ORIGINAL ARTICLE

Health Effects of Medical Radiation on Cardiologists Who Perform Cardiac Catheterization

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Background: We investigated the health effects of low-dose radiation on cardiologists exposed to scattered radiation while performing cardiac catheterization (CC) in a hospital setting from 2003 to 2006.

Methods: We performed a 4-year retrospective study on 2,292 medical doctors, using claims data from all contracted hospitals of the Bureau of National Health Insurance, Taiwan. We gathered statistical data regarding radiation-related diseases using the International Classification of Diseases, 9th Revision, Clinical Modification record numbers of each doctor.

Results: Of the 2,292 doctors evaluated, 1,721 were aged 35–50 years and the remaining 571 were aged 51–65 years. There were 892 cardiologists who performed CC (experimental group), and the majority of these (733/892, 82.17%) were aged 35–50 years. There were 1,400 medical doctors who performed no CC from 2003 to 2006 (control group). A total of 988 of these belonged to the 35–50 years age group and 412 to the 51–65 years group. In the 35–50 years group, the controls had significantly more medical visits for hematological and thyroid cancer ($p < 0.05$), skin disease ($p < 0.001$), and acute upper respiratory tract infection ($p < 0.001$) compared with the experimental group. In contrast, cardiologists who performed catheterization had more cataracts compared with the control group, but this difference was not significant.

Conclusion: Doctors who did not perform CC had more visits for radiation-related diseases than those who performed catheterization. In the experimental group, cardiologists aged 35–50 years who were exposed to radiation during CC had more visits for cataracts than the control group. We recommend that radiation protection concepts be emphasized to cardiologists, and that hospital managers be obligated to upgrade angiography equipment because the newer models have less scattered radiation. [*J Chin Med Assoc* 2010;73(4):199–204]

Key Words: cardiac catheterization, cataract, radiation exposure

Introduction

Medical application of radiation began a few months after the discovery of X-rays by the German physicist Wilhelm Conrad Röntgen more than 100 years ago. The harmful biological effects of ionizing radiation became apparent shortly after its utilization. Since 1920, health professionals in contact with radiation have worn lead protective clothing to reduce the harmful effects of ionizing radiation.

Brenner et al have reported that an increase in carcinogenic risk is observed when the acute radiation exposure dose reaches 10–50 mSv, whereas the carcinogenic risk for long-term radiation exposure occurs at a higher accumulated dose of 50–100 mSv.[1] Recently, many studies have been performed on medical radiation protection for patients and medical professionals using thermoluminescent dosimetry to measure the radiation dose received at the body surface.[2,3] Data from the Armed Forces Radiobiology Research Institute

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(Bethesda, MD, USA) have indicated that when the human body is directly exposed to radiation, it experiences a decrease in lymphocyte count, in the acute phase, within 1.5 weeks. The most obvious damage from radiation exposure occurs in tissues with the most direct exposure, such as the skin and eyes. When direct radiation exposure reaches 2–3 Gy, skin erythema occurs within a few hours and cataracts form approximately 6 months after exposure.[4]

The largest epidemiological study of radiation pollution was performed on the survivors of the US atomic bombing of Japan. Excess relative risk (ERR) at 1 Sv ($ERR_{1\ Sv}$) significantly increased for solid cancers of the breast ($ERR_{1\ Sv}$ = 1.59), thyroid ($ERR_{1\ Sv}$ = 1.15), urinary bladder ($ERR_{1\ Sv}$ = 1.02), ovary ($ERR_{1\ Sv}$ = 0.99), lung ($ERR_{1\ Sv}$ = 0.95), and colon ($ERR_{1\ Sv}$ = 0.72).[5] The most notable domestic radiation pollution study was performed on the Min-Shen community in 1992. More than 10,000 people who resided in houses that contained radiation-contaminated steel–concrete reinforcement bars have become victims of low-dose ionizing radiation exposure, based on a long-term follow-up. Hwang et al, using calculated standardized incidence ratios, found a significantly increased risk of hematopoietic cancer in the male victims and a marginally significant increased risk of thyroid cancer in the female victims.[6]

Most large-scale epidemiological studies have been performed on non-medical artificial radiation, although medical radiation accounts for most of the artificial radiation exposure.[7] In fact, studies on medical ionizing radiation damage to medical workers have been rarely performed. This is likely to have been because, in general, the radiation dose received by medical workers is insufficient to cause disease. The competent authority in our country, the Atomic Energy Commission Executive Yuan, monitors and conducts physical examinations on relevant personnel, according to the law, but does not carry out further control or follow-up on high-risk groups such as doctors who are involved in interventional radiological examinations and treatment. Therefore, this issue needs to receive more serious attention from doctors, medical institutions, and health authorities.

Methods

Subjects

We divided medical doctors into those who performed cardiac catheterization [(CC), experimental group] and those who did not perform such examinations (control group). We also divided the medical doctors into 2 age groups: 35–50 and 51–65 years old. The 2 age groups were based on a cardiologist's education. The average age of cardiologists starting practice is approximately 35 years, because students who graduate from medical school are required to perform 2 years of military service, and then take 4–6 years of additional internal medicine training and cardiology specialty training. Current standards define anyone over 65 years of age as elderly. The age calculation was based on age at December 31, 2006.

The diseases caused by radiation exposure included those that can develop within 5 years of exposure, such as skin disease, damage to the lens that leads to cataract, hematological cancer, thyroid cancer and thyroid-related diseases, and acute upper respiratory tract infection (URTI). In particular, acute URTI was included because studies have indicated that radiation exposure decreases immune function and increases incidence of URTI, which had the highest application frequency to the National Health Insurance reimbursement program. The International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) codes extracted from the National Health Insurance reimbursement applications were used to calculate the average number of medical visits for the 4 types of radiation-exposure-related diseases between 2003 and 2006.

Data sources

Our data source was the 2003–2006 outpatient and admission reimbursement applications from the database of the Bureau of National Health Insurance, Republic of China (Yang Ming University Hospital 2009 research plan number RD2008-011). The 2,292 medical doctors enrolled were chosen according to their reimbursement applications for cardiac diseases. To maximize these doctors' visits for rare diseases such as cancer and cataract, we did not make annual divisions within our database. These records included details of medical orders for outpatient visits and admissions from reimbursement applications at clinics of Western medicine and the hospital global budget.

Dependent variables

The average numbers of medical visits of the 2 age groups of doctors were considered as continuous variables (number of doctors as denominator, and number of ICD-9-CM diagnoses between 2003 and 2006 as the numerator).

This study assumed that the ICD-9-CM diagnostic codes for the 4 diseases correlated with radiation exposure were as follows: (1) 200–208, hematological cancers, including all main and sub-diagnoses;

193, 240–242 and 244–246, thyroid cancer and related diseases, including all main and sub-diagnoses; (2) 690–692, 694 and 695, skin diseases, including all main and sub-diagnoses; (3) 460–466 and 480–487, acute respiratory infection, including all main and sub-diagnoses; (4) 366, cataract, including all main and sub-diagnoses.

The above diagnostic codes include codes to the right of the decimal point for body parts such as ICD-9-CM 240, including 240.21, and 240.31 to 240.91.

Independent variables

Radiation exposure was considered positive if the doctors had ever performed CC during the 4 years between 2003 and 2006. There were 2 age groups of doctors: 35–50 and 51–65 years. Radiation exposure and age groups were considered categorical variables.

Statistical analysis

Statistical analyses were performed using SPSS version 15.0 (SPSS Inc., Chicago, IL, USA) for Windows. Subject characteristics were described by frequencies for categorical data, and by mean for numeric variables in each group. Categorical variables in Tables 1 and 4 were compared using the χ^2 test, and continuous variables shown in Tables 2 and 3 were compared using an independent *t* test. A 2-tailed p value < 0.05 was considered significant.

Results

Descriptive statistics

There were 1,721 doctors aged 35–50 and 571 aged 51–65 years. Sex distribution showed that there were 159 female doctors (6.9%) aged 35–65 years among the 2,292 doctors. Only 33 of these 159 had applied for CC reimbursement, which amounted to 20.8% of all female doctors and 3.7% of all the cardiologists who performed CC. Therefore, most cardiologists who performed CC were male. This result might be related to radiation effects on female fertility.[8]

Inferential statistics

Relationship between doctors performing CC and age

There were 892 cardiologists who performed CC. A total of 733 of these were in the 35–50 years age group, i.e. 82.17% of all cardiologists who performed CC. There were 159 cardiologists in the 51–65 years age group, and they comprised 17.83% of all cardiologists who performed CC. Table 1 shows the relationship between age and whether or not cardiologists performed CC. There was a significant difference ($p < 0.001$) between CC performance and age. Cardiologists who performed CC were younger than those who did not.

Relationship between doctors' medical visits and CC

Independent *t* tests were performed on the 35–50 and 51–65 years age groups of doctors and their average medical visits. Doctors in the 35–50 years age group (Table 2) who did not perform CC had significantly more visits during 2003–2006 for hematological and thyroid cancer ($p = 0.045$), skin diseases ($p < 0.001$), and URTI ($p < 0.001$) compared with those who did perform CC. Conversely, cardiologists who performed CC had more visits for cataract, but this result was not statistically significant. In the 51–65 years age

Table 1. Relationship between cardiologist age and performance of cardiac catheterization*

Age group (yr)	Cardiologists performing CC ($n = 892$)	Doctors not performing CC ($n = 1,400$)	p
35–50	733 (82.2)	988 (70.6)	< 0.001
51–65	159 (17.8)	412 (29.4)	

*Data presented as n (%). CC = cardiac catheterization.

Table 2. Relationship between average number of visits by doctors aged 35–50 years and performance of cardiac catheterization

Radiation-related disease	Cardiologists performing CC ($n = 733$)	Doctors not performing CC ($n = 988$)	p
Hematological and thyroid cancers	0.15	0.37	0.045
Skin-related diseases	1.43	2.71	< 0.001
URTI	6.59	10.74	< 0.001
Cataract	0.04	0.02	0.306

CC = cardiac catheterization; URTI = upper respiratory tract infection.

Table 3. Relationship between average number of visits by doctors aged 51–65 years and performance of cardiac catheterization

Radiation-related disease	Cardiologists performing CC ($n = 159$)	Doctors not performing CC ($n = 412$)	p
Hematological and thyroid cancers	0.33	1.12	0.196
Skin-related diseases	0.87	2.31	< 0.001
URTI	4.53	7.16	0.001
Cataract	0.14	0.18	0.703

CC = cardiac catheterization; URTI = upper respiratory tract infection.

Table 4. Cancer and cataract sufferers aged 35–50 years and performance of cardiac catheterization*

	Cardiologists performing CC ($n = 733$)	Doctors not performing CC ($n = 988$)	p
Cancer sufferers†	30 (4.1)	53 (5.4)	0.22
Cataract sufferers†	9 (1.2)	8 (0.8)	0.39

**Data presented as n (%); †doctors with visits for hematological and thyroid cancers and thyroid-related diseases are defined as cancer sufferers, and those with cataract are defined as cataract sufferers. CC = cardiac catheterization.*

group (Table 3), the average number of visits during 2003–2006 for those who did not perform CC was higher compared with those who did perform catheterization, for all 4 types of diseases, but only skin diseases ($p < 0.001$) and URTI ($p = 0.001$) reached statistical significance.

Relationship between cancer and cataract sufferers aged 35–50 years and CC

We performed a χ^2 test to establish the relationship between doctors in the 35–50 years age group with cancer and cataracts and whether or not they performed CC (Table 4). There were more cancer sufferers among doctors who did not perform CC, while there were more cataract sufferers among cardiologists who performed CC, but this result was not statistically significant.

Discussion

Our statistical analysis reveals that doctors who did not perform CC between 2003 and 2006 had more medical visits for hematological and thyroid cancer, skin disease, and URTI compared with those who did perform CC, in both age groups. In the 35–50 years age group, the number of visits for cataract was higher in those who performed CC, but in the 51–65 years group, the number of visits for cataract was lower in those who performed CC.

The Taiwanese medical environment is similar to that in medically advanced countries such as the USA, in that medical doctors are highly autonomous professionals. The massive amount of data on health conditions necessary for epidemiological studies, such as white blood cell count, skin condition on the back of the left hand, and level of turbidity of cataracts, are difficult to obtain. We would also face an issue of fewer samples if we limited ourselves to 1 single medical institution, and this would also lead to difficulty in maintaining data significance. Most of the published epidemiological studies on radiation damage, either in Taiwan or overseas, have investigated patients who received high-dose radiation as part of their treatment. Weiss et al used long-term follow-up studies and found that ankylosing spondylitis patients who received repeated X-ray examination eventually developed cancer.[9] The risk of developing leukemia, non-Hodgkin's lymphoma, multiple myeloma and many solid cancers has increased, according to these studies. On the other hand, studies on medical workers have mainly focused on radiation dose estimation at the body surface.[10] Studies on the influence of long-term, low-dose medical ionizing radiation on the health of doctors are rare. The *American Journal of Neuroradiology* recently published a volunteer recruitment notice for a multicenter study on the influence of medical radiation on the health of doctors who work in radiation-related fields.[11] This study has received assistance from 4 large interventional radiological societies, the Society for Cardiac Angiography and Intervention, the Society of Interventional Radiology, the Heart Rhythm Society, and the American Society of Interventional and Therapeutic Neuroradiology, which have provided health data on their members. *The Lancet* has targeted male British radiologists and found that those who joined the British Radiological Society between 1887 and 1920 had a 75% higher rate of death from cancer compared with general physicians.[12] This occurred because there was no concept of radiation protection before 1920; however, those radiologists who joined the society between 1920 and 1977 already knew they had to wear lead protective clothing, which greatly reduced the radiation dose to the body. The death rate of radiologists from cancer in the latter group was the same as in general physicians, but the death rate was 14% lower ($p < 0.05$) for non-cancer causes in the radiologists compared with the reference group.

An animal experiment by Wolf et al has indicated that giving 2-month-old white mice 11 Gy of low-energy radiation to the lens epithelial cells produced damage after 5 minutes, and repair started after 30 minutes.[13] Their results indicate that cataract formation occurred 5–11 months after receiving radiation and rapidly worsened after 30 days. Radiation-induced cataract is different from the naturally occurring, age-related cataract, which only occurs after a long period of time. After receiving radiation for 11 months, more than 80% of mice had 3–4-degree cataracts.

In addition to radiologists and radiological technicians, medical radiation workers include cardiologists who perform CC, gastroenterologists who perform endoscopic retrograde cholangiopancreatography, and orthopedic surgeons who perform implant operations. These doctors receive the highest radiation exposure apart from the patients who undergo radiological examinations. It is estimated that 93% of doctors underestimate their own radiation exposure when performing radiological examinations.[14] Based on our own personal experience gleaned from years of working in a radiology department, we feel that there is a need to re-educate specialists who operate radiology equipment, especially those who work outside the radiology department. It is also important that competent authorities in the area of radiation protection are made aware of this problem.

Our study has several limitations. First, because our data source was limited to the 4 years between 2003 and 2006, it was an unnatural cross section. Damage caused by radiation exposure usually cannot be seen in the short term. Some cancer and cataracts can develop later, after a 4-year follow-up period. Disease incidence during our observation period could have been a consequence of some older cardiologists performing CC previously. Therefore, the total follow-up period should be longer. Second, the relationship between performing CC and cancer/cataract should mainly correlate with total accumulated dose of radiation. Therefore, the number of CCs performed, and years of CC performance by each cardiologist should be collected. Radiation can disrupt the naturally rapid proliferation of epithelial and blood cells. This causes diseases such as cataracts, leads to skin damage, and decreases the blood lymphocyte index. This pathogenic mechanism requires a "lowest dose" of radiation. Our study did not set the lowest dose limit for cardiologists receiving radiation exposure, i.e. a minimum number of CCs performed. Therefore, the epithelial and blood cell damage caused by radiation would have had time to repair, so that disease did not occur. The sample size of ill subjects would then be insufficient when it comes to observing the statistical difference between the numbers of medical visits of the 2 groups.

Although the current understanding is that radiation exposure damages the human body, a group of American researchers, including Luckey, have proposed that low-dose radiation—or hormesis—is actually beneficial to human health.[15] Matanoski et al proposed the "healthy worker effect" a few years later.[16] The United Nations Scientific Committee on the Effects of Atomic Radiation has defined a dose of ionizing radiation < 200 mSv as being beneficial to human health. Our own statistical results indicate that cardiologists who perform CC have a lower rate of medical visits for cancer; thus, whether or not low-dose radiation has a positive or negative effect on health requires more long-term investigation.

On the other hand, because cancer and cataracts are uncommon diseases in young age groups, doctors aged 35–50 years had few medical visits for cancer and cataracts in our study. The number of visits for cancer and cataracts could have been overestimated if a single doctor had many visits. Although the results in Table 4 did not reach statistical significance, they showed that doctors in the 35–50 years age group who did not perform CC still tended to have more cancer. Also, the younger cardiologists who performed CC not only had more visits for cataract (Table 2), but also had more cataracts. This result agrees with the assumption in overseas epidemiological literature and animal experiments that those who receive higher doses of radiation have higher prevalence of cataract. Despite the limitations of our study, we believe that it still reflects the trend that actual prevalence of cataract in cardiologists who perform CC is higher than in physicians who are not exposed to radiation at work. Doctors who are exposed to ionizing radiation at work, such as radiologists who perform interventional procedures, cardiologists who perform CC, and orthopedic surgeons who use X-ray machines, should pay close attention to the results of the present study.

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