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Health Effects Associated with Occupational Exposure to Gamma Radiation in Aircrew: A Case Study on Mehrabad Airport in 2021

Morteza Mortazavi [1], Parvin Ahmadinejad [2], Sara Arjmand [2], Milad Derakhshanjazari [3*]

[1] Department of Occupational Health, School of Public Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran.
[2] Department of Occupational Health and Safety Engineering, Shiraz University of Medical Sciences, Shiraz, Iran.
[3] Military Health Research Center, Life Style Institute, Baqiyatallah University of Medical Sciences, Tehran, Iran.

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Corresponding Author:
Milad Derakhshanjazari

Email:
Derakhshan_milad@bmus.ac.ir

Tel:
+98 21 87555523

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ABSTRACT

Introduction: Aircrew is exposed to harmful levels of gamma radiation with unknown effects. This study aims to investigate occupational exposure to cosmic gamma radiation and its associated health effects among the aircrew members of Iran Airlines.

Methods: This analytical cross-sectional study was carried out on the crew from four internal flights departing from Mehrabad Airport in 2021. The participants were divided into two groups of 100 aircrew members flying on low-altitude and high-altitude routes, and the history of their illnesses in the past thres years was extracted from medical records. The average annual effective dose (ED) of gamma radiation for the aircrew was measured by dosimeter (CEM DT-9501), and data analysis was done using SPSS16 software.

Results: This study found that the average annual ED of gamma rays was approximately 1.5 millisieverts higher in flight crews on high-altitude flights compared to the low-altitude ones. Moreover, a significant relationship was observed between exposure to gamma and occupational disease in the studied subjects ($P < 0.05$). Therefore, the risk of gastrointestinal, skin, and cardiovascular diseases was 3.55, 3.63, and 12.4 times higher for the crew on high-altitude flights compared with those on low-altitude flights.

Conclusion: High-altitude flights are associated with increased exposure to gamma radiation, leading to a threefold higher risk of occupational diseases such as gastrointestinal, skin, and cardiovascular conditions among aircrew members. These findings highlight the importance of reducing health risks of exposure to gamma rays in aviation industry and emphasize the need for preventive measures to protect the well-being of aircrew personnel.

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Introduction

The exposure of aircrew to occupational radiation in aviation industry has become a topical issue in recent years. The aircrew, including pilots, co-pilots, in-flight security officers, and flight attendants, are exposed to harmful levels of cosmic rays such as gamma radiation which can have adverse effects on their health [1-4]. Accordingly, the International Commission on Radiological Protection (ICRP) has recommended an occupational dose limit of 20 mSv /year for the aircrew members and public, and a non-occupational dose limit of 5 mSv /year [5]. Many factors, including flight duration, geographical locations and aviation altitudes, affect the level of exposure to natural gamma rays. It is important to

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note that due to the high number of airlines, long working hours, and long internal flights at the vastness of Iran, exposure to this radiation can be a threat to Iranian aircrew. Furthermore, there is little information about the exposure of domestic airline flight crews to natural gamma rays and their effects. Therefore, Gholipour P. reported that average annual effective dose of gamma radiation received by the pilots with the annual working time of 500 h was 2 µSv/hour, equivalent to 0.95 mSv/year, regarding Iran domestic flights (Tehran-Bandar Abbas) [6]. Annual radiation dose estimates vary, depending largely on a worker's job, but it is estimated that flight personnel receive an annual dose ranging between 0.2 and 9.1 mSv/year [7]. Lewis B et al. reported an average of 1 - 25 µSv/hour for exposure of the aircrew depending on flight duration and altitude. The highest radiation exposure level was reported about a flight which lasted 834 minutes [8,9]. In addition, Paschal Ikenna Enyinna et al. assessed the average annual effective dose of gamma radiation received by the aircrew as 2.94 mSv/year concerning the trip from Houston Intercontinental Airport to Lagos International Airport in Nigeria. On the other hand, the risks of mortality and cancer caused by exposure to gamma rays in aircrew were estimated to be 14.7×10^{-5} and 29.4×10^{-4}, respectively [10].

Over the years, a great deal of research has been done on the effects of aircrew's exposure to gamma radiation. However, there are many uncertainties regarding the exact cause of these effects on the flight crew. Recent reports highlighting increased incidence of cancer among airline pilots and cabin crew have renewed concerns about possible exposure to harmful levels of cosmic radiation at altitude. Such low energy gamma radiation has been shown to cause double stranded DNA deletions and induce genomic instability in human chromosomes [11]. In Rafnsson et al.'s study, it was found that exposure to gamma rays increases the risk of melanoma in aircrew by 10.2 times [12]. In the study by Lee C. Yong [13] and Ewelina Maculewicz [14], the possible cause of cardiovascular diseases due to exposure to cosmic rays, including gamma rays, has been mentioned. In the study by Jeoum Nam Kim [15] et al., the suppression of the immune and cutaneous disease system of the personnel inside aircraft was caused by exposure to cosmic gamma radiation.

Reviewing the results of past studies indicated that exposure to this natural radiation was a threat to the health of aircrew. Therefore, more studies are needed by all the countries to make policies and reduce exposure to this natural radiation. In addition, demand for the number of flights in Iran has increased. Daily, more than 100 domestic flights are made from Tehran to other cities at altitudes of 21,000 to 31,000 feet. This issue increases the working hours of the aircrew in the flying plane, which highlights the importance of the research.

Given that no comprehensive study has been conducted regarding the evaluation of aircrew exposure to natural gamma radiation with respect to domestic airline routes the harmful effects of exposure to this radiation on the crew's health have not been reported, and reliable information is not available for aircrew health promotion planning, this study aims to evaluate the exposure of aircrew to gamma radiation in low- (Tehran-Rasht, Tehran-Isfahan) and high-altitude (Tehran-Bandar Abbas, Tehran-Mashhad) airlines and determine the risk of the related diseases in Mehrabad Airport , in 2021.

Materials and Methods

Phase 1: Data on participants and occupational diseases

This case-control analytical study was performed on aircrews of 4 Iran domestic flights (2021). 200 people were selected from among the 407 aircrew members regarding 2 low-altitudes (below 21,000 feet) airways (Tehran-Rasht and Tehran-Isfahan) and 2 high -altitude (below 31,000 feet) airways (Tehran-Mashhad and Tehran-Bandar Abbas). Considering the fact that in past studies, point factor played a role in the amount of exposure to gamma radiationin this study, high-altitude and low-altitude flights were selected in the way that both groups differed only in the level of exposure to gamma rays. Determining the effects of exposure to this radiation in the flight

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crew should be comparable based on disease records. Because, in this study, the effect of aircraft altitude on occupational exposure to gamma rays was also needed, flights with this altitude were selected. The sample size was calculated (198 individuals) by Cochran's equation ($\alpha = 0.05$). However, 200 people were selected for better distribution of the participants, who operated Fokker 100 produced in the Netherlands. They were assigned to case and control groups; thus, 100 aircrew members operating Tehran-Rasht and Tehran-Isfahan flights were selected as control and 100 aircrew members operating Tehran-Mashhad and Tehran-Bandar Abbas flights were selected as case.

The inclusion criteria were having at least 5 years of work experience, ages between 20 and 60 years, and working the day-shift. The exclusion criteria were having underlying genetic diseases, and a temporary or a second job. The information was obtained using medical records. Then, demographic data were collected using medical records including age, gender, level of education, body mass index (BMI), work experience, daily working hours, and the history of occupational diseases over the last 3 years. The restriction of researchers' access to aircrew's medical records was lifted by removing personal and security information.

Phase 2: Determining the level of exposure to cosmic gamma rays

First, required permits for measuring the aircrew's exposure to cosmic gamma radiation were obtained from flight control and security unit in Mehrabad International Airport in summer. According to the consultations conducted with flight protection officer and the presentation of the proposal approved by the funding university, permission was issued to the researchers to enter dosimeter and GPS to the plane to measure the amount of exposure to gamma rays and location. Then, as shown in Figure 1, at different time intervals and distances, the average effective dose of gamma radiation hourly received by the aircrew on each aviation route was measured at several waypoints with different longitude, latitude, and altitudes, including 3 waypoints on each of Tehran-Rasht and Tehran-Isfahan routes, 6 waypoints on Tehran-Mashhad route, and 9 waypoints on Tehran-Bandar Abbas route. Gamma measurement was repeated 3 times in each flight.

ETREX 10 GPS was used to measure latitude, longitude, and altitude. Then, the effective doses of gamma radiation hourly (μSv/h) at the given waypoints were measured once using a personal calibrated gamma radiation dosimeter (DGM CEM DT-9501) with radiation does rate of 0.01 μSv/h-1000 μSv/h [10,16]. It was done according to the guidelines for measuring the dose of environmental gamma rays [17]. The gamma measuring device was placed at a height of 90 cm on a fixed base in the path of the passengers, and gamma measurement was performed along the entire flight path. Considering the fact that the plane spends time for increasing altitude and decreasing altitude, for average amount of gamma exposure in each of the flight lines, gamma measurements were made at time intervals with changes in the altitude of the aircraft. The location (longitude, latitude, and altitude) was measured over time by gamma measurement. Finally, the arithmetic average of aircrew's exposure to gamma radiation was calculated. Next, the average effective doses of gamma radiation received annually by aircrew regarding the low- (Tehran-Rasht and Tehran-Isfahan) and high- altitude flights (Tehran-Mashhad and Tehran-Bandar Abbas) were calculated separately using Equation 1 based on their daily and annual working hours [18].

Using gamma ray spectroscopy measurements to assess the average effective dose from the analysis of 226 Ra, 232 Th and 40k in soil samples

$AEDR = ED_h \times N \times K$ Equation (1)

N: Average amount of workdays per year

K: Working hours per day

ED_h: Average effective dose hourly

AEDR: Average effective dose annually

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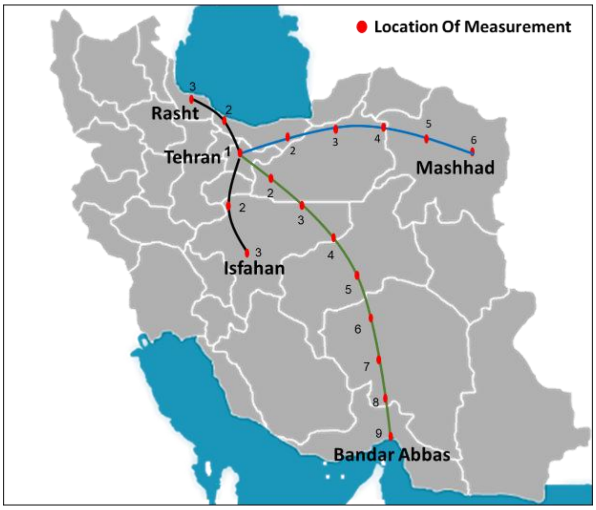

Figure 1: Waypoints for measuring the effective dose of gamma radiation on airways

Data analysis

The normality of data was first confirmed using Kolmogorov-Smirnov test at 0.05 level of significance. Then, the correlations between the variables were tested using parametric tests. Logistic regression with a 95% confidence interval was used to compare the risk of occupational diseases among the aircrew. Data were analyzed using SPSS software version 19.0.

Results

The mean (SD) ages of the aircrew regarding low- and high-altitude flights were 36.1 (± 4.7) and 37 (± 4.4) years. The mean (SD) BMI was 27.1 (± 1.7) kg/m^2 for the aircrew for low-altitude flights, and 26.5 (± 1.55) kg/m^2 for the high-altitude ones. The mean (SD) work experience was 14 (± 3.9) years for the aircrew regarding the low-altitude flights and 13.3 (± 3.46) years for the high-altitude flights. For the low-altitude flights, the mean working hours daily was 7.04 (± 2.5) hours and for the high-altitude flights, it was 7.64 (± 2.7) hours. More details are presented in Table 1.

Table 1: Socio-demographic characteristics of the selected workers (N = 100 aircrew in high altitude, 100 aircrew in low altitude)

Variables		Number of aircrew members	
		High altitude	Low altitude
Age (year)	20-30	23	25
	30-40	46	45
	40-50	24	22
	50-60	7	8
	Total	100	100
Gender	Male	54	55
	Female	46	45
	Total	100	100
Level of education	Bachelor’s degree >	63	62
	Bachelor’s degree <	37	38
	Total	100	100
BMI	< 24.9	33	32
	25-29.9	45	48
	> 30	22	20
	Total	100	100
Work experience (year)	< 10	27	31
	20-10	61	56
	< 20	12	13
	Total	100	100

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Variables		Number of aircrew members	
		High altitude	Low altitude
Daily working hours	< 4	6	10
	8-4	50	55
	8 <	44	35
	Total	100	100
History of occupational diseases	Yes	85	50
	No	15	50
	Total	100	100

According to Table 1, there was no significant difference between the two groups (the crews on low- and high- altitude flights) (P > 0.05) regarding demographic and occupational characteristics. However, there was a difference in the history of occupational diseases. As shown in Table 1, 135 personnel had experienced occupational diseases, of whom 63% were worked in high altitude and 37% in low altitude.

Table 2 shows the association between demographic and occupational characteristics and the history of occupational diseases for the crew in low altitude and high-altitude flights.

Table 2: The association between demographic and occupational characteristics and the history of occupational diseases for the aircrew in low- and high-altitude flights

Variables		Frequency of history of occupational diseases			
		High altitude	P-value	Low altitude	P-value
Age (year)	20-30	16	P = 0.03	10	P = 0.05
	30-40	41		16	
	40-50	23		20	
	50-60	5		4	
	Total	85		50	
Gender	Male	41	P = 0.21	24	P = 0.18
	Female	44		26	
	Total	85		50	
Level of Education	Bachelor	54	P = 0.40	32	P = 0.37
	Bachelor <	31		18	
	Total	85		50	
BMI	< 24.9	26	P = 0.17	15	P = 0.48
	25-29.9	39		25	
	> 30	20		10	
	Total	85		50	
Work experience (Year)	< 10	16	P = 0.04	10	P = 0.02
	20-10	59		31	
	< 20	10		9	
	Total	85		50	
Daily working hours	< 4	1	P = 0.01	3	P = 0.03
	8-4	41		22	
	8 <	43		25	
	Total	85		50	

As shown in Table 2, in both groups, the history of occupational diseases was significantly associated with age, work experience, and daily working hours (P < 0.05); so, an increase in each of these factors could lead to an increased risk of occupational diseases. A significant association was observed between BMI and history of occupational diseases (P < 0.05). On average, the aircrew under investigation would fly 245 days a year. The average (SD) daily working hours was 7.26 (± 2.5) hours. Therefore, each participant would fly an average of 1778.7 hours per year. On the other hand, the hourly and annual effective dose of gamma radiation received by the aircrew varied at different flight altitudes. The details of exposure to cosmic gamma radiation are given in Table 3.

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Table 3: Average annual effective doses of gamma radiation received by the aircrew at different altitudes

Airline route	Flight altitude	Flight altitude (feet) (max)	Level of exposure to gamma	Effective dose (mSv/year)				P-value	P-value
				Min	Mean	Max	SD		
Tehran-Rasht	Low altitude	21000	Low level	2.99	3.46	4.38	0.79	P = 0.31	P = 0.02
Tehran-Isfahan				2.95	3.73	4.93	1.05		
Tehran-Mashhad	High altitude	31000	High level	3.09	4.91	7.31	1.91	P = 0.15	
Tehran-Bandar Abbas				3.16	5.01	6.86	1.41		

As presented in Table 3, there was no significant difference between Tehran-Rasht flight and Tehran-Isfahan flights (low-altitude flights) ($P > 0.05$) regarding average annual effective dose of gamma radiation received by the aircrews. Also, there was no significant difference between the personnel on Tehran-Mashhad flights and those on Tehran-Bandar Abbas flights (high-altitude flights) ($P > 0.05$) in the average annual effective dose of gamma radiation received. However, a significant difference was observed between low-and high-altitude flights ($P < 0.05$) regarding the average annual effective dose of gamma radiation.

Pearson correlation coefficient was used to investigate the association between the annual effective dose of cosmic gamma radiation and flight altitudes. The annual and hourly effective doses of gamma radiation increased with altitude ($P < 0.05$). Figure 2 shows the effective doses of cosmic gamma radiation at different altitudes.

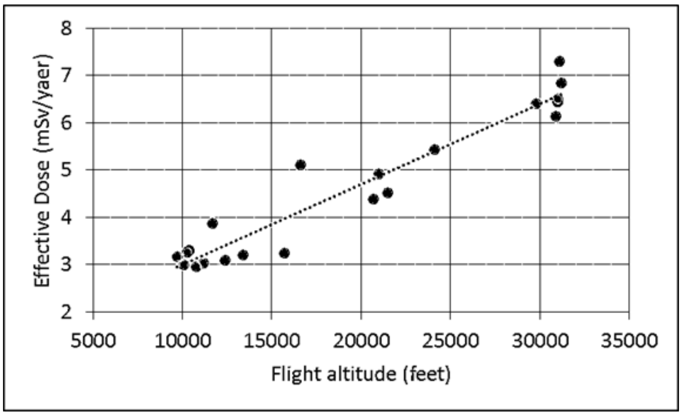

Figure 2: Annual effective doses at different flight altitudes

Figure 2 shows that the average annual effective dose of gamma radiation would increase by 1.5 mSv with every 10,000 feet of increased altitude. There was a significant difference ($P < 0.05$) between low altitude flights (21000 feet) and high-altitude flights ($P < 0.05$) regarding the average effective dose of gamma radiation. The results suggested that an increase in the effective dose of gamma radiation could increase the frequency of occupational diseases among the aircrew ($P < 0.05$). Thus, the highest prevalence of occupational diseases was observed among Tehran-Bandar Abbas and Tehran-Mashhad flight crew members since the average annual effective dose of cosmic gamma radiation varied at different altitudes. Table 4 shows the association between the exposure to gamma radiation and the history of occupational diseases.

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Table 4: The association between the aircrew exposure to gamma radiation and history of occupational diseases

Airline Route	Mean of effective dose (mSv/year) (± SD)	Frequency of occupational disease history (%)
Tehran-Rasht	3.46 (± 0.79)	21 (15.5)
Tehran-Isfahan	3.73 (± 1.05)	29 (21.5)
Tehran-Mashhad	4.91 (± 1.91)	42 (31.2)
Tehran-Bandar Abbas	5.01 (± 1.41)	43 (31.8)
P-value	P = 0.001	

In general, 135 crew members (67.5%) had experienced occupational diseases. The diseases had been experienced by 85% and 50% of the participants at high and low altitudes, respectively (Figure 3).

The results of this study showed that five types of occupational diseases including gastrointestinal, cutaneous, hormone, blood, and cardiovascular diseases had been reported over the last three years. However, the logistic regression with a 95% confidence interval revealed that increased exposure to gamma radiation can increase the risk of some occupational diseases. Table 5 shows the risk of occupational diseases caused by exposure to gamma radiation.

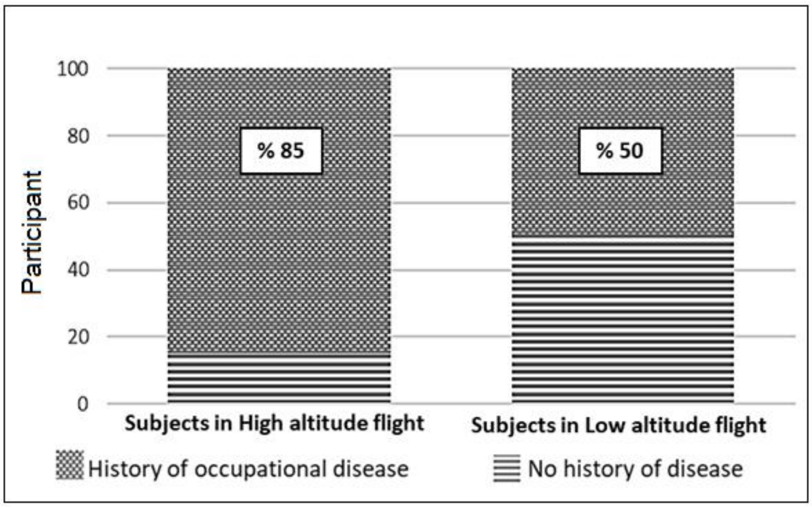

Figure 3: History of occupational diseases regarding the flight crews at different attitudes

Table 5: Risk of occupational diseases induced by exposure to gamma radiation

History of occupational diseases		Number of people exposed to gamma: High exposure	Low exposure	RR (CI; %95)	Pvalue
Gastrointestinal diseases	yes	26	9	3.55 (1.17-6.00)*	0.016
	no	74	91		
Cutaneous diseases	yes	24	8	3.63 (1.25-6.4)*	0.018
	no	76	92		
Hormone diseases	yes	27	12	2.71 (0.95-4.24)	0.64
	no	73	88		
Blood diseases	yes	8	9	0.87 (0.25-1.83)	0.43
	no	92	91		
Cardiovascular diseases	yes	11	1	12.4 (1.33-31.9)*	0.006
	no	89	99		

RR: Risk Ratio
*Statistically significant at $p < 0.05$

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Table 5 shows that exposure to gamma radiation was significantly associated with the experience of gastrointestinal, cutaneous, and cardiovascular diseases ($P < 0.05$). The crew on high altitude flights were more exposed to cosmic gamma radiation and had 3.55, 3.63 and 12.4 times a higher risk of developing gastrointestinal, cutaneous, and cardiovascular diseases, as compared with the aircrew on low-altitude flights, respectively.

Discussion

There was significant difference between the average annual effective dose of gamma radiation at low altitudes (3.6 mSv / year) and high altitudes (4.96 mSv / year). Moreover, exposure to radiation increased the overall risk of occupational diseases. Thus, the prevalence of occupational diseases was 85% and 50% among the aircrew members on the high-and low-altitude flights. In addition, the risk of gamma radiation related diseases, including gastrointestinal, skin, and medical diseases, was 3.55, 3.63, and 12.4 times higher for the personnel in high altitude compared to those in low altitude.

Lewis B et al. found that the average annual dose of cosmic ionizing rays including gamma and neutrons received by the aircrew in Canada ranged from 1 to 5 mSv/year [8]. Furthermore, Hajo Zeeb et al. reported that average annual exposure to cosmic rays ranged from 2 to 5 mSv/year [19]. Lewis BJ et al. revealed that the average annual exposure to cosmic rays was 2-6 mSv/year for the aircrew [20]. The results of this study showed that the average annual effective dose of gamma radiation at high altitudes (31000 feet) was about 5 mSv/year. Probably, long working hours had increased the annual dose calculation in this study.

Many studies have been conducted on the potential harmful effects of cosmic rays [21] on health Li C et al. reported a high prevalence of gastrointestinal disease (39.22%) among the crew. However, there were many ambiguities about the causes of this disease [22]. In the present study, the prevalence rates of gastrointestinal disease were 9% and 26%, for the aircrew in low-and high-altitude flights, respectively. Hence, the average annual effective dose of gamma radiation could be associated with the increased risk of gastrointestinal diseases among the crew at high altitudes. Although this study was not free of error, occupational and demographic characteristics were the same for both groups, while the flight altitude and mean annual effective dose of gamma radiation were different for the two groups. Therefore, it can be concluded that exposure to gamma rays can play an effective role in the spread of gastrointestinal diseases among the aircrew members. Dreger S et al. and Meier MM et al. attributed the increased prevalence of cutaneous diseases among the aircrew to the average annual effective dose of gamma radiation [23,24]. In the study by Rafnsson et al. it was shown that exposure to gamma rays increased the risk of melanoma in aircrew by 10.2 times [25]. The aircrew on high-altitude flights, who were more exposed to cosmic gamma radiation, were 3.63 times more likely to develop skin diseases compared to those on low-altitude flights. Gamma radiation seems to play a role in the incidence of cutaneous diseases among the aircrew members. On the other hand, according to Gudmundsdottir et al.'s study cockpit windshields protected the aircrew from UV-A radiation, which can damage the skin [26]. Therefore, exposure to gamma in this study can be more likely to cause skin disease.

Chairina N et al. revealed that pilots were at a higher risk of death from heart attacks [27]. In this study, exposure to gamma radiation was introduced as an effective factor in the incidence of cardiovascular diseases. Exposure to this radiation could increase the risk of cardiovascular disease by 12 times. The reason for this complication was exposure to gamma, which had been pointed out by similar studies, indicating that exposure to gamma radiation may induce oxidative stress and trigger changes in lipoprotein structure as well as lipid metabolism disorders. In particular, an increase in oxidative stress-induced lipid as a defense mechanism against lipid peroxidation in cellular membranes leads to dyslipidemia and increased blood lipid levels [28]. Thus, high blood lipid levels are known to be risk factors for

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cardiovascular diseases. Atherosclerosis can lead to a sudden and fatal heart attack. Moreover, a significant correlation was found between BMI and prevalence of diseases among the aircrew members at high altitudes due to increased lipid peroxidation induced by gamma radiation.

One of the limitations of this study was that all the occupational and environmental harmful factors such as job stress, unhealthy diet, and circadian rhythm sleep disorders caused by irregular working patterns, and exposure to noise, vibration, ozone, and airborne chemical contaminants can impact the development of occupational diseases. The roles of these factors in the incidence of diseases had not been investigated in the present study due to financial constraints. Therefore, exposure to gamma radiation cannot be considered the main cause of cardiovascular diseases despite the similarities in occupational and demographic characteristics between the two groups. The weakness of the studies in this scientific field had also been cited by Kim JN and Rafnsson V [15,29]. Moreover, an exact dose-response relationship had not been observed between gamma exposure and the incidence of various cancers and occupational diseases among the aircrew members, and it was difficult to interpret the dose-response data [23].

Conclusion

High-altitude flights are associated with increased exposure to gamma radiation, leading to a three-fold increased risk of occupational diseases such as gastrointestinal, skin, and cardiovascular diseases among flight crew members. These findings highlight the importance of reducing health risks regarding gamma radiation exposure in the aviation industry and emphasize the need for preventive measures to protect the well-being of aircrew. Given that there is much uncertainty about the exact cause of these effects in flight crews. Therefore, more studies in this field are needed by all countries to adopt policies to reduce and control exposure to these natural radiations. It is suggested that the first step is to take preventive health measures, such as reducing working hours, planning high-speed flights at low altitudes, and creating rotating shift programs with sufficient rest between shifts.

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Conflict of interest

The authors declared no conflict of interest.

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Ethical considerations

Authors were aware of, and complied with the best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, and competing interests regarding research ethics. Authors adhered to the publication requirements that required the submitted work to be original and that it had not been published elsewhere and in any languages.

Code of ethics

Code no. IR.BMSU.REC.1399.576.

Authors' contributions

All the authors contributed to data collection, data analyses and manuscript writing.

References

1. Mishev A, Usoskin I. Assessment of the radiation environment at commercial jet flight altitudes during GLE 72 on 10 September 2017 using neutron monitor data. Space Weather. 2018;16(12):1921-9.
2. Cinelli G, Gruber V, De Felice L, et al. European annual cosmic-ray dose: estimation of population

exposure. Journal of maps. 2017;13(2):812–21.
3.Shouop CJG, Moyo MN, Mekongtso EJN, et al. Radiological protection requirements with regard to cosmic ray exposure during air travel. Eur Phys J Plus. 2020;135(5):438.
4.Mertens CJ, Grajewski B, Kress BT, et al. Atmospheric ionizing radiation from galactic and solar cosmic rays. Intech Open. 2012:683-738.
5.Protection I. Recommendations of the international commission on radiological protection: Adopted January 17. International Commission on Radiological Protection. 1977.
6.Gholipour Peyvandi R. Gamma radiation exposure of aircrew in tehran-bandarabbas flights. J Nucl Sci Technol. 2011;32(2):37-40.
7.Friedberg W, Faulkner D, Snyder L, et al. Galactic cosmic radiation exposure and associated health risks for air carrier crewmembers. Aviat Space Environ Med. 1989;60(11):1104-8.
8.Lewis B, McCall M, Green A, et al. Aircrew exposure from cosmic radiation on commercial airline routes. Radiat Prot Dosimetry. 2001;93(4):293-314.
9.Eyvazlou M, Asghari A, Mokarami H, et al. Musculoskeletal disorders and selecting an appropriate tool for ergonomic risk assessment in the dental profession. Work. 2021;68(4):1239-48.
10. Enyinna PI. Radiological risk assessment of cosmic radiation at aviation altitudes (a trip from Houston Intercontinental Airport to Lagos International Airport). J Med Phys. 2016;41(3):205.
11. Lim M. Cosmic rays: are air crew at risk?. Occup Environ Med. 2002;59(7):428-32.
12. Rafnsson V, Hrafnkelsson J, Tulinius H. Incidence of cancer among commercial airline pilots. Occup Environ Med. 2000;57(3):175-9.
13. Yong LC, Pinkerton LE, Yiin JH, et al. Mortality among a cohort of US commercial airline cockpit crew. Am J Ind Med. 2014;57(8):906-14.
14. Maculewicz E, Pabin A, Dziuda L, et al. Selected exogenous (occupational and environmental) risk factors for cardiovascular diseases in military and aviation. J Clin Med. 2023;12(23):7492.
15. Kim JN, Lee BM. Risk factors, health risks, and risk management for aircraft personnel and frequent flyers. J Toxicol Environ Health B. 2007;10(3):223-34.
16. Mahmoud Pashazadeh A, Aghajani M, Nabipour I, et al. Annual effective dose from environmental gamma radiation in Bushehr city. J Environ Health Sci Eng. 2014;12:1-4.
17. Spiers FW, Thompson I, Gibson J. A guide to the measurement of environmental gamma-ray dose rate. CM-P00066948; 1981.
18. Mehra R. Use of gamma ray spectroscopy measurements for assessment of the average effective dose from the analysis of 226Ra, 232Th, and 40K in soil samples. Indoor Built Environ. 2009;18(3):270-5.
19. Zeeb H, Hammer GP, Blettner M. Epidemiological investigations of aircrew: an occupational group with low-level cosmic radiation exposure. J Radiol Prot. 2012;32(1):N15.
20. Lewis B, Bennett L, Green A, et al. Aircrew dosimetry using the predictive code for aircrew radiation exposure (PCAIRE). Radiat Prot Dosimetry. 2005;116(1-4):320-6.
21. Šupić A, Bečirović A, Zrilić M, et al. Radiation effects in aircraft and the impact on human body. 2018:3(5):34.
22. Li C, Xu J, Yin D, et al. Prevalence and trigger factors of functional gastrointestinal disorders among male civil pilots in China. Sci Rep. 2021;11(1):2021.
23. Dreger S, Wollschläger D, Schafft T, et al. Cohort study of occupational cosmic radiation dose and cancer mortality in German aircrew, 1960–2014. Occup Environ Med. 2020;77(5):285-91.
24. Meier MM, Matthiä D. Assessment of the skin dose for aircrew. J Radiol Prot. 2017;37(2):321.
25. Radon K, Aberl S, Nowak D, et al. Incidence of cancer among commercial airline pilots. Occup Environ Med. 2000;57(12):843.
26. Gudmundsdottir EM, Hrafnkelsson J, Rafnsson V. Incidence of cancer among licenced

[DOI: 10.18502/jehsd.v9i1.15118]

commercial pilots flying North Atlantic routes. Environmental Health. 2017;16(1):1-10.

27. Chairina N, Werdhani R, Gathmyr D. Association of total flight hours with lipid blood profiles among civilian pilots in Indonesia. J Phys Conf Ser. 2018;1073(4):042012.
28. Huang H, Liu J, Feng Y, et al. The distribution of apolipoprotein E gene polymorphism in Chinese civil aircrews, and a possible risk factor to their overweight and dyslipidemia is cumulative flight time. Clin Chim Acta. 2013;416:36-40.
29. Rafnsson V, Hrafnkelsson J, Tulinius H, et al. Risk factors for cutaneous malignant melanoma among aircrews and a random sample of the population. Occup Environ Med. 2003;60(11): 815-20.

