ORIGINAL ARTICLE

Incidence and mortality risks for circulatory diseases in US radiologic technologists who worked with fluoroscopically guided interventional procedures, 1994–2008

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▸ Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/oemed-2015-102888).

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Received 11 February 2015
Revised 23 July 2015
Accepted 17 August 2015
Published Online First 8 September 2015

ABSTRACT

Objectives Although fluoroscopically guided interventional procedures (FGIP) have provided major advances in the treatment of various common diseases, radiation exposures associated with these procedures may cause adverse health effects in workers. We assess risk of circulatory disease incidence and mortality in medical radiation workers performing FGIP.

Methods A US nationwide prospective cohort study of 90 957 radiologic technologists who completed a cohort survey during 1994–1998 was followed until completion of a subsequent survey during 2003–2005 for circulatory disease incidence, or until 31 December 2008 for mortality. Incidence analyses were restricted to the 63 482 technologists who completed both the second survey (1994–1998) and the third survey (2003–2005). Cox proportional hazards models were used to assess adjusted HR and 95% CIs for mortality from all causes, all circulatory diseases, all heart diseases, ischaemic heart disease, stroke, acute myocardial infarction and hypertension in participants who reported ever performing FGIP compared to technologists who never performed FGIP procedures. Adjusted HRs were calculated for self-reported hypertension, stroke and myocardial infarction.

Results We observed a 34% increase in stroke incidence (HR=1.34, 95% CI 1.10 to 1.64) in technologists who performed FGIP compared to those who never performed these procedures. Mortality from stroke was also modestly elevated, although not statistically significant (HR=1.22, 95% CI 0.85 to 1.73). We observed no statistically significant excess risks of incidence or mortality from any other outcome evaluated.

Conclusions Our finding of elevated risk of stroke in workers performing FGIP needs to be confirmed in studies with individual radiation dose data, but nonetheless underlines the need to keep radiation exposure as low as reasonably achievable without compromising key diagnostic information.

What this paper adds

- ▸ Fluoroscopically guided interventional procedures (FGIP) have provided major advances in treatment, but radiation exposures associated with these procedures may be associated with long-term health effects in workers. Very little epidemiological data exist regarding incidence or mortality risks for circulatory disease after performing FGIP.
- ▸ We observed increased risk of incident stroke in technologists who report ever working with FGIP.
- ▸ While these findings need to be confirmed in future epidemiological studies of technologists and physicians who perform or assist with FGIP, they nonetheless underscore the need to keep radiation exposure as low as reasonably achievable without compromising key diagnostic information.

INTRODUCTION

Fluoroscopically guided interventional procedures (FGIP) have allowed major advances in the treatment of various common diseases, and provide indisputable benefits for patients. Nonetheless, these procedures produce radiation doses that may cause adverse effects in patients and medical workers.[1] There is considerable evidence indicating that exposures to ionising radiation at moderate to high levels (≥100 milliSievert (mSv) of cumulative or acute exposure) are associated with a range of adverse effects in the circulatory system, including damage to the structures of the heart and to the coronary, carotid and other large arteries.[2] However, there is a need for better information regarding disease risks at radiation doses below 100 mSv, such as those encountered from FGIP.

Cardiac examinations comprised the largest fraction (25%) of the approximately 17 million FGIP performed in the USA in 2006.[3] Although estimated radiation exposure levels to medical workers performing most types of specific FGIP are generally low, cumulative exposure levels from multiple procedures performed over many years may be substantial.[4] Despite the growing use of FGIP, there is very little published research regarding late health effects in patients undergoing these procedures, or in medical workers who perform or assist with FGIP.

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To cite: Rajaraman P, Doody MM, Yu CL, *et al*. *Occup Environ Med* 2016;**73**:21–27.

In the only previous epidemiological study of long-term health effects related to working with FGIP, we reported non-statistically significant 40–70% excess risks of cerebrovascular disease mortality in US radiologic technologists (USRT) who reported performing or assisting with FGIP during different time periods.[5] However, the short follow-up period (5–9 years), relatively limited number of deaths (n=151) and broadly grouped outcome in the previous study limited the power to detect moderate increases in mortality risk. In the current study, we add 5 years of follow-up, examine a larger number of specific outcomes and separately assess incidence and mortality risks where data are available.

METHODS

Overview and history

The USRT study is a long-standing collaboration between the US National Cancer Institute, the University of Minnesota and the American Registry of Radiologic Technologists (ARRT). The study population and methods have been described in detail elsewhere.[6] Briefly, the USRT cohort of 146 022 radiologic technologists was identified from the records of the ARRT and consists of technologists who resided in any US state or territory and were certified for at least 2 years prior to 1983. The cohort is followed through yearly re-certification records from ARRT, linkage of individuals who do not recertify with the Social Security Administration database to ascertain vital status, and linkage of those who are found deceased or presumed deceased with National Death Index (NDI-*Plus*) records to ascertain cause of death information.

In addition, cohort follow-up was conducted through a series of mailed questionnaire surveys. The first two questionnaires (administered during 1983–1989 and 1994–1998, respectively) collected detailed information about employment as a radiologic technologist, disease risk factors, history of personal diagnostic and therapeutic medical radiation procedures, and diagnoses of specific types of circulatory diseases, cancer and other health outcomes. Work history information on FGIP was first ascertained in the second survey. The third questionnaire, administered during 2003–2005, expanded on previous work history and risk factor information, and captured incident events for a larger number of specific health outcomes. Non-respondents to LQ3 were somewhat more likely to be male, and African-American, than those eligible for this study.

Current study population and outcome assessment

The 90 957 of 126 628 living technologists (72%) who completed the second survey questionnaire during 1994–1998 (collection of data on performing FGIP) were potentially eligible for this study. Vital status was determined for all second survey responders until 31 December 2008 and, for decedents, underlying causes of death were obtained from NDI-*Plus*. Incidence analyses were restricted to the 63 482 technologists who completed both the second survey and third survey (collection of self-reported incidence).

Circulatory disease events were defined on the basis of death records (mortality) or questionnaire responses (incidence). Specific outcomes evaluated were: mortality from all causes, all circulatory diseases (ICD-8 390–458; ICD-9 390–459; ICD-10 I00–I99), all heart diseases (ICD-8 390–429; ICD-9 390–429; ICD-10 I00–I52), ischaemic heart disease (ICD-8 410–414; ICD-9 410–414; ICD-10 I20–I25), acute myocardial infarction (ICD-8 410; ICD-9 410; I21), stroke (ICD-8 430–434, 436; ICD-9 430–434, 436; ICD-10 I60-I64) and hypertension (ICD-8 400–401, 436; ICD-9 401, ICD-10 110–115). In addition, self-reported incidence data (Did a doctor ever tell you that you had any of the following cardiovascular conditions: high blood pressure (If yes, have you ever taken medicine for high blood pressure); stroke (cerebrovascular accident); transient ischaemic attack; angina pectoris (If yes, was this confirmed by angiography)) were available and evaluated for stroke, myocardial infarction and hypertension.

For all circulatory disease incidence and mortality outcomes, individuals had to be free of the particular circulatory disease outcome of interest at baseline (1994–1998). For those with diagnoses of more than one circulatory disease, the first circulatory disease outcome of interest was evaluated. Specific exclusions for each outcome are outlined in tables 1 (incidence) and 2 (mortality).

Exposure assessment

The second questionnaire explicitly asked responders to categorise how often (never or rarely, monthly, weekly or daily) they worked with specific radiologic procedures, including FGIP, in three defined time periods (before 1980, during 1980–1989, and during 1990 or later): "Please indicate how frequently you worked or assisted on a regular basis with each of the following procedures during the specified calendar years. If you never worked with a particular procedure, mark the circle for 'Never worked with' and leave all other columns blank for that procedure." Technologists were coded as 'ever' worked with FGIP if they reported working with FGIP 'monthly', 'weekly' or 'daily' in any of the three time periods. If they reported 'never' working with FGIP in the initial overall question, or 'never or rarely' working with FGIP in all three time periods, they were classified as 'never' working with FGIP. All other combinations, including participants who reported 'never' working in one or more periods but were missing data on FGIP use for one or more periods, were classified as 'unknown.'

Further analysis by time period of exposure was not conducted due to small numbers of outcomes and strong correlations (r=0.7–0.9) for report of FGIP use within individual time periods. Information on potential exposure to FGIP as a patient was not collected at the time of the second questionnaire.

Other covariates assessed include the total number of years worked as a radiologic technologist in different time periods (1–4 or 5+ years worked in each of <1950, 1950–1959, 1960–1969, 1970+) as a proxy for unmeasured total occupational radiation dose (collected at the baseline questionnaire), and the following covariates reported at the second questionnaire: work with brachytherapy and other radionuclide procedures, smoking status (never, former, current), number of alcoholic drinks consumed per week (1–6, 7–13, 14+), and body mass index (BMI) (<18.5, 18.5–24.9, 25.0–29.9, 30.0–34.9, ≥35). These covariates were chosen on the basis of the known/potential relationship with outcome, and potential relationship with exposure.

Statistical analysis

Circulatory disease risks were estimated using Cox proportional hazard models that compared technologists who ever performed or assisted with FGIP to others who never worked with FGIP. To be eligible for incidence analyses, technologists had to complete both the second and third surveys. Follow-up began at completion of the second survey, and ended at the earliest of date of diagnosis of the outcome of interest, date of diagnosis of other events or date of completion of the third survey. To be eligible for mortality analyses, technologists had to complete the second survey; follow-up began at completion of the second

Table 1 Exclusions for circulatory disease incidence outcomes

Circulatory disease incidence	Answered second survey (1994–1998)	Third survey (2003–2005) missing N (%)	Outcome before second survey, 1994–1998 (pre-existing condition) N (%)	Outcome missing status* N (%)	Outcome missing date N (%)	Final number in incidence analysis cohort
Stroke	90 957	23 701 (26)	468 (1)	3992 (4)	68 (0.1)	62 728
Myocardial infarction	90 957	23 701 (26)	915 (1)	3995 (4)	72 (0.1)	62 274
Hypertension†	90 957	33 746 (37)	9955 (11)	3893 (4)	575 (0.6)	42 788

*"Outcome missing status" means that we do not know whether the participant had the specific outcome. 'Outcome missing date' means that the individual had the specific outcome, but the date was unknown.
†Since there were three different versions of the third questionnaire, and hypertension was not collected on all of them, we could not ascertain hypertension history for some participants. These participants were considered not to have answered the third question.

survey and ended at the earliest of date of death or 31 December 2008 (end of study).

HRs and 95% CIs were derived from Cox models that used age as the time scale, stratified on birth cohort (<1950, 1950–1959, 1960–1969, 1970+) to control for secular trends, and adjusted for gender (minimally adjusted). Risks were also estimated from 'fully adjusted' models that additionally included indicator variables for total number of years worked as a radiologic technologist in different time periods (1–4 or 5+ years worked in each of <1950, 1950–1959, 1960–1969, 1970+) as a proxy for unmeasured total occupational radiation dose, reported work with brachytherapy and other radionuclide procedures, smoking status (never, former, current), number of alcoholic drinks consumed per week and BMI. Analyses were also performed stratified by gender. Likelihood ratio tests were used to evaluate possible interaction with gender and FGIP status. All statistical tests were two sided and were conducted using the SAS V.9.2 statistical software (Cary, North Carolina, USA). Missing values were included as a separate category for all categorical variables. Formal tests indicated no lack of convergence in the Cox models and no departures from proportionality of hazards over the age time scale. Sensitivity analyses included models accounting for competing risk, models including only participants with non-missing data on all covariates, and models excluding the 88 participants who reported performing FGIP but indicated on a previous survey that they had not worked as a radiologic technologist.

RESULTS

After exclusions for pre-existing conditions and missing data on the third survey, there were 62 728, 62 274 and 42 788 participants, respectively, who were eligible for assessment of incidence of stroke, myocardial infarction and hypertension (table 1). For mortality analyses, the eligible populations for the various outcomes ranged from 68 188 for all circulatory disease to 90 955 for all-cause mortality (table 2).

Table 3 summarises selected demographic characteristics stratified by having ever worked with FGIP for the 90 955 radiologic technologists who completed the second questionnaire and were eligible for any mortality or incidence analysis. In total 22 209 (24%) technologists reported working with FGIP in any period. More technologists reported working with FGIP in earlier periods than in later periods (21%, 16% and 9% described working with FGIP before 1980; during 1980–1989 and in 1990 or later, respectively). While differences were small, technologists who reported ever working with FGIP were more likely to be male, younger, better educated, more affluent, users of alcohol and tobacco and to have worked more years as radiologic technologists compared to technologists who never worked with FGIP. Distributions of these characteristics were very similar in the population of 63 482 technologists eligible for any circulatory disease incidence analysis (see online supplementary table S2).

Incidence and mortality risks from minimally adjusted and fully adjusted Cox proportional hazards models were similar (table 4). We observed no statistically significant excesses of mortality from all causes, all circulatory diseases combined, all heart diseases combined, ischaemic heart disease, acute myocardial infarction, stroke or hypertension in technologists who performed or assisted with FGIP. However, we found an elevated risk of incidence from stroke (HR=1.34, 95% CI 1.10 to 1.64) in the 158 technologists who reported working with FGIP

Table 2 Exclusions for circulatory disease mortality outcomes

Circulatory disease mortality	Answered second survey (1994–1998)	Outcome before second survey, 1994–1998 (pre-existing condition) N (%)	Death with unknown date* N (%)	Death with unknown cause N (%)	Outcome missing status† N (%)	Outcome missing date N (%)	Final number in mortality analysis cohort
All-cause mortality	90 957	0 (0)	2 (0.002)	0 (0)	0 (0)	0 (0)	90 955
All circulatory disease	90 957	18 107 (20)	2 (0.002)	154 (2)	3824 (4)	682 (0.7)	68 188
Stroke	90 957	805 (1)	2 (0.002)	154 (2)	3992 (4)	68 (0.1)	85 936
All heart diseases	90 957	17 387 (19)	2 (0.002)	154 (2)	3843 (4)	645 (0.7)	68 926
Ischaemic heart disease	90 957	17 387 (19)	2 (0.002)	154 (2)	3843 (4)	645 (0.7)	68 926
Myocardial infarction	90 957	1542 (2)	2 (0.002)	154 (2)	3995 (4)	72 (0.1)	85 192
Hypertension	90 957	15 566 (17)	2 (0.002)	154 (2)	3893 (4)	574 (0.6)	70 768

*'Outcome missing status' means that we do not know whether the participant had the specific outcome. 'Outcome missing date' means that the individual had the specific outcome, but the date was unknown.
†Participants who died of unknown cause were included in the all-cause mortality analysis if the date of death was known.

Table 3 Distribution of selected characteristics in 90 955 radiologic technologists who completed the second survey (1994–1998) and were eligible for any overall mortality, circulatory disease mortality or incidence analyses, according to whether they performed fluoroscopically guided interventional procedures (FGIP)

	Performed FGIP						
	Ever		Never		Unknown		Total
Characteristic	N	Per cent*	N	Per cent	N	Per cent	N
Total	22 209	24	58 645	65	10 101	11	90 955
Sex							
Female	14 822	67	47 416	81	7746	77	69 984
Male	7387	33	11 229	19	2355	23	20 971
Year of birth							
<1930	761	3	3988	7	1658	16	6407
1930–1939	2213	10	8262	14	2043	20	12 518
1940–1949	7191	32	19 880	34	3279	32	30 350
1950–1959	11 825	53	26 053	44	3077	30	40 955
≥1960	219	1	462	1	44	0	725
Age at completion of second survey							
30–39	4227	19	9196	16	939	9	14 362
40–49	11 662	53	27 358	47	3633	36	42 653
50–59	4567	21	14 078	24	2752	27	21 397
≥60	1753	8	8013	14	2777	27	12 543
Race							
Caucasian	20 865	94	55 807	95	9397	93	86 069
African-American	764	3	1596	3	416	4	2776
Other	561	3	1183	2	259	3	2003
Unknown	19	–	59	–	29	–	107
Income							
<$50K	2177	17	7967	24	1371	30	11 515
$50–$74K	3489	27	9089	28	1153	26	13 731
$75–$99K	3187	24	7205	22	852	19	11 244
$100+K	4292	33	8766	27	1137	25	14 195
Unknown	9064	–	25 618	–	5588	–	40 270
Education							
High school or less	79	1	368	1	77	1	524
Other (vocational)	465	3	1330	2	283	5	2078
Rad tech programme	5990	42	18 374	31	2606	48	26 970
College	7604	54	16 953	29	2506	46	27 063
Unknown	8071	–	21 620	–	4629	–	34 320
Alcohol intake, per week							
<1	11 334	55	33 111	61	4624	60	49 069
1–6	6569	32	15 313	28	2078	27	23 960
≥7	2781	13	6185	11	986	13	9952
Unknown	1525	–	4036	–	2413	–	7974
Cigarette smoking							
Never smoked	11 386	51	31 489	54	5016	51	47 891
Former smoker	7240	33	19 242	33	3667	37	30 149
Current smoker	3410	15	7512	13	1239	12	12 161
Unknown	173	–	402	–	179	–	754
Body mass index, kg/m^2							
<25	10 599	49	30 443	53	5087	52	46 129
25.0–29.9	7293	34	17 642	31	3083	32	28 018
≥30.0	3855	18	9446	16	1550	16	14 851
Unknown	462	–	1114	–	381	–	1957
Year first worked as a radiologic technologist							
Never worked	88	0	454	1	116	1	658
<1960	2601	12	11 217	20	3198	34	17 016
≥1960	18 748	87	45 094	79	6142	65	69 984
Unknown	772	–	1880	–	645	–	3297
Age first worked as a radiologic technologist							
Never worked	88	0	454	1	116	1	658

Continued

Table 3 Continued

Characteristic	Performed FGIP						
	Ever		Never		Unknown		Total
	N	Per cent*	N	Per cent	N	Per cent	N
<21	12 947	60	34 944	62	5325	56	53 216
≥21	8402	39	21 367	38	4015	42	33 784
Unknown	772	–	1880	–	645	–	3297
Number of years worked as a radiologic technologist (at second questionnaire 1994–1998)							
Never worked	88	0	454	1	116	1	658
<10	2311	11	12 332	24	2229	28	16 872
10–19	7792	39	19 483	37	2477	31	29 752
≥20	9949	49	20 063	38	3051	39	33 063
Unknown	2069	–	6313	–	2228	–	10 610
Performed brachytherapy							
Yes	2241	11	3830	93	738	56	6809
No	18 440	89	52 439	7	4049	42	74 928
Unknown	1528	–	2376	–	5314	–	9218
Performed diagnostic radionuclide							
Yes	5238	25	7710	87	1322	69	68 264
No	15 313	75	49 972	13	2979	31	14 270
Unknown	1658	–	963	–	5800	–	8421
Performed radioactive iodine therapy							
Yes	3331	84	6569	88	1253	56	11 153
No	17 487	16	49 067	12	3829	42	70 383
Unknown	1391	–	3009	–	5019	–	9419
Performed other radionuclide therapy							
Yes	1961	9	2872	5	557	11	5390
No	18 775	91	53 746	95	4299	89	76 820
Unknown	1473	–	2027	–	5245	–	8745

*Percentages based on non-missing individuals.

versus 357 who reported not working with FGIP. While fewer individuals died of stroke, the direction and magnitude of mortality risk was similar (HR=1.22, 95% CI 0.85 to 1.73), but not statistically significant. Risk of incident stroke was significantly elevated in women, but not men, although the difference between men and women was not statistically significant (HR_{men}=1.10, 95% CI 0.79 to 1.53; HR_{women}=1.55, 95% CI 1.23 to 1.96, p_{het}=0.82). Additional models accounting for competing risk left our risk estimates virtually unchanged, as did models including only participants with non-missing data on all covariates, and models excluding the 88 participants who reported performing FGIP but indicated on a previous survey that they had not worked as a radiologic technologist (results not shown).

DISCUSSION

In this large population-based study of radiologic technologists, we evaluated incidence and mortality risks for several circulatory disease outcomes in radiologic technologists working with FGIP. During our follow-up period, we observed a 34% increase in risk for incidence of stroke in technologists who reported working with FGIP, which was statistically significant in women but not men. Excess risk from stroke mortality was similar in magnitude, but not statistically significant. We observed no excess risks for all circulatory diseases combined or for any other circulatory disease condition in technologists performing FGIP.

Although there is convincing evidence of radiation-related heart disease among patients receiving high doses of radiotherapy to the thorax,[7] the evidence is less clear at moderate to low doses of radiation. Potential biological mechanisms underlying radiation-related circulatory disease risks include cell-killing effects on capillaries and endothelial cells at high radiation doses (>5 Gy), and anti-inflammatory effects for exposures <0.5 Gy.[8 9] A recent meta-analysis among occupational and other groups found increased mortality from circulatory diseases, particularly cerebrovascular diseases, with estimated radiation exposures <0.5 Gy.[10] Recent findings from studies of the atomic bomb survivors indicated significantly increased excess relative risks (ERR) for mortality from stroke (ERR per Gy 0.09; 95% CI 0.01 to 0.17), all circulatory disease (ERR per Gy=0.11; 95% CI 0.05 to 0.17) and all heart disease (ERR per Gy=0.14; 95% CI 0.06 to 0.23) with increasing doses of radiation.[11] In our earlier study, USRT cohort members who began working before 1940, when radiation doses would be expected to be higher, had increased mortality risk from all circulatory diseases (HR=1.42, 95% CI 1.04 to 1.94), and particularly from cerebrovascular disease (HR=2.40, 95% CI 1.09 to 5.31), compared with those who began working in 1960 and later.[12] Our previous analysis of risk in technologists who used FGIP in this cohort, based on 5 years of follow-up and only 151 deaths from all cerebrovascular disease, revealed non-statistically significant excesses of 40–70% for all cerebrovascular diseases combined. No excesses were observed for deaths from all circulatory system diseases combined.[5] In the current extended follow-up, which includes 515 incident cases of stroke (158 in exposed vs 357 in unexposed), we observed a statistically significant elevated risk of incident stroke in technologists who ever worked

Table 4 HRs and 95% CIs for all-cause mortality and selected circulatory disease outcomes associated with working with fluoroscopically guided interventional procedures (ever vs never) in US radiologic technologists who completed the second survey (1994–1998)

	Incidence (n=63 482)			Mortality (n=90 957)		
	Cases (ever/never)	HR (95% CI)*, minimally adjusted	HR (95% CI)†, fully adjusted	Cases (ever/never)	HR (95% CI), minimally adjusted	HR (95% CI), fully adjusted
All-cause mortality	–			1319/4202	1.06 (0.99 to 1.13)	1.01 (0.94 to 1.07)
All circulatory disease	–			166/531	1.15 (0.97 to 1.38)	1.04 (0.87 to 1.26)
Stroke	158/357	**1.37 (1.13 to 1.67)**	**1.34 (1.10 to 1.64)**	46/151	1.25 (0.89 to 1.75)	1.22 (0.85 to 1.73)
All heart diseases	–			136/430	1.15 (0.94 to 1.40)	1.03 (0.84 to 1.27)
Ischaemic heart disease	–			86/271	1.13 (0.88 to 1.45)	1.03 (0.80 to 1.34)
Myocardial infarction	260/629	1.01 (0.88 to 1.18)	0.95 (0.81 to 1.10)	62/199	1.07 (0.80 to 1.43)	0.97 (0.71 to 1.33)
Hypertension	2388/6515	1.01 (0.96 to 1.06)	0.99 (0.94 to 1.04)	5/25	0.78 (0.29 to 2.08)	0.66 (0.23 to 1.86)

*HRs and 95% CIs derived from Cox models using age as the time scale, stratified on birth cohort (<1950, 1950–1959, 1960–1969, 1970+) and adjusted for gender (minimally adjusted).
†Fully adjusted models additionally included total years worked as a radiologic technologist in different time periods (<1950, 1950–1959, 1960–1969, 1970+), reported work with brachytherapy and other radionuclide procedures, smoking status (never, former, current), number of alcoholic drinks consumed per week (0, 1–6, 7–13, 14+), and body mass index (<18.5, 18.5–24.9, 25.0–29.9, 30.0–34.9, ≥35).

with FGIP (HR=1.34, 95% CI 1.10 to 1.64). Excess risk was consistent (HR=1.22), but not statistically significant, for the 197 deaths from stroke (46 in exposed vs 151 in unexposed).

Data from two comprehensive reviews of occupational radiation exposure from FGIP indicate that physician operators in the past had a wide variance in their typical radiation dose.[4 13] At present, a physician who performs FGIP on a regular basis and uses appropriate protective measures could be expected to receive an annual occupational radiation dose of 2–4 mSv.[14–17] To the best of our knowledge, annual occupational radiation doses to technologists involved in performing FGIP procedures have not been reported in the literature. Radiologic technologists in the USA today typically wear lead aprons but use of radiation-protective eyewear is not universal, and use of thyroid collars is also limited, particularly in earlier decades.

The key strength of our study is the cohort design, which allowed for assessment of exposure before the ascertainment of outcome, minimising the potential for recall bias from differential misclassification of the exposure or outcomes. Additionally, the large size of the cohort and relatively long follow-up provided adequate power to detect modest associations. The ability to examine circulatory disease outcomes separately for women is an additional strength given that previous studies of medical radiation workers included mostly men. Finally, we were able to adjust for a number of non-radiation risk factors since detailed covariate information was available for all study members.

Nonetheless, our analysis is limited by the lack of information on radiation doses, particularly organ doses, related to performing FGIP. Our questionnaire did not capture detailed information on frequency, intensity and types of FGIP procedures performed by time period, or on related work practices that may have led to variation in exposures over time. Additionally, although we controlled for other potential exposures, including number of years worked as a radiologic technologist in different time periods and administration of radionuclides (as proxies for occupational radiation exposure), and circulatory disease-specific risk factors (eg, BMI and smoking), residual confounding by these or other unmeasured factors may have contributed to the observed risks. For incidence outcomes, self-report of outcomes is a further limitation. While the validity of self-reported circulatory disease outcomes varies depending on the population studied, reporting is generally most accurate for myocardial infarction, followed by stroke and then hypertension.[18 19] Misclassification of outcome is most likely to have been non-differential, since participants were unaware of the particular exposures under study. Non-differential misclassification of exposure or outcome could have reduced our power, obscuring effects in some of the circulatory disease outcomes. Finally, a high proportion of participants were missing information on FGIP. Too little information was collected in the second questionnaire on radiologic technologists' work procedures involving FGIP to meaningfully impute values for those who did not respond. While the various outcomes are competing risks for each other, fitting models accounting for competing risk left our risk estimates virtually unchanged. These results may not be representative of all radiologic technologists, since non-participants to our baseline survey were somewhat more likely to be male, African-American and be born before 1935.

FGIP have provided enormous benefits for patients, and their use is likely to grow further. Our finding of increased risk of stroke in technologists who worked with these procedures needs to be confirmed in future epidemiological studies of technologists and physicians who perform or assist with FGIP, ideally with individual organ-specific radiation doses estimated from detailed data on type and frequency of FGIP procedures performed and related work practices and protection measures. While patients must continue to undergo medically necessary imaging examinations,[20] our findings nonetheless underscore the need to keep radiation exposure as low as reasonably achievable without compromising key diagnostic information.

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Acknowledgements The authors thank the radiologic technologists who participated in the study, Jerry Reid of the American Registry of Radiologic Technologists for continued support, and Diane Kampa and Allison Iwan of the University of Minnesota for data management and collection.

Contributors All authors contributed to the design and conduct of the study, critically reviewed manuscript drafts, and approved the final version. PR, MMD and

MSL had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Funding The research was funded by the intramural programme of the Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, Department of Health and Human Services, USA.

Competing interests None declared.

Ethics approval The USRT study has been approved annually by the human subjects review boards of the National Cancer Institute Special Studies Institution Review Board (SSIRB; protocol OH97-C-N053) and the University of Minnesota Human Research Protection Program Institution Review Board (Study number 8005M02489).

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement Data from the USRT study may be made available on request from the principal investigator, MSL.

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