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Work history and radioprotection practices in relation to cancer incidence and mortality in U.S. radiologic technologists performing nuclear medicine procedures

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Abstract

Technologists working in nuclear medicine (NM) are exposed to higher radiation doses than most other occupationally-exposed populations. The aim of this study was to estimate the risk of cancer in NM technologists in relation to work history, procedures performed, and radioprotection practices.

Methods—From the U.S. Radiologic Technologists cohort study, 72,755 radiologic technologists who completed a 2003–2005 questionnaire were followed for cancer mortality through December 31, 2012 and for cancer incidence through completion of a questionnaire in 2012–2013. Multivariable-adjusted models were used to estimate hazard ratios (HR) for total cancer incidence and mortality by history of ever performing NM procedures and frequency of performing specific diagnostic or therapeutic NM procedures and associated radiation protection measures by decade.

Results—During follow-up (mean=7.5 years), 960 incident cancers and 425 cancer deaths were reported among the 22,360 technologists who worked with NM procedures. We observed no increased risk of cancer incidence (HR=0.96, 95% confidence interval [CI] 0.89,1.04) or death (HR=1.05, 95% CI, 0.93,1.19) among workers who ever performed NM procedures. HRs for cancer incidence but not mortality were higher for technologists who began performing therapeutic procedures in 1960 and later compared to the 1950s. Frequency of performing diagnostic or therapeutic NM procedures and use of radioprotection measures were not

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Competing interest: none

consistently associated with cancer risk. No clear associations were observed for specific cancers, but results were based on small numbers.

Conclusion—Cancer incidence and mortality were not associated with NM work history practices, including greater frequency of procedures performed.

Keywords

cohort study; ionizing radiation; nuclear medicine; cancer

Introduction

Ionizing radiation (IR) at high and moderate doses (>100 mGy) is a recognized risk factor for cancer (1), as reported from the follow-up of the cohort of Japanese atomic bomb survivors (2), and from epidemiological studies of patients undergoing radiotherapy (3). Although recent studies of nuclear workers exposed to protracted low-dose radiation have also shown increased risks of leukemia (4) and solid tumors (5), debate continues about cancer risks in populations exposed to low doses (<100 mSv) (1,3).

Because of the high radiation doses they received in the early 20th century, medical radiation workers, particularly radiologists, were among the first workers to be investigated for radiation-induced cancer risks (6). For medical radiation workers who were employed before 1950, excess risks have been observed for total cancer (6–8) and for several cancer sites, including leukemia (6,7,9,10), breast cancer (9,11–13), thyroid cancer (9,14), and skin cancer (9,13,15). The increased risks were mostly observed for exposures occurring before 1950 and for prolonged exposures at higher doses than those currently reported (7,10). Indeed, average annual doses to medical radiation workers dramatically declined from an estimated 100 mSv before the 1940s to 0.7 mSv in 2000 (1), owing to technological advances in x-ray equipment and radiation safety measures aimed at protecting both patients and workers from the health effects of IR.

However, nuclear medicine (NM) technologists, who comprise around 120,000 workers worldwide, may be exposed to relatively higher doses of IR than other medical professionals through the handling of radionuclides used for organ imaging and treatment (1). Furthermore, the dramatic increase of NM procedures over the past 40 years, increasing from 7 million in the early 1980s to 18 million in 2006, and the increase of higher-dose NM procedures, such as cardiac scans (17) and positron emission (PET) imaging (18), has led to increased IR exposure for the medical staff performing these procedures (19). A recent publication on a sample of U.S. NM technologists reported a relatively constant annual median equivalent dose during the period between 1992 and 2015 (overall median during this period of 2.18 mSv), while maximum values generally increased over time (20). These values were consistent with effective doses reported for NM workers from other countries, ranging from 1.5 to 3.5 mSv (21–24), but higher than doses reported for other medical staff (1).

In contrast to the majority of other medical staff, NM technologists cannot avoid close contact with radioactive pharmaceuticals when preparing and/or administering injections of

the radionuclides and during the imaging process. The use or not of various radiation safety techniques, such as the use of shielding devices or limiting time spent within close proximity to treated patients, can substantially modify the magnitude of exposure (1). A description of radiation protection measures and patterns of use while performing NM procedures by radiologic technologists from 1945 to 2009 has shown a large increase in the use of most radiation protection measures, except for a dramatic decrease of the wearing of lead aprons from 81% in the 1950s to 7% in the 2000s (25). More study is needed on the impact of use of radiation protection equipment and related measures in relation to cancer risks. Sparse information is available for NM workers on potential health effects of occupational radiation exposure. We previously conducted the only assessment to date of health risks in a large cohort of radiologic technologists performing NM procedures (n=22,000) (11), named the U.S. Radiologic Technologists (USRT). Based on information provided on the second USRT survey, we observed an increased risk of lung cancer mortality associated with ever performed NM procedures and an increased risk of squamous cell carcinoma incidence for those who performed diagnostic radionuclide procedures. However, we were not able to investigate associations with frequency of NM procedures performed or use of radiation protection measures due to unavailability of data from that survey.

In our large-scale epidemiologic study of radiologic technologists performing nuclear medicine procedures, the exposure assessment focused on work history involving NM tasks and procedures collected for the first time in the third USRT survey (2002–2005). We prospectively evaluated cancer risks associated with the detailed NM work history information, including questions about the decade first worked with and frequency of performing diagnostic and therapeutic NM procedures, specific tasks performed during NM procedures, and use of radiation protection measures during NM procedures by decade.

Subjects and methods

Study population and follow-up

The U.S. Radiologic Technologists study is a collaborative project between the U.S. National Cancer Institute, the University of Minnesota, and the American Registry of Radiologic Technologists (ARRT).

A detailed description of the study population and methods is provided elsewhere (26–27) and can be found on the U.S. Radiologic Technologists Study website (<https://radtechstudy.nci.nih.gov/>). Briefly, 146,022 radiologic technologists who were certified for at least 2 years during 1926–1982 and were U.S. residents were identified from the ARRT records. Active follow-up of the cohort has been conducted through mailed surveys starting with the first in 1983–1989. Passive follow-up of the cohort for vital status has been performed by linkage with yearly ARRT recertification records and periodic linkage with the Social Security Administration database for those who do not recertify. Those deceased, presumed deceased, or with unknown vital status were linked with the National Death Index (NDI Plus, U.S. Centers for Disease Control and Prevention) to verify vital status and obtain causes of death.

This study has been approved annually by the institutional review boards of the National Cancer Institute and the University of Minnesota.

Exposure assessment

The work history section of the third mailed survey (2003–2005) included general questions about decade first worked as a radiologic technologist, and specific questions about performing or assisting with diagnostic and therapeutic NM, fluoroscopy, and X-ray procedures during four time periods (1950–1959, 1960–1969, 1970–1979, 1980 to date of third survey completion). For technologists who reported performing NM procedures, questions were asked about the frequency of performing each type of NM procedure during a “typical week” within each decade, with no quantitative information on the number of years worked with NM procedures within the decade. Questions were also asked on radioprotection measures used in performing NM procedures, such as percentages of time wore a lead apron, maintained distance from treated patients, used a protective shield around the radioactive source, and used an afterloading device to transfer the radionuclide from the safe to the patient. Technologists were classified as ever having worked with NM if they reported performing at least one diagnostic or therapeutic procedure per week in any decade on the third survey.

Other available information

Other questionnaire information evaluated included race, education, marital status, smoking status, alcohol intake, solar ultraviolet radiation (UVR) exposure, body mass index (BMI), and medical history including medical exposure to radiation and diagnoses of cancer. For women, additional information was available on parity, age at first pregnancy, use of oral contraceptive and/or menopausal hormonal therapy, and familial history of breast cancer. Intensive efforts were made to validate self-reported breast, melanoma, non-melanoma skin, thyroid, and hematological malignancies through medical record review.

Eligible population for this study

The analysis was restricted to the 72,255 radiologic technologists who were free of cancer (except non-melanoma skin cancer (NMSC)) at the time of the completion of the third survey (2002–2005). An important reason for excluding those with cancer was to exclude individuals who may have received high-dose radiotherapy. We also excluded subjects who reported a history of radiotherapy for non-cancer purposes (n=898). Participants were followed from the third survey completion date to the earliest of date of death or December 31, 2012 for the mortality analysis (N=72,255 technologists). For the cancer incidence analysis, the technologists were followed from the third survey until the earliest of date of first primary cancer diagnosis other than NMSC or date completed the fourth questionnaire. As cancer incidence data were derived solely from the fourth survey (2012–2013), incidence analyses were restricted to the 46,038 radiologic technologists who completed both the third and fourth questionnaires.

“All-cancers combined” was the primary outcome of interest in the mortality and incidence analyses. Secondary outcomes of interest included female breast, lung, melanoma, non-melanoma skin cancer, thyroid, colorectal, and haematological malignancies because of their

known radiation aetiology. Brain tumor incidence was not included due to poor medical record validation of self-reported diagnoses. Both incidence and mortality risks were assessed for all cancers combined, female breast, non-melanoma skin, colorectal and haematological malignancies. For thyroid and non-melanoma skin cancers, only incidence analyses were performed because of their low fatality rates. For lung cancer, only mortality analyses were performed due to its poor prognosis.

Statistical Analysis

Baseline characteristics for the study population were reviewed, including demographic characteristics, work history, and radiation safety practices. Cox proportional hazards models were used to calculate hazard ratios (HRs) and 95% confidence intervals (CIs) for cancer mortality and incidence in technologists who ever, compared with never, performed NM procedures. All models were fitted with age as the time scale, stratified on birth cohort (< 1930, 1930–1939, 1940–1949, 1950+) to control for secular trends, and adjusted for sex and race. Other factors known to be associated with specific cancer outcomes (smoking, alcohol, medical history including personal medical exposure to radiation, other X-ray occupational exposure), as well as demographic factors (marital status, education), were evaluated as potential confounders. Decade-specific risks were assessed according to the weekly frequency of performing procedures and the use of radiation protection measures. Because adjustment for potential confounders had little influence on the HRs, the results we present are based on minimally-adjusted models, i.e., adjusted only for sex and race and stratified by birth cohort. P-trends were calculated by modeling categorical variables as continuous with exclusion of the unknown and not applicable categories.

Specific cancer sites analyses are presented in supplementary tables when, at least 100 incident cases (breast cancer, melanoma, basal and squamous skin cancer) or 90 deaths by cancer site (lung cancer mortality), were reported in exposed workers.

In Cox models, scaled Schoenfeld residuals (28) were examined to assess the proportional hazards assumption with age as the time scale. All analyses were two-sided and were performed using SAS software (version 9.3, SAS Institute).

Results

Demographic characteristics of the 72,755 respondents to the third survey are summarized in Table 1. The majority (79%) of participants were women. The mean age at completion of the third questionnaire was 57 years and the mean follow-up was 7.8 years. A total of 22,360 technologists (31% of the 72,755 participants) reported ever working with procedures involving radionuclides, 18,932 (27%) with diagnostic procedures and 12,177 (17%) with therapeutic procedures. Compared to technologists who never performed NM procedures, those who ever performed such procedures were slightly more likely to be male, to have been born before 1950, and to have completed college. The percentage of technologists working in the NM field increased from 6% of the study population before 1950 to a maximum of 23% in the 1960–69 period, then decreased to 14% in the period from 1980 to date of third survey completion.

Cancer risks

Mortality analyses—Total cancer deaths were 1365 and 425, respectively, in all respondents (N=72,755) and in responding technologists who ever performed NM procedures (N=22,360) (Table 2). A non-significant increase in all cancer mortality (HR=1.05, 95% CI 0.93, 1.19) was observed among technologist who ever compared to those who never worked with NM procedures (Table 2). Similarly, mortality risks from various cancer sites were not significantly associated with ever performing diagnostic or therapeutic NM procedures (Table 3).

The risk of total cancer mortality did not increase with increasing numbers of diagnostic or therapeutic NM procedures performed within any of the decades examined (Table 4). We observed a significantly reduced total cancer mortality risk for those who eluted kits in the 1970–79 period. This result was not observed for any other decade. Lack of apron use was not significantly associated with total cancer mortality risk. Typically standing closer than three feet from the patient in the 1950–59 period, but not in other time periods, and maintaining the radioactive source in the 1960–69 period, but not in other time periods, were associated with significantly increased mortality risks (Table 4). Radioprotection measures and work practices were generally not associated with mortality from selected types of cancer (data not shown, except lung cancer deaths presented in supplementary table 1).

Incidence analyses—Between the third and fourth surveys, 3,126 technologists out of the 46,038 respondents self-reported a diagnosis of cancer, including 960 out of the 14,079 technologists who reported ever working with NM. Risk for all cancers combined was not increased in technologists who ever versus never worked with NM procedures (HR=0.96, 95% CI, 0.89, 1.04). HRs were higher for technologists who began performing therapeutic procedures in 1960 and later compared to the 1950–1959 period (Table 2). Incidence risks for the specific cancer sites evaluated did not differ significantly between those who ever versus never performed NM procedures (Table 3). The risk of cancer increased with greater number of diagnostic NM procedures performed in the 1970–1979 period (p trend=0.02), but not in other time periods (Table 5). The lack of lead apron use during therapeutic NM procedures in the 1960–1969 period, but not in other time periods, and maintenance or transport of the radioactive source in the 1970–79 period, but not in other time periods, were associated with significant increased risks for all-cancer incidence. For the studied cancer sites, a few associations of risks with lack of radioprotection measures and increased numbers of procedures performed were observed, but the risk patterns were generally not consistent (data shown in supplementary tables 2, 3, 4, 5 respectively for breast cancer, melanoma, squamous cell and basal cell skin cancers).

Discussion

Despite increases over time in the number of diagnostic NM procedures performed per week, the types and frequency of NM procedures performed and associated radiation safety practices were not clearly associated with increased total or specific cancer incidence or mortality in the NM technologists in the USRT cohort study.

Medical workers performing NM procedures may have greater exposure to IR than other medical workers (20), due to the dramatic increase of NM procedures over years (16) but also because their close contact with radionuclides when preparing, injecting and with the patients during the examination. Thus, there is increasing concern about long-term IR-related health risks for this population. A previous analysis in the USRT cohort focused on 22,000 NM technologists revealed no significant increased risks associated with ever performing NM procedures for all-cancer mortality or incidence (11). However, lung cancer mortality was elevated in technologists who performed any radionuclide procedures and breast cancer mortality was increased in technologists who performed radiotherapy other than brachytherapy or radioactive iodine therapy, and squamous cell carcinoma incidence was elevated in technologists who performed diagnostic NM procedures. Our analyses, focusing on the same population but on a more recent period of follow-up (the third survey (2003–2005) to the fourth survey (2010–2013)), did not show any significant risks associated with performing NM procedures for all-cancer combined and the several cancer sites studied, including lung cancer, breast cancer, and squamous cell carcinoma of the skin. As wording of questions about the procedures performed was different in the third survey compared to the second one, with lack of detailed questions on brachytherapy in the third survey, we therefore could not estimate specific risks according to this type of procedures.

Focusing our analysis on a more recent period implied the exclusion of older people who died or developed a cancer before the study period. These older workers were likely to be exposed during more prolonged periods than younger workers, resulting in potentially higher cumulative doses. Their exclusion from the current analysis might have removed the most at-risk population and might explain the trends in incidence we observed for the technologists performing NM procedures in the 1960s and after compared to those who began in the 1950s or before. On the other hand, the dramatic increase of the number of NM procedures performed after 1960, especially those associated with relatively high doses in the recent decades, could have resulted in higher cumulative doses for technologists who worked in more recent years.

To our knowledge, this study is the first to evaluate detailed work history and radiation safety measures over decades in relation to cancer incidence and mortality risks in radiologic technologists performing NM procedures. Since 1950, the use of radiation safety tools has largely increased in NM practice, although lead apron use has dramatically decreased over time in this population possibly due to increasing awareness of its limited effectiveness in comparison with other radiation protection techniques (25). Our findings are primarily null, with a few modest associations in risk observed with usual work practices and use of radiation protection measures. We observed increased cancer risks with wearing no apron in the 1960–69 period, staying close to the patient during procedures in the 1950–59 period, and maintaining the unprotected radioactive source in the 1970–79 period, practices that might be associated with higher radiation doses for the worker. However, these results were not observed consistently across decades or in both mortality and incidence analyses. The surprising finding of a decreased risk for all-cancer mortality in technologists who eluted kits in the 1970s could be due to chance alone in view of the large number of associations examined.

Prior studies have documented the beneficial role of radiation safety measures and equipment in the reduction of the received dose by the technologists (1,29), stating that the decrease of doses would also reduce the risk associated with IR exposure. However, this hypothesized decreased risk associated with radiation safety measures has not been observed in our study. Our results warrant cautious interpretation as several limitations should be mentioned. First, the lack of statistical power linked to the short follow-up in our study and to the rather small number of workers (N=22,361) involved in NM procedures in the USRT cohort could be responsible for the null results. Indeed, even if the USRT cohort is one of the largest occupational medical cohorts, this cohort is still too small to assess cancer-specific risks given the small excess risks expected. Lack of complete ascertainment of cancer cases from substantial numbers of non-respondents and ascertainment of incidence based on self-report are also limitations of our study. However, a previous effort to compare self-reported cancer diagnoses with population-based cancer registry data revealed about 25% under-ascertainment which varied according to type of cancer (30). Lack of organ dose assessment is one of the main limits of our study. Our currently available historical dose reconstruction and estimation of individual worker annual and cumulative dose (31) is based on USRT cohort member badge doses collected only through 1997. In addition, our historical dose reconstruction utilized information on work history to account for periods when each individual's badge dose data were not available in the cohort. But the work history procedures we considered did not include sufficient detail about NM procedures. Hence, our estimates for individual technologists do not account for exposure to higher-energy radionuclides or frequency of performing NM procedures and thus would result in an underestimation of organ and tissue doses of the NM professionals performing such procedures. Thus, we did not assess risks according to organ and tissue doses in the current analysis. Furthermore, information retrieved from the questionnaires on the number of NM procedures performed by technologists could not be used to estimate duration of conducting NM procedures in the cumulative work history as the technologists were not asked to report how many years they worked with NM procedures in each decade.

Last, self-report of outcomes and work history could be a source of bias. However, given their medical training, the technologists would be expected to provide a more accurate medical history compared to members of the general population, and comparison of self-report with medical records in this population demonstrated a high level of agreement (27). Recall bias about self-report of work history and radioprotection measures used over decades was prevented by the collection of occupational exposure data prior to the assessment of the outcome.

Strengths of this study included the collection of comprehensive data on individual risk factors that allowed for adjustment of potential confounders. We found that risk estimates adjusted on lifestyle risk factors, medical personal exposure and other occupational IR exposure were similar to those estimated with minimal adjustment on race and sex, and therefore we do not report results based on adjustment for the multiple factors. Another strength is the assessment of NM work history over several decades, including radiation safety measures and types of performed procedures in one of the largest occupationally-exposed cohorts of medical workers internationally.

Conclusion

The association between occupational radiation exposure and cancer has been well-documented. Among medical staff, technologists working in the field of NM are known to be among the more highly radiation exposed (19). However, few studies have evaluated health risks in this group. We observed little evidence that cancer risk was associated with performing diagnostic or therapeutic NM procedures, related work practices, or use of radiation safety measures. Longer follow-up, a larger sample size through collaborative joint analysis of several international cohorts, and dose-response analyses are needed for a more comprehensive evaluation of cancer and other disease risks in technologists performing NM procedures.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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What is already known about this subject?

- Although average annual doses to medical radiation workers has dramatically declined over years, the large increase over the past 40 years of higher-dose imaging techniques, including nuclear medicine (NM) procedures, may have led to increased IR exposure for the medical staff performing these procedures. However, few studies have evaluated health risks in technologists working in the NM field.

What are the new findings?

- Radiologic technologists who ever performed diagnostic or therapeutic NM procedures did not have an increased risk of cancer compared to radiologic technologists who did not perform these procedures. Radioprotection measures, including use of lead aprons, did not modify these risks. No clear associations were observed for specific cancers, but results were based on small numbers.

How might this impact on policy or clinical practice in the foreseeable future?

- These results are reassuring for this population of relatively highly-exposed medical workers.
- Nevertheless, increased follow-up of these workers, improved exposure assessment and pooled analyses of several national cohorts are needed for a more precise estimation of cancer risks.

Table 1

Characteristics of the study population (N=72,755) from the U.S. Radiologic Technologists Study

	Ever worked with nuclear medicine procedures	Never worked with nuclear medicine procedures
Percentage of participants	22,360(31%)	50,395 (69%)
Gender		
Female	16,853 (75%)	40,290 (80%)
Race		
White non-Hispanic	21,227 (95%)	47,869(95%)
Hispanic	588 (3%)	1,375 (3%)
Black	261 (1%)	529 (1%)
Asian/PI or other	284 (1%)	622 (1%)
Birth cohort		
before 1930	698 (3%)	2,545 (5%)
1930–39	3,208 (14%)	6,530 (13%)
1940–49	8,830 (39%)	16,218 (32%)
1950+	9,624 (44%)	25,102 (50%)
Education status		
≤ 12 years	94 (0%)	452 (1%)
2-year radiologic technologist program	8,506 (38%)	22,079 (44%)
College	9,425 (42%)	19,404 (39%)
Other or unknown	4,335 (19%)	8,460 (17%)
Marital status		
Married or living together	1049 (5%)	2,368 (5%)
Separated/divorced/widowed	13,548 (61%)	31,766 (63%)
Never married	3,373 (15%)	7,697 (15%)
Unknown	4,390 (20%)	8,564 (17%)
Body mass index at third survey completion		
<18.5	230 (1%)	516 (1%)
18.5–24	6,861 (31%)	16,814 (33%)
25–29	7,862 (35%)	17,090 (34%)
≥30	6,049 (27%)	12,241 (24%)
Unknown	1,358 (6%)	3,734 (7%)
Smoking status		
Never smoker	11,843 (53%)	26,828 (53%)
Current smoker	2,766 (12%)	5,529 (11%)
Past smoker	7,205 (32%)	15,339 (30%)
Unknown	546 (2%)	2,699 (5%)

The eligible population included all the participants who reported no cancer diagnosis (except non-melanoma skin cancer) at the third questionnaire.

Table 2

HRs and 95% CIs for all-cancer mortality and incidence in U.S. radiologic technologists according to nuclear medicine (NM) work history characteristics

	All cancer					
	Mortality analysis			Incidence analysis		
	Eligible population/No. cases	HR	95% CI	Eligible population/No. cases	HR	95% CI
Total	72,755/1365			46,038/3,126		
Ever worked with NM procedures						
No	40,112/588	1.00	reference	26,486/1748	1.00	reference
Yes	22,360/425	1.05	(0.93,1.19)	14,079/960	0.96	(0.89,1.04)
UK	8,066/180			4,794/344		
Ever worked with diagnostic NM procedures						
No	43,988/668	1.00	reference	28,958/1920	1.00	reference
Yes	18,932/344	0.99	(0.87,1.13)	11,876/800	0.95	(0.87,1.03)
UK	7,470/173			4,471/328		
Decade first worked with diagnostic NM procedures						
1950–59	1,980/106	1.00	reference	1,017/84	1.00	reference
1960–69	5,565/110	0.76	(0.54,1.09)	3,440/259	1.28	(0.96,1.72)
1970–79	9,072/100	0.77	(0.54,1.09)	5,905/381	1.57	(1.16,2.12)
1980 +	2,252/28	0.89	(0.55,1.41)	1,470/72	1.23	(0.85,1.76)
UK	63/0			44/4		
p value for trend		0.77			0.13	
Ever worked with therapeutic NM procedures						
No	49,023/722	1.00	reference	32,080/2114	1.00	reference
Yes	12,177/256	1.11	(0.96,1.28)	7,696/536	0.97	(0.88,1.07)
UK	9,191/205			6,262/476		
Decade first worked with therapeutic NM procedures						
1950–59	1,412/71	1.00	reference	742/61	1.00	reference
1960–69	3,661/89	0.98	(0.68,1.41)	2,312/179	1.37	(0.97,1.93)
1970–79	4,874/71	1.06	(0.70,1.61)	3,250/206	1.48	(1.03,2.12)

	All cancer					
	Mortality analysis			Incidence analysis		
	Eligible population/No. cases	HR	95% CI	Eligible population/No. cases	HR	95% CI
1980 +	1,653/14	0.64	(0.34,1.20)	1,112/67	1.51	(1.00,2.30)
UK	577/11			280/23		
p value for trend		0.39			0.04	

The eligible population included all the participants who reported no cancer diagnosis (except non melanoma skin cancer) at the third questionnaire;

Mortality analyses concerned all the participants who completed the third questionnaire and for whom the vital status was assessed on December 31, 2012; non-applicable question for 2217, 2365 and 2364 technologists who ever worked with NM procedures, with diagnostic procedures and with therapeutic procedures, respectively;

The incidence analyses were limited to the subset of technologists who completed both the third and fourth questionnaires; non-applicable question for 679, 679 and 730 technologists who ever worked with NM procedures, with diagnostic procedures and with therapeutic procedures, respectively;

1980+:1980 to date of third survey completion (2003–2005); UK: Unknown answer; HR: hazard ratio fitted with age as the time scale to control for age, stratified on birth cohort (< 1930, 1930–1939, 1940–1949, ≥1950) and adjusted for gender and race; CI: Confidence interval; p-trends were calculated using continuous data, when available, and excluding unknowns. HRs for unknown answers not shown.

Table 3

HRs and 95% CIs for mortality and incidence of cancer at specific sites in U.S. radiologic technologists according to nuclear medicine (NM) work history characteristics

	Mortality analysis				Incidence analysis			
	No. total of cases	No. exposed cases	HR	95% CI	No. total of cases	No. exposed cases	HR	95% CI
Ever worked with NM procedures								
Cancer site								
Eligible population *	72755				46038			
Lung	350	97	0.92	(0.71,1.19)	∫	∫	∫	∫
Melanoma	37	9	0.58	(0.26,1.3)	426	120	0.83	(0.67,1.03)
Colo-rectal	91	23	0.97	(0.57,1.66)	137	44	1.17	(0.80, 1.72)
Thyroid	∫	∫	∫	∫	155	48	1.19	(0.83,1.70)
Lymphoma	56	18	0.83	(0.45,1.52)	122	47	1.39	(0.94,2.06)
Leukemia	46	17	1.25	(0.64,2.45)	67	27	1.38	(0.83,2.31)
Leukemia excluding CLL	41	15	1.22	(0.61,2.43)	25	12	1.99	(0.87,4.54)
Eligible population **					41506			
Non melanoma skin cancer	∫	∫	∫	∫	2875	916	1.01	(0.94,1.1)
Basal cell	∫	∫	∫	∫	2353	756	1.03	(0.94,1.13)
Squamous cell	∫	∫	∫	∫	522	160	0.94	(0.77,1.14)
Eligible population ***	57143				36661			
Female breast	135	40	0.85	(0.58,1.26)	1035	304	0.97	(0.84,1.11)

The eligible population included all the participants who reported no cancer diagnosis (except non-melanoma skin cancer) at the third questionnaire. Mortality analyses concerned all the participants who completed the third questionnaire and for whom the vital status was assessed on December 31, 2012. The incidence analyses were limited to the subset of technologists who completed both the third and fourth questionnaires. ICD-10 codes for cancer sites: lung C34; melanoma C43; non-melanoma skin cancer C44, C46; thyroid C73; lymphoma C81, C82–C85, C96.3; leukemia C91–C95; leukemia excluding CLL C91–C95 excluding C91.1; breast C50. ICD-O-3 codes for non melanoma skin cancer: Basal cell skin cancer histology 8090–8119; Squamous cell skin cancer histology 8050–8089. UK: Unknown answer; HR: Hazard ratios from Cox proportional hazards models fitted with age as the time scale, stratified on birth cohort (< 1930, 1930–1939, 1940–1949, ≥1950) and adjusted for gender and race; CI: Confidence interval;

∫: analysis not performed;

* including all technologists free of cancer at the third questionnaire at the exclusion of non-melanoma skin cancer;

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** including all technologists free of cancer at the third questionnaire;

*** including all female technologists free of cancer at the third questionnaire at the exclusion of non-melanoma skin cancer; Lymphoma: Hodgkin and Non Hodgkin lymphoma; CLL: chronic lymphocytic leukemia;

Table 4

HRs and 95% CIs for mortality from all cancers combined in U.S. radiologic technologists performing nuclear medicine (NM) procedures (N=22,360), according to NM work history characteristics for each decade worked.

	Work history by decade							
	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)
	1950–1959		1960–1969		1970–1979		1980+	
<i>Diagnostic NM procedures</i>								
Number of procedures per week								
0	1491/77	1 reference	4529/150	1 reference	8019/169	1 reference	9578/172	1 reference
<10	1339/74	1.12 (0.82,1.55)	3862/91	0.86 (0.66,1.11)	4599/73	1.06 (0.80,1.40)	1884/26	0.8 (0.53,1.21)
10–24	392/18	0.89 (0.53,1.49)	1343/35	0.81 (0.56,1.18)	2410/32	0.74 (0.51,1.09)	1480/22	0.89 (0.57,1.39)
25–49	160/5	0.58 (0.23,1.42)	690/16	0.71 (0.43,1.20)	2626/42	0.95 (0.68,1.35)	2142/31	0.96 (0.66,1.42)
50+	66/6	2.02 (0.88,4.65)	325/7	0.62 (0.29,1.32)	1523/14	0.52 (0.30,0.90)	1605/20	0.80 (0.50,1.27)
UK	1122/31		2245/50		1232/44		1908/49	
p value for trend		0.79		0.07		0.10		0.40
Number of kits eluted per week								
0	1115/53	1 reference	2891/58	1 reference	3314/60	1 reference	1598/19	1 reference
<10	540/29	1.11 (0.71,1.75)	2096/43	0.91 (0.62,1.36)	3733/40	0.46 (0.31,0.69)	2479/26	0.85 (0.47,1.53)
10–24	111/8	1.48 (0.70,3.12)	682/17	1.03 (0.60,1.77)	2257/22	0.39 (0.24,0.63)	1604/19	0.93 (0.49,1.76)
25+	78/5	1.40 (0.56,3.50)	384/13	1.28 (0.70,2.33)	1671/27	0.60 (0.38,0.94)	1347/28	1.47 (0.82,2.63)
UK	1151/26		2314/44		1303/39		1924/45	
p value for trend		0.35		0.90		0.001		0.22
Percentage time used lead aprons								
75% +	698/40	1 reference	1456/44	1 reference	1137/18	1 reference	330/3	1 reference
<75%	320/16	0.85 (0.47,1.51)	1051/34	1.13 (0.72,1.76)	1595/27	1.14 (0.63,2.08)	803/15	2.71 (0.78,9.37)
No	427/26	1.01 (0.62,1.66)	2288/47	0.74 (0.49,1.12)	5935/87	1.07 (0.64,1.79)	4638/62	2.28 (0.71,7.28)
UK	784/24		1555/33		1207/29		1528/35	
Shielding the radioactive source injections or administrations								
Yes	906/51	1 reference	2988/84	1 reference	6046/93	1 reference	4798/65	1 reference
No	422/27	1.20 (0.75,1.92)	1655/35	0.79 (0.53,1.18)	2454/36	0.95 (0.65,1.40)	955/15	1.19 (0.68,2.09)

	Work history by decade							
	1950–1959	1960–1969	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases
UK	872/26	1680/39		1347/31	1980+	1539/35		
Distance from patient								
3+ feet	922/43	2951/77	1 reference	6068/89	1 reference	4475/61	1 reference	1 reference
<3 feet	519/39	1845/47	1.59 (1.03,2.45)	2575/43	0.96 (0.67,1.39)	1295/19	1.05 (0.73,1.52)	1.02 (0.61,1.71)
UK	805/26	1559/36		1235/29		1531/35		
Therapeutic NM procedures								
Number of procedures per week								
0	1968/105	6334/164	1 reference	12583/209	1 reference	12330/209	1 reference	1 reference
1–2	987/48	3189/86	0.94 (0.67,1.32)	4974/85	1.12 (0.86,1.46)	3370/42	1.19 (0.92,1.53)	0.84 (0.60,1.17)
3+	371/21	951/36	1.08 (0.67,1.72)	1155/29	1.37 (0.96,1.97)	712/16	1.39 (0.94,2.06)	1.22 (0.73,2.03)
UK	1244/31	2520/50		1697/44		2185/49		
p value for trend			0.95		0.07		0.04	0.95
Percentage time used lead aprons								
75% +	656/38	1677/52	1 reference	1507/35	1 reference	578/12	1 reference	1 reference
<75%	235/13	677/28	0.92 (0.49,1.73)	831/20	1.32 (0.83,2.08)	436/4	0.96 (0.56,1.67)	0.42 (0.14,1.3)
No	294/13	1158/29	0.72 (0.38,1.34)	2772/47	0.84 (0.53,1.32)	2407/32	0.81 (0.52,1.25)	0.82 (0.42,1.6)
UK	761/21	1552/41		1388/34		1733/39		
Use of afterloading device to remotely transfer the source								
Yes	389/26	1145/40	1 reference	1528/37	1 reference	1054/17	1 reference	1 reference
No	632/30	2181/60	0.74 (0.44,1.25)	3439/55	0.85 (0.57,1.27)	2278/25	0.71 (0.46,1.07)	0.70 (0.38,1.3)
UK	812/22	1676/41		1481/34		1788/38		
Shielding the radioactive source injections or administrations								
Yes	918/51	2714/88	1 reference	3791/69	1 reference	2628/32	1 reference	1 reference
No	281/13	790/21	0.79 (0.43,1.46)	1299/31	0.82 (0.51,1.33)	783/15	1.35 (0.88,2.06)	1.60 (0.87,2.96)
UK	759/21	1560/41		1408/36		1743/40		
Percentage time maintaining or transporting the source								
0	1053/46	3315/72	1 reference	5738/91	1 reference	4390/55	1 reference	1 reference
>0%	729/42	2005/81	1.22 (0.81,1.86)	2876/60	1.57 (1.14,2.16)	2016/36	1.11 (0.80,1.54)	1.31 (0.86,2.00)

Work history by decade								
	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)
	1950–1959		1960–1969		1970–1979		1980+	
UK	1258/31		2544/50		1727/45		2233/50	

The eligible population included all the participants who reported no cancer diagnosis (except non-melanoma skin cancer) at the third questionnaire and reported having performed NM procedures...

Mortality analyses concerned all the participants who completed the third questionnaire and for whom the vital status was assessed on December 31, 2012.

1980+: 1980 to date of third survey completion (2003–2005); UK: Unknown answers; HR: Hazard ratios from Cox proportional hazards models fitted with age as the time scale, stratified on birth cohort (< 1930, 1930–1939, 1940–1949, ≥1950) and adjusted for gender and race; CI: Confidence interval; p-trends were calculated using continuous data, when available, and excluding unknowns; HRs for unknown answers not shown.

Table 5

HRs and 95% CIs for incidence of all cancers combined in U.S. radiologic technologists performing nuclear medicine (NM) procedures (n= 14,079), according to NM work history characteristics for each decade worked.

	Work history by decade							
	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)
	1950–1959		1960–1969		1970–1979		1980+	
<i>Diagnostic NM procedures</i>								
Number of procedures per week								
0	804/85	1 reference	2838/236	1 reference	5111/333	1 reference	6139/388	1 reference
<10	705/61	0.83 (0.59,1.15)	2437/172	0.89 (0.73,1.08)	2922/185	1.15 (0.95,1.38)	1201/76	1.06 (0.83,1.36)
10–24	200/15	0.68 (0.40,1.19)	762/72	1.12 (0.86,1.46)	1518/93	1.00 (0.79,1.26)	978/59	0.98 (0.74,1.29)
25–49	75/4	0.48 (0.18,1.30)	399/30	0.88 (0.60,1.29)	1691/123	1.21 (0.98,1.49)	1422/102	1.19 (0.96,1.49)
50+	29/4	1.39 (0.51,3.78)	167/11	0.74 (0.40,1.35)	976/79	1.31 (1.02,1.68)	1036/74	1.18 (0.92,1.52)
UK	588/53		1221/85		691/57		1049/85	
p value for trend		0.12		0.53		0.02		0.08
Number of kits eluted per week								
0	598/48	1 reference	1805/127	1 reference	2033/129	1 reference	998/59	1 reference
<10	281/28	1.23 (0.77,1.96)	1296/98	1.05 (0.81,1.37)	2430/155	0.89 (0.70,1.13)	1675/108	1.06 (0.77,1.46)
10–24	50/1	0.23 (0.03,1.69)	375/33	1.13 (0.77,1.67)	1514/104	0.91 (0.70,1.18)	1060/70	1.05 (0.74,1.48)
25+	30/1	0.39 (0.05,2.79)	225/20	1.14 (0.71,1.83)	1046/88	1.08 (0.82,1.42)	875/72	1.28 (0.90,1.80)
UK	606/56		1252/89		736/57		1052/84	
p value for trend		0.59		0.73		0.98		0.23
Percentage time used lead aprons								
75% +	370/30	1 reference	919/67	1 reference	715/53	1 reference	188/15	1 reference
<75%	173/10	0.68 (0.33,1.40)	683/53	1.07 (0.75,1.54)	1061/68	0.85 (0.59,1.22)	539/38	0.91 (0.50,1.66)
No	235/21	1.08 (0.62,1.89)	1487/115	1.09 (0.81,1.48)	4190/290	0.93 (0.69,1.25)	3310/225	0.89 (0.53,1.51)
UK	465/45		980/64		746/56		915/74	
Shielding the radioactive source injections or administrations								
Yes	481/37	1 reference	1910/134	1 reference	4168/289	1 reference	3368/238	1 reference

	Work history by decade						
	1950–1959	1960–1969	1970–1979	1980+	Eligible pop/ No. cases	HR (95% CI)	
No	237/18	1084/95	1696/115	659/37	1.03 (0.58,1.80)	0.97 (0.78,1.2)	0.80 (0.56,1.13)
UK	1516/143	1061/68	835/62	921/77			
Distance from patient							
3+ feet	489/43	1929/143	4224/290	3189/229	1 reference	1 reference	1 reference
<3 feet	286/18	1158/93	1726/117	856/48	0.71 (0.41,1.22)	0.98 (0.79,1.21)	0.78 (0.57,1.06)
UK	475/46	983/63	764/60	908/75			
Therapeutic NM procedures							
Number of procedures per week							
0	1030/105	3909/316	7946/519	7875/497	1 reference	1 reference	1 reference
1–2	542/47	2033/154	3297/220	2286/157	0.86 (0.61,1.21)	1.06 (0.91,1.24)	1.14 (0.95,1.37)
3+	181/13	513/45	682/57	431/30	0.67 (0.37,1.19)	1.25 (0.95,1.65)	1.07 (0.74,1.55)
UK	649/57	1369/91	984/74	1233/100			
p value for trend					0.12	0.44	0.21
Percentage time used lead aprons							
75% +	365/29	1084/73	1003/63	371/25	1 reference	1 reference	1 reference
<75%	132/10	421/27	561/34	300/15	0.94 (0.46,1.94)	0.92 (0.61,1.40)	0.71 (0.37,1.35)
No	161/14	760/73	1942/150	1746/128	1.07 (0.56,2.03)	1.25 (0.93,1.67)	1.16 (0.75,1.78)
UK	434/37	964/64	867/69	1055/93			
Use of afterloading device to remotely transfer the source							
Yes	208/17	683/51	986/77	726/45	1 reference	1 reference	1 reference
No	367/26	1497/115	2444/165	1650/118	0.88 (0.48,1.61)	0.86 (0.65,1.12)	1.11 (0.79,1.57)
UK	468/43	1034/69	925/72	1085/96			
Shielding the radioactive source injections or administrations							
Yes	500/41	1754/134	2602/180	1857/124	1 reference	1 reference	1 reference
No	154/12	509/37	992/65	558/43	0.93 (0.49,1.78)	1.07 (0.80,1.42)	1.17 (0.83,1.65)
UK	438/37	966/66	879/71	1057/94			
Percentage time maintaining or transporting the source							

	Work history by decade							
	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)	Eligible pop/ No. cases	HR (95% CI)
	1950–1959		1960–1969		1970–1979		1980+	
0	520/33	1 reference	1930/149	1 reference	3306/207	1 reference	2458/170	1 reference
>0%	362/34	1.44 (0.89,2.32)	1148/95	0.99 (0.76,1.28)	1769/150	1.26 (1.02,1.56)	1293/87	0.94 (0.73,1.22)
UK	655/59		1386/90		1013/76		1267/108	

The eligible population included all the participants who reported no cancer diagnosis (except non-melanoma skin cancer) at the third questionnaire and reported having performed NM procedures. The incidence analyses were limited to the subset of technologists who completed both the third and fourth questionnaires

1980+: 1980 to date of third survey completion (2003–2005); UK: Unknown answers; HR: Hazard ratios from Cox proportional hazards models fitted with age as the time scale, stratified on birth cohort (< 1930, 1930–1939, 1940–1949, ≥1950) and adjusted for gender and race; CI: Confidence interval; p-trends were calculated using continuous data, when available, and excluding unknowns; HRs for unknown answers not shown.