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Cataract risk in US radiologic technologists assisting with fluoroscopically-guided interventional procedures: a retrospective cohort study

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Abstract

Objectives: To assess radiation exposure-related work history and risk of cataract and cataract surgery among radiologic technologists assisting with fluoroscopically-guided interventional procedures (FGIP).

Methods: This retrospective study included 35,751 radiologic technologists who reported being cataract-free at baseline (1994–1998) and completed a follow-up questionnaire (2013–2014). Frequencies of assisting with 21 types of FGIP and use of radiation protection equipment during five time periods (before 1970, 1970–79, 1980–89, 1990–99, 2000–09) were derived from an additional self-administered questionnaire in 2013–2014. Multivariable-adjusted relative risks

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Contributorship: RVK, DB, ESG, KM, JLF, JWW, MSL, and CMK conceived and designed the study, and produced an analytical plan. RVK, MSL, and CMK were responsible for acquisition and processing of data. RVK was responsible for data analysis and drafted the manuscript. ESG verified the analytic methods. RVK, DB, ESG, MSL, and CMK, interpreted the results. All authors reviewed the manuscript and provided intellectual input. CMK is the principal investigator and the guarantor of the study.

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(RRs) for self-reported cataract diagnosis and cataract surgery were estimated according to FGIP work history.

Results: During follow-up, 9,372 technologists reported incident physician-diagnosed cataract; 4,278 of incident cases reported undergoing cataract surgery. Technologists who ever assisted with FGIP had increased risk for cataract compared to those who never assisted with FGIP (RR: 1.18, 95% CI: 1.11–1.25). Risk increased with increasing cumulative number of FGIP; the RR for technologists who assisted with >5,000 FGIP compared to those who never assisted was 1.38 (95% CI: 1.24–1.53; p-trend<0.001). These associations were more pronounced for FGIP when technologists were located ≤3 feet (≤0.9 meters) from the patient compared to >3 feet (>0.9 meters) (RRs for >5,000 at ≤3 feet versus never FGIP were 1.48, 95% CI: 1.27–1.74 and 1.15, 95% CI: 0.98–1.35, respectively; p-difference=0.04). Similar risks, albeit not statistically significant, were observed for cataract surgery.

Conclusion: Technologists who reported assisting with FGIP, particularly high-volume FGIP within 3 feet of the patient, had increased risk of incident cataract. Additional investigation should evaluate estimated dose response and medically-validated cataract type.

Keywords

retrospective exposure assessment; cataract; cataract surgery; fluoroscopy; occupational exposure

INTRODUCTION

Cataracts are the leading cause of blindness worldwide.^{1,2} Globally, 95 million people have visually impairing cataract,³ and cataract incidence is expected to increase over time due to the aging of the population.⁴ Known risk factors for cataract include age, sex, diabetes, high body mass index (BMI), cigarette smoking, and ionizing and ultraviolet radiation (UVR) exposure.⁵

Cataracts were one of the first known adverse effects of high-dose ionizing radiation (>0.50 gray (Gy)).⁶ Early clinical studies suggested a radiation dose threshold of ~2 Gy for cataract development following acute or protracted exposures.^{7–9} More recent epidemiologic studies of Japanese atomic bomb survivors and Chernobyl clean-up workers have provided evidence of a dose threshold as low as 0.35 Gy, prompting the International Commission on Radiological Protection to substantially lower the suggested occupational radiation dose limits to the lens of the eye, from 150 mSv to 20 mSv per year, averaged over 5 years, with no annual dose in a single year exceeding 50 mSv.¹⁰ However, there is some evidence that doses of ~0.10 Gy may confer increased cataract risk.¹¹

Studies of medical radiation workers may provide insights on cataract risks associated with low-dose (<0.10 Gy), protracted radiation exposure. Up to a six-fold increased risk of cataract has been observed for interventional cardiologists who perform fluoroscopically-guided interventional procedures (FGIP), interventions increasingly used by physicians in a variety of medical and surgical specialties due to the benefits offered to patients over conventional surgery.¹² Interventional cardiologists are the closest medical staff in cardiac catheterization labs or operating rooms to the principal source of scattered radiation (the

patient). However, studies of staff performing FGIP have been limited by very small samples sizes (ranging from 4 to 466 exposed workers), lack of detail on work history and doses, and limited study of staff, including radiologic technologists and nurses, who assist with these procedures.^{11,13,14}

In a previous analysis of U.S. radiologic technologists (USRT) followed from 1985–2005, which included 35,705 participants in our current study, self-reported radiotherapy to the head and 15 cumulative diagnostic x-rays were significantly associated with increased cataract risk.¹⁵ Additionally, there appeared to be a positive relationship of cataract risk with occupational radiation exposure.¹⁶ An increased risk of cataract was also reported in a subset of 12,964 technologists followed between 2003–2005 and 2012–2013 who reported ever working with nuclear medicine procedures.¹⁷ However, there has been no large-scale investigation of cataract risk in a subset of radiologic technologists working with FGIP that evaluates work history, proximity to the patient, and use of personal or other protective equipment. In the current study, we hypothesize that cataract and cataract surgery risk will increase with greater number of FGIP reported, compared to radiologic technologists who did not work with these procedures.

MATERIALS AND METHODS

Study population

Details of the USRT study population and survey methods have been published previously.^{18,19} The population eligible for the current analysis included the 53,850 radiologic technologists who completed both the second (administered 1994–1998) and fourth questionnaires (administered 2013–2014). An additional detailed work history module on FGIP was sent to participants who reported working with FGIP on the fourth questionnaire (administered 2013–2014). Self-reported physician-diagnosed cataract and cataract surgery and year of each were first ascertained on the second questionnaire, and subsequently collected on the third (administered 2003–2005) and fourth questionnaires. Eligible subjects in the population of 53,850 technologists were excluded for the following reasons: report of a physician-diagnosed cataract prior to the year of completion of the second questionnaire or missing year of cataract diagnosis (N=3,632), missing FGIP work history on the fourth questionnaire (N=185), did not complete the FGIP module (N=9,400), lacking detailed information on years worked with FGIP or the specific FGIP performed (N=951), or report of a very large number (>200) of FGIP per month (N=496) (Figure 1). Participants were also excluded if they had a history of working with nuclear medicine procedures, which has been associated with cataract risk in this cohort (N=3,435).¹⁷ The final analytic sample in the current investigation included 35,751 radiologic technologists, of whom 6,262 (18%) reported ever working with FGIP and 29,489 reported never working with FGIP (82%).

Exposure assessment

FGIP work history—Participants who reported working with FGIP on the fourth questionnaire and completed the subsequent FGIP work history module were asked to report how many times per month they assisted with 21 specific types of FGIP and the proportion of time for each procedure that they were located within three feet (0.9 meters) of the patient

(zero, 1–24%, 25–74%, 75–100%) during five time-periods (before 1970, 1970–1979, 1980–1989, 1990–1999, 2000–2009). Distance of the technologist from the patient during FGIP was dichotomized on the questionnaire as ≤ 3 versus >3 feet, as technologists within 3 feet of the patient during procedures are more likely to be scrubbed in and directly assisting the physician (and thus have greater potential for exposure to scatter radiation) compared to technologists assisting at a greater distance. The cumulative number of diagnostic FGIP was calculated using participant responses from 1970–2009 while cumulative therapeutic FGIP was calculated using responses from 1980–2009, based on the years in which medical devices (e.g., angioplasty catheters, stents) required for performing diagnostic or therapeutic FGIP became widely available.²⁰ Use of lead glasses, ceiling, or mobile floor shields was estimated based on the average proportion of time a participant reported using each protective measure across the decades worked, and was categorized as 0, $\leq 50\%$, and $>50\%$.

We classified the 21 FGIP according to diagnostic versus therapeutic and low-dose versus high-dose. We used an estimated literature-based diagnostic reference level (DRL) value for a dose-area product of $10,000 \text{ cGy}\cdot\text{cm}^2$ as an initial cut-off between low-dose and high-dose procedures, after consultation with an interventional radiologist and medical physicists (D.L. Miller, D. Borrego, and S. Balter) (Supplemental Table 1). While DRL values do not represent a dose to any individual or a recognized demarcation between exposure levels, DRL values are often set at the 75th percentile of the distribution of sampled doses, and as such are a useful metric in this context to separate higher and lower doses.²¹ Following this initial categorization, procedures were reclassified as high-dose (N=6) if it were deemed that the radiologic technologist would be positioned close to the patient during the procedure (D.L. Miller and S. Balter) (see footnote to Supplemental Table 1).

Statistical analysis

A person-year table was created that was stratified by attained age (5-year intervals), sex, and cumulative number of FGIP procedures (0, 1– <500 , 500– $<1,000$, 1,000– $<2,000$, 2,000– $<3,000$, 3,000– $<4,000$, 4,000– $<5,000$, 5,000– $<6,000$, 6,000– $<7,000$, 7,000– $<8,000$, 8,000– $<9,000$, 9,000– $<10,000$, $\geq 10,000$), and other cataract risk factors. Participants were followed from the completion of the second questionnaire until the first (incident) report of physician-diagnosed cataract (or cataract surgery, defined as the first report of cataract surgery in those who reported incident cataract, in a separate analysis), or December 31st, 2014, whichever occurred first. Relative risks (RRs) and 95% confidence intervals (CIs) were calculated using Poisson regression models adjusted for age and sex. The exposure response was assessed by estimating the RR for each cumulative FGIP work history category using the following grouped categories (Never FGIP, 1– $<1,000$, 1,000– $<3,000$, 3,000– $<5,000$, $\geq 5,000$) compared with radiologic technologists who never worked with FGIP. To account for the latency period between exposure and cataract onset, FGIP work history was treated as a time-dependent variable and lagged 10 years for the main analyses.⁷ Additional adjustment for each of the covariates listed in Table 1, as well as education (rad tech program, some college, other, unknown), cancer other than non-melanoma skin cancer (NMSC) (yes, no, unknown), hypercholesterolemia (yes, no, unknown), rheumatoid arthritis (yes, no, unknown), glaucoma (yes, no, unknown), years on prescription hormone replacement therapy (0, 1–4, 5+, unknown), smoking status (never, former, current, unknown), cigarettes

per day (0, 1-<10, 10-<20, 20, unknown), radiotherapy to the head or neck (yes, no, unknown), radiographs to the head and neck (yes, no, unknown), computed tomography (CT) scans (yes, no, unknown), and dental radiographs (0, <30, 30, unknown) did not change the effect estimate for FGIP work history (dichotomized as ever FGIP/never FGIP) and cataract or cataract surgery risk by more than 10%; therefore, none of these additional covariates were retained in the final models.

To test for trend, we fitted the linear model $RR = 1 + \beta x$, where x is the number of FGIP (in thousands) and β is the linear coefficient or excess relative risk ($ERR=RR-1$) per 1,000 FGIP. We used a likelihood ratio test for the null hypothesis that $\beta=0$. Likelihood ratio tests were also used to test for differences in the ERR per 1,000 FGIP between subgroups of FGIP (diagnostic, therapeutic, low-dose, and high-dose) and distance from the patient during FGIP (<3 feet and >3 feet) compared to the main model (total FGIP irrespective of distance) to determine if the ERR varied by these characteristics. The Epicure AMFIT module was used to compute the maximum-likelihood estimates.²² All statistical tests were two-sided, and p-values <0.05 were considered statistically significant.

Sensitivity analyses were conducted to compare the results excluding those with a previous history of cancer who may have undergone radiotherapy, those who reported a history of radiotherapy to the head or neck, and those with a previous history of glaucoma, age-related macular degeneration, or diabetes, as these participants may be under increased medical surveillance for cataract. A comparison of the results under different lag assumptions (0-, 5-, and 10-year lag) and exposure-time windows (0-<5 years, 5-<10 years, and 10 years before the time at risk since last worked with FGIP), using person-year tables stratified on these variables, was performed by assessing model goodness-of-fit using the likelihood ratio test. Cataract risk was not significantly associated with cumulative FGIP work history occurring 0-<5 years ($p=0.25$) or 5-<10 years ($p>0.50$) before the time at risk since last worked with FGIP, thus supporting our use of a 10-year lag for the main analysis (Supplemental Table 2).

RESULTS

During follow-up, 9,372 technologists reported physician-diagnosed incident cataract. Among these incident cataract cases, 4,278 also reported having undergone cataract surgery. The mean follow-up time from completion of the second questionnaire was 15 years (range 1–20). The majority of participants were female (>80%) and white (>90%), similar to the entire USRT population.²³ Older age, higher BMI, a history of smoking, diabetes, and hypertension were significantly associated with increased cataract and cataract surgery risk (Table 1). Male sex, non-white race, and alcohol consumption were associated with a decreased risk of cataract and cataract surgery. Eye color and UVR exposure were not associated with cataract and cataract surgery risk.

Radiologic technologists who ever assisted with FGIP were at an increased risk of cataract diagnosis compared to technologists who never assisted with FGIP (RR: 1.18, 95% CI: 1.11–1.25) (data not shown in tables). There was a statistically-significant increasing trend in cataract risk with greater cumulative number of FGIP reported (ERR per 1,000 FGIP: 0.025, 95% CI: 0.015–0.035, p -trend<0.001) (Table 2, Supplemental Figure 1, Supplemental

Table 3). The RR was 1.38 for technologists who assisted with >5,000 cumulative FGIP compared to those who never assisted with FGIP (95% CI: 1.24–1.53) (Table 2).

Distance of the technologist from the patient (≤3 versus >3 feet) during these procedures significantly modified this risk (p-difference=0.04). Compared to technologists who never assisted with FGIP, a strong increased risk was observed for technologists assisting with >5,000 FGIP while located within 3 feet of the patient (RR: 1.48, 95% CI: 1.27–1.74, p-trend<0.001), but not for those assisting with the same number of FGIP while >3 feet from the patient (RR: 1.15, 95% CI: 0.98–1.35, p-trend=0.17) (Table 2). No significant differences were observed between FGIP sub-groups (diagnostic versus therapeutic FGIP within 3-feet of the patient, p-difference>0.50 and low-dose versus high-dose FGIP within 3-feet of the patient, p-difference>0.50). Cataract risk also did not appear to vary significantly by sex (Supplemental Table 4).

Although we had fewer number of cases for cataract surgery, similar patterns were observed, though less pronounced than for cataract incidence (Supplemental Figure 1, Supplemental Table 5 & 6).

Greater use of lead glasses, ceiling suspended shields, or mobile floor shields were not significantly associated with decreased risk of cataract (Table 3). These associations were similar for cataract surgery (data not shown).

Sensitivity analyses indicated that excluding those with a previous history of cancer, radiotherapy to the head or neck, glaucoma, age-related macular degeneration, or diabetes did not meaningfully change the observed risk estimates, nor did the inclusion of those reporting >200 FGIP per month or the use of other cut-points for number of FGIP reported per month (>150 FGIP, >300 FGIP, >450 FGIP) (data not shown). We therefore did not exclude these subgroups of technologists.

DISCUSSION

Our investigation represents the first large, comprehensive study to evaluate cataract risk according to detailed work history in medical radiation workers performing FGIP and provides several novel findings. We observed that radiologic technologists reporting a high cumulative volume of FGIP were at increased risk of self-reported cataract. The risk was greatest for those assisting with many FGIP and standing within 3 feet of the patient, with less evidence of risk observed for cumulative FGIP and standing >3 feet from the patient. We also observed increased risk, although not statistically significant, with cataract surgery which supports our findings with cataract incidence. There did not appear to be significant variation in cataract risk by type of procedure performed. Since the dose received by medical staff decreases with increasing distance from the radiation source, the distance of the technologist from the patient during procedures would be a stronger proxy measure for expected dose than the type of procedure conducted. As such, these findings may be indicative of cataract risk associated with increasing occupational radiation exposure.

We did not observe a clear attenuation in cataract risk with self-reported use of personal protective equipment in this population. This finding should be interpreted with caution, as

few cases reported ever using lead glasses (n=167). Hu et al. demonstrated a substantial reduction in radiation dose to the eye during FGIP with the use of lead glasses.²⁴ The lack of trend in cataract risk with greater use of ceiling suspended shields and mobile floor shields is expected, as technologists typically stand outside the shielded area even when they are positioned near the patient.

Our findings are comparable with results from previous studies examining cataract risk among interventional cardiologists and support staff (Supplemental Table 7). The more modest relative risks observed in our study may reflect lower doses received by technologists compared to interventional cardiologist operators. Vano et al. reported a higher risk of cataract among interventional cardiologists (n=58) compared to medical support staff (n=58) working in interventional cardiology suites (RR: 1.80, 95% CI: 1.00–3.30).²⁵ A substantial limitation of previous literature is the small size of the studies and lack of detailed work history information, as only five of eleven studies of cataract risk in medical workers have examined FGIP work history and included more than 100 participants.¹¹ Additionally, only one of these larger studies have included an assessment of exposure-response.²⁶ Jacob and colleagues observed a significantly increased risk of cataract for interventional cardiologists performing 7,800 cumulative FGIP compared to those who never worked with FGIP (RR: 5.75, 95% CI: 1.64–20.19), but did not observe clear evidence of increasing risk with greater number of procedures performed.²⁶

Our study had several important strengths. Few studies have assessed cataract risk among medical support staff working with FGIP or populations with similar low levels of radiation exposure. The USRT cohort is largely comprised of women, which allowed for the first evaluation of sex differences in cataract risk among medical radiation workers assisting with FGIP. In addition to the large sample of radiologic technologists included in our study and the large number of technologists reporting physician-diagnosed cataracts (9,372 cataract cases out of 35,751 radiologic technologists), our detailed FGIP module allowed for a thorough assessment of workload by collecting information on 21 common procedures and radiation protection practices. We used a methodologically rigorous approach in which we assessed work history as a time-dependent variable and examined different potential lag periods and exposure-time windows to account for disease latency. In addition, the rich covariate data collected in the self-administered surveys allowed us to evaluate the potential for confounding by a wide range of known and suspected risk factors for cataract. Adjustment for these factors had little to no influence on our results, suggesting that our results are unlikely to be explained by non-occupational exposures.

While early studies have demonstrated an inverse relationship between cataract latency and dose, there are few studies on low-to-moderate dose radiation exposure and cataract risk which have accounted for latency.²⁷ Merriam and Focht reported an average latency of 9 years for cataract development in patients receiving radiation treatment (dose to air at the location of the eye: 1.76–5.72 Gy).⁷ For patients receiving higher doses during treatment (>5.72 Gy), the average time between exposure and cataract onset was only 4 years. In a study of Chernobyl clean-up workers, cataracts were observed 12–14 years after radiation exposure.²⁸ While physicians have reported using lead glasses more frequently during FGIP in recent years,²⁹ we may see medical staff with exposures in the past who are at risk

presently for cataract, which underscores the importance of considering latency in populations exposed to protracted low-doses of radiation. While the actual latency of radiation cataract is unknown, we determined a range of 0–10 years would be reasonable for evaluation based on previous literature.

To provide additional insight about exposure of the eye lens and subsequent risk of cataract development, an important next step will be to evaluate the dose-response relationship between estimated dose to the lens of the eye and incident cataract among these technologists who performed or assisted with FGIP. Annual estimates of doses to 12 organs and tissues, including the lens of the eye, were estimated for the entire USRT cohort using historical information on occupational radiation doses to medical staff, personal dosimeter readings, and other work history factors³⁰. However, it is clear to us that some different dosimetric assumptions are needed for the subset of the cohort who performed or assisted with FGIP than made for other workers, e.g., more detailed consideration on the placement of the badges (above-apron versus above-and-below-apron), and the use of personal protective equipment, such as lead glasses. For example, Vano et al. reported that greater variation in the location of medical support staff in the FGIP lab during procedures and in the tasks performed contributed to more inaccuracies in lens dose estimation for radiologic technologists compared to physicians.²⁵ Presently, the current annual lens dose estimates are complete only through the year 1997; subsequent years represent a period of increasing performance of FGIP by these technologists. An update of the cohort dosimetry to account for dosimeter readings after 1997 and information collected in the FGIP detailed work history questionnaire module (2013–14) regarding badge placement, types of procedures performed, and use of personal protective equipment has recently been launched.

Our assessment of work history also reflects historical exposures received from 1970–2009 and does not account for changes in occupational radiation doses per procedure over time nor is necessarily indicative of future exposures, which limits the generalizability of our findings for radiation protection purposes. The use of self-reported work history that was collected after outcomes were ascertained may be a source of recall bias. However, we posit that since work history may be a reasonable proxy for occupational radiation dose, our study contributes to the limited literature on ionizing radiation exposure and cataract risk in medical radiation workers. In our study population, we found that cumulative absorbed dose to the lens of the eye from occupational radiation exposure increased with greater number of FGIP reported (Supplemental Table 8). We are in the process of developing lens dose estimates based on more recent personal dosimeter data and self-reported FGIP work history information where dosimeter data are incomplete or absent.

Additionally, since increased cataract risk has been observed in interventional cardiologists performing FGIP, technologists assisting with FGIP may be under increased medical surveillance, which could result in cataract being diagnosed more frequently in these workers. Self-reported physician-diagnosed cataract outcomes also have lower sensitivity and specificity compared to ophthalmologic exams. In the population-based Maryland, U.S. Salisbury Eye Evaluation (SEE) study, the sensitivity of self-reported cataract was 55% while the specificity was 77%.³¹ Conversely, Bowie et al. reported up to 94% sensitivity and 100% specificity for self-reported cataract surgery, which may be a more accurate measure

of a cataract outcome than self-reported history of cataract diagnosis.³² Since early-stage (mild) cataracts are smaller and do not cause substantial visual impairment, cataract surgery may also imply a more severe cataract than cataract diagnosis. Information on cataract subtype was not collected, so potential heterogeneity in risk among radiation-associated versus non-radiation-associated subtypes could not be explored. Posterior subcapsular and cortical cataracts are most strongly associated with exposure to ionizing radiation.³³ The inclusion of nuclear cataracts, which are the most common cataract subtype and are not associated with radiation exposure, would attenuate the observed associations.^{34,35} In the SEE Cataract Genetics Study (SEECAT), 78% of cataract surgery cases were nuclear or nuclear combination cataracts.³⁶ It is possible that our findings for cataract surgery risk are particularly prone to attenuation towards the null due to the large number of surgeries that may attributed to nuclear cataract types. However, given the large size of the USRT cohort, it would be impractical to collect information on cataract subtype via clinical examination, though a smaller validation study may be conducted in the future. Lastly, while prevalent cataract cases and those missing information on cataract history were excluded, these individuals did not report working with FGIP more often than those included in the analysis, so it is unlikely that this biased the study findings.

Overall, we found increased risk of self-reported physician-diagnosed cataract among radiologic technologists assisting with a greater cumulative number of FGIP, particularly for technologists assisting within 3 feet of the patients, who are the major source of occupational radiation exposure for medical staff due to scatter radiation. Whether our results reflect a radiation-related risk or other occupational exposure should be evaluated in future studies, using a more objective measure of cumulative occupational radiation dose as well as ophthalmologic examination or medical record validation of cataract type.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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WHAT IS ALREADY KNOWN ABOUT THIS SUBJECT?

- Physicians performing fluoroscopically-guided interventional procedures (FGIP) appear to be at increased risk of cataract, but little is known about cataract risk in other medical staff assisting with FGIP, who receive less occupational exposure to ionizing radiation than physicians.

WHAT ARE THE NEW FINDINGS?

- In this large retrospective cohort of 35,751 US radiologic technologists, those who reported assisting with a high-volume of FGIP over their work history experienced a significantly higher risk of cataract.

HOW MIGHT THIS IMPACT ON POLICY OR CLINICAL PRACTICE IN THE FORESEEABLE FUTURE?

- In addition to past monitoring of medical workers, ongoing surveillance is needed to improve exposure assessment and to medically validate cataract cases. Multiple large-scale cohort studies of medical radiation staff assisting with FGIP are needed to assess risk of cataract and cataract surgery that include high-quality estimated individual occupational radiation eye lens doses and medical validation of cataracts.
- For the cohort studies, validated information about work history and occupational radiation protection practices would also be helpful.
- If associations of occupational radiation exposure-response to the eye lens and risk of cataract and cataract surgery are confirmed in multiple future studies, there may be a need for additional radiation protective measures along with further dose optimization techniques for operators and staff in the U.S.

Figure 1. Flowchart of study population Exclusions

Abbreviations: FGIP-fluoroscopically-guided interventional procedures, NM-nuclear medicine, Q2-Questionnaire 2, Q4-Questionnaire 4

Table 1

Associations between known or suspected risk factors and cataract and cataract surgery risk, United States Radiologic Technologists Study, 1994–2014, (N=35,751)

Baseline Characteristic	Cataract			Cataract Surgery		
	Cases	RR ^a	95% CI	Cases	RR ^a	95% CI
Total	9,372			4,278		
Age						
30–<40	357	0.33	0.30–0.37	93	0.30	0.24–0.38
40–<50	3,378	ref	ref	1,021	ref	ref
50–<60	3,899	2.59	2.47–2.71	1,811	3.86	3.57–4.17
60	1,738	5.76	5.45–6.10	1,353	12.02	11.08–13.04
Sex						
Female	7,764	ref	ref	3,467	ref	ref
Male	1,608	0.75	0.71–0.79	811	0.84	0.78–0.91
Race						
White	9,021	ref	ref		ref	ref
Non-white	351	0.80	0.72–0.90		0.76	0.65–0.90
Iris Color						
Dark	3,119	ref	ref	1,438	ref	ref
Grey/blue/green	3,998	0.96	0.91–1.00	1,831	0.95	0.88–1.02
Hazel	2,138	1.04	0.98–1.10	952	0.99	0.92–1.08
Other/unknown	117	1.10	0.92–1.33	57	1.18	0.91–1.55
Body mass index (kg/m²)						
<18.5	106	1.16	0.95–1.40	47	1.16	0.87–1.55
18.5–24.9	3,884	ref	ref	1,713	ref	ref
25.0–29.9	3,281	1.11	1.06–1.16	1,544	1.12	1.04–1.20
30	1,930	1.27	1.20–1.34	884	1.30	1.19–1.41
Unknown	171	1.00	0.86–1.16	90	1.19	0.96–1.47
Alcohol consumption (drinks/wk)						
0	4,472	ref	ref	1,992	ref	ref
<2	1,473	0.91	0.86–0.96	620	0.89	0.81–0.97
2–4	1,274	0.86	0.81–0.91	590	0.92	0.84–1.01
5	1,463	0.84	0.79–0.89	698	0.89	0.81–0.97
Unknown	690	0.83	0.77–0.91	378	0.98	0.88–1.09
Smoking pack-years						
Never smoker	4,783	ref	ref	2,101	ref	ref
1–<10	1,498	0.97	0.92–1.03	652	0.96	0.88–1.05

Baseline Characteristic	Cataract			Cataract Surgery		
	Cases	RR ^a	95% CI	Cases	RR ^a	95% CI
10<20	1,057	1.14	1.07–1.22	470	1.12	1.02–1.24
20	1,704	1.24	1.17–1.31	892	1.36	1.26–1.47
Unknown	330	0.98	0.88–1.09	163	1.04	0.89–1.22
History of diabetes						
No	8,830	ref	ref	3,972	ref	ref
Yes	336	2.15	1.92–2.39	197	2.48	2.15–2.87
Unknown	206	0.82	0.72–0.94	109	0.96	0.79–1.16
History of hypertension						
No	7,453	ref	ref	3,310	ref	ref
Yes	1,713	1.19	1.13–1.25	859	1.20	1.11–1.29
Unknown	206	0.83	0.72–0.96	109	0.92	0.80–1.17
Lifetime average ambient UVR (quintile)^b						
Q1	1,401	ref	ref	501	ref	ref
Q2	968	0.94	0.87–1.02	327	0.91	0.79–1.04
Q3	1,023	1.00	0.92–1.08	340	0.95	0.82–1.09
Q4	1,259	1.09	1.01–1.17	452	1.06	0.93–1.20
Q5	1,203	1.05	0.97–1.14	442	1.06	0.93–1.20
Unknown	137	0.95	0.79–1.13	63	1.15	0.89–1.50

Abbreviation: RR – relative risk, CI – confidence interval, ref – referent group, UVR – ultraviolet radiation

^a Adjusted for attained age and sex

^b Restricted to participants who responded to the third questionnaire with follow-up 2003–2014

Table 2
FGIP work history and cataract risk, United States Radiologic Technologists Study, 1994–2014, (N=35,751)

Cumulative FGIP (1970–2009)			Total procedures			Procedures >3 feet from the patient			Procedures 3 feet from the patient			
	Cases	PYR	RR ^a	95% CI	Cases	PYR	RR ^{ab}	95% CI	Cases	PYR	RR ^{ac}	95% CI
Any FGIP												
Never worked with FGIP	7,981	449,724	ref	ref	7,981	449,724	ref	ref	7,981	449,724	ref	ref
0<1,000	575	41,375	1.10	1.01–1.19	821	59,120	1.11	1.03–1.20	898	64,830	1.12	1.04–1.20
1,000<3,000	284	22,268	1.14	1.01–1.29	277	19,140	1.19	1.05–1.35	216	15,738	1.24	1.08–1.43
3,000<5,000	149	10,730	1.21	1.03–1.42	105	7,595	1.02	0.84–1.25	89	6,536	1.28	1.04–1.59
5,000	383	23,535	1.38	1.24–1.53	188	12,054	1.15	0.98–1.35	188	10,805	1.48	1.27–1.74
p-trend ^f				<0.001				0.17				<0.001
Diagnostic FGIP ^{d,h}												
Never worked with FGIP	7,981	449,724	ref	ref	7,981	449,724	ref	ref	7,981	449,724	ref	ref
0<1,000	929	66,465	1.13	1.05–1.22	1,100	78,352	1.13	1.05–1.21	1,126	79,406	1.15	1.07–1.23
1,000<3,000	213	15,641	1.17	1.02–1.35	183	11,932	1.17	1.01–1.37	111	10,200	1.01	0.83–1.22
3,000<5,000	81	5,864	1.14	0.91–1.43	41	3,593	0.88	0.64–1.21	63	3,586	1.41	1.09–1.83
5,000	168	9,938	1.39	1.17–1.65	67	4,032	1.21	0.94–1.57	91	4,717	1.52	1.22–1.89
p-trend ^f				0.001				0.17				0.005
Therapeutic FGIP ^{e,i}												
Never worked with FGIP	7,981	449,724	ref	ref	7,981	449,724	ref	ref	7,981	449,724	ref	ref
0<1,000	787	57,066	1.09	1.01–1.18	969	70,086	1.10	1.03–1.19	1,059	76,666	1.11	1.04–1.19
1,000<3,000	236	18,504	1.15	1.01–1.32	223	15,457	1.20	1.04–1.38	173	11,949	1.33	1.13–1.57
3,000<5,000	136	8,987	1.28	1.08–1.53	102	5,782	1.26	1.02–1.55	73	4,471	1.59	1.25–2.02
5,000	232	13,351	1.33	1.15–1.54	97	6,583	1.00	0.80–1.24	86	4,822	1.34	1.06–1.68
p-trend ^f				0.02				>0.50				0.009
Low-dose FGIP ^{f,j}												
Never worked with FGIP	7,981	449,724	ref	ref	7,981	449,724	ref	ref	7,981	449,724	ref	ref

Cumulative FGIP (1970–2009)	Total procedures				Procedures >3 feet from the patient				Procedures 3 feet from the patient			
	Cases	PYR	RR ^a	95% CI	Cases	PYR	RR ^{ab}	95% CI	Cases	PYR	RR ^{ac}	95% CI
0<1,000	949	71,753	1.09	1.01–1.17	1,119	81,469	1.12	1.04–1.20	1,192	86,742	1.12	1.04–1.20
1,000<3,000	278	16,494	1.34	1.17–1.52	195	11,583	1.19	1.02–1.40	144	7,918	1.45	1.21–1.74
3,000<5,000	95	5,306	1.27	1.02–1.57	48	2,946	1.05	0.78–1.42	32	1,955	1.20	0.84–1.73
5,000	69	4,354	1.03	0.79–1.33	29	1,911	0.90	0.61–1.30	23	1,293	1.08	0.71–1.64
p-trend ⁱ				0.15				0.30				0.45
High-dose FGIP^{g,k}												
Never worked with FGIP	7,981	449,724	ref	ref	7,981	449,724	ref	ref	7,981	449,724	ref	ref
0<1,000	722	52,198	1.11	1.03–1.20	943	67,620	1.12	1.04–1.20	996	71,143	1.13	1.05–1.21
1,000<3,000	279	19,937	1.22	1.08–1.39	250	16,340	1.20	1.05–1.38	175	13,385	1.22	1.04–1.43
3,000<5,000	121	8,740	1.23	1.03–1.48	72	5,593	0.92	0.72–1.17	70	5,228	1.23	0.96–1.57
5,000	269	17,035	1.34	1.17–1.54	126	8,355	1.08	0.88–1.33	150	8,151	1.56	1.30–1.87
p-trend ⁱ				<0.001				>0.50				<0.001

Abbreviations: FGIP – fluoroscopically-guided interventional procedures, PYR – person-years at risk, RR – relative risk, CI – confidence interval, ref – referent group

^a Adjusted for attained age and sex with stratification of FGIP work history in a person-year table categorized as 0, 500, 1000–10,000 [intervals of 1,000 procedures], 10,000+

^b Adjusted for cumulative procedures 3 feet

^c Adjusted for cumulative procedures >3 feet

^d Adjusted for cumulative therapeutic FGIP work history

^e Adjusted for cumulative diagnostic FGIP work history

^f Adjusted for cumulative high-dose FGIP work history

^g Adjusted for cumulative low-dose FGIP work history

^h Diagnostic FGIP includes electrophysiology diagnostic studies, diagnostic cardiovascular catheterizations, and diagnostic neuroangiography

ⁱ Therapeutic FGIP includes electrophysiology ablations, peripherally inserted central catheter placement, port placement, inferior vena cava filter placement, endoscopic retrograde cholangiopancreatography, orthopedic extremity nailing, percutaneous coronary interventions, pacemaker or intracardiac defibrillator implantations, embolizations, endovascular therapeutic procedures, dialysis interventions, peripheral vascular interventions, transjugular intrahepatic portosystemic shunts, aortic stent grafts, percutaneous nephrolithotomy, nephrostomy, biliary tract procedures, and vertebroplasty

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Low-dose FGIP includes electrophysiology diagnostic studies, electrophysiology ablations, peripherally inserted central catheter placement, port placement, inferior vena cava filter placement, endoscopic retrograde cholangiopancreatography, and orthopedic extremity nailing
High-dose FGIP includes diagnostic cardiovascular catheterizations, diagnostic neuroangiography, percutaneous coronary interventions, pacemaker or intracardiac defibrillator implantations, embolizations, endovascular therapeutic procedures, dialysis interventions, peripheral vascular interventions, transjugular intrahepatic portosystemic shunts, aortic stent grafts, percutaneous nephrolithotomy, nephrostomy, biliary tract procedures, and vertebroplasty
Based on the likelihood ratio test for the continuous term

Table 3

FGIP work history (0-<5,000 FGIP within 3 feet of the patient (referent group) versus 5,000 FGIP within 3 feet of the patient) and cataract risk, by frequency of use of PPE, United States Radiologic Technologists Study, 1994–2014, (N=6,262)

Proportion of time used PPE during FGIP (1970–2009)	Cases	PYR	RR ^{a,b}	95% CI
Lead glasses				
Never used lead glasses	1,224	84,437	1.29	1.08–1.53
50%	144	11,064	1.46	1.07–1.99
>50%	23	2,407	0.73	0.33–1.63
p-trend ^c				0.23
Ceiling suspended shields				
Never used ceiling suspended shields	1,213	82,923	1.29	1.07–1.56
50%	136	11,608	1.38	1.05–1.82
>50%	42	3,377	1.03	0.62–1.72
p-trend ^c				>0.50
Mobile floor shields				
Never used mobile floor shields	803	56,908	1.26	0.99–1.60
50%	502	35,736	1.28	1.12–1.68
>50%	86	5,264	0.95	0.55–1.64
p-trend ^c				0.41

Abbreviations: FGIP – fluoroscopically-guided interventional procedures, PYR – person-years at risk, RR – relative risk, CI – confidence interval, PPE – personal protective equipment

^a Adjusted for attained age and sex with stratification of FGIP work history in a person-year table categorized as 0, 500, 1000–10,000 [intervals of 1,000 procedures], 10,000+

^b FGIP work history dichotomized as 0-<5,000 FGIP within 3 feet of the patient (**referent group**), 5,000 FGIP within 3 feet of the patient

^c Based on the likelihood ratio test for the continuous term