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Radiation-related neoplasms, circulatory diseases, and cataracts among radiological technologists

S.F. Li, C.T. Hung, M.W. Lee*

Department of Healthcare Administration, Central Taiwan University of Science and Technology, Taiwan, (R.O.C.)

▸ ***Original article***

***Corresponding author:**
Dr. Mei-Wen Lee,
***Fax:** +886 4 2239 1000*
***E-mail:** mwlee@ctust.edu.tw*

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ABSTRACT

Background: In response to the need for diagnosis and treatment, medical radiation has been increasingly used worldwide. This study investigated the medical utilization of radiation-related diseases among radiological technologists (RTs) and factors that influence such diseases. ***Materials and Methods***: Data were collected from the Taiwan National Health Insurance Research Database. A panel study was conducted with a sample of 3,432 RTs obtained in 2007 and followed up until 2011. Logistic regression applying generalized estimating equations was used for investigating the relationship between RTs and radiation-related diseases. ***Results:*** Among the RTs, the annual medical utilization rate of hospitalization for radiation-related neoplasms was 1.17‰-4.43‰, that for circulatory diseases was 4.68‰-11.50‰, and the annual medical utilization rate of outpatient visits for cataracts was 2.91‰-7.38‰. After sex, age, hospital accreditation level, and hospital ownership were controlled, the odds of hospitalization for neoplasms and circulatory diseases among the RTs were nonsignificantly higher than those of pharmacists, and the odds of outpatient visits for cataracts among the RTs were nonsignificantly lower than those of pharmacists. ***Conclusion:*** No sufficient evidence exists to substantiate the argument that the exposure of RTs to current doses of radiation could increase the risk of neoplasms, circulatory diseases, and cataracts. Considering the increased use of radiation treatment in current medical facilities, all speculation on occupational radiation-induced diseases must be further investigated and verified.

Keywords: *Radiological technologist, occupational exposure, neoplasm, circulatory disease, cataract.*

INTRODUCTION

The application of numerous novel radiological procedures in contemporary medicine has considerably increased the use of medical radiation. A previous study indicated that the annual average effective dose for radiologic technologists (RTs) was more than 2 times higher than that for physicians, dentists, dental hygienists, and other radiation workers [(1)]. Another study determined that because of increased patient workload and insufficient physical or engineering measurement of radiation safety, technologist groups were subject to higher levels of radiation exposure compared with other medical radiation workers [(2)]. An additional study compared the annual average effective doses for medical radiation workers in 2004–2007 and 2008–2011 and found that the doses were significantly reduced in the latter period. This reduction was associated with the improvements (e.g., provision of new equipment and enhanced radiological protection in the work environment) that these workers' departments had made over the 8-year period. Although the annual average effective doses of the 2 periods for RTs were higher than those for physicians, physicists, and ancillary staff [(3)].

There are 2 types of radiation effects: stochastic and deterministic effects. Stochastic effects primarily concern cancers, whereas most discussions on deterministic effects include damage to the eyes and skin. In addition, experimental evidence suggests that stochastic effects can involve other no cancer effects, such as neurovascular and neurodegenerative effects [4]. Since 2011, the International Commission on Radiological Protection has focused substantially on circulatory diseases and cataracts because of recent evidence indicating higher incidences of injury than expected after exposure to low doses of radiation; therefore, threshold doses are seemingly lower than those previously considered [5]. According to the literature, this study examined the relationship between RTs and radiation-related diseases and mainly focused on neoplasms, circulatory diseases, and cataracts.

Nikjoo[6] reported that ionizing radiation induces bodily damage; regarding the time scale of radiation effects on biological systems, energy transfer (physical stage) begins before a femtosecond has elapsed; these radiation effects can be extended up to several years, causing tumors or secondary tumors (carcinogenesis). In addition, multiple studies have indicated that the long-term exposure of medical radiation workers to occupational low-dose ionizing radiation increases cancer risk; however, the results of these studies have often been inconsistent [7]. A study on cytogenetic monitoring revealed that the frequency of chromosomal aberrations among exposure groups (RTs) was significantly higher than those among control groups [8]. No consensus has been attained among the studies on the correlation between the exposure of RTs to low-dose ionizing radiation and cancer. Several studies have confirmed the influence of radiation exposure on cancer [9,10], whereas others have observed no such phenomenon [11-13].

Although patients receiving radiotherapy have increased mortality rates for circulatory diseases, the effects of chronic exposure to low-dose radiation remain uncertain [14]. In addition, the possible mechanisms by which low -dose and chronic exposure to radiation influence the development of cardiovascular diseases have yet to be determined [15]. Epidemiological data on low-dose radiation exposure groups are scarce and contradictory. Previous U.S. studies have reported that radiologists exhibited increased risks of cardiovascular diseases [16], whereas no similar phenomena were observed among radiologists in the United Kingdom [17]. A study suggested that U.S. RTs (USRTs) before 1950 exhibited a significantly increased mortality rate from circulatory diseases because of occupational exposure to considerably high doses of radiation. In addition, that study indicated that inconsistent results could be attributed to the unexplainable confounding effects of the potential risk factors for circulatory diseases [14].

Radiation effects on cataracts were previously considered to be deterministic and are currently recognized as possibly stochastic in nature. In addition, such effects occur at considerably lower radiation exposure levels than previously believed [18]. Ainsbury *et al.* [19] and Hammer *et al.* [20] have suggested that cortical cataracts could be related to ionizing radiation exposure, and evidence has indicated that nuclear cataracts are radiogenic. Studies have mainly focused on interventional radiology physicians to examine the influence of occupational radiation exposure on the eyes, and only limited research has investigated the influence on other medical staff. According to a survey examining the risk of cataracts among USRTs after exposure to low doses of ionizing radiation, workers in the highest category (mean, 60 mGy) compared with those in the lowest category (mean, 5 mGy) of occupational dose to the lens of the eye exhibited an adjusted hazard ratio of 1.18 for cataracts [21].

Currently, the health effects of low-dose ionizing radiation exposure remain undetermined. Large-scale cohort studies can provide useful information on the relationship between the risk of radiation-related diseases and occupational exposure to low-dose radiation. Most studies on the occupational radiation doses of interventional radiology have focused on physicians, and only limited research has explored the effect of exposure on medical staff (e.g., nurses and RTs). This study adopted data from the Taiwan National Health Insurance

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Research Database (NHIRD) to examine the medical utilization of radiation-related diseases among RTs and risk factors for such diseases.

MATERIALS AND METHODS

Data sources

The National Health Insurance program was implemented in Taiwan on March 1, 1995. The NHIRD contains nationwide data on outpatient visits, hospitalization, and medication, and every hospital and clinic is required to report the charges for outpatient visits, hospitalization, and medication to the Bureau of National Health Insurance monthly. The current coverage proportion of health insurance exceeds 99%, and thus, the health insurance data have become representative empirical data for studies on medicine and health. Before using the NHIRD, researchers must apply to the National Health Research Institutes and present evidence of approval from an institutional review board. After experts have reviewed and approved the application, the applicants can then access the NHIRD. The NHIRD is a large and comprehensive database constructed using population-based data sources. It provides encrypted patient identification numbers; information on patient sex, birth dates, medical records, medical treatments, medical costs, and occupation; and International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes of diagnoses and procedures. Therefore, this nationwide database provides an exclusive opportunity for researchers to investigate the relationship between the occupational exposure of RTs and radiation-related diseases.

Research design and samples

In this study, data were retrieved from the NHIRD, and a panel study was conducted to extract samples from the database. We collected repeated measurement data from 2007 to 2011 for investigating the medical utilization of radiation-related diseases among these patients during this 5-year period. Finally, in 2007, the cohort was composed of 3,432 RTs and 5,380 pharmacists. According to the purpose of this study, we followed up with these subjects for 5 years after 2007. A panel study was subsequently conducted to investigate the morbid conditions of the subjects during a specific time frame and changes in their medical utilization over multiple years.

In the NHIRD, the RTs in the category of medical staff were designated as the exposure group in this study. We used pharmacists as the control group for 2 reasons. First, RTs and pharmacists are both medical staff, which prevents the research results from being influenced by the healthy worker effect. Second, pharmacists' low probability of exposure to the sources of low-dose ionizing radiation reduces the influence of such exposure on the morbidity of radiation-related diseases. Considering the age at which medical staff started practicing medicine, we excluded participants whose working age was lower than 22 years or higher than 65 years. Moreover, pharmacists were excluded who practiced in nonmedical systems (e.g., pharmaceutical manufacturers or distributors). The hospital accreditation hierarchy and scale in Taiwan are related to the number of medical services. The hierarchy contains medical centers, regional hospitals, district hospitals, and basic medical facilities. On the basis of the levels of the institutions for which the RTs worked, the control group was selected from medical centers, regional hospitals, and district hospitals.

Definitions of variables

Dependent variables

Radiation-related diseases, such as neoplasms, circulatory diseases, and cataracts, were investigated in this study. According to the literature and to modify on radiation-related diseases among medical professionals, the ICD-9-CM diagnostic codes are 140–239, 390–459, and 366 for neoplasms [11,17], circulatory diseases [14,15], and cataracts [22], respectively.

Independent variables

To ascertain the influence of confounders other than occupation on the dependent variables, we used medical staff, sex, age,

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hospital accreditation level, and hospital ownership as independent variables.

Statistical analysis

Descriptive statistics were applied for analyzing the medical utilization of radiation-related diseases among the RTs and pharmacists during the specified years. A χ^2 test was adopted for testing the difference between the demographic variables of the RTs and pharmacists. A logistic regression analysis applying generalized estimating equations assumed the working correlation matrix to be autoregressive [AR(1)] after the confounders were controlled, and then the odds ratio (OR) of the medical utilization of radiation-related diseases among the RTs to those among the pharmacists was estimated. SPSS 17.0 for Windows was used for statistical data analysis, in which statistical significance was defined as $p < 0.05$ (2-tailed).

RESULTS

Regarding the radiation-related diseases among the RTs from 2007 to 2011, the annual medical utilization rate of hospitalization for neoplasms was 1.17‰–4.43‰, the annual medical utilization rate of hospitalization for circulatory diseases was 4.68‰–11.50‰, and the annual medical utilization rate of outpatient visits for cataracts was 2.91–7.38‰. Among the pharmacists, the annual medical utilization rate of hospitalization for neoplasms and circulatory diseases and that of outpatient visits for cataracts were 2.42‰–3.91‰, 4.65‰–9.68‰, and 4.83‰–8.61‰, respectively (table 1).

Table 1. Medical utilization rate of radiation-related diseases among study subjects

Year	Radiological technologists			Pharmacists		
	Neoplasms	Circulatory diseases	Cataracts	Neoplasms	Circulatory diseases	Cataracts
2007	1.17	5.83	2.91	2.42	4.65	4.83
2008	2.05	4.68	4.68	2.98	5.02	7.81
2009	2.95	11.50	4.42	3.01	6.78	6.97
2010	4.43	6.49	7.38	3.91	7.63	8.61
2011	3.55	7.70	5.03	3.50	9.68	8.24

The demographic data of the samples indicated that the RTs and pharmacists had significantly different sex and age distributions. The hospitalization for neoplasms and circulatory diseases and outpatient visits for cataracts between the RTs and pharmacists differed nonsignificantly. In addition, the distributions of hospital accreditation level and hospital ownership between the RTs and pharmacists did not vary significantly (table 2).

Logistic regression analysis applying generalized estimating equations was used for examining the factors that influenced the hospitalization for neoplasms among the RTs. After sex, age, hospital accreditation level, and hospital ownership were controlled, the odds of hospitalization for neoplasms among the RTs were higher than those among the pharmacists, but the difference was statistically nonsignificant (OR = 1.231, p = 0.440). The male medical staff yielded significantly lower odds of hospitalization for neoplasms than the female medical staff did (OR = 0.439, p = 0.005). In addition, the medical staff aged 36–45, 46–55, and 56–65 years had significantly higher odds of hospitalization than those aged 22–35 years did (OR = 3.324, p = 0.004; OR = 7.248, p < 0.001; OR = 16.150, p < *0.667*). The analysis of factors influencing the hospitalization for circulatory diseases among the RTs revealed that after the confounders were controlled, the RTs had higher odds of hospitalization for circulatory diseases than the pharmacists did, but the difference was statistically nonsignificant (OR=1.112, p = 0.448). The male medical staff yielded significantly higher odds of

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Table 2. Characteristics of study subjects in 2007.

	Radiological technologists(RTs) n (%)	Pharmacists n (%)	*p*
Sex			<0.001
Male	1,580(46.0)	1,733(32.2)	
Female	1,852(54.0)	3,647(67.8)	
Age			
22-35	2,190(63.8)	2,973(55.3)	
36-45	851(24.8)	1,456(27.1)	<0.001
46-55	285(8.3)	782(14.5)	
56-65	106(3.1)	169(3.1)	
Neoplasms			
Yes	4(0.1)	13(0.2)	0.192
No	3,428(99.9)	5,367(99.8)	
Circulatory diseases			
Yes	20(0.6)	25(0.5)	0.448
No	3,412(99.4)	5,355(99.5)	
Cataracts			
Yes	10(0.3)	26(0.5)	0.168
No	3,422(99.7)	5,354(99.5)	
hospital accreditation level			
Medical center	1,198(34.9)	1,843(34.3)	0.090
Regional hospital	1,373(40.0)	2,075(38.6)	
District hospital	861(25.1)	1,462(27.2)	
Hospital ownership			0.063
Public hospital	1,062(30.9)	1,763(32.8)	
Nonprofit hospital	1,447(42.2)	2,137(39.7)	
Private hospital	923(26.9)	1,480(27.5)	

X^2 tests is applied to analyze the data between RTs and pharmacists.

hospitalization for circulatory diseases than the female medical staff did (OR = 1.627, $p < 0.001$). Moreover, the odds of hospitalization for circulatory diseases in medical staff aged 36–45, 46–55, and 56–65 years were significantly higher than in those aged 22–35 years (OR=1.908, $p < 0.001$; OR = 4.211, $p < 0.001$; OR = 7.499, $p < 0.001$). Subsequently, we examined the factors that influenced the outpatient visits for cataracts among the RTs and found that after the confounders were controlled, the RTs yielded lower odds of outpatient visits for cataracts than the pharmacists did, but the difference was statistically nonsignificant (OR=0.788, $p = 0.214$). Medical staff aged 36–45, 46–55, and 56–65 years had significantly higher odds of outpatient visits for cataracts than those aged 22–35 years did (OR = 2.353, $p = 0.004$; OR = 7.996, $p < 0.001$; OR = 40.817, $p < 0.001$). In addition, the medical staff working in regional hospitals had significantly lower odds of outpatient visits for cataracts than those working in district hospitals did (OR=0.603, p=0.044) (table 3).

DISCUSSION

The relationship between low-dose ionizing radiation and latent cancer risk remain undetermined, and the extrapolation of animal experimental results still involves numerous uncertainties. Therefore, long-term and continual monitoring of occupational chronic exposure to low-dose ionizing radiation is necessary.

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Table 3. Factors influencing of radiation-related diseases according to logistic regression applying generalized estimating equations.

	neoplasms			circulatory diseases			cataracts		
Variables	OR	95% CI	*p*	OR	95%CI	*p*	OR	95%CI	*p*
Sex									
Male	0.439	0.249-0.775	0.005	1.627	1.240-2.134	<0.001	0.886	0.625-1.257	0.499
Female	Reference			Reference			Reference		
Medical staff									
Radiologic technologists	1.231	0.726-2.088	0.440	1.112	0.846-1.461	0.448	0.788	0.541-1.148	0.214
Pharmacists	Reference			Reference			Reference		
Age									
36-45	3.324	1.483-7.452	0.004	1.908	1.351-2.695	<0.001	2.353	1.320-4.196	0.004
46-55	7.248	3.559-14.761	<0.001	4.211	2.964-5.981	<0.001	7.996	4.691-13.630	<0.001
56-65	16.150	7.248-35.982	<0.001	7.499	4.861-11.569	<0.001	40.817	24.190-68.871	<0.001
22-35	Reference			Reference			Reference		
Hospital accreditation level									
Medical center	1.082	0.592-1.978	0.798	0.852	0.583-1.246	0.410	0.678	0.411-1.118	0.128
Regional hospital	0.780	0.389-1.565	0.484	0.931	0.633-1.368	0.715	0.603	0.369-0.987	0.044
District hospital	Reference			Reference			Reference		
Hospital ownership									
Public hospital	1.045	0.572-1.909	0.886	1.034	0.703-1.520	0.865	1.183	0.738-1.897	0.484
Nonprofit hospital	0.895	0.441-1.817	0.760	1.000	0.687-1.455	0.998	0.878	0.537-1.438	0.606
Private hospital	Reference			Reference			Reference		

OR = Odds ratio; CI = confidence interval.

No conclusion has been consistently deduced on the mortality rate or risk of radiogenic cancers caused by chronic low-dose radiation exposure among RTs. We investigated the factors influencing the hospitalization for neoplasms and determined that the RTs had higher odds of hospitalization for neoplasms compared with the pharmacists, but the difference was statistically nonsignificant. Similarly, a USRT cohort study revealed that the incidences of all cancers exhibited marginal increases [10]. That study indicated that USRTs hired in 1940 or earlier exhibited higher risks of all cancers compared with those hired in 1960 or after [9]. Another study on USRTs investigated the influence of chronic low-dose ionizing radiation exposure on all cancers, and although no influence was observed, the results revealed a strong healthy worker effect [12]. A cohort study on Japanese male RTs indicated that the standardized mortality ratios of all malignant neoplasms were 0.81. In addition, that study showed no significant correlation between the relative risks of cancers of major sites and the estimated cumulative radiation doses [11]. A previous study that involved collecting data from the National Dose Registry of Canada, which is linked to the Canada Cancer Database, for analyzing cancer incidence and occupational radiation exposure indicated that a deficit existed in the standardized incidence ratios of all cancers among dental, medical, industrial, and nuclear power workers [13]. In this study, we identified that the male medical staff exhibited significantly lower odds of hospitalization for neoplasms compared with the female medical staff. This finding is consistent with that of Sigurdson *et al.* [10] who indicated that female RTs had an increased risk of all solid tumors, whereas male RTs experienced a decreased risk of solid tumors. In this study, the RTs and pharmacists with increased age exhibited significantly higher odds of hospitalization for neoplasms. A study investigating the influence of long-term radiation exposure on the frequency of chromosomal aberrations presented a similar result in that both RTs and the control group exhibited increased frequencies as their age increased [8].

Concerns regarding the correlation between low-dose ionizing radiation exposure and the incidence of circulatory diseases began emerging among cohorts, who were subjected to various types of occupational exposure, and Japanese atomic bomb survivors; however, the correlation between the 2 remained considerably controversial [23]. In addition, few studies have focused on medical staff. A USRT study indicated that the possibly high doses of occupational radiation exposure before 1950 increased the mortality rate caused by circulatory diseases [14]. According to a cohort study based on the National Dose Registry of Canada, the highest annual average medical worker radiation exposure occurred in the mid-1950s, after which the doses declined, reached extremely low levels in the mid-1970s, and remained at similar levels afterward [7]. Compared with the influence of high radiation doses on circulatory diseases before 1950, the radiation hazard to health should have decreased as the radiation doses decreased. The statistics published by the Atomic Energy Council in Taiwan showed that the annual average dose of all medical radiation workers from 2007 to 2011 was 0.04–0.03 mSv, and that of the medical radiation workers who had positive dose measurements was 0.78–0.51 mSv. Both doses were low and declined annually, indicating that the influence of radiation on health was decreasing. The results of the current study showed that the RTs yielded higher odds of hospitalization for circulatory diseases than the pharmacists did, but the difference was statistically nonsignificant. Our research results were consistent with those presented in a systematic review of low-dose ionizing radiation and circulatory diseases. According to this review, previous epidemiological studies have not provided compelling evidence that, on the basis of the data of the atomic bomb survivors, ionizing doses of 0–4 Sv could result in risks of circulatory diseases [24]. This study found that the male medical staff exhibited significantly higher odds of hospitalization for circulatory diseases compared with the female medical staff. The cohort study based on the National Dose Registry of Canada can be referred to when discussing the health effects of sex on the occupational radiation exposure of medical staff. That study indicated that men had significantly increased risks of circulatory diseases, whereas women did not [25]. In the present study, the odds of hospitalization for circulatory diseases among medical staff significantly increased over time. However, nun RTs had decreased risks of ischemic heart disease as their age increased [26]. The epidemiological evidence concerning medium- and low-dose ionizing radiation and the effects of circulatory diseases remained suggestive instead of persuasive [15]. In short, except for the atomic bomb study, other studies have not provided strong evidence of increased risk of circulatory diseases below doses of a few Sv [27]. Therefore, the relationship between low-dose ionizing radiation and circulatory disease requires additional studies and data on occupational exposure.

Although the mechanisms of radiation-induced cataracts remain undetermined, a 20-year prospective cohort study found that the low-dose ionizing radiation exposure of USRTs could damage the lens of the eye and increase the long-term risks of cataracts formation [21]. Another study indicated that, compared with unexposed medical workers, radiologists and RTs had a higher prevalence of cataracts [28]. In this study, we corrected the confounders and subsequently found that the RTs exhibited lower odds of outpatient visits for cataracts compared with the pharmacists, but the difference was statistically nonsignificant. In addition to age and sex, the risk factors for cataracts include sunlight exposure, genetic factors, diabetes, obesity, alcohol consumption, smoking, and using corticosteroids [19-21]. Because of the limitations of the database, we could not eliminate the influence of these risk factors on cataracts. This study found that as age increased, the medical staff had significantly increased odds of outpatient visits for cataracts, which is consistent with a study that revealed that Finnish physicians (including radiologists and cardiologists) exposed to ionizing radiation had

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increased prevalence of lens opacity as their age increased [29].

This study had 3 advantages. First, we analyzed the low-dose ionizing radiation exposure among a high number of samples during a specific period and compared the exposure and control groups. Second, the samples were drawn from the nationwide data in the NHIRD. Finally, both the exposure and control groups constituted medical staff, which reduced the healthy worker effect. Nevertheless, this study had 3 limitations. First, similar to previous studies that have investigated the occupational radiation exposure of RTs and disease mortality rates [9,12,14,30], this study lacked individual dose estimates. Therefore, causal relationships could not be established in this study. Second, general low-dose radiation exposure does not cause health effects over short periods, and several radiation-related diseases could occur after 5 years of follow-up. Therefore, the follow-up period in subsequent studies should be extended for determining the relationship between low-dose radiation exposure and health effects. Finally, in addition to age and sex, other risk factors for neoplasms, cardiovascular diseases, and cataracts were unavailable in the database, which could have generated confounding biases.

CONCLUSIONS

No sufficient evidence exists to substantiate the argument that the exposure of RTs to current doses of radiation could increase the risk of neoplasms, circulatory diseases, and cataracts. In response to the need for diagnosis and treatment, medical radiation has been increasingly used worldwide. In most recent studies, workers have been followed up for relatively short periods; thus, continual monitoring of the health status of medical radiation workers is necessary. Nonetheless, considering the increased use of radiological treatment in contemporary medical facilities, all speculation related to occupational radiation-induced diseases must be further explored and verified.

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Conflict of interest*: *Declared none.

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