HISTORICAL PATTERNS IN THE TYPES OF PROCEDURES PERFORMED AND RADIATION SAFETY PRACTICES USED IN NUCLEAR MEDICINE FROM 1945–2009

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Abstract—**The authors evaluated historical patterns in the types of procedures performed in diagnostic and therapeutic nuclear medicine and the associated radiation safety practices used from 1945–2009 in a sample of U.S. radiologic technologists. In 2013–2014, 4,406 participants from the U.S. Radiologic Technologists (USRT) Study who previously reported working with medical radionuclides completed a detailed survey inquiring about the performance of 23 diagnostic and therapeutic radionuclide procedures and the use of radiation safety practices when performing radionuclide procedure-related tasks during five time periods: 1945–1964, 1965–1979, 1980–1989, 1990–1999, and 2000–2009. An overall increase in the proportion of technologists who performed specific diagnostic or therapeutic procedures was observed across the five time periods. Between 1945–1964 and 2000–2009, the median frequency of diagnostic procedures performed substantially increased (from 5 wk^{-1} to 30 wk^{-1}), attributable mainly to an increasing frequency of cardiac and non-brain PET scans, while the median frequency of therapeutic procedures performed modestly decreased (from 4 mo^{-1} to 3 mo^{-1}). Also a notable increase was observed in the use of most radiation safety practices from 1945–1964 to 2000–2009 (e.g., use of lead-shielded vials during diagnostic radiopharmaceutical preparation increased from 56 to 96%), although lead apron use dramatically decreased (e.g., during diagnostic imaging procedures, from 81 to 7%). These data describe historical practices in nuclear medicine and can be used to support studies of health risks for nuclear medicine technologists.**

Health Phys. 111(1):37–46; 2016

Key words: exposure, occupational; nuclear medicine; radiation protection; radionuclide

INTRODUCTION

DIAGNOSTIC AND therapeutic radionuclide procedures in medicine, also known as nuclear medicine procedures, have gained widespread use in healthcare in the past 45 y. For example, from 1973 to 2005, there was an estimated five-fold increase in the number of in vivo diagnostic nuclear medicine procedures performed in the United States (NCRP 1989; Benchmark 2004–2006; Mettler et al. 2009). Technology in the field has also evolved substantially over time, with major changes in the types of radionuclides used, in particular the introduction of ^{99m}Tc in the 1960s. Many of these changes have resulted in reduced per-procedure radiation doses to patients while increasing per-procedure doses to technologists (Drozdovitch et al. 2014, 2015).

Monitoring trends of radionuclide procedure performance and radiation safety use is important from a public health and radiation safety standpoint, as ionizing radiation exposure even within the low-dose range (below 100 mGy) has been associated with an increased risk of some types of cancer (Gilbert 1992, 2009; Leuraud et al. 2015; Preston et al. 2012; Schubauer-Berigan et al. 2015) and increased mortality from circulatory diseases (Hauptmann et al. 2003; Little et al. 2012). Although previous studies and reports have examined the trends of radionuclide procedure use in patients (NCRP 1989, 2009; Mettler et al. 2009; Benchmark 2004–2006) and among radiologic technologists (Drozdovitch et al. 2014, 2015; Kitahara et al. 2015), there are still limited data on the changing trends in the performance of specific radionuclide procedures. Procedures introduced in more recent time periods, such as positron emission tomography (PET) and cardiac scans, may have yielded some of the highest per-procedure radiation doses to technologists due to increases in use and technologist workload (Mettler et al. 2009; Shackett 2009). There is a similar paucity of data regarding the use of radiation safety practices and safety equipment during the performance of radionuclide procedures.

The authors used recently-collected, detailed work history information on specific radionuclide procedures

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The authors declare no conflicts of interest.

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Supplemental Digital Content is available in the HTML and PDF versions of this article on the journals Web site www.health-physics.com.

(*Manuscript accepted* 30 *October* 2015)
0017-9078/16/0

DOI: 10.1097/HP.0000000000000519

performed and associated radiation safety practices used between 1945 and 2009 from a subgroup of participants from the U.S. Radiologic Technologists (USRT) Study (Boice et al. 1992; Doody et al. 1998; Sigurdson et al. 2003) to evaluate historical changes in these practices over time. The cohort subgroup studied in this work consists of those who reported having ever worked with radionuclide procedures. The data gathered in this study are useful for understanding trends in occupational medical exposure in the U.S. and for estimating exposures in retrospective health risk studies; e.g., the USRT.

METHODS

Study population

The USRT Study is a collaborative effort between the American Registry of Radiologic Technologists (ARRT), the University of Minnesota School of Public Health, and the National Cancer Institute with goals of understanding health risks of chronic radiation exposure, particularly in the medical radiation field. In the USRT study, detailed occupational exposure and health outcome information has been collected from a nationwide cohort of radiologic technologists. The USRT cohort includes 146,022 technologists who were certified by the ARRT for at least 2 y during the years 1926–1982. Complete details on the study population and methods were published previously (Boice et al. 1992; Doody et al. 1998; Sigurdson et al. 2003) and can be found online (www.radtechstudy.nci.nih.gov). The USRT Study has been approved annually by the institutional review boards of the National Cancer Institute and the University of Minnesota.

Three surveys of the cohort of technologists were sent by mail in 1983–1989, 1994–1998, and 2003–2005 to learn about demographics, work practices, various exposure-related variables, and health outcomes. A fourth cohort survey was administered in 2012–2013 to 93,787 living technologists who had responded to the first and/or second surveys and who had a valid address; this survey was completed by 51,389 (55%) technologists. A supplemental questionnaire focused exclusively on radionuclide procedures was sent in 2013–2014 to 9,398 technologists who reported on the fourth survey that they had ever performed diagnostic radionuclide procedures at least once a week, or therapeutic radionuclide procedures at least once a month for a year or more. A total of 6,117 participants (65%) returned the supplemental questionnaire on radionuclide procedures. Of the 6,117 responders, 4,406 provided data on radionuclide procedures performed and use of radiation safety practices and were included in the analytic sample whose findings are reported here.

Diagnostic and therapeutic radionuclide procedures

Technologists who reported performing any diagnostic radionuclide procedures were asked if, and how many times per week (on average), they had performed any of 16 types of diagnostic radionuclide procedures (e.g., cardiac or brain scans) in each of five time periods: 1945–1965, 1965–1979, 1980–1989, 1990–1999, 2000–2009. Technologists who reported performing any therapeutic radionuclide procedures were asked if and how many times per month they had performed any of seven therapeutic procedures (e.g., thyroid ablation or cancer therapy) in each of the same five time periods. A subset of technologists who responded to the special radionuclide survey (n = 469) also completed a more detailed questionnaire that elicited information on specific radiopharmaceuticals used (e.g., ^{99m}Tc Sestamibi, ^{99m}Tc Sulfur Colloid). Those technologists who reported performing at least one diagnostic radionuclide procedure per week or at least one therapeutic radionuclide procedure per month in a given time period were considered, for purposes of this analysis, to have "ever" performed diagnostic or therapeutic radionuclide procedures, respectively, in that time period.

Radiation safety practices

For each of the five time periods, technologists were also asked if they used any radiation protection and whether they used specific safety practices at least 50% of the time when performing diagnostic and therapeutic radionuclide-related tasks, including: preparing the radiopharmaceuticals, eluting the ^{99m}Tc generator, administering oral ^{131}I, injecting patients with radiopharmaceuticals, imaging patients, and assisting patients in the procedures. Radiation protection practices queried included use of lead aprons, fume hoods, lead shielded syringes or vials, L-Blocks, L-shields, lead L's, and moving more than 3 feet away from the patient.

Demographics and work history

Demographic characteristics (year of birth, race, gender, education) and general work history information (year first worked as a radiologic technologist, number of years worked) were collected on the first (1983–1989), second (1994–1998), third (2003–2005), or fourth (2012–2013) surveys, before the 2013–2014 supplemental radionuclide work history questionnaire was administered. Certification information was obtained from ARRT records.

Statistical analyses

In this analysis, the authors determined the proportions of technologists who performed specific diagnostic or therapeutic procedures in each time period from the total number who reported having ever performed any diagnostic or any therapeutic radionuclide procedures, respectively. Of those who reported performing a specific procedure in a given time period, the authors further examined the number of times, on average, they performed the procedures per week (diagnostic procedures) and per month (therapeutic procedures), as well as the percentages of technologists who employed specific radiation protection practices 50%

or more of the time when performing radionuclide-related tasks, such as preparing the radiopharmaceuticals and eluting the ^{99m}T generator in the same five time periods from 1945–2009. In supplementary analyses, statistical tests (e.g., T-tests and ANOVAs) were conducted to determine differences in the number of types of procedures performed between male and female technologists and between technologists born after 1949, between 1941–1949, and before 1941. A significance level of 0.05 was used to determine statistical significance. All analyses were conducted using SAS Version 9.3 (SAS Institute, Inc., Cary, NC).

RESULTS

Participant characteristics

Demographic and work history characteristics are shown in Table 1 for the sample of 4,406 radiologic technologists included in this study. The sample was 70% female and 96% Caucasian. The mean age at the completion of the supplementary radionuclide questionnaire was 65.3 y, and 46% and 34% of technologists reported completing college or a 2-y radiologic technologist program, respectively. Participants on average worked at least 20 y as a radiologic technologist, and most (58%) became ARRT certified between 1970 and 1980. More than half of the technologists (54%) first worked with radionuclide procedures in the earliest time period, and most (65%) worked with radionuclide procedures for fewer than 5 y.

Trends in the performance of diagnostic radionuclide procedures

The proportion of technologists performing any diagnostic radionuclide procedure slightly increased from 88 to 95% between 1945–1964 and 2000–2009 (Supplementary Table 1, http://links.lww.com/HP/A61). The proportion of technologists who reported performing cardiac and PET scans consistently increased over time (28 to 70% for cardiac scans between 1965–1979 and 2000–2009; 1 to 13% and 1 to 20% for brain and non-brain PET scans, respectively, between 1980–1989 and 2000–2009; Fig. 1; Supplementary Table 1, http://links.lww.com/HP/A61). The proportion of technologists performing lung ventilation, lung perfusion, gastrointestinal bleeding, thyroid, liver, renal, gallbladder, bone marrow, and bone scans and thyroid uptake procedures increased from 1945–1964 to 1980–1989 or 1990–1999 and then remained relatively constant or slightly decreased by 2000–2009. The proportion of technologists performing brain and pancreas scans increased, peaking in 1965–1979 and subsequently declined (Fig. 1; Supplementary Table 1, http://links.lww.com/HP/A61).

Trends in the frequency of diagnostic radionuclide procedures

The median frequency of total diagnostic procedures performed significantly increased over time (from 5 wk^{-1}

Table 1. Demographic and work history characteristics among radiologic technologists who regularly performed diagnostic or therapeutic radionuclide procedures during years 1945–2009, U.S. Radiologic Technologists Study (N=4,406)[a].

Characteristic	N	%
Gender[b,c]		
Female	3,077	70
Race[b,c]		
Caucasian	4,238	96
Birth cohort[b,c]		
≤1940	672	15
1941–1949	1,723	39
≥1950	2,011	46
Age completed supplemental radionuclide procedures questionnaire[b,c]		
52–59	981	22
60–69	2,368	54
≥70	1,057	24
Education[d,e]		
High school	14	<1
2-year rad tech program	1,282	34
Some college	1,737	46
Graduate school	522	14
Vocational or other	195	5
Year first certified as a radiologic technologist[f]		
1942–1959	306	7
1960–1969	1,561	35
1970–1980	2,539	58
Year first worked as a radiologic technologist[b,d]		
1938–1959	491	12
1960–1969	1,570	37
≥1970	2,229	52
Number of years worked as a radiologic technologist[b,d]		
<5	591	14
5–9	474	11
10–19	1,000	23
≥20	2,299	53
Year first worked with radionuclide procedures[c,g]		
1946–1959	2,366	54
1960–1969	505	12
1970–1979	1,019	23
≥1980	503	11
Number of years worked with radionuclide procedures[c,g]		
<5	2,850	65
5–14	599	14
≥15	957	22

[a]The study population includes technologists who reported performing diagnostic radionuclide procedures at least once a week or therapeutic radionuclide procedures at least once a month for a year or more during 1945–2009 on the fourth cohort survey of the U.S. Radiologic Technologists (USRT) Study conducted in 2012–2013 and completed a follow-up radionuclide procedure work history questionnaire in 2013–2014.
[b]Data from the first (1983–1989) or second (1994–1998) USRT surveys.
[c]<1% missing responses.
[d]<15% missing responses.
[e]Data from the third (2003–2005) USRT survey.
[f]All participants were certified by the American Registry of Radiologic Technologists for at least 2 y during 1926–1982.
[g]Data from the fourth (2012–2013) USRT survey.

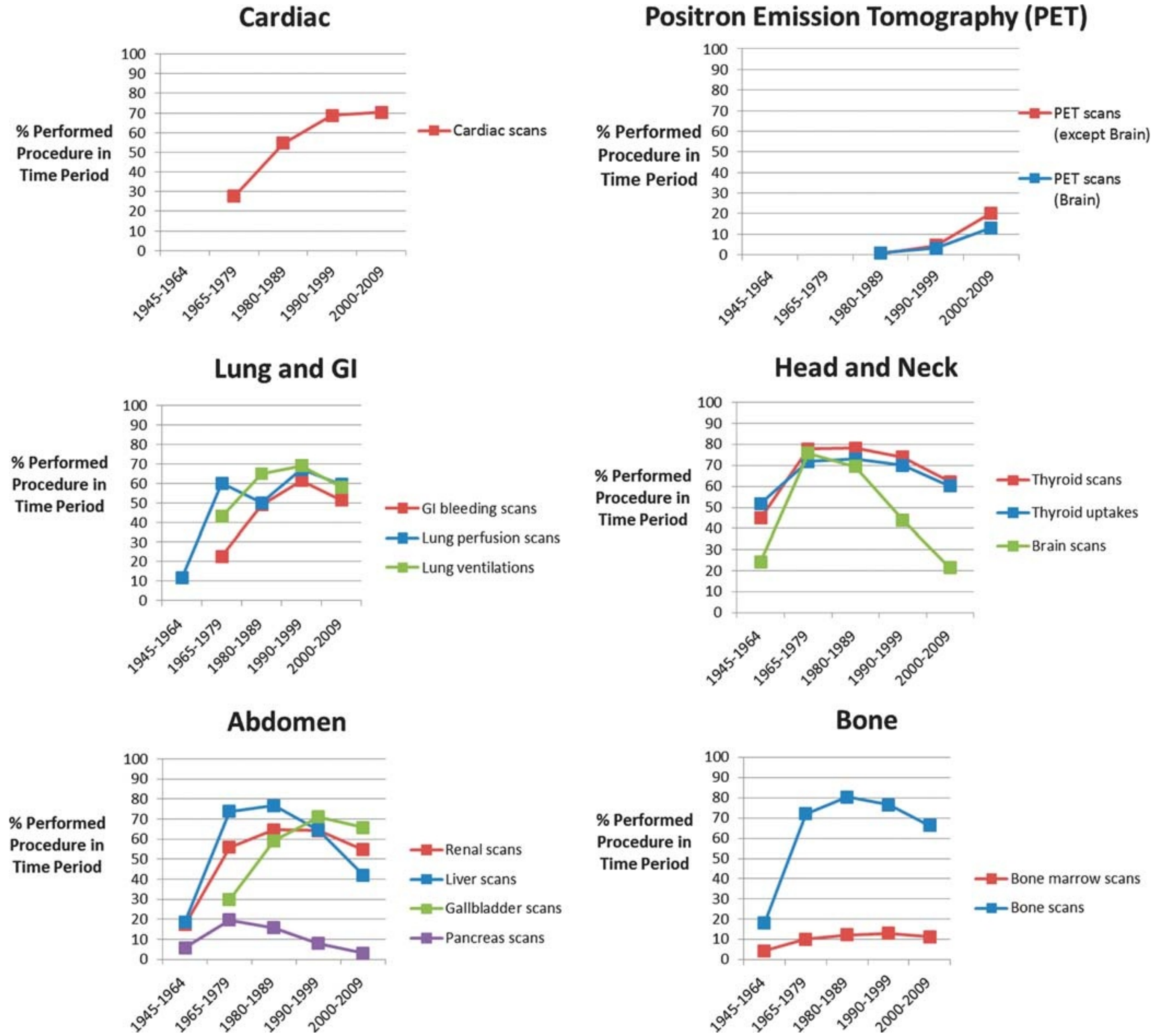

Fig. 1. Proportion of radiologic technologists who performed specific types of diagnostic radionuclide procedures in five time periods from 1945 to 2009, U.S. Radiologic Technologists Study. Denominators are those who reported ever working with diagnostic radionuclide procedures in a specific time period (1946–1964 = 626), (1965–1979 = 3,267), (1980–1989 = 2,620), (1990–1999 = 1,798), (2000–2009 = 1,358). See Supplementary Table 1 (http://links.lww.com/HP/A61) for the N's of the technologists who reported "ever" conducting specific diagnostic radionuclide procedures performed during five time periods from 1945 to 2009. GI = gastrointestinal.

to 30 wk^{-1}). Cardiac and PET scans for anatomic sites other than the brain (i.e., non-brain PET scans) increased particularly rapidly from 1965–1979 to 2000–2009 (from 4 wk^{-1} to 15 wk^{-1}), becoming the most frequent procedures performed in 2000–2009 (Fig. 2; Supplementary Table 1, http://links.lww.com/HP/A61). Similarly, non-brain PET scans increased twofold from 1980–1989 to 2000–2009 (from 5 wk^{-1} to 10 wk^{-1}; Fig. 2; Supplementary Table 1, http://links.lww.com/HP/A61). Gallbladder scans also increased from 2 wk^{-1} in 1965–1979 to 5 wk^{-1} in 2000–2009. However, the frequency of brain PET, lung ventilation, brain, pancreas, and bone marrow scans and thyroid uptake procedures decreased over time. Liver, renal, thyroid, gastrointestinal bleeding, and lung perfusion scans modestly increased, stabilized, and then slightly decreased over time (Fig. 2; Supplementary Table 1, http://links.lww.com/HP/A61).

Among the sample of 469 technologists who completed the more detailed radionuclide questionnaire (data not shown), an increase in the use of ^{99m}Tc radiopharmaceuticals for cardiac scans was observed. The use of ^{99m}Tc Sestamibi 1-d protocol for cardiac scans increased from a median of 3 to 12 procedures wk^{-1}, and ^{99m}Tc labeled red blood cells for

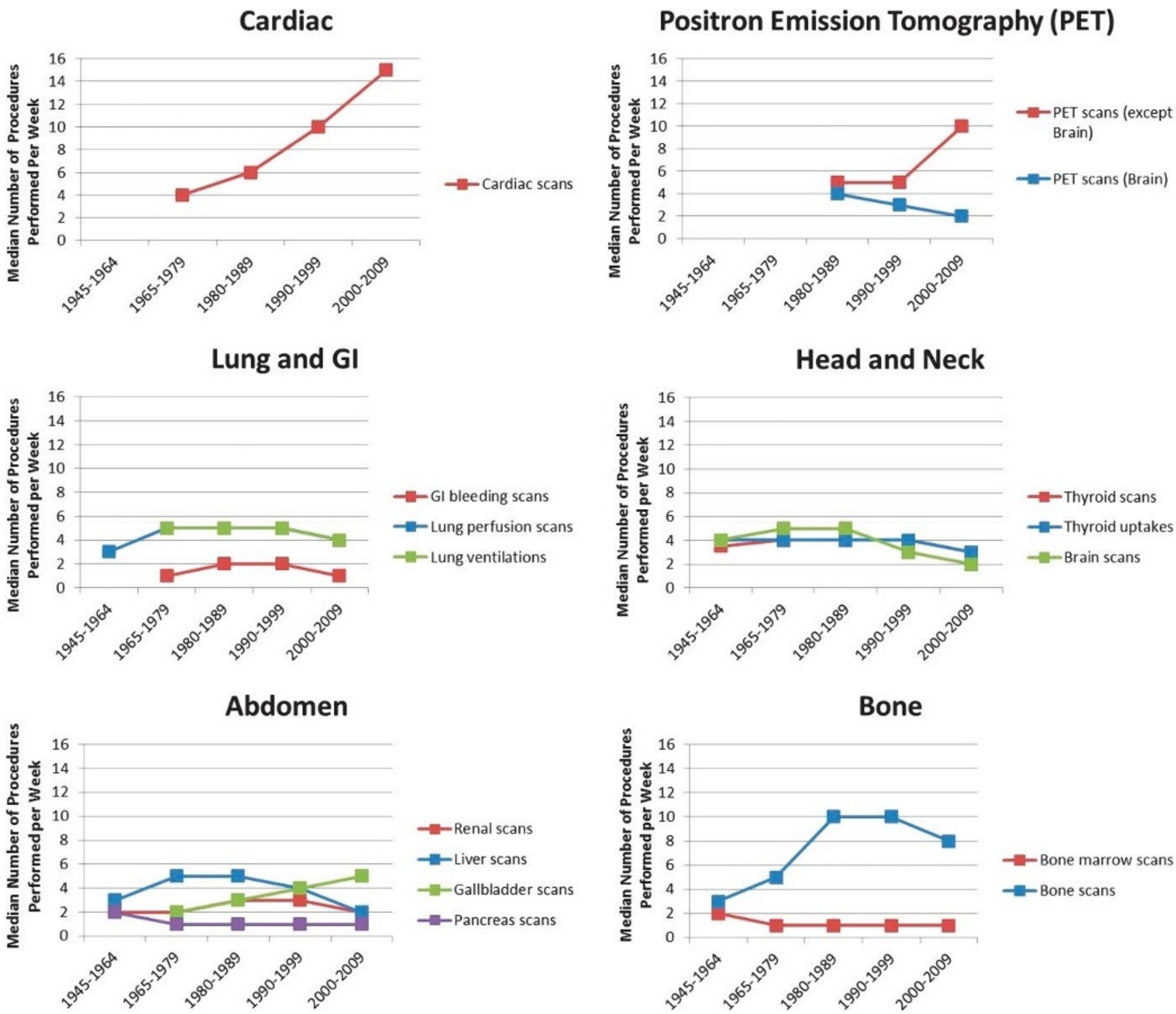

Fig. 2. Median number of specific types of diagnostic radionuclide procedures performed by radiologic technologists in five time periods from 1945 to 2009, U.S. Radiologic Technologists Study. See Supplementary Table 1 (http://links.lww.com/HP/A61) for the N's of the technologists who reported the frequency of specific diagnostic radionuclide procedures performed during five time periods from 1945 to 2009. GI = gastrointestinal.

cardiac scans increased from a median of 2 to 3 procedures wk^{-1} from 1965–1979 to 2000–2009. The use of F-18-Fluorodeoxyglucose (FDG) also increased twofold (from 5 wk^{-1} to 10 wk^{-1}) from 1980–1989 to 2000–2009.

Trends in the performance and frequency of therapeutic radionuclide procedures

The proportion of technologists performing any therapeutic radionuclide procedure slightly increased from 44% in 1945–1964 to 53% in 2000–2009 (Supplementary Table 1, http://links.lww.com/HP/A61). The proportion of technologists performing hyperthyroidism, thyroid cancer, thyroid ablation (and thyroid ablation follow-up), bone metastases, and Non-Hodgkin's Lymphoma or liver tumor therapies increased from 1945–1964 to 2000–2009. The proportion of technologists performing malignant effusion therapy decreased from 11% in 1945–1964 to 4% in 1980–1989, however.

Contrary to the increase in the proportion of technologists performing therapy radionuclide procedures, the authors observed an overall decrease in the frequency of therapeutic radionuclide procedures performed over time, from a median of 4 mo^{-1} to 3 mo^{-1} from 1945–1964 to 2000–2009 (Supplementary Table 1, http://links.lww.com/HP/A61). Specifically, the performance of therapy procedures for thyroid cancer (using ^{131}I) and bone metastases (using ^{153}Sm) decreased from a median of 2 mo^{-1} to 1 mo^{-1} from 1945–2009; however, other procedures for thyroid ablation (using ^{131}I), follow-up after thyroid ablation, malignant effusion (using Au-198-colloid), and non-Hodgkin's Lymphoma (using ^{90}Y) remained constant over time at a median frequency of 1 procedure mo^{-1} (Supplementary Table 1, http://links.lww.com/HP/A61).

Trends in the conduct of diagnostic radionuclide-related tasks

Among technologists who ever conducted diagnostic radionuclide procedures, 93% injected patients with diagnostic radionuclides at least once a week, on average, in 2000–2009 compared to 35% in 1945–1964, making injecting diagnostic radionuclides the most commonly performed radionuclide-related task in more recent time periods (data not shown). Among those who injected patients with diagnostic radionuclides, the median number of injections of diagnostic radionuclides per week increased over time from 5 wk^{-1} to 25 wk^{-1} from 1945–1964 to 2000–2009. Among technologists who ever conducted diagnostic radionuclide procedures, the proportion who prepared diagnostic radiopharmaceuticals was 44% in 1945–1964 but later peaked in 1980–1989 at 82% before declining to 58% in 2000–2009. The median frequency with which technologists prepared diagnostic radiopharmaceuticals remained relatively constant at about 5 wk^{-1}. The proportion of technologists who eluted ^{99m}Tc declined from 88 to 27% from 1945–1964 to 2000–2009, although the frequency with which technologists performed this task remained constant at 5 elutions wk^{-1}.

Trends in the conduct of therapeutic radionuclide-related tasks

Among those who ever conducted therapeutic radionuclide procedures, the proportion of technologists who injected therapeutic radionuclides and administered oral ^{131}I modestly increased from 15% in 1945–1964 to 22% in 2000–2009, and from 66% in 1945–1964 to 75% in 2000–2009, respectively (data not shown). However, the median frequency of patient injections with therapeutic radionuclides decreased over time (4 mo^{-1} in 1945–1964 to 1 mo^{-1} in 2000–2009) as did the administrations of oral ^{131}I (3 mo^{-1} in 1945–1964 to 2 mo^{-1} in 2000–2009). The proportion of technologists who prepared therapeutic radiopharmaceuticals similarly decreased from 31 to 20% between 1945–1964 and 2000–2009, while the median number of therapeutic radiopharmaceutical preparations remained relatively constant at 3 mo^{-1} (data not shown).

Trends in the use of radiation safety equipment and practices

As indicated, the authors inquired about radiation safety practices used 50% or more of the time during radionuclide-related tasks. It was found that the use of radiation safety equipment and practices 50% or more of the time in diagnostic radionuclide-related tasks significantly increased over time for most practices and equipment (Table 2). However, significant declines were observed in the use of lead aprons for diagnostic radionuclide-related tasks. Similar trends were observed among technologists conducting therapeutic radionuclide-related tasks.

Performance of radionuclide procedures by technologists according to gender and birth cohort

Compared to women, men performed a greater variety of diagnostic and therapeutic nuclear medicine procedures. On average, men performed 9.0 different types of diagnostic radionuclide procedures and 2.6 different types of therapeutic radionuclide procedures compared to women, who on average performed 7.5 and 2.3 different types of diagnostic and therapeutic radionuclide procedures, respectively (P-value <0.01; Supplementary Table 2, http://links.lww.com/HP/A66). Also, the authors found that technologists born in 1950 or later on average performed a greater variety of diagnostic and therapeutic procedures, including cardiac scans, compared to technologists born between 1941–1949 and before 1941 (diagnostic procedures: 9 vs. 7.7 vs. 5.7; therapeutic procedures: 2.6 vs. 2.5 vs. 1.6, respectively; P-value <0.01; Supplementary Table 3, http://links.lww.com/HP/A63).

DISCUSSION

Changes in frequency and workload

Using self-reported work history information collected in 2013–2014 from a sample (n = 4,406) of U.S. radiologic technologists who reported performing radionuclide procedures on a regular basis, increasing trends were found in the proportion of technologists performing diagnostic procedures and the frequency with which those procedures were performed across five time periods between 1945 and 2009. This overall increase was attributable mainly to the increasing use of cardiac and non-brain PET scans. Increasing proportions of technologists performing therapeutic radionuclide procedures were also observed, although the median number of procedures performed per month modestly declined. The findings for trends in diagnostic radionuclide procedure performance and frequency are generally consistent with previous data reported by Mettler et al. (2009) based on a benchmark report (Benchmark 2004–2006), which showed diagnostic nuclear medicine studies worldwide had increased from 23.5 million procedures in 1980–1984 to 37 million procedures annually in 2000–2007. The data further suggest that the increase in the performance of diagnostic radionuclide procedures may have begun earlier than was documented in that report and was accompanied by a similar increase in the use of most radiation safety practices, which was previously unknown.

In these data, although it was found that a relatively small proportion of technologists performed non-brain PET procedures compared to other diagnostic procedures, the

Table 2. Percentage of technologists who used radiation protection 50% or more of the time when performing specific radionuclide procedure-related tasks, 1945 to 2009.

	1945–1964	1965–1979	1980–1989	1990–1999	2000–2009
Diagnostic radionuclide procedure tasks[a]					
Preparing diagnostic radiopharmaceuticals	N=190	N=2,386	N=1,952	N=1,160	N=689
Lead shielded vial, %	56	86	91	95	96
Lead shielded syringe, %	36	71	85	90	90
Lead apron, %	41	24	18	12	8
Fume hood, %	26	36	42	42	42
L-block, L-shield, or lead L, %	42	64	74	83	89
Eluting Tc99m generator	N=74	N=1,974	N=1,654	N=787	N=291
Lead shielded vial, %	70	90	92	95	95
Lead apron, %	28	23	19	14	10
Fume hood, %	50	35	38	35	34
Injecting diagnostic radionuclides	N=119	N=2,207	N=2,097	N=1,495	N=1,140
Lead shielded syringe, %	46	78	90	94	94
Lead apron, %	28	14	11	7	4
Assisting patients during diagnostic procedure	N=197	N=1,523	N=1,323	N=956	N=753
Lead apron, %	81	34	22	14	8
Moved more than 3ft away from patient, %	57	85	90	93	95
Imaging patient	N=217	N=1,563	N=1,373	N=997	N=815
Lead apron, %	81	31	18	10	7
Moved more than 3ft away from patient, %	62	88	94	96	97
Therapeutic radionuclide procedure tasks[b]					
Preparing therapeutic radiopharmaceuticals	N=68	N=535	N=401	N=234	N=127
Lead shielded vial, %	71	85	88	89	90
Lead shielded syringe, %	47	57	60	59	59
Lead apron, %	54	34	26	17	19
Fume hood, %	43	47	57	59	55
L-Block, L-shield or lead L, %	40	70	82	88	90
Administering Oral I-131	N=119	N=916	N=854	N=608	N=408
Lead apron, %	62	41	33	27	21
Injecting therapeutic radionuclide	N=25	N=173	N=166	N=160	N=125
Lead apron, %	68	35	23	13	8
Lead shielded syringe, %	52	73	81	86	88
Assisting patients during therapeutic procedure	N=156	N=942	N=867	N=674	N=480
Lead apron, %	78	42	31	26	19
Moved more than 3ft away from patient, %	54	86	91	91	95

[a]Among technologists who reported ever working with radionuclides, ever working with diagnostic radionuclides in the specific time period, ever performing specific task, and provided information on specific safety practice.

[b]Among technologists who reported ever working with radionuclides, ever working with therapeutic radionuclides in the specific time period, ever performing specific task, and provided information on specific safety practice.

frequency with which technologists were performing those procedures rapidly increased between 1980 and 2009. This may reflect increased specialization in non-brain PET procedures by some of the radiologic technologists in this study. Similar trends have been observed elsewhere. Between 2008 and 2010 alone, a 14.7% increase in clinical PET studies was described in another report (IMV 2011), where in 2010, 96% of all PET studies performed were in an outpatient setting versus in a hospital (IMV 2011). Further evidence of this growing trend of specialization could be seen with the relatively recent creation of the new certification by the Nuclear Medicine Technology Certification Board specifically for PET (Nuclear Medicine Technology Certification Board).

Changes in radiation safety practices

The authors found that technologists reported an overall increase in the use of radiation safety practices, except for the use of lead aprons in all diagnostic and therapeutic-related tasks and the use of fume hoods specifically for ^{99m}Tc generator elution. This increase in use corresponds to the implementation of standards for protection against radiation between the 1950s to 1970s (Part 20, Title 10 Code of Federal Regulations) (USNRC 1991; Siegel 2002). The decreased use of lead aprons likely results from two factors. First, it may reflect a more widespread awareness of their limited effectiveness with therapy-related radionuclides or higher energy radionuclides, such as PET tracers, which emit gamma photons with a 511 keV energy (Fog and Collins 2008; Young 2013). Second, for many technologists, lead aprons are simply too heavy and other radiation safety equipment (e.g., lead syringe shield) too bulky and a hindrance to efficiently complete tasks such as injecting radionuclides. Although the absence of protective lead aprons likely results in an increase in nuclear medicine technologists' exposure to radiation, their low ability to shield against higher energy photon radiation and their heavy weight may be a reasonable and low consequence trade-off.

Implications for exposure and health risk

PET technologists, particularly in outpatient settings, may be receiving relatively high radiation doses because these procedures are performed at an increasing rate, and radiation safety measures, such as lead aprons, are less effective for moderate to high energy exposures (e.g., 511 keV gamma rays) (IMV 2008). Compared to other non-cardiac procedures performed in the time period 2000 to 2009, the number of cardiac radionuclide scans was relatively high, consistent with a 2008 report (IMV 2008). The observed increase in the proportion of technologists performing cardiac scans and the frequency with which cardiac scans are performed may be associated with increases in cumulative radiation exposure to technologists. These procedures require technologists to spend more time with patients during various tasks (e.g., stress tests, injections, camera positioning) than other general diagnostic radionuclide procedures and commonly require two injections of ^{99m}Tc per procedure, potentially leading to higher exposure rates to technologists. Although the radionuclide most commonly used in cardiac scans, ^{99m}Tc, has a lower primary gamma ray energy (140 keV) than the radionuclides used in PET procedures (i.e., ^{18}F, 511 keV), technologists could be spending more time with patients who are being injected with larger amounts of radioactivity (Shackett 2009). The younger technologists in this sample were more likely than older technologists to have ever performed cardiac scans. Considering that ^{99m}Tc was introduced in nuclear medicine in the mid-1960s, technologists trained more recently may be subject to higher doses from diagnostic radionuclide procedures than those trained in earlier years, though this has not been definitively determined.

Although the proportion of technologists who performed radionuclide therapy procedures increased, the frequency with which these procedures were performed declined. This may be evidence of the shift in the tertiary care of certain conditions, including certain cancers (e.g., thyroid cancer). Further, the responsibility of conducting radionuclide therapy procedures may also be shared by professionals other than general radiologic technologists (e.g., certified nuclear medicine technologists).

Long-term health risks associated with a well-documented increase in PET scans and the decrease in use of lead aprons among technologists conducting radionuclide procedures are currently unknown and may warrant further investigation in light of the results from a recent study showing that very low levels of exposure to ionizing radiation may be associated with certain cancers (Leuraud et al. 2015).

CONCLUSION

This study uses data collected from a subset of technologists who reported performing radionuclide procedures on a regular basis from the USRT study, a large, national cohort of radiologic technologists with detailed work history information. These data corroborate findings from other surveys showing increases in diagnostic nuclear medicine procedures and further support the need to study this occupational population. This is the first study to describe self-reported work history data specifically with regard to radionuclide procedures and associated radiation safety practices. This is the first description of these data, which will later be used to estimate individual occupational radiation doses (Simon et al. 2014) from conducting nuclear medicine procedures and investigate associations with radiation-related health outcomes in the USRT cohort, including certain cancers and cardiovascular diseases (Kitahara et al. 2015).

There are limitations that need to be considered in the interpretation and implications of these findings. First, information was self-reported, with technologists having been queried on work habits up to more than 50 y in the past. Such information may have been reported with some degree of error, which may be greater for earlier time periods. The sample of technologists described in the current report consists of general radiologic technologists who were certified for at least 2 y through 1982. This subset of technologists completed multiple, lengthy work history questionnaires many years after beginning work as radiologic technologists and were eligible for the current study because they had previously reported that they ever performed nuclear medicine procedures. Thus, these results may have limited generalizability, potentially overestimating the workload and use of radiation safety practices of all radiologic technologists. On the other hand, these results may also underestimate the number of procedures performed by technologists specifically certified and specializing in nuclear medicine, particularly during more recent years.

Although it was found that the use of radiation safety practices among technologists performing radionuclide-related tasks has increased over time, the observed increase in the proportions of technologists who performed diagnostic cardiac scans and non-brain PET scans and the increasing frequency with which these procedures were performed, specifically in more recent decades, suggests that radiation exposure from radionuclide procedures may have increased in this subset of radiologic technologists. Additional studies are needed to determine whether these trends apply to radiologic technologists more broadly and to certified nuclear medicine technologists more specifically. This descriptive analysis represents the first step in estimating doses to radiologic technologists in the USRT study who ever performed radionuclide procedures, which will form the basis of future health risk analyses to quantify the dose-response relationship for radiation-related cancer, circulatory diseases, and other serious health outcomes (Kitahara et al. 2015).

Acknowledgments—We thank the participants of the U.S. Radiologic Technologists Study, Jerry Reid of the American Registry of Radiologic Technologists for continued support, Diane Kampa and Allison Iwan of the University of Minnesota for study management and data collection, and Jeremy Miller of Information Management Services for data preparation. This work was supported by the Intramural Research Program of the Division of Cancer Epidemiology and Genetics of the National Cancer Institute.

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