13	43.3	30	100.0	0.720
≥1,850 hours	25	61	16	39	41	100.0	

Table 3 shows variations in hemoglobin levels across age, gender, length of service, and workload. Workers aged 26–45 years and 46–65 years mostly had normal hemoglobin, while younger workers (18–25 years) tended to have more abnormal levels. Male workers had a higher proportion of normal hemoglobin than females, and workers with shorter service duration showed better hemoglobin levels compared to those with longer service. Higher workload was associated with a greater proportion of abnormal hemoglobin. However, statistically, none of these variables had a significant effect on hemoglobin levels ($p > 0.05$), indicating that the observed differences were not significant.

Table 4. Cross Tabulation between Characteristics of Respondents to Hematocrit Profile of Radiology Unit Workers with Radiation Exposure Dose ≤20 mSv at X Hospital in 2020

Characteristics of Respondents	Hemoglobin				Total		p-value
	Normal		Abnormal				
	n	%	n	%	n	%	
Age							
18 – 25	3	42.9	4	57.1	7	100.0	0.294
26 – 45	35	58.3	25	41.7	60	100.0	
46 – 65	3	75	1	25	4	100.0	
Gender							
Male	19	79.2	5	20.8	24	100.0	0.009
Female	22	46.8	25	53.2	47	100.0	
Length of Service							
<5 Years	13	56.5	10	43.5	23	100.0	0.980
5 – 19 Years	22	59.5	15	40.5	37	100.0	
>20 Years	6	54.5	5	45.5	11	100.0	
Workload							
<1,850 hours	15	50	15	50	30	100.0	0.265
≥1,850 hours	26	63.4	15	36.6	41	100.0	

Results show that hematocrit levels tended to be more stable in older age groups, although age was not significantly associated ($p=0.294$). Male workers had a higher proportion of normal hematocrit (79.2%) compared to females (46.8%), and gender was the only variable with a

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significant effect on hematocrit levels (p=0.009). Meanwhile, length of service and workload showed some variation in proportions but were not statistically significant (p=0.980 and p=0.265, respectively).

Table 5. Cross Tabulation between Characteristics of Respondents and Erythrocyte Profile of Radiology Unit Workers with Radiation Exposure Dose ≤20 mSv at X Hospital in 2020

Characteristics of Respondents	Erythrocyte				Total		p-value
	Normal		Abnormal				
	n	%	n	%	n	%	
Age							
18 – 25	5	71.4	2	28.6	7	100.0	0.918
26 – 45	43	71.7	17	28.3	60	100.0	
46 - 65	3	75.0	1	25.0	4	100.0	
Gender							
Male	17	70.8	7	29.2	24	100.0	0.896
Female	34	72.3	13	27.7	47	100.0	
Length of Service							
<5 Years	18	78.3	5	21.7	23	100.0	0.883
5 – 19 Years	24	64.9	13	35.1	37	100.0	
>20 Years	9	81.8	2	18.2	11	100.0	
Workload							
<1,850 hours	23	76.7	7	23.3	30	100.0	0.448
>=1,850 hours	28	68.3	13	31.7	41	100.0	

Table 5 shows that the majority of workers across all age groups had normal erythrocyte levels, with slightly higher proportions in older age groups. Based on gender, both male (70.8%) and female (72.3%) workers predominantly had normal erythrocytes, indicating no meaningful difference. Variations were observed in length of service and workload, where workers with longer service and lower workload tended to have higher proportions of normal erythrocytes. However, statistically, all independent variables—age (p=0.918), gender (p=0.896), length of service (p=0.883), and workload (p=0.448)—did not show a significant relationship with erythrocyte levels ($p > 0.05$).

Discussion

The statistical test results show that age does not significantly affect the hematological profile of radiology workers, with p-values for hemoglobin 0.089, hematocrit 0.294, and erythrocytes 0.918, indicating that there is no significant relationship between age and these three parameters at X Hospital in 2020. Research by (24) and (25) also supported these findings, showing no significant correlation between age and hemoglobin, hematocrit, and erythrocyte

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levels. Other studies by (26). also found similar results, confirming that age did not affect hematological levels, including leukocytes and platelets, which are more influenced by other factors such as length of service and type of radiation exposure. Age is an important factor that may relationship hematological parameters due to physiological changes such as decreased bone marrow function and erythropoiesis, as well as increased oxidative stress (27,28). However, this study found that age did not significantly affect hemoglobin (p=0.089), hematocrit (p=0.294), or erythrocyte levels (p=0.918), indicating no significant relationship between age and hematological profile among radiology workers. These findings are consistent with previous studies showing no significant association between age and hematological parameters in radiation workers (29).

The lack of significant effect may be explained by the dominance of respondents in the productive age group, stable physiological conditions, controlled radiation exposure within permissible limits (≤20 mSv), and effective implementation of radiation protection measures. Additionally, other factors such as nutritional status, lifestyle, and overall health condition may have a greater relationship on hematological parameters than age alone (30,31). Although (24) found that hemoglobin levels in females were higher than in men, research by (32) at Jemursari Islamic Hospital Surabaya showed no significant difference in hemoglobin levels between the two genders, although levels in women were more often abnormal. Other research by (33) about Effects of exposure to low-dose ionizing radiation on changing platelets, also support this findings the differences in the distribution of hemoglobin are statistically significant ($P < 0.05$) radiation nurses have the lowest hemoglobin on occupation, The differences in the distribution of red blood cells are statistically significant ($P \leq 0.001$), mainly in that females have lower red blood cells than males, radiation nurses have the lowest red blood cells on occupation, and red blood cells decrease with the baseline age and the effect of smoking is similar to hemoglobin.

Gender is a biological factor that can relationship hematological parameters due to hormonal differences, particularly the role of androgens in stimulating erythropoiesis and the effect of menstrual blood loss in females, which may lead to lower hemoglobin and hematocrit levels (31,34). In occupational settings, these physiological differences may contribute to variations in blood profiles between male and female workers. In this study, 48.9% of female workers had abnormal hemoglobin levels; however, statistically, gender did not show a significant effect on hemoglobin and erythrocyte levels. This finding is consistent with previous studies indicating no significant association between gender and hematocrit (31), and no significant differences in erythrocyte levels based on gender (21). Similarly, research conducted

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at Bahteramas Kendari Regional General Hospital found that gender did not significantly affect hematological parameters, including hemoglobin, leukocytes, and platelets (23). Another study at Purwakarta Hospital reported that changes in blood parameters were more strongly influenced by radiation exposure and the use of personal protective equipment than by gender (32). Recent evidence also supports that occupational exposure factors play a more dominant role than biological sex in determining hematological outcomes among radiation workers (22,35). The lack of significant effect of gender in this study may be explained by controlled radiation exposure levels (≤20 mSv), standardized work procedures, and consistent use of personal protective equipment among workers, which reduce differential exposure between males and females. In addition, other factors such as nutritional status, health condition, and lifestyle may have a greater relationship on hematological parameters than gender alone, thereby minimizing observable differences between groups (4,23,34).

Length of service represents the duration of occupational exposure, which theoretically reflects cumulative radiation exposure over time. Prolonged exposure is often associated with potential biological effects, including alterations in hematological parameters due to cumulative damage to bone marrow and blood cell production (29,31). Therefore, workers with longer service duration are generally expected to show greater changes in hematological profiles. However, the results of this study indicate that length of service does not have a significant effect on hemoglobin (p=0.165), hematocrit (p=0.980), and erythrocyte levels (p=0.883). These findings are in line with previous studies showing no significant relationship between length of service and hematological parameters (34), as well as studies (6) and (23), which reported that hematological changes are more influenced by radiation exposure levels and the use of personal protective equipment than by duration of employment. Although study (21) found that workers with more than 5 years of service tended to have more abnormal hemoglobin levels, this trend was not statistically significant in the present study.

The absence of a significant effect of length of service may be explained by the fact that all workers were exposed to radiation within permissible limits (≤20 mSv), minimizing cumulative biological effects. In addition, the consistent implementation of radiation protection measures, such as the use of personal protective equipment and routine dose monitoring, likely reduces long-term exposure risks. Furthermore, individual factors such as nutritional status, health condition, and lifestyle may have a more substantial relationship on hematological parameters than length of service alone (22). Research in Papua and West Papua by (36) also showed similar results.

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Workload reflects the intensity and duration of occupational exposure, particularly in radiology settings where higher workload may increase the frequency and duration of exposure to ionizing radiation. Theoretically, increased workload can lead to cumulative radiation exposure, which may affect hematological parameters through biological mechanisms such as oxidative stress, DNA damage, and inflammatory responses involving pathways like nuclear factor kappa B (NF-κB) and signal transducers and activators of transcription (STATs) (31). These processes may alter blood cell production and immune responses, potentially leading to abnormalities in hemoglobin, hematocrit, and erythrocyte levels. However, the results of this study indicate that workload does not have a significant effect on hemoglobin (p=0.720), hematocrit (p=0.265), and erythrocyte levels (p=0.448). These findings are consistent with previous studies showing no significant relationship between workload and hematological parameters (21). Research in Papua and West Papua (34) also reported similar results, where workload-related radiation exposure did not significantly affect platelet and erythrocyte levels, although a decrease in leukocytes was observed. Other studies (23) suggest that prolonged radiation exposure may increase leukocyte levels as part of the body's response to stress or cellular damage. Although some studies (35) indicate that workload can relationship workers' health and contribute to abnormal hemoglobin levels, this effect was not statistically evident in the present study. The absence of a significant effect of workload may be explained by controlled radiation exposure levels that remain within permissible limits (≤20 mSv), as well as the consistent implementation of radiation protection measures, including the use of personal protective equipment and routine dose monitoring. These controls likely minimize the biological impact of workload-related exposure. Additionally, other factors such as individual health status, nutritional intake, and lifestyle may have a more dominant relationship on hematological parameters than workload alone (37).

Conclusion

Based on the analysis results, it can be concluded that age, length of service, workload, and radiation exposure dose do not have a significant effect on hemoglobin, hematocrit, and erythrocyte levels in radiology unit workers at X Hospital in 2020. However, gender has a significant effect on hematocrit levels, but does not affect hemoglobin and erythrocyte levels.

Suggestion

This research still has shortcomings, namely that if the sample size is small, the results may not represent the general population of radiation workers. Therefore, it is necessary to pay attention to other factors that can relationship hemoglobin levels, such as diet, general health status, and lifestyle, to determine further the impact of radiation.

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