Radiology

Cataract Risk in a Cohort of U.S. Radiologic Technologists Performing Nuclear Medicine Procedures[1]

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Purpose: To estimate the risk of cataract in a cohort of nuclear medicine (NM) radiologic technologists on the basis of their work histories and radiation protection practices.

Materials and Methods: In the years 2003—2005 and 2012—2013, 42 545 radiologic technologists from a U.S. prospective study completed questionnaires in which they provided information regarding their work histories and cataract histories. Cox proportional hazards models, stratified according to birth-year cohort (born before 1940 or born in 1940 or later) and adjusted for age, sex, and race, were used to estimate hazard ratios (HRs) for the risk of cataract in radiologic technologists according to NM work history practices according to decade.

Results: During the follow-up period (mean follow-up, 7½ years), 7137 incident cataracts were reported. A significantly increased risk of cataract (HR, 1.08; 95% confidence interval [CI]: 1.03, 1.14) was observed among workers who performed an NM procedure at least once—as opposed to never. Risks of cataract were increased in the group who had performed a diagnostic (HR, 1.07; 95% CI: 1.01, 1.12) or therapeutic (HR, 1.10; 95% CI: 1.04, 1.17) NM procedure. Risks were higher for those who had first performed diagnostic NM procedures in the 1980s to early 2000s (HR, 1.30; 95% CI: 1.08, 1.58) and those who had performed therapeutic NM procedures in the 1970s (HR, 1.11; 95% CI: 1.01, 1.23) and in the 1980s to early 2000s (HR, 1.14; 95% CI: 1.02, 1.29). With the exception of a significantly increased risk associated with performing therapeutic NM procedures without shielding the radiation source in the 1980s (HR, 1.32; 95% CI: 1.04, 1.67), analyses revealed no association between cataract risk and specific radiation protection technique used.

Conclusion: An increased risk of cataract was observed among U.S. radiologic technologists who had performed an NM procedure at least once. This association should be examined in future studies incorporating estimated lens doses.

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Diagnostic and therapeutic nuclear medicine (NM) procedures involve the use of ionizing radiation to assess organ function and treat patients with a wide range of diseases. The number of NM procedures performed in the United States has increased dramatically during the past few decades, from 7 million in the early 1980s to 18 million in 2006 (1). This trend is largely being driven by an increasing use of high-radiation-dose procedures, including cardiac imaging (2) and positron emission tomography (PET) (3).

Some of the radionuclides used for organ imaging in NM practices are high-energy, highly penetrating gamma emitters (4). In contrast to professionals who work with standard radiologic procedures, those who work with NM procedures cannot avoid being in close contact with radioactive pharmaceuticals when they prepare and/or administer injections and during the imaging process. Although the annual mean effective radiation dose has been reported to be 0.7 mSv worldwide (5), the effective dose can reach several millisieverts, depending on the procedure type and the method and behavior used in performing the procedure (5–8). However, radiation exposure levels can be reduced by using shielding devices and/or reducing the time spent in close proximity to patients who are undergoing a procedure involving radiation. Notable variations in work practices and radiation protection techniques can result in heterogeneous levels of occupational exposure from NM procedures (5).

The potential health effects of occupational radiation exposure on medical staff have been investigated in cohort studies (9–14); however, sparse information is available for NM workers. In 2000, there were approximately 120 000 NM workers worldwide. Although they represented only 5% of all medically exposed workers, they reportedly received 10% of the collective radiation dose (5). To our knowledge, only one study (15) has evaluated the long-term health risks in this population. Kitahara et al (15) observed an increased risk of lung cancer mortality in association with performing NM procedures in 22 000 U.S. radiologic technologists who reported having performed a NM procedure at least once and an increased risk of squamous cell carcinoma among those who reported having performed diagnostic radionuclide procedures. Cataract outcome was not investigated.

Cataract was identified early on as a late effect of ionizing radiation, and for more than 50 years it has been considered a tissue reaction (formerly considered a deterministic effect) with a threshold of 2 Gy. Recent epidemiologic studies have yielded new evidence of radiation-induced cataract at lower doses (16), leading the International Commission on Radiological Protection to lower the assumed threshold to 0.5 Gy (17). However, investigators in some literature reviews focused on more recent epidemiologic and biologic study findings (18,19) have questioned whether the data are still consistent with the theory that cataract is a tissue reaction and have described potential stochastic phenomena linked to DNA damage as an explanation for the increased risks at lower radiation exposure levels. In a previous analysis and follow-up investigation (20) conducted from 1983 to 2004 and involving 35 705 U.S. radiologic technologists from the current study, personal medical radiation exposure, defined as radiation therapy to the head and neck or exposure to a large number (>15) of radiographic procedures, was found to be associated with an increased risk of cataract. However, the estimated occupational radiation exposure dose was not significantly associated with this risk.

In the current study, we focused on occupational histories and more recently collected radiation exposure information (including the use of radiation protection techniques) according to decade worked, as well as follow-up data from the U.S. Radiologic Technologists cohort study (20). We estimated the risk of cataract in NM technologists, taking into account their work histories and radiation protection practices.

Advances in Knowledge

- A significantly increased risk of cataract (hazard ratio, 1.08; 95% confidence interval: 1.03, 1.14) was observed among U.S. radiologic technologists who had performed a nuclear medicine (NM) procedure at least once, as compared with those who had never performed them.
- Significantly increased risks of cataract were observed for those radiologic technologists who had performed a diagnostic (7% risk increase) or therapeutic (10% risk increase) NM procedure at least once, as opposed to never.
- No strong association between cataract risk and either number of diagnostic or therapeutic NM procedures performed or specific radiation protection technique used was observed.

Materials and Methods

U.S. Radiologic Technologist Cohort

The U.S. Radiologic Technologist cohort study was established under a collaboration among the National Cancer Institute, the University of Minnesota,

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Abbreviations:
CI = confidence interval
HR = hazard ratio
NM = nuclear medicine

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Guarantors of integrity of entire study, M.O.B., D.V.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; agrees to ensure any questions related to the work are appropriately resolved, all authors; literature research, M.O.B., D.V., C.M.K.; clinical studies, M.O.B.; statistical analysis, M.O.B., N.J., D.V., M.S.L., C.M.K.; and manuscript editing, all authors

Conflicts of interest are listed at the end of this article.

and the American Registry of Radiologic Technologists.

A description of the study population and methods can be found on the U.S. Radiologic Technologists website (https://study.nci.nih.gov.study.nci.nih.gov/). Briefly, 146 022 radiologic technologists who were U.S. residents and had been certified for at least 2 years in the years 1926–1982 were identified from the American Registry of Radiologic Technologists records. Passive follow-up of this cohort to obtain vital status data has been based on linkage to yearly American Registry of Radiologic Technologists recertification records and Social Security Administration database records for those who did not recertify. Technologists identified as deceased, presumed to be deceased, or with unknown vital status were linked to the National Death Index (NDI Plus, U.S. Centers for Disease Control and Prevention, Atlanta, Ga) to confirm their vital status and obtain their causes of death.

Additional information was acquired from a series of questionnaires, which were mailed and completed in the years 1983–1989, 1994–1998, 2003–2005, and 2012–2013. The questionnaires included questions regarding work history, demographic characteristics, lifestyle, and other disease risk factors; personal diagnostic and therapeutic medical procedures performed; and health outcomes, including age at the time of cataract diagnosis or cataract surgery. This study was approved by the institutional review boards of the National Cancer Institute and the University of Minnesota.

Study Population and Follow-up

The baseline questionnaire (mailed and completed in years 1983–1989) for the present study was completed by 73 613 radiologic technologists, who were then followed up and sent a subsequent survey. Of these 73 613 technologists, 51 291 completed the third and fourth questionnaires. After the exclusion of 8746 of the 51 291 technologists (17%) because they reported receiving a diagnosis of cataract at the time of or before the third survey, the study population included 42 545 technologists. Participants were followed up from the date on which the third survey was completed to the date on which cataract was diagnosed or the date on which the fourth survey was completed (during 2012–2013).

Exposure Assessment

The work history reported by individuals on the third questionnaire (in years 2003–2005) referred to the worker's first year of employment as a radiologic technologist and specific questions about performing diagnostic and therapeutic NM, fluoroscopically guided interventional procedures, and radiographic procedures. For specific time periods (before 1940, 1940–1949, 1950–1959, 1960–1969, 1970–1979, and 1980 to present), questions were asked about the frequency of performing NM procedures per week, the specific tasks performed, and the radiation protection measures taken, including the amount of time wearing a lead apron and standing in close proximity to the patient and the use of a protective shield around the radioactive source and afterloading devices to transfer the radioactive source from the safe to the patient. No information regarding the use of lead glasses by technologists was available from the third survey. Because few participants reported working with NM procedures before 1950, responses related to the two earliest time periods (before 1940 and 1940–1949) were combined with those related to the 1950–1959 period in the analysis. Technologists were classified as having ever worked in NM if they reported having performed at least one NM procedure per week in any decade. Other baseline information evaluated included race, education, marital status, smoking status, eye color, solar ultraviolet radiation exposure, medical history, and medical exposure to radiation.

Statistical Analyses

With use of Cox proportional hazards regression, hazard ratios (HRs) and corresponding 95% confidence intervals (CIs) were calculated to evaluate the risk of cataract in radiologic technologists who ever, as compared with never, performed NM procedures. All models were fitted with age as the time scale metric to control for age, stratified according to birth-year cohort (born before 1940 or born in 1940 or later) to control for secular trends, and adjusted for sex and race. Additional adjustments were made for potential confounders known to be associated with cataract, such as smoking, body mass index, eye color, ultraviolet radiation exposure, diabetes (21), personal history of medical exposure to radiation (22–25), and occupational radiation exposure related to fluoroscopically guided interventional radiology practice (26–28). Decade-specific risks were assessed according to frequency of performing procedures per week and use of radiation protection measures. Missing or inapplicable values for categorical variables were removed from the specific analyses. *P* values for trend were calculated by using continuous data, when available, and excluding missing or inapplicable values.

Statistical significance was estimated by using likelihood ratio tests. Scaled Schoenfeld residuals (29) were examined to assess the proportional hazards assumption over the age time scale. All analyses were two sided and performed by using software (SAS, version 9.3; SAS Institute, Cary, NC).

Results

The demographic characteristics of the 42 545 technologists who were cataract free at completion of the third survey (in years 2003–2005) and who completed the fourth survey (in years 2012–2013) are summarized in Table 1. Of the 42 545 technologists, 34 096 (80%) were women, 40 694 (96%) were white, and 36 540 (86%) attended more than 12 years of education. The mean ages at completion of the third and fourth surveys were 55 and 62½ years, respectively, with a mean follow-up of 7½ years between the two questionnaires. Of the 42 545 technologists in the study population, 40 725 (96%) reported having performed a radiographic procedure at least once and 10 434 (25%)

Table 1

Characteristics of U.S. Radiologic Technologists Who Were Cataract Free at Completion of the Third Survey and Who Completed the Fourth Survey, Stratified according to NM Work History

Parameter	Never Worked with NM Procedures (*n* = 29 581)*	Ever Worked with NM Procedures (*n* = 12 964)
Sex		
F	24 195 (82)	9901 (76)
M	5386 (18)	3063 (24)
Race		
White non-Hispanic	28 316 (96)	12 378 (96)
Hispanic	615 (2)	277 (2)
Black	300 (1)	144 (1)
Asian (Pacific Islander or unknown)	350 (1)	165 (1)
Age at completion of third follow-up survey (y)		
<60	23 568 (80)	9947 (77)
60–69	5191 (18)	2690 (21)
≥70	822 (3)	327 (2)
Birth year		
Before 1940	2514 (8)	1213 (9)
1940–1949	9774 (33)	5246 (40)
1950–1959	16 946 (57)	6428 (50)
1960 or later	347 (1)	77 (1)
Smoking status at completion of third survey		
Never smoker	17 244 (58)	7267 (56)
Current smoker	2982 (10)	1400 (11)
Past smoker	8856 (30)	4145 (32)
Unknown	499 (2)	152 (1)
Education status		
≤12 years	119 (.4)	39 (.3)
2 years of radiologic technologist training	13 548 (46)	5147 (40)
1–4 years of college	12 153 (41)	5952 (43)
Other or unknown	3761 (13)	1826 (14)
Marital status		
Married or living together	1,227 (4)	539 (4)
Separated, divorced, or widowed	20 562 (70)	8784 (68)
Never married	3977 (13)	1788 (14)
Unknown	3815 (13)	1853 (14)
BMI at completion of third survey (kg/m^2)		
<18.5	211 (1)	104 (1)
18.5–24.0	9984 (34)	4033 (31)
25–29	9980 (34)	4603 (36)
≥30	7086 (24)	3406 (26)
Unknown	2320 (8)	818 (6)
Occupational radiation exposure		
Performed x-ray–based procedures	29 059 (98)	11 666 (90)
Performed fluoroscopically guided interventional radiology procedures		
Yes	7096 (24)	3338 (26)
Unknown	1766 (6)	860 (7)

Note.—Data are numbers of radiologic technologists, with percentages in parentheses. The third survey was completed in the years 2003–2005, and the fourth survey was completed in the years 2012–2013. BMI = body mass index.

* Included 3754 workers with unknown status.

reported having performed a fluoroscopically guided interventional radiology procedure at least once. Thirty percent (n = 12 964) of the technologists reported having worked at least once a week with NM procedures. Compared with the technologists who never worked with NM, those who did were more likely to be men and older and were less likely to have completed only 2 years of radiologic technologist training.

There were a total of 7137 self-reported diagnoses of cataract, and 2458 of these diagnoses were in technologists who reported performing an NM procedure at least once (Table 2). The main results were adjusted for sex and race because additional adjustments for other known risk factors did not modify the estimates (data not shown). Having ever worked with any NM procedure was associated with a significantly increased risk of cataract (HR, 1.08; 95% CI: 1.03, 1.14).

A modest increase in the risk of developing cataract was apparent for technologists who had ever performed diagnostic NM procedures (HR, 1.07; 95% CI: 1.01, 1.12) as compared with those who had never performed them. However, the risks were higher for technologists who first performed diagnostic NM procedures in the 1980s (HR, 1.30; 95% CI: 1.08, 1.58) than for those who started performing these procedures in the 1950s ($P < .001$ for the trend). Among the technologists who had ever performed diagnostic NM procedures, cataract risk was not associated with number of performed diagnostic procedures or number of prepared or eluted radiopharmaceutical kits. Cataract risk was not associated with the use of radiation protection measures, including shielding the radioactive source during administration of the radioactive material and standing at least 3 feet away from the patient during the procedure (Table 3).

Having ever performed a therapeutic NM procedure was associated with a significantly increased risk of developing cataract (HR, 1.10; 95% CI: 1.04, 1.17), and the risk increased significantly by decade worked (P value

Table 2

Cataract Frequency and Surgery in U.S. Radiologic Technologists according to NM Work History Characteristics (*n* = 42 545)

Parameter	Cataract Diagnosis: No. of Cases*	Cataract Diagnosis: HR†	Cataract Surgery: No. of Cases‡	Cataract Surgery: HR†
Ever worked with NM procedures				
No (*n* = 25 827)	3965	1.00 (Ref)	1316	1.00 (Ref)
Yes (*n* = 12 964)	2458	1.08 (1.03, 1.14)§	850	1.09 (1.00, 10.18)
Missing (*n* = 3754)	714	…	306	…
Ever worked with diagnostic NM procedures				
No (*n* = 27 415)	4281	1.00 (Ref)	1425	1.00 (Ref)
Yes (*n* = 10 967)	2060	1.07 (1.01, 1.12)§	711	1.07 (0.98, 1.17)
Missing (*n* = 4163)	796	…	336	…
Decade first worked with diagnostic NM procedures				
1950s (*n* = 642)	258	1.00 (Ref)	142	1.00 (Ref)
1960s (*n* = 3084)	812	0.97 (0.84, 1.13)	286	0.95 (0.77, 1.17)
1970s (*n* = 5787)	777	1.09 (0.94, 1.27)	208	0.97 (0.78, 1.22)
1980 and after (*n* = 1418)	204	1.30 (1.08, 1.58)§	73	1.48 (1.11, 1.97)§
Missing (*n* = 36)	9	…	2	…
P value for trend	…	<.001	…	<.01
Ever worked with therapeutic NM procedures				
No (*n* = 30 403)	4713	1.00 (Ref)	1569	1.00 (Ref)
Yes (*n* = 7005)	1436	1.10 (1.04, 1.17)§	489	1.07 (0.96, 1.18)
Missing (*n* = 5137)	998	…	414	…
Decade first worked with therapeutic NM procedures				
1950s (*n* = 467)	190	1.00 (Ref)	100	1.00 (Ref)
1960s (*n* = 2041)	566	1.00 (0.84, 1.18)	207	1.08 (0.84, 1.38)
1970s (*n* = 3150)	479	1.18 (0.99, 1.40)	124	1.07 (0.82, 1.41)
1980 or after (*n* = 1086)	149	1.15 (0.93, 1.44)	37	0.96 (0.65, 1.40)
Missing (*n* = 261)	52	…	21	…
P value for trend	…	<.01	…	.77

Note.—Missing answers were due to unknown answers or nonapplicable questions.

* Data are numbers of cases of a self-reported diagnosis of cataract in the population of radiologic technologists in the given subgroup.

† HRs were calculated by using Cox proportional hazards models fitted with age as the time scale metric, stratified according to birth-year cohort (born before 1940 or born in 1940 or later), and adjusted for sex and race. Numbers in parentheses are 95% CIs. Ref = reference.

‡ Data are numbers of cases of cataract removal surgery in the population of radiologic technologists with self-diagnosed cataract in the given subgroup.

§ Statistically significant.

for trend = .01). Among the technologists who had performed a therapeutic NM procedure at least once, we observed significantly increased risks for those who performed one or more therapeutic NM procedures per week in the 1970s and 1980s (Table 3). With the exception of a significantly increased risk related to the lack of radioisotope source shielding during therapeutic procedures in the 1980s, cataract risk was not associated with specific activities or radiation protection measures.

Similar findings were observed when the analysis was limited to cases of cataracts that were surgically removed (*n* = 2472) (Table 4). However, owing to the small number of surgeries reported, some of the risk data were less precise. The risks were also similar when we included cataract diagnoses that were rendered before the third survey was conducted (data not shown).

Discussion

In this study, we found an increased risk of cataract in a population of medical workers who performed NM procedures and who were followed up from the time of completion of the third cohort survey in the years 2003–2005 to the time of completion of the fourth survey in the years 2012–2013. Increased risks were observed in those technologists who conducted diagnostic and therapeutic NM procedures, as compared with those who did not perform NM procedures. With the exception of the reduced risk associated with shielding the radioactive source when performing therapeutic NM procedures in the 1980s, no association between cataract risk and either use of radiation protection techniques or usual practices for handling radionuclides was observed for those technologists who performed NM procedures. Adjustments for known cataract risk factors, personal radiation exposure from radiographic or other medical procedures, or other occupational radiation exposure did not modify the risk estimates.

Although an increased risk of cataract among medical workers who were occupationally exposed to radiation has been previously reported (19), mainly among those who performed fluoroscopically guided interventional procedures, to our knowledge such a risk increase has never been reported for NM workers. The radiation doses to the eyes of NM workers are expected to be low because only photon emitters of low energy and/or beta emitters with energy levels higher than 0.7 MeV penetrate deep enough to reach the lens. However, among NM workers, estimated annual radiation doses to the eyes have ranged from 0.9 to 25.0 mGy, depending on the type of procedure performed (6,30–32); these radiation doses could contribute to a relatively high cumulative dose after several decades of work. Increases in radiopharmaceutical production, iodine 131 therapy administration, and PET/computed

Table 3

Frequency of Cataract in U.S. Radiologic Technologists Who Ever Performed NM Procedures, Stratified according to Work History Characteristics for Each Decade Worked

	Worked Years 1950–1959		Worked Years 1960–1969		Worked Years 1970–1979		Worked Year 1980 and Later	
Parameter	No. of Cases*	HR†	No. of Cases*	HR†	No. of Cases*	HR†	No. of Cases*	HR†
No. of diagnostic isotopic procedures per week								
0	203/493	1.00 (Ref)	697/2357	1.00 (Ref)	1004/4655	1 (Ref)	1092/5684	1.00 (Ref)
1–9	183/462	0.89 (0.73, 1.09)	592/2151	0.94 (0.84, 1.05)	412/2804	1.06 (0.94, 1.19)	182/1128	1.12 (0.96, 1.31)
10–24	44/111	1.01 (0.73, 1.39)	174/638	0.89 (0.75, 1.05)	219/1448	0.88 (0.76, 1.02)	133/923	0.98 (0.82, 1.18)
25–49	24/48	1.18 (0.77, 1.81)	102/366	0.91 (0.74, 1.13)	277/1628	1.04 (0.91, 1.19)	222/1379	1.08 (0.93, 1.25)
≥50	7/21	0.80 (0.38, 1.71)	33/129	0.85 (0.6, 1.2)	151/935	0.97 (0.82, 1.16)	164/988	1.10 (0.93, 1.30)
P value for trend	…	.73	…	.09	…	.83	…	.19
No. of kits eluted per week								
0	149/386	1.00 (Ref)	433/1599	1.00 (Ref)	239/1971	1.00 (Ref)	155/964	1.00 (Ref)
1–9	77/172	1.27 (0.96, 1.67)	307/1124	1.00 (0.86, 1.16)	369/2352	1.01 (0.85, 1.18)	224/1599	0.86 (0.70, 1.05)
10–24	14/35	1.07 (0.62, 1.86)	95/327	1.07 (0.85, 1.33)	251/1431	1.09 (0.91, 1.30)	169/1031	0.95 (0.77, 1.18)
≥25	8/24	0.87 (0.43, 1.78)	62/194	1.19 (0.91, 1.56)	189/997	1.07 (0.89, 1.30)	147/810	0.96 (0.76, 1.20)
P value for trend	…	.40	…	.60	…	.31	…	.74
Shielding the radioactive source injections or administrations								
No	58/145	1.02 (0.75, 1.40)	282/932	1.15 (0.99, 1.34)	275/1600	1.05 (0.91, 1.21)	103/631	1.03 (0.83, 1.27)
Yes	122/318	1.00 (Ref)	446/1668	1.00 (Ref)	620/3999	1.00 (Ref)	512/3206	1.00 (Ref)
Distance from patient								
<3 feet	66/167	0.98 (0.73, 1.33)	297/1000	1.05 (0.91, 1.21)	274/1647	0.93 (0.80, 1.07)	124/837	0.84 (0.69, 1.03)
≥3 feet	123/312	1.00 (Ref)	459/1667	1.00 (Ref)	637/4028	1.00 (Ref)	489/3012	1.00 (Ref)
No. of therapeutic procedures per week								
0	261/622	1.00 (Ref)	940/3318	1.00 (Ref)	1364/7426	1.00 (Ref)	1335/7378	1.00 (Ref)
1–2	141/346	0.98 (0.80, 1.20)	498/1767	0.97 (0.87, 1.08)	529/3138	1.11 (1.01, 1.23)‡	355/2158	1.14 (1.02, 1.29)‡
≥3	45/121	0.87 (0.64, 1.20)	128/426	0.96 (0.80, 1.15)	122/631	1.04 (0.86, 1.25)	65/389	1.01 (0.79, 1.29)
P value for trend	…	.58	…	.48	…	.12	…	.13
Percentage of time shielding the radioactive source injections or administrations								
0%	35/87	0.88 (0.59, 1.29)	140/454	1.06 (0.87, 1.30)	159/865	1.05 (0.86, 1.27)	101/528	1.32 (1.04, 1.67)‡
<75%	42/120	0.82 (0.57, 1.18)	150/523	0.99 (0.81, 1.21)	123/770	0.86 (0.70, 1.06)	71/414	1.15 (0.88, 1.51)
≥75%	89/208	1.00 (Ref)	276/964	1.00 (Ref)	292/1670	1.00 (Ref)	207/1326	1.00 (Ref)
Use of afterloading device for remote transfer of radioisotope								
No	96/249	0.95 (0.67, 1.33)	384/1270	1.12 (0.93, 1.34)	405/2327	1.05 (0.88, 1.26)	258/1548	1.01 (0.81, 1.26)
Yes	51/130	1.00 (Ref)	164/594	1.00 (Ref)	159/929	1.00 (Ref)	114/690	1.00 (Ref)
Percentage of time maintaining or transporting radioactive source								
0%	134/337	1.00 (Ref)	468/1668	1.00 (Ref)	518/3147	1.00 (Ref)	374/2327	1.00 (Ref)
>0%	91/223	1.1 (0.84, 1.43)	291/975	1.00 (0.87, 1.16)	292/1664	0.94 (0.82, 1.09)	204/1205	1.07 (0.90, 1.27)

Note.—Unknown or nonapplicable answers were removed from this specific analyses.

* Data are numbers of cases of cataract in the population of radiologic technologists in the given subgroup who worked in the given decade.

† HRs were calculated by using Cox proportional hazards models fitted with age as the time scale metric, stratified according to birth-year cohort (born before 1940 or born in 1940 or later), and adjusted for sex and race. Numbers in parentheses are 95% CIs. Ref = reference.

‡ Statistically significant.

Table 4

Cataract Surgery in U.S. Radiologic Technologists Who Ever Performed NM Procedures, Stratified according to Work History Characteristics for Each Decade Worked

Parameter	Worked Years 1950–1959 No. of Cases*	Worked Years 1950–1959 HR†	Worked Years 1960–1969 No. of Cases*	Worked Years 1960–1969 HR†	Worked Years 1970–1979 No. of Cases*	Worked Years 1970–1979 HR†	Worked Years 1980 and Later No. of Cases*	Worked Years 1980 and Later HR†
No. of diagnostic isotopic procedures per week								
0	107/493	1.00 (Ref)	274/2357	1.00 (Ref)	353/4655	1.00 (Ref)	343/5684	1.00 (Ref)
<10	96/462	0.89 (0.73, 1.09)	205/2151	0.94 (0.84, 1.05)	114/2804	1.06 (0.94, 1.19)	72/1128	1.12 (0.96, 1.31)
10–24	26/111	0.99 (0.72, 1.37)	68/638	0.89 (0.75, 1.05)	74/1448	0.88 (0.76, 1.02)	115/923	0.98 (0.82, 1.18)
25–49	14/48	1.18 (0.77, 1.81)	41/366	0.91 (0.74, 1.13)	80/1628	1.04 (0.91, 1.19)	48/1379	1.08 (0.93, 1.25)
≥50	6/21	0.80 (0.38, 1.71)	18/129	0.85 (0.60, 1.20)	52/935	0.97 (0.82, 1.16)	872/988	1.10 (0.93, 1.30)
P value for trend	…	.81	…	.74	…	.95	…	.17
No. of kits eluted per week								
0	78/386	1.00 (Ref)	157/1599	1.00 (Ref)	65/1971	1.00 (Ref)	58/964	1.00 (Ref)
1–9	42/172	1.27 (0.96, 1.67)	98/1124	1.00 (0.86, 1.16)	106/2352	1.01 (0.85, 1.18)	71/1599	0.86 (0.70, 1.05)
10–24	8/35	1.07 (0.62, 1.86)	43/327	1.07 (0.85, 1.33)	78/1431	1.09 (0.91, 1.30)	54/1031	0.95 (0.77, 1.18)
≥25	4/24	0.87 (0.43, 1.78)	30/194	1.19 (0.91, 1.56)	62/997	1.07 (0.89, 1.30)	50/810	0.96 (0.76, 1.20)
P value for trend	…	.56	…	.29	…	.43	…	.25
Shielding the radioactive source injections or administrations								
No	31/145	1.09 (0.71, 1.68)	94/932	1.04 (0.80, 1.33)	67/1600	0.86 (0.65, 1.14)	29/631	0.90 (0.61, 1.34)
Yes	61/318	1.00 (Ref)	168/1668	1.00 (Ref)	190/3999	1.00 (Ref)	171/3206	1.00 (Ref)
Distance from patient								
<3 feet	30/167	0.79 (0.52, 1.22)	104/1000	0.99 (0.78, 1.27)	79/1647	0.91 (0.70, 1.18)	43/837	0.92 (0.66, 1.30)
≥3 feet	70/312	1.00 (Ref)	173/1667	1.00 (Ref)	185/4028	1.00 (Ref)	154/3012	1.00 (Ref)

Table 4 *(continues)*

tomography use in recent decades may have contributed to higher eye lens doses in technologists who perform NM procedures (30,31). In addition, in recent reviews in the epidemiologic literature, there has been discussion of a potential effect on cataract development from radiation doses lower than the previously accepted threshold of 0.5 Gy (18,19).

We observed modest increases in cataract risk in association with ever—as opposed to never—performing diagnostic (7% risk increase) and therapeutic (10% risk increase) NM procedures. No trend was observed with increasing number of procedures performed. The increase in cataract risk was smaller than that reported for interventional radiologists and cardiologists (2.5%–5.7% higher risk compared with that reported for unexposed groups) (27–29,34). However, radiation doses to the eye can be much higher in interventional physicians—sometimes cumulating to more than 1 Gy during all years worked (27,34).

The reported trends of increased cataract risk for workers performing NM procedures during the more recent decades (1970s and 1980s) may reflect the possibility that these technologists were still performing NM work in the year 2000 and afterward, when the use of higher-radiation-dose procedures such as PET and cardiac scintigraphy were increasing—and potentially resulting in higher cumulative doses to the eye (30,31). Selection bias linked to the exclusion of cataract diagnoses before the study period was ruled out in a sensitivity analysis that included cases that occurred before the third survey (data not shown).

Not shielding the radioactive source when performing therapeutic procedures, which leads to increased radiation exposure to the technologists, was associated with an increased risk of cataract in the 1980s. Risk was not associated with other work practices or radiation safety measures used. In addition, the technologists may have had a tendency to overreport their use of radiation protection tools and may have had difficulty remembering other

Table 4 (continued)

Cataract Surgery in U.S. Radiologic Technologists Who Ever Performed NM Procedures, Stratified according to Work History Characteristics for Each Decade Worked

	Worked Years 1950–1959		Worked Years 1960–1969		Worked Years 1970–1979		Worked Years 1980 and Later	
Parameter	No. of Cases*	HR†	No. of Cases*	HR†	No. of Cases*	HR†	No. of Cases*	HR†
No. of therapeutic procedures per week								
0	138/622	1.00 (Ref)	355/3318	1.00 (Ref)	459/7426	1.00 (Ref)	433/7378	1.00 (Ref)
1–2	74/342	0.98 (0.80, 1.20)	196/1767	0.97 (0.87, 1.08)	162/3138	1.11 (1.01, 1.23)‡	108/2158	1.14 (1.02, 1.29)‡
≥3	23/118	0.89 (0.65, 1.21)	46/426	0.96 (0.80, 1.15)	33/631	1.04 (0.86, 1.25)	25/389	1.01 (0.79, 1.29)
P value for trend	...	.40	...	.98	...	.91		.14
Percentage of time shielding the radioactive source injections or administrations								
None	16/87	0.73 (0.41, 1.28)	54/454	1.02 (0.74, 1.42)	48/865	1.05 (0.74, 1.49)	32/528	1.41 (0.92, 2.16)
<75%	24/120	0.82 (0.50, 1.33)	53/523	0.83 (0.60, 1.15)	35/770	0.77 (0.52, 1.14)	22/414	1.11 (0.68, 1.81)
≥75%	48/208	1.00 (Ref)	110/964	1.00 (Ref)	88/1670	1.00 (Ref)	62/1326	1.00 (Ref)
Use of afterloading device for remote transfer of radioisotope								
No	47/249	0.79 (0.50, 1.24)	146/1270	1.11 (0.83, 1.49)	124/2327	1.23 (0.87, 1.74)	81/1548	1.18 (0.78, 1.77)
Yes	30/130	1.00 (Ref)	64/594	1.00 (Ref)	43/929	1.00 (Ref)	32/690	1.00 (Ref)
Percentage time maintaining or transporting the source								
0%	72/337	1.00 (Ref)	186/1668	1.00 (Ref)	178/3147	1.00 (Ref)	125/2327	1.00 (Ref)
>0%	53/223	1.18 (0.83, 1.69)	111/975	0.92 (0.73, 1.17)	84/1664	0.77 (0.59, 1.00)	73/1205	1.18 (0.88, 1.58)

Note.—Unknown or nonapplicable answers were removed from this specific analyses.

* Data are numbers of cases of cataract surgery in the population of radiologic technologists in the given subgroup who worked in the given decade.

† HRs were calculated by using Cox proportional hazards models fitted with age as the time scale metric, stratified according to birth-year cohort (born before 1940 or born in 1940 or later), and adjusted for sex and race. Numbers in parentheses are 95% CIs. Ref = reference.

‡ Statistically significant.

work practices used in the distant past. However, the collection of occupational exposure data before the assessment of outcomes minimized potential recall bias.

These results should be interpreted with consideration of the following limitations: The cataract diagnoses were self-reported, and the types of cataract were not available. However, surgically removed cataracts—especially those reported by medically trained workers—should be reported with greater accuracy (35). Sensitivity analyses restricted to cataract extractions yielded similar findings, suggesting that any misclassifications were minimal. This study was mainly limited by a lack of individual occupational dosimetry estimates specific to NM technologists. Individual occupational dosimetry reconstructions have been performed for all study participants on the basis of literature review, work history, and dosimetric measurements (36). However, procedure-specific exposures from the differing energy levels emitted by the radiopharmaceuticals used in NM procedures were not taken into account when the estimated doses were calculated. An updated organ dose reconstruction effort for technologists who work with NM procedures is under way but not yet complete. In addition, in the current analysis, we did not consider the changes in NM work history practices during follow-up, which may have introduced some bias; however, the direction of that bias is unknown.

The strengths of this study include the large size of the technologist cohort and the collection of detailed data on work history practices and radiation protection measures used according to decade. The information collected from the comprehensive questionnaires enabled us to rule out confounding bias from known risk factors for cataract (21–25).

In conclusion, the association between occupational exposure of medical and other radiation workers and cataract frequency has been widely reported in studies conducted during the past several years, with new findings from epidemiologic studies supporting increasingly lower radiation dose thresholds (17). Nevertheless, our finding of an increased risk of cataract in a population of NM workers should be interpreted with caution, as the exposure categories are based only on reports of working with these procedures and specific types of cataract were not available. To confirm and quantify this relationship, the estimation of individual radiation doses to the eye lens from both occupational and personal medical sources should be a key focus of further study. Specific information about performing relatively high-dose NM procedures and assessment according to cataract type are also needed.

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References

1. Mettler FA Jr, Bhargavan M, Faulkner K, et al. Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources—1950–2007. Radiology 2009;253(2):520–531.
2. Bolus NE. NCRP report 160 and what it means for medical imaging and nuclear medicine. J Nucl Med Technol 2013;41(4):255–260.
3. Smith-Bindman R, Miglioretti DL, Johnson E, et al. Use of diagnostic imaging studies and associated radiation exposure for patients enrolled in large integrated health care systems, 1996-2010. JAMA 2012;307(22):2400–2409.
4. 2007 Recommendations of the International Commission on Radiological Protection: ICRP publication 103. Ann ICRP 2007;37 (2-4):1–332.
5. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Sources and effects of ionizing radiation: report to the general assembly with scientific annexes. Volume I. New York, NY: United Nations, 2008.
6. Kubo AL, Mauricio CL. TDL occupational dose distribution study in nuclear medicine. Radiat Meas 2014;71:442–446.
7. Kopec R, Budzanowski A, Budzynska A, et al. On the relationship between whole body, extremity and eye lens doses for medical staff in the preparation and application of radiopharmaceuticals in nuclear medicine. Radiat Meas 2011;46(11):1295–1298.
8. Mauricio CL, Lima AL, da Silva HL, Souza-Santos D, Silva CR. Nuclear medicine annual external occupational dose distribution: Rio de Janeiro, Brazil, year 2005. Radiat Prot Dosimetry 2011;144(1-4):510–514.
9. Linet MS, Kim KP, Miller DL, Kleinerman RA, Simon SL, Berrington de Gonzalez A. Historical review of occupational exposures and cancer risks in medical radiation workers. Radiat Res 2010;174(6):793–808.
10. Lee T, Sigurdson AJ, Preston DL, et al. Occupational ionising radiation and risk of basal cell carcinoma in US radiologic technologists (1983-2005). Occup Environ Med 2015;72(12):862–869.
11. Berrington de González A, Ntowe E, Kitahara CM, et al. Long-term mortality in 43 763 U.S. radiologists compared with 64990 U.S. psychiatrists. Radiology 2016;281(3):847–857.
12. Preston DL, Kitahara CM, Freedman DM, et al. Breast cancer risk and protracted low-to-moderate dose occupational radiation exposure in the US Radiologic Technologists Cohort, 1983–2008. Br J Cancer 2016;115(9): 1105–1112.
13. Rajaraman P, Doody MM, Yu CL, et al. Cancer risks in U.S. radiologic technologists working with fluoroscopically guided interventional procedures, 1994–2008. AJR Am J Roentgenol 2016;206(5):1101–1108; quiz 1109.
14. Rajaraman P, Doody MM, Yu CL, et al. Incidence and mortality risks for circulatory diseases in US radiologic technologists who worked with fluoroscopically guided interventional procedures, 1994–2008. Occup Environ Med 2016;73(1):21–27.
15. Kitahara CM, Linet MS, Drozdovitch V, et al. Cancer and circulatory disease risks in US radiologic technologists associated with performing procedures involving radionuclides. Occup Environ Med 2015;72(11):770–776.
16. Neriishi K, Nakashima E, Minamoto A, et al. Postoperative cataract cases among atomic bomb survivors: radiation dose response and threshold. Radiat Res 2007;168(4):404–408.
17. Stewart FA, Akleyev AV, Hauer-Jensen M, et al. ICRP statement on tissue reactions: early and late effects of radiation in normal tissues and organs—threshold doses for tissue reactions in a radiation protection context: ICRP publication 118. Ann ICRP 2012;41(1/2):1–322.
18. Ainsbury EA, Barnard S, Bright S, et al. Ionizing radiation induced cataracts: recent biological and mechanistic developments and perspectives for future research. Mutat Res 2016;770(Pt B):238–261.
19. Seals KF, Lee EW, Cagnon CH, Al-Hakim RA, Kee ST. Radiation-induced cataractogenesis: a critical literature review for the interventional radiologist. Cardiovasc Intervent Radiol 2016;39(2):151–160.
20. Chodick G, Bekiroglu N, Hauptmann M, et al. Risk of cataract after exposure to low doses of ionizing radiation: a 20-year prospective cohort study among US radiologic technologists. Am J Epidemiol 2008;168(6): 620–631.
21. Chang JR, Koo E, Agrón E, et al. Risk factors associated with incident cataracts and cataract surgery in the Age-related Eye Disease Study (AREDS): AREDS report number 32. Ophthalmology 2011;118(11):2113–2119.
22. Chodick G, Sigurdson AJ, Kleinerman RA, et al. The risk of cataract among survivors of childhood and adolescent cancer: a report from the Childhood Cancer Survivor Study. Radiat Res 2016;185(4):366–374.
23. Hall P, Granath F, Lundell M, Olsson K, Holm LE. Lenticular opacities in individuals exposed to ionizing radiation in infancy. Radiat Res 1999;152(2):190–195.
24. Yuan MK, Tsai DC, Chang SC, et al. The risk of cataract associated with repeated head and neck CT studies: a nationwide population-based study. AJR Am J Roentgenol 2013;201(3):626–630.
25. Klein BE, Klein RE, Moss SE. Exposure to diagnostic x-rays and incident age-related eye disease. Ophthalmic Epidemiol 2000;7(1):61–65.
26. Jacob S, Boveda S, Bar O, et al. Interventional cardiologists and risk of radiation-induced cataract: results of a French multicenter observational study. Int J Cardiol 2013;167(5):1843–1847.
27. Ciraj-Bjelac O, Rehani M, Minamoto A, Sim KH, Liew HB, Vano E. Radiation-induced eye lens changes and risk for cataract in interventional cardiology. Cardiology 2012;123(3):168–171.
28. Vano E, Kleiman NJ, Duran A, Romano-Miller M, Rehani MM. Radiation-associated lens opacities in catheterization personnel: results of a survey and direct assessments. J Vasc Interv Radiol 2013;24(2):197–204.
29. Lagakos SW, Schoenfeld DA. Properties of proportional-hazards score tests under misspecified regression models. Biometrics 1984;40(4):1037–1048.
30. Summers EC, Brown JL, Bownes PJ, Anderson SE. Eye doses to staff in a nuclear

medicine department. Nucl Med Commun 2012;33(5):476–480.

31. Leide-Svegborn S. External radiation exposure of personnel in nuclear medicine from 18F, 99mTC and 131I with special reference to fingers, eyes and thyroid. Radiat Prot Dosimetry 2012;149(2):196–206.

32. Dabin J, Kopeć R, Struelens L, Szumska A, Tomaszuk M, Vanhavere F. Eye lens doses in nuclear medicine: a multicentric study in Belgium and Poland. Radiat Prot Dosimetry 2016;170(1-4):297–301.

33. Bruchmann I, Szermerski B, Behrens R, Geworski L. Impact of radiation protection means on the dose to the lens of the eye while handling radionuclides in nuclear medicine. Z Med Phys 2016;26(4):298–303.

34. Jacob S, Donadille L, Maccia C, et al. Eye lens radiation exposure to interventional cardiologists: a retrospective assessment of cumulative doses. Radiat Prot Dosimetry 2013;153(3):282–293.

35. Patty L, Wu C, Torres M, Azen S, Varma R; Los Angeles Latino Eye Study Group. Validity of self-reported eye disease and treatment in a population-based study: the Los Angeles Latino Eye Study. Ophthalmology 2012;119(9):1725–1730.

36. Simon SL, Preston DL, Linet MS, et al. Radiation organ doses received in a nationwide cohort of U.S. radiologic technologists: methods and findings. Radiat Res 2014;182(5):507–528.