Hospitalization for cancer among radiologists in Taiwan

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Key words
Radiologists; occupational exposure; neoplasms; low-dose ionizing radiation

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Summary
Background: *Population aging and the incremental use of high-tech instruments increase the demand for radiological examinations and treatments in medical services. The exposure of radiologists and other medical workers to medical treatment radiation may thus be increased.* **Objectives:** *The aim of the study was to explore the average number of cancer hospitalizations and use of hospitalization as cancer treatment for radiologists compared with that for family medicine physicians, as well as the trends in the annual average number of cancer hospitalizations among radiologists.* **Methods:** *Research data were obtained from the 2000-2010 Taiwan National Health Insurance Research Database. These samples collected for this study were unbalanced panel data.* **Results:** *The average number of cancer hospitalizations for radiologists from 2000 to 2010 ranged between 3.67 and 28.26 ‰. After controlling the effects of gender, age, hospital accreditation level and year using generalized estimating equations with a binomial distribution and logit link function, our study found that radiologists had an insignificantly higher risk of cancer hospitalizations compared with family medicine physicians. However, the average number of cancer hospitalizations for radiologists showed an annual decline from 2000 to 2010.* **Conclusions:** *Compared with family medicine physicians, radiologists had an insignificantly higher risk of cancer hospitalizations. The data period examined in this study was only 11 years. Considering the numerous new radiological procedures currently in use in modern medical treatments, the health status of medical radiation workers should be continuously monitored in the future.*

Riassunto
«Incidenza di ricoveri ospedalieri per cancro tra i radiologi di Taiwan». **Introduzione:** *Il generale invecchiamento delle popolazioni e l'aumentato utilizzo di strumenti ad alta tecnologia, ha incrementato la richiesta di indagini radiologiche e di trattamenti terapeutici radianti nelle strutture mediche. E' pertanto aumentata la esposizione dei radiologi e di altri lavoratori della sanità alle radiazioni utilizzate a scopo medico.* **Obbiettivi:** *Lo studio è stato condotto al fine di determinare il numero di casi di ricovero ospedaliero e di utilizzo del ricovero in ospedale per trattamenti oncologici fra i radiologi in confronto a quelli rilevabili nella categoria dei medici di famiglia. Si è voluto anche valutare il trend annuale del numero di casi di ricovero per neoplasia fra i radiologi.* **Metodi:** *I dati*

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sono stati ottenuti dai Registri dell'Istituto Assicurativo Nazionale per le malattie in Taiwan nel periodo 2000-2010. **Risultati:** *Il numero medio di ricoveri per neoplasia fra i radiologi negli anni considerati variava fra 0,37 e 2,83%. Dopo aver controllato per l'effetto di genere, età, livello di accreditamento ospedaliero e anno, utilizzando modelli GEE basati su distribuzione binominale dei dati e funzione logit di link, il nostro studio ha documentato una maggiore, seppur non significativa, ospedalizzazione per cancro nei radiologi rispetto ai medici di medicina generale. Tuttavia il numero medio di ricoveri per neoplasia dei radiologi è andato diminuendo ogni anno dal 2000 al 2010.* **Conclusioni:** *In confronto ai medici di famiglia, i radiologi hanno una non significativa maggiore incidenza di ricoveri ospedalieri per neoplasia. Il periodo di osservazione di questo studio è stato però di soli 11 anni. Considerando d'altra parte le numerose nuove procedure radiologiche, introdotte nella pratica medica odierna, lo stato di salute dei lavoratori esposti alle radiazioni dovrebbe essere continuamente controllato nel tempo.*

Introduction

Continued population aging and the use of high-tech instruments is expected to increase demands for radiology services in medical treatments. The use of fluoroscopy in modern medical treatments has rapidly increased. Consequently, the radiation risks faced by medical workers in interventional radiology procedures have become a focal topic of occupational radiation protection for numerous hospitals. Although the average annual effective dose that radiologists are exposed to has declined significantly over the years, major changes in medical equipment have led to physicians performing fluoroscopically guided procedures, which differ from other diagnostic procedures. Clinically, physicians are generally closer to patients and the X-ray imager, which increases the difficulty of avoiding exposure to scatter radiation during procedures.

Currently, there is high uncertainty regarding extrapolating low-dose radiation rates to cancer risks. Data on low-dose radiation are mostly obtained from insights regarding the interaction mechanisms between radiation and live cells, which are investigated during cell research and animal experiments related to radiobiology (19). Limitations exist in radiobiological research. For example, the radiation-induced biological endpoints were observations of cells and laboratory animals, which are often not reproducible and cannot directly reflect the carcinogenic effects of radiation on humans (19). Therefore, conducting a large-scale occupational exposure study can provide valuable data regarding this topic.

Previous studies have indicated that radiologists are the first occupational population to be exposed to ionizing radiation. Monitoring the trends of their disease mortality rates provided an understanding of the long-term effects that fractionated exposures to low-dose ionizing radiation have on health (1). Numerous research reports have indicated that radiologists employed before the 1950s may have been exposed to relatively higher doses of radiation. Significant radiogenic cancers commonly observed include leukaemia (1, 14, 20), non-Hodgkin lymphomas (1, 14), thyroid cancer (22), and breast cancer (21). Research indicates that since 1920, the activities of the U.K. X-Ray Safety Committee led to a decrease in radiation exposures of British radiologists. Consequently, the health of radiologists significantly improved after the 1920s (3).

Reviews of literature related to the health effects of occupational exposure to low-dose ionizing radiation for radiologists are rare. Carpenter et al (4) indicated that the total mortality and total cancer incidence among 1,589 British radiologists and radiotherapists monitored from 1962 to 1992 did not significantly exceed that of other physicians. However, death due to respiratory diseases among radiologists and radiotherapists significantly increased. Matanoski et al (13) found that radiologists in the United States exhibited a significant 1.38-fold increase in the standardized mortality ratio (SMR) for all cancers compared with physicians in other specialties. Compared to other medical practitioners, British radiologists showed a significant 1.16-fold increase in the SMR for all cancers (1).

Currently, there is no significant evidence that exposure to low-dose ionizing radiation among medical radiation workers increases their cancer risks. However, numerous new radiological procedures in use in modern medical treatments may increase demands for radiology services in medical treatments and the workloads of radiologists. Therefore, the health effects of exposure to low-dose ionizing radiation during procedures should be continuously monitored. To date, studies related to the health effects of radiation exposure for radiologists are limited. Moreover, such studies typically use the SMR or relative risk (RR) of all cancers or site-specific cancers for investigation (1, 2, 4, 10, 21). This study differs from other research studies, which adopted generalized estimating equations (GEEs) with a binomial distribution and logit link function that was used to control the confounding factors in the collected unbalanced panel data before comparing cancer hospitalization between radiologists and family medicine physicians. Furthermore, this study explored the relationship between occupational exposure to low-dose ionizing radiation and cancer hospitalization by radiologists. Because many studies monitored medical radiation workers for an insufficient number of follow-up periods, and considering the significant increase of new radiological procedures introduced in modern medical treatments, continuously monitoring the health status of radiologists is essential. The objectives of this study were to analyse the annual average number of cancer hospitalizations of radiologists between 2000 and 2010, control the confounding factors before evaluating and comparing cancer hospitalization among radiologists with that among family medicine physicians, and examine the trends in the annual average number of cancer hospitalizations of radiologists.

Methods

Database

The data used for this study were obtained from the National Health Insurance Research Database (NHIRD) provided by Taiwan's National Health Research Institutes. The National Health Insurance (NHI) project in Taiwan began on March 1, 1995. The NHI is a social insurance scheme mandatory for all citizens. Currently, the NHI covers almost all Taiwanese citizens. As of 2012, 23.2 million of the 23.26 million people in Taiwan are enrolled in the NHI scheme, for an insurance coverage rate of close to 99.8%. The NHIRD contains comprehensive hospitalization and treatment data, including the register for contracted medical facilities (HOSB), register for board-certified specialists (DOC), and inpatient expenditure by admission (DD). Each piece of hospitalization data features the patient's principal diagnostic code and principal operational procedure code, as well as four secondary diagnosis codes and four principal operational procedure codes, as specified in the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM). Among current population-based international databases, the NHIRD comprises data of a large number of people and covers a wide range of dimensions. Therefore, this database offers a unique opportunity to explore the relationship between occupational exposure to low-dose ionizing radiation and hospitalization for cancer.

Study design and sample

The data in this research were obtained for the years 2000 to 2010 from the NHIRD. The samples collected were unbalanced panel data. This study retrieved repeated measurement data from 2000 to 2010 from the Taiwan NHIRD. Analysis of pooled data collected for the 11 years showed that the observed number of radiologists and family medicine physicians was 8,512 and 9,889, respectively. Adopting panel data analysis that includes the concepts of cross-sections and time-series, we can observe a group of people's data in both space and time dimension. Furthermore, the quality and quantity data can be enhanced in panel data analysis.

Physicians in the exposure group of this study were selected from the NHIRD in the fields of diagnostic radiology, radiation oncology, and nuclear medicine. Cardiologists with higher radiation doses were excluded from the sample. To prevent the healthy worker effect from influencing the research results, physicians (the control group) were selected from the same professional group as the radiologists (9). The ages of all study subjects were limited between 30 and 65 years. The reasons for selecting family medicine physicians as the control group were as follows: (a) Family medicine physicians have a low probability of coming into contact with instruments that emit low-dose ionizing radiation during their work procedures, thus reducing the effects of low-dose ionizing radiation on the cancer risks of the control group; and (b) the accreditation level and scale of hospitals in Taiwan are related to the range of medical treatment services provided. Hospital accreditations categorize institutions that provide health care as medical centres, regional hospitals, district hospitals, or primary care clinics. Radiologists are typically not employed at primary care clinics. To match the professional status of the exposure group, only physicians employed at medical centres, regional hospitals, and district hospitals were recruited for the control group; physicians at primary care clinics were eliminated from the sample. Finally, this study selected family medicine physicians, obtaining an approximate 1:1 ratio to radiologists.

Research variables

Dependent variables

To explore whether fractionated exposures to low-dose ionizing radiation have health effects for physicians of various specialties, this study used whether staying in hospitals or not for cancer among radiologists and family medicine physicians in the years investigated as the dependent variable. The ICD-9-CM cancer confirmation code is 140-239. To improve the accuracy of the retrieved data, those participants who died after being selected for this study and were diagnosed with cancer before becoming practitioners were eliminated from the samples. Regarding the exclusion of mortality, we removed all sample observations involving deceased persons at the year of death and for all subsequent years; thus, the observations of cancer hospitalization while they were alive remain unaffected. Regarding the exclusion of data involving physicians whose cancer was diagnosed prior to commencing their clinical practice, those who obtained their certificate after the year 2000 were omitted, because they were neither a radiologist nor a family medicine physician before receiving their certificates.

Independent variables

To control the potential effect of other confounders on the dependent variable, this study used gender, age, hospital accreditation level and year, in addition to physician specialties, as the independent variables.

Statistical analysis

Descriptive statistical methods were used to analyse the number of radiologists who were hospitalized for cancer during the years investigated and their average number of cancer hospitalizations. For researchers GEEs was a method developed to analyze highly correlated panel data (23). GEEs was applied to explain the correlation among repeated measures annual observations. GEEs with a binomial distribution and logit link function assumes an exchangeable working correlation matrix, which is then used to control confounding factors, thereby estimating the correlation between physicians with various specialties and the cancer hospitalization. This study used Stata statistical software, version 11.0, for statistical analysis. Additionally, a scatter plot was used to explore the long-term cancer hospitalization trends of radiologists between 2000 and 2010.

Results

The total number of radiologists and family medicine physicians observed during the 11 years were 8,512 and 9,889, respectively. Regarding gender distribution, the average proportions of male radiologists and male family medicine physicians were 84.6% and 84.3%, respectively, which are clearly far higher than the proportion of females in the sample. The average age of the radiologists was 43.220 years, younger than that of the family medicine physicians, which was 45.405 years. The average number of cancer hospitalizations was 0.014 for the radiologists and 0.005 for the family medicine physicians. Regarding the distribution of hospital accreditation levels, radiologists practicing at medical centres accounted for the highest average proportion (47.7%), followed by those practicing at regional hospitals (34.2%), and those at district hospitals (18.1%); the average proportions for family medicine physicians are listed in the order of practicing at district hospitals (38.3%), regional hospitals (38.0%), and medical centres (23.8%) (table 1).

The average number of cancer hospitalizations of radiologists from 2000 to 2010 ranged between 3.67 and 28.26 ‰. The lowest average number of cancer hospitalizations observed was for 2001, and the highest average number of cancer hospitalizations observed was for 2004. In addition, we also found that the average number of cancer hospitalizations of family medicine physicians from 2000 to 2010 ranged between 0.00 and 12.16 ‰ (table 2). However, one radiologist diagnosed with breast cancer was hospitalized 12 times in 2004, 12 times in 2003, and twice in 2002. This had a manifest effect on the number of cancer hospitalizations during 2004, 2003, and 2002. Another radiologist diagnosed with liver cancer was hospitalized 5 times in 2004, 6 times in 2003, and 7 times in 2002. This also affected the number of cancer hospitalizations for those three years.

GEEs with a binomial distribution and logit link function was used to estimate cancer hospitalization among physicians with various specialties. The results showed that after controlling gender, age, hospital accreditation level and year, radiologists had an insignificantly higher risk of cancer hospitalization than that of family medicine physicians (OR, 1.23). The odds ratio of cancer hospitalization was significantly lower for males than for females (OR, 0.47). In addition, cancer hospitalization significantly increased with increasing age (OR, 1.07) (table 3).

Analysis of the relationship between average number of cancer hospitalizations and year indicated that the average number of cancer hospitalizations of radiologists exhibited a declining trend from 2000 to 2010 (figure 1).

Table 1 - Characteristics of radiologists and family medicine physicians in Taiwan, 2000-2010

	Radiologists n=8,512 Mean(SD)	Family medicine physicians n=9,889 Mean(SD)
Gender		
Male	0.846(0.023)	0.843(0.030)
Female	0.154(0.023)	0.157(0.030)
Age	43.220(0.754)	45.405(0.531)
Average number of hospitalizations for cancer	0.014(0.009)	0.005(0.005)
Hospital accreditation level		
Medical centre	0.477(0.030)	0.238(0.015)
Regional hospital	0.342(0.030)	0.380(0.039)
District hospital	0.181(0.005)	0.383(0.031)

Distribution of gender and hospital accreditation levels are presented after calculating the mean and standard deviation of the distribution proportions of gender and hospital accreditation levels over 11 years.
Age and average number of cancer hospitalizations are presented after calculating the mean and standard deviation of age and average number of cancer hospitalizations over 11 years.

Table 2 –Average number of cancer hospitalizations among study subjects

Year	Radiologists			Family medicine physicians		
	Number of hospitalizations	Number of physicians	Average number of cancer hospitalizations (‰)	Number of hospitalizations	Number of physicians	Average number of cancer hospitalizations (‰)
2000	4	511	7.83	2	584	3.42
2001	2	545	3.67	8	658	2.16
2002	10	586	17.06	1	724	1.38
2003	18	646	27.86	1	819	1.22
2004	21	743	28.26	4	940	4.26
2005	11	820	13.41	4	994	4.02
2006	7	868	8.06	0	1081	0.00
2007	5	923	5.42	6	1024	5.86
2008	8	958	8.35	11	1040	10.58
2009	5	952	5.25	6	1027	5.84
2010	6	960	6.25	7	998	7.01

Number of hospitalized subjects: cumulative number of individual hospitalizations.
Average number of cancer hospitalizations: (number of hospitalized subjects/ number of practicing subjects)*1000

Discussion

This study used data from the NHIRD provided by Taiwan's National Health Research Institutes for statistical analysis. Among current population-based international databases, the NHIRD contains data on a large number of people and covers a wide range of dimensions. Therefore, this database offers a unique opportunity to explore the relationship between occupational exposure to low-dose ionizing radiation and cancer hospitalization. A cohort study of the Canadian National Dose Registry showed that medical workers were exposed to the highest average annual radiation dose in the mid-1950s, after which the annual radiation dose declined. Doses in the mid-1970s were extremely low, and remained at similar levels thereafter (22). Recent studies related to cardiologists and other physicians who perform invasive procedures have shown that the effective doses to which such physicians are exposed fluctuate significantly. Since the mid-1960s, the development of diagnostic imaging, radiotherapy, catheter and other equipment that involves fluoroscopically guided interventions, and nuclear medicine procedures, has led to a major revolution in medical practices. However, these technological developments have obviously increased the likelihood of radiation exposure (10).

This study used GEEs with a binomial distribution and logit link function to analyze cancer hospitalization among physicians with various specialties. The results showed that after controlling confounders, radiologists exhibited an insignificantly higher risk of cancer hospitalization compared with family medicine physicians (table 3). Although the effects that low-dose ionizing radiation has on cancer remains unclear, the results of this study are similar to those reported by studies that performed cytogenetic monitoring to examine occupational exposure of hospital workers to low-dose ionizing radiation and indicated a significant correlation. One study regarding the possible effects that long-term exposure to low-dose ionizing radiation has on cells and organs and resulting health conditions showed that the exposure group (radiologists, pneumologists, and X-ray examination technicians) exhibited higher chromosomal abnormalities (of all types) compared with the control group. However, no significant differences existed between exposure groups (15). A study of chromosomal abnormalities among Croatian hospital staff occupationally exposed to low doses of ionizing radiation indicated that the exposure group (anaesthesiologists,

Table 3 - Analysis of cancer hospitalizations among physicians by using GEEs

Variables	OR	95% CI	p value
Gender			0.046*
Male	0.47	0.22-0.99	
Female	Reference		
Specialty			0.514
Radiologists	1.23	0.66-2.30	
Family medicine physicians	Reference		
Age	1.07	1.03-1.10	0.000***
Hospital accreditation leve			
Medical centre	1.26	0.61-2.59	0.537
Regional hospital	0.69	0.33-1.45	0.333
District hospital	Reference		
Year			
2010	1.59	0.41-6.21	0.505
2009	1.78	0.46-6.84	0.401
2008	2.19	0.59-8.20	0.243
2007	1.76	0.46-6.75	0.411
2006	0.73	0.16-3.41	0.693
2005	1.26	0.30-5.18	0.752
2004	1.55	0.39-6.23	0.537
2003	0.88	0.18-4.26	0.875
2002	0.95	0.20-4.67	0.954
2001	1.90	0.46-7.87	0.374
2000	Reference		

OR: odds ratio; CI: confidence interval.
*P<0.05; *** p<0.001.

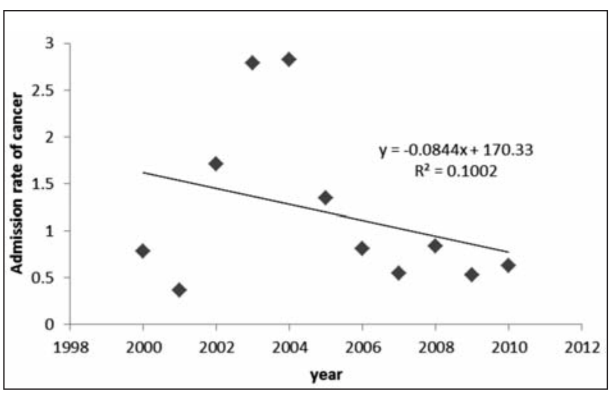

Figure 1 - Analysis of relationship between average number of cancer hospitalizations and year for radiologists

anaesthia technicians, radiology technicians, operating theatre nurses, surgeons, nurses, radiologists, and urologists/gynaecologists) exhibited an increase in all types of chromosomal abnormalities (8). Another study reported that physicians and technicians in radiology, radiotherapy, and cardiology departments presented significantly higher frequencies of aberrant cells and chromosome breaks compared to the control group (11). The results of a study indicated that the group (radiotherapy, nuclear medicine, cardiology, radiology, and medical workers of pediatric operating theatres) that was exposed to ionizing radiation showed higher frequencies of micronucleated lymphocytes caused by chromosomal damage compared to the control group. This phenomenon occurred even at an extremely low-dose exposure of <1 mSv medical irradiation (17).

The results of this study are similar to related studies regarding the effects that low doses of ionizing radiation have on the incidence of cancer among radiologists. A study investigating the mortality rate for cancers and all other causes among British radiologists found that radiologists who entered the profession before 1921 had a 75% higher cancer mortality rate than that of general practitioners. The excess of deaths from pancreas, lung, and skin cancer and leukaemia among male radiologists was found statistically significant (18). The results of a cohort study conducted in the United States showed that before the 1950s, radiologists exhibited a higher cancer mortality rate compared with that of other physicians with varying specialties (14). Another study investigated the rates of mortality from cancer and other causes among British radiologists from 1897 to 1997. It showed that British male radiologists who registered with a radiological society between 1897 and 1979 exhibited a small but significantly increasing cancer mortality (SMR=1.16) and a small but significantly decreasing non-cancer mortality (SMR=0.86) compared with that for all male physicians (1). A review of an epidemiological study on the cancer risks of eight cohorts of radiologists and technicians in different countries (a total of 270,000 people) also showed that workers employed before the 1950s exhibited increased mortality from leukaemia caused by high radiation exposure. In the early stage, increased work duration also increased the risks of leukaemia. This result provides relevant evidence of the relationship between increased leukaemia risks at that time and occupational radiation exposure. Furthermore, an epidemiological study also reported inconsistent results for other solid cancers. Nevertheless, a number of studies provide evidence of the effects of radiation on breast cancer and skin cancer (21). A study on the incidence of cancer among Finnish physicians occupationally exposed to ionizing radiation showed that the standardized incidence ratio (SIR) of all cancers in physicians monitored for radiation (radiologists, surgeons, cardiologists, interventional radiologists, oncologists, and physicians with other specialties) and physicians not monitored for radiation was 1.0 and 1.0, respectively, compared with that of the Finnish population. For site-specific cancers, female physicians monitored for radiation had slightly increased breast cancer risks compared with that of physicians not monitored for radiation (rate ratio=1.7) (6). A study conducted on physicians, surgeons, anaesthetists, radiologists, and physicians working in the laboratories of a university hospital in Grenoble reported that their incidence rates for all cancers did not differ from those of the general population (SIR=0.97). However, the haematological cancer incidence rate among these physicians exhibited a significant increase (SIR=5.45) (12). In addition, a report on the mortality rates of physicians with various specialties indicated that radiologists and radiotherapists did not show higher cancer death rates compared with consultants (rate ratios=0.99) (4). One study that explored the cancer risks of Lithuanian medical radiation workers (diagnostic radiology, radiotherapy, and nuclear medicine) indicated that during the monitored period from 1978 to 2004, 159 cancer cases were reported. However, the overall cancer risks were not increased for the male participants (SIR=0.92) or the female participants (SIR=0.97) (16).

The results obtained in this study show that the average number of cancer hospitalizations for radiologists gradually declined from 2000 to 2010 (figure 1). Relevant studies have consistently shown that radiologists and radiology technicians employed before 1950 exhibited increased leukaemia mortality because of their exposure to high-dose radiation at the time. However, the sub-cohorts of these studies did not clearly indicate an increase in cancer risks for recent radiologists and radiology technicians (21). Observation data on British radiologists collected over 100 years show that radiologists registered after 1954 may have been exposed to very low doses of radiation; thus, their cancer mortality rate shows no increase (1). In recent years, revisions to radiation protection standards and improvements in radiological protection practices have reduced the associated health risks and occupational exposure to radiation.

This study had the following research limitations: (a) the external exposure dose of the participants could not be obtained, hindering the establishment of a causal relationship between low-dose ionizing radiation and cancer hospitalization. (b) The data examined were from 2000 to 2010 (limited to 11 years of data). The latency period for most solid cancers ranges between 10 and 20 years (5); thus, cancer hospitalization cannot not be accurately estimated. (c) The sample size was insufficient, limiting the statistical power of the results.

Considering the time lag between radiologists' occupational exposure to low-dose ionizing radiation and the development of cancer, as well as the many new radiological procedures introduced in modern medical treatments, monitoring of medical radiation workers' health status should be maintained.

In conclusion, extant studies can provide quantitative estimations of the effects of radiation exposure and cancer risks for humans exposed to high-dose (acute) ionizing radiation. However, these estimates are inadequate for evaluating the risks of fractionated or low-dose exposures. Population aging and the incremental use of high-tech instruments increase the demand for radiological examinations and treatments in health services. Consequently, the exposure of radiologists and other medical workers to medical treatment radiation may be increased. Statistical data published by Taiwan's Ministry of Health and Welfare, Executive Yuan, showed 450 diagnostic radiologists were registered in Taiwan in 2000, which is equivalent to approximately 20 diagnostic radiologists per 1 million people. This is far lower than the standard adopted in Western countries, where the average is at least 31 diagnostic radiologists per 1 million people (31 in the United Kingdom, 59 in Australia, 91 in the United States, and 100 in France per 1 million people) (7). Because of an inadequate number of radiological personnel and increasing demand for radiological medical treatments and services, issues concerning the continuous exposure of radiological personnel to scatter radiation is worthy of attention. This study used GEEs with a binomial distribution and logit link function to assess cancer hospitalization among physicians with various specialties. The results indicated that compared to family medicine physicians, radiologists exhibited an insignificantly higher risk of cancer hospitalization. The data observation period for this study was only 11 years. Considering the numerous new radiological procedures used in modern medical treatments, monitoring of medical radiation workers' health status should be maintained.

NO POTENTIAL CONFLICT OF INTEREST RELEVANT TO THIS ARTICLE WAS REPORTED

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