Physician Knowledge of Nuclear Medicine Radiation Exposure

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Purpose Because physician knowledge of patient exposure to ionizing radiation from computed tomography (CT) procedures previously has been recognized as poor, the purpose of this systematic review is to determine whether physician or physician trainee knowledge of patient exposure to radiation from nuclear medicine procedures is similarly insufficient.

Methods Online databases and printed literature were systematically searched to acquire peer-reviewed published research studies involving assessment of physician or physician trainee knowledge of patient radiation exposure levels incurred during nuclear medicine and CT procedures. An a priori inclusion/exclusion criteria for study selection was used as a review protocol aimed at extracting information pertaining to participants, collection methods, comparisons within studies, outcomes, and study design.

Results Fourteen studies from 8 countries were accepted into the review and revealed similar insufficiencies in physician knowledge of nuclear medicine and CT patient radiation exposures. Radiation exposure estimates for both modalities similarly featured a strong tendency toward physician underestimation.

Discussion Comparisons were made and ratios established between physican estimates of patient radiation exposure from nuclear medicine procedures and estimates of CT procedures. A theoretical median of correct physician exposure estimates was used to examine factors affecting lower and higher estimates.

Conclusion The tendency for ordering physicians to underestimate patient radiation exposures from nuclear medicine and CT procedures could lead to their overuse and contribute to increasing the public's exposure to ionizing radiation.

According to a 2009 report from the National Council on Radiation Protection & Measurements (NCRP), ionizing radiation exposure to the U.S. population more than doubled between the early 1980s and 2006.[1] The main factor in the higher exposure estimates was a 7-fold increase in medical radiation exposure during this same period. The estimates of health risks this poses varies. A National Research Council committee report on health risks from low-level exposure to ionizing radiation concluded that lifetime effects of 1-time exposures less than 100 mSv were difficult to estimate, but a 1-time exposure of 100 mSv increased lifetime risk of cancer development by 1%.[2] (Annual average radiation exposure to the public is about 3.5 mSv.[3]) The National Cancer Institute estimates that 29 000 new cancer cases will result from computed tomography (CT) imaging conducted in 2007 alone.[4] Others estimate that 2% of cancers will be attributable to the recent increase of CT use.[5]

Literature Review

Increased levels of exposure as a result of medical procedures and the associated health risks has prompted recent research intended to estimate the hazard and identify ionizing radiation procedure use trends more accurately. Brenner et al concluded that cumulative exposures of greater than 50 mSv from the types of ionizing radiation used in medical imaging reasonably predict increased cancer risk.[6] The same researchers indicated that risk from a 1-time exposure of 10 mSv or less was still difficult to assess, but when considered among a sizeable population, a very small risk would likely affect a large number of people.[6] (Ionizing radiation exposure from 1 abdominal CT equals 10 mSv.[7]) Other medical procedures besides CT significantly contribute to increased exposure of the population. Fazel et al found that nuclear medicine myocardial perfusion imaging accounted for 22% of medical imaging exposures.[8] Nuclear medicine myocardial perfusion imaging results in about 12 mSv of total exposure to the patient.[7]

Physicians in different specialties order these procedures for their patients and a number of researchers have investigated the knowledge physicians have of patient exposure to ionizing radiation from medical procedures — particularly CT.[9,10] Krille et al conducted a systematic review to assess physician knowledge about patient exposure to medical radiation as well as the risks posed by exposure to radiation from CT and concluded that a majority of physicians lack sufficient knowledge of exposures and risks.[11]

Because nuclear medicine myocardial perfusion imaging represents a substantial portion of medical radiation exposure to the population and other types of nuclear medicine procedures result in similar levels of exposure to patients, a systematic review focused on nuclear medicine procedures might demonstrate similar insufficient physician knowledge. In addition, same-study comparisons of physician knowledge of nuclear medicine and CT exposures might reveal homogeneity or heterogeneity regarding physician radiation exposure perceptions in these 2 medical imaging modalities. Such same-study comparisons could further define the need for improving physician awareness of medical procedural radiation exposures and foster better judgment in weighing the risks and benefits. Increased prudence in medical imaging utilization has the potential to improve public health by reducing radiation exposure to the population.

The aim of this study was to use a systematic review to assess physician knowledge of patient ionizing radiation exposure from nuclear medicine diagnostic procedures and relate it to physician knowledge of radiation exposure from CT imaging. The hypothesis is that physician knowledge of patient ionizing radiation exposure from nuclear medicine and CT procedures will be similarly insufficient.

Methods

An analytical and evaluative systematic review was conducted using guidelines set forth by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement[12] and the *Cochrane Handbook for Systematic Reviews*.[13] Eight core articles were used as models for developing inclusion and exclusion criteria as well as search strategies. A detailed systematic review protocol was developed as recommended by the PRISMA statement and the *Cochrane Handbook*.

Using the core articles, the authors determined that the study population should include multinational physicians and physician trainees in a variety of specialties and clinical settings.

Information Collected

In agreement with the PRISMA statement, the review was designed to address participants, interventions, comparisons, outcomes, study appraisal, design, and synthesis.[12] These elements are incorporated into this review but are not considered in that order. It was apparent from the core articles that research in this field often was based on cross-sectional methods rather than random controlled trials; therefore, interventions for this review were considered to be the data collection method used in each individual study. According to the a priori review protocol, a variety of variables were selected for evaluating and comparing studies, as well as study participants, data collection techniques, and outcomes (see **Box 1**).

Search Strategy

Study searches used online databases as well as limited hand searches of hard copies of the literature. The searches were conducted between February 17 and March 23, 2012. Online databases accessed through the Virginia Commonwealth University Library Web site included PubMed/MEDLINE (U.S. National Library of Medicine, Bethesda, Maryland); Scirus (Elsevier, Amsterdam, The Netherlands); the Cochrane Library (both the Health Technology Assessment and Cochran Databases of Systematic Reviews); Cumulative Index to Nursing and Allied Health Literature (EBSCO Industries, Ipswich, Massachusetts); and Web of Science (Thomson Reuters, New York, New York); as well as CSA's Biological Sciences, Conference Papers Index, BioOne Abstracts and Indexes, Environmental Sciences and Pollution Management, and Safety Science and Risk databases. After these, a series of final online searches was made using Google Scholar (Mountain View, California). No publication date limits were set for online searches. Hard copy searches of the *Journal of Nuclear Medicine*, the *Journal of Nuclear Medicine Technology*, and the *Journal of Nuclear Cardiology* were conducted through all issues published between January 2005 and February 2012. Finally, references cited by accepted articles for the review were evaluated for inclusion.

Box 1

Variables

- Original research design.
- National location.
- Number, type, specialty, and experience of subjects.
- Method of information collection.
- Basis of radiologic exposure comparison.
- Nuclear medicine exposure knowledge outcomes.
- CT exposure knowledge outcomes.
- Other radiologic exposure knowledge outcomes (if reported).
- Nonradiologic exposure knowledge outcomes (if reported).
- Cancer risk assessment (if reported).

The following items were selected to appraise the quality of study design:

- Randomization.
- Blinding.
- Outcome reporting.
- Potential sources of bias.
- Quality of subject clinical settings and site locations.
- Author-identified limitations.
- Funding sources.
- Provision of key conclusions.

For inclusion in the review, studies were required to have been:

- Published in a peer-reviewed research journal.
- Directed toward physicians or physician trainees as subjects.
- Inclusive of both nuclear medicine and CT subject radiation exposure estimates.
- Designed using cross-sectional, case control, or prospective methods.

Studies were excluded from the review if they were:

- Presented in an online journal only (vs a print journal).
- Duplicates of studies from previously selected articles.

An iterative process was used in developing an effective online search strategy through PubMed. Prior to online searching, the 8 core articles were reviewed and key terms extracted. These terms plus terms from article titles were examined using Medical Subject Headings (MeSH) term trees available through the PubMed Web site. Multiple queries were conducted in MEDLINE in an iterative fashion using compilations of different subject terms and MeSH terms with attention to the number of resulting acceptable articles. In a single search, the seventh iterative query produced all 8 of the original core articles. (Prior to conducting this review, the core articles were acquired through multiple unsystematic searches.) This indicated that the search strategy for the seventh query was sensitive enough to return all of the articles known to the researcher at that time from a single database (MEDLINE). Minor limiting terms were then added to that query's search terms to improve specificity, and the resulting search strategy was adapted for use with other online databases. Details of this query's search strategy appear in **Box 2**. Also, daily automated e-mail notifications of additions to the 7 MEDLINE queries were established through PubMed.

With the exception of Google Scholar, all titles from each query were reviewed for indications of possible inclusion. If a study title presented the possibility that knowledge about radiation exposure was being assessed, then it was more closely examined — first by abstract. If the abstract indicated that the study centered on an evaluation of knowledge concerning CT or other radiographic procedures, then the complete article was examined because most core articles did not address nuclear medicine procedures in their abstracts. Titles that clearly pertained to topics such as treatment

Box 2

MEDLINE Search Strategy With Limits

(Physician OR Physicians OR Medical staff* OR Pediatrician OR Pediatricians OR Radiologist OR Radiologists OR Intern OR Interns) AND (Knowledge OR Clinical competence*) AND (Radiation OR Radiation dosage OR A.L.A.R.A.) NOT (Case study OR Case studies OR Case reports OR Editorial OR Editorial comment OR Animal) procedures, nonionizing procedural techniques, or editorial commentary were not examined past the title level.

Because the operation of Google Scholar is not entirely based on Boolean logic, which combines, separates, and eliminates key search terms by using the operators "AND," "OR," and "NOT" between terms, the MEDLINE-developed search strategy limitedly was applied to Google Scholar. Because of limited resources and the magnitude of raw hit values for some queries, searches through Google Scholar titles ended after 300 consecutive nonrelevant titles were examined.

Comparisons

Two macro-synthesis matrices were developed to compare extracted study characteristics pertaining to quality and outcomes. Portions of these matrices appear in the results section of this review.

Results

Regarding online actual database search queries, MEDLINE produced the greatest number of raw hits (873), followed by Web of Science (257). Google Scholar is considered a search engine rather than a database and those searches yielded extraordinarily high raw hit values. A summary of searches appears in **Table 1**. Hand searches and review article references did not produce any additional acceptable studies.

The 12 online search queries plus the automated PubMed e-mail follow-up notifications resulted in 91 articles being further evaluated for acceptance into the

Table 1

Summary of Search Queries

Query	Date	Web site	Database	Raw Hits	Accepted	New
1	02/17/12	PubMed	MEDLINE	341	2	2
2	02/19/12	PubMed	MEDLINE	327	5	4
3	02/24/12	PubMed	MEDLINE	515	2	0
4	02/24/12	PubMed	MEDLINE	758	2	0
5	02/24/12	PubMed	MEDLINE	280	1	1
6	02/26/12	PubMed	MEDLINE	873	10	3
7a	03/02/12	PubMed	MEDLINE	510	11	1
7b (limits)[a]	03/09/12	PubMed	MEDLINE	462	11	0
8	03/02/12	SCIRUS	SCIRUS	127	9	0
9	03/02/12	Cochr Lib	CDSR/HTA	177	0	0
10	03/02/12	EBSCO	CINAHL	82	2	1
11	03/02/12	Web of K	Web of Science	257	11	3
12	03/15/12	CSA	(multiple)	122	0	0
Google Search	03/10-15/12	Google	Google Scholar	204 000 (highest)	13	2
Hand Search	03/03/12		JNM, JNMT, JNC	(2005-Feb 2012)	0	0
Reference Review	03/23/12		Accepted articles	(208 references)	0	0
					Total[b]:	17

Abbreviations: CDSR/HTA, Cochrane Database of Systematic Reviews/Health Technology Assessment Database; Cochr Lib, Cochrane Library; JNC, Journal of Nuclear Cardiology; *JNM,* Journal of Nuclear Medicine; *JNMT,* Journal of Nuclear Medicine Technology; *Web of K, Web of Knowledge.*

[a] *Limiting "NOT" (Boolean logic) terms were added to query 7a to improve specificity, yet produced same number of acceptable results.*

[b] *Three studies were later excluded, leaving a total of 14 acceptable studies.*

review. Of these, 17 were initially accepted; however, 3 of the initially accepted articles did not fully meet the inclusion criteria for this review, leaving 14 studies meeting the inclusion/exclusion criteria.

All 14 accepted studies appeared in peer-reviewed journals that at least had limited hard-copy publishing, and all were of cross-sectional design using a survey or questionnaire instrument as the data collection method. Six studies were conducted in the United Kingdom,[14-19] with a seventh being conducted in Northern Ireland (which is considered part of the UK).[20] Two studies were conducted in Hong Kong, China.[21,22] The remaining studies were conducted in Belgium, the Republic of Ireland, Iran, Canada, and Australia.[23-27] No studies conducted in the United States fully met the inclusion criteria. The 3 excluded articles either mentioned a nuclear medicine procedure without providing exposure estimates[30] or did not contain CT exposure estimates as originally assumed.[28-30]

Participants

Physicians were included as subjects in all studies, but at least 2 studies identified intern physicians and medical students as subjects.[24,27] In 1 of these studies, interns were the highest ranking physician.[27] One study included medical physicists among the subjects.[15] Physicians of various ranks participated in 10 of the studies.[14-16,18-20,22,23,25,26] Multiple varieties of specialists were assessed in 9 studies.[14-18,20,23-25] One of these studies[23] targeted nonradiologists and another[17] mostly cardiologists. Other studies targeted emergency physicians[22] and pediatricians.[26] One study was solely aimed at junior clinicians.[21] Three studies compared results based on years of service[17,26] or educational level.[27] There was a combined total of 2122 participants for all 14 studies. **Table 2** shows a breakdown of participant frequencies (when provided) for studies in this review.

Methods Used for Information Collection

All 14 studies used a questionnaire or survey conducted by various means to obtain information concerning participant knowledge of radiation exposures. Self-written surveys were reported for 8 studies[16,18,20,21,23-26] with at least 1 reporting postal participation[25] and a second reporting both postal and e-mail participation.[20] One of the self-written surveys was completed by participants with the researchers present.[23] The remainder of the studies used face-to-face interviews.[14,15,17,19,22,27]

The questionnaires or surveys all asked participants to estimate patient radiation exposure from diagnostic procedures but with variation in the metrics used to obtain this information. Two studies asked participants to directly estimate patient radiation exposure resulting from radiologic procedures in millisievert. One of these studies[15] accepted estimations within ±10% of the true value as correct; the other accepted as correct those responses within ±20%.[23] One study asked participants to estimate patient radiation exposure resulting from radiologic (and nonradiologic) procedures using equivalent exposures based on a hand radiograph.[25] The remaining 11 studies in the review used the radiation exposure equivalent of a chest radiograph as a unit for participant estimations of other procedural radiation exposures.[14,16-22,24,26,27]

Among these 11 studies, however, there was some variation in the exposure value assigned to a chest radiograph. For the study involving pediatricians by Thomas et al, the assigned exposure value (0.006 mSv) was based on a standard chest radiograph technique for a 5-year-old child.[26] Two studies used a chest radiograph exposure value of 0.2 mSv as a unit reference.[20,27] For the study conducted by Soye and Paterson, however, this figure might have been a typographical error since it was obtained from the same source (the Royal College of Radiologists[31]) used by other studies in the review that defined a chest radiograph exposure as 0.02 mSv.[20] The 0.2 mSv value appeared as the correct answer choice in the study questionnaire (the questionnaire did not offer 0.02 mSv as a choice).[20] The Belgian study by Gervais et al defined the exposure value of a chest radiograph as 0.1 mSv (no reference source was provided).[23] Two studies using chest radiograph radiation exposure equivalents as a means to estimate doses did not define the exposure value for a chest radiograph.[14,24] All other studies in the review that used chest radiograph equivalents for estimating patient exposure to radiologic studies used the 0.02 mSv value. Some authors provided a reference source from which they obtained their assigned chest radiograph values. Three studies that used the chest radiograph as an exposure unit reference and defined it with a value in mSv did not provide the source of their information.[16,21,27] The pediatric study by Thomas et al

Table 2

Breakdown of Study Characteristics by First Author

1st Author	Year	Country	N[a]	Type or Specialty (n)	Survey Type
Bosanquet[14]	2011	UK	112	"variety including": Med (NA), Surgery (NA), Anaesthetics (NA)	Interview
Gervais[23]	2011	Belgium	50	Permanent (28) ED, Resident (22) ED	Interview & self-written
Groves[15]	2006	UK	161	Med Physicists (16), Radiologists (102), NM (13), NM/Radiologists (7), Pulmonology (23)	Interview
Jacob[16]	2004	UK	240	Med (107), Surgical (83), Anaesthetics (18), Radiology (22), Others (7), Unaccounted (3)	Self-written
Lee[21]	2011	China	158	Internal Med (53), Surgery (41), Pediatrics (12), Emergency Med (27), Radiology (25)	Self-written
Luk[22]	2010	China	63	Junior Clinicians (63)	Self-written
McCusker[24]	2009	Ireland	269	Preclinic Med Student (76), Clinical Med Student (85), Interns (61), Senior House Officers (19), Registrars (28)	Self-written
Nicol[17]	2008	UK	47	Cardiologists (43), Others (4)	Interview
Quinn[18]	1997	UK	86	Consultants (15), Senior Registrars (11), Registrars (19), Senior House Officers (19), House Officers (22)	Self-written
Sani[25]	2009	Iran	120	General Physicians (86), Specialist Physicians (34)	Self-written
Shiralkar[19]	2003	UK	130	NA (NA)	Interview
Soye[20]	2008	Northern Ireland	153	Gen Med (35), Surgical Specialist (22), Anaesthetics (18), Pediatrics (15), Others (63)	Self-written
Thomas[26]	2006	Canada	220	Pediatricians (220)	Self-written
Zhou[27]	2009	Australia	313	Senior Med Student (NA), Interns (NA)	Interview

Abbreviations: ED, emergency doctors; Med, medicine or medical; NA, not available; NM, nuclear medicine; UK, United Kingdom.
[a] Total N = 2122

obtained the exposure value for the child chest radiograph from internal institutional measurements.[26]

Six studies[16,17,20,22,26,27] asked participants to estimate the cancer risk posed by a single CT examination, and 2 studies[17,20] asked participants to estimate risk for other radiologic procedures. All 6 studies used multiple-choice answers on the questionnaires or surveys indicating a range of probabilities regarding risk.

Outcomes: Exposure Estimates

Participants' exposure estimates involved a variety of nuclear medicine procedures. Participant estimates of patient radiation exposure from thyroid scans were obtained in 5 studies,[14,19,21,24,25] lung ventilation/perfusion scans in 5 studies,[15,16,20,23,27] bone scans in 4 studies,[16,18,22,27] positron emission tomography (PET) or PET-CT scans in 3 studies,[21,24,27] and myocardial perfusion imaging[17,27] and renal scans[27,26] in 2 studies each. Nicol et al presented their estimation results as interquartile medians.[17] (An interquartile median is obtained from a narrowed range of obtained values that excludes the first and last 25% of the true complete range.) All other studies at least summarized or provided some manner in which to deduce (ie, through implication or graph interpolation) the percentage of correct answers concerning participant estimates of ionizing radiation exposures for nuclear medicine examinations. The lowest percentage of correct estimations was for both thyroid and PET scans (0% each) and appeared in the article by Lee et al with nonradiologist physicians making the poorest estimation.[20] In that same study, 97% of the nonradiologist physicians underestimated the thyroid scan exposure, and 98% of the same population underestimated the PET scan exposure. The highest percentage of correct estimation, made by physicians who received special regulatory radiation training, was 36.7% for a lung ventilation/perfusion scan.[16] Percent underestimates and overestimates were available from 6 studies,[18,22,24-27] and underestimation percentages were usually much higher than overestimation percentages, with the ratio always exceeding 2:1.

Participants' exposure estimates also involved a variety of CT procedures. Participants estimated patient radiation exposures for an abdominal CT scan in 8 studies,[16,18-20,25-27] a chest CT scan in 2 studies,[25,26] as well as a brain CT scan in 2 studies.[22,24] Participants made additional estimates for CT images of the:

- Skull.[25]
- Chest, abdomen, and pelvis.[24]
- Spiral abdomen.[14,19]
- Coronary arteries.[17]
- Head.[26]
- Lumbar spine.[18]
- Neck and torso.[26]

One study obtained exposure estimates for either a CT scan of the abdomen or pelvis.[22] Again, except for Nicol et al, all studies provided means to determine the percentage of correct exposure estimates from the participants for CT procedures.[17] Lee et al reported that nonradiologists provided the lowest correct estimate percentage (0%) for patient exposures from thoracic and abdominal CT scans, with 99% of these physicians underestimating exposure.[21] The Groves et al study involved physician participants from a variety of specialties and had the highest percentage of correct estimates (43%) for the CT procedure pulmonary angiography.[15] The same 6 studies mentioned in the nuclear medicine outcomes provided means of determining participant under- and overestimates of patient radiation exposure from CT procedures. As with the nuclear medicine procedures, underestimate percentages far exceeded overestimate percentages, with the lowest ratio being more than 4:1.[18,22,24-27]

Figure 1 represents the available average percent correct estimates, where a dotted line divides the percentage of correct estimates at the theoretical median between 0%

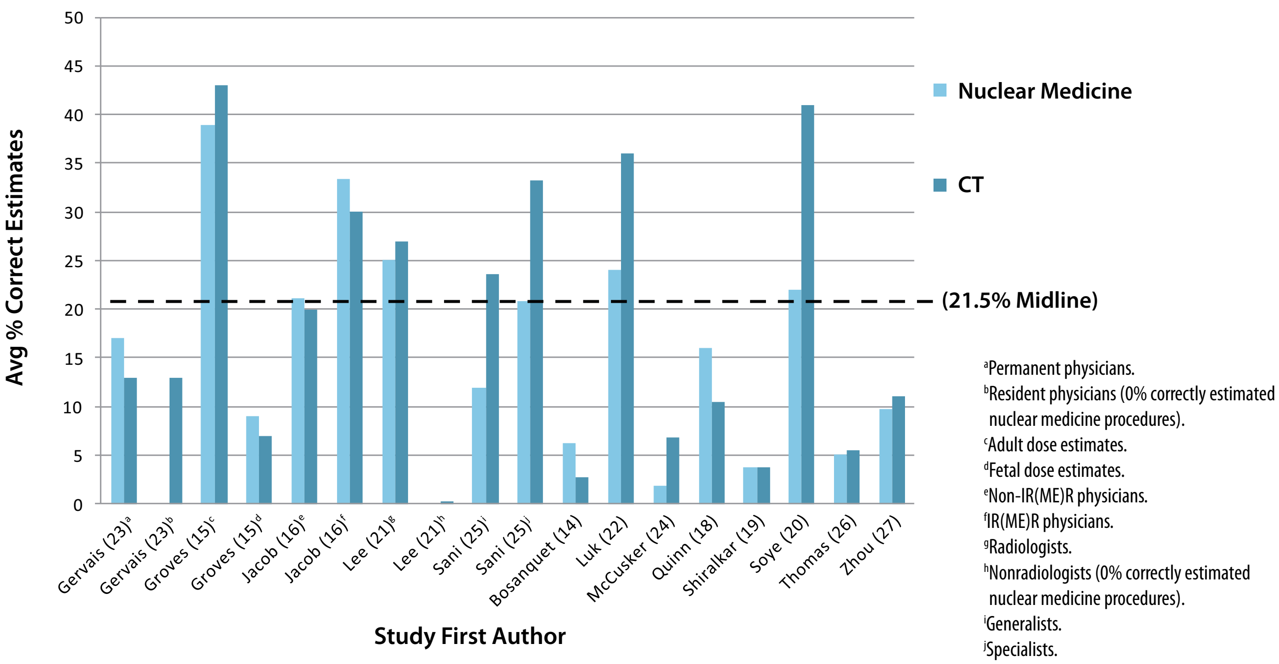

Figure 1. *Participant average percent correct estimates of patient radiation exposure from nuclear medicine and computed tomography (CT) procedures by study first author (reference number in parentheses). IR(ME)R referenced with the Jacob et al study refers to Ionising Radiation (Medical Exposure) Regulations passed in the United Kingdom to protect patients.*

Table 3

Average Percent Correct Estimates and Underestimates With Nuclear Medicine to CT Ratios

1st Author	Group (If Applicable)	NM Procedures Avg % Correct	NM Procedures Avg % Underest	CT Procedures Avg % Correct	CT Procedures Avg % Underest	NM:CT Ratios % Correct	NM:CT Ratios % Underest
Lee[21]	Nonradiologists	0.0	97.5	0.3	99.0	0.0	1.0
	Radiologists	25.0	30.5	27.0	31.0	0.9	1.0
Sani[25]	Generalist physician	11.9	81.1	23.6	77.8	0.5	1.0
	Specialist physician	20.9	72.2	33.3	61.4	0.6	1.2
Luk[22]		24.0	44.0	36.0	59.5	0.7	0.7
McCusker[24]		1.9	96.0	6.8	79.0	0.3	1.2
Quinn[18]		16.0	76.0	10.5	82.5	1.5	0.9
Thomas[26]		5.0	94.0	5.5	94.0	0.9	1.0
Zhou[27]		9.7	77.4	11.1	88.9	0.9	0.9
Jacob[16]	Referrer physician	21.1	NA	20.0	NA	1.1	NA
	Practitioner physician[a]	33.4	NA	30.0	NA	1.1	NA
Gervais[23]	Resident physician	0.0	NA	13.0	NA	0.0	NA
	Permanent physician	17.0	NA	13.0	NA	1.3	NA
Groves[15b]	For fetal exposure	9.0	NA	7.0	NA	1.3	NA
	For adult exposure	39.0	NA	43.0	NA	0.9	NA
Bonsanquet[14]		6.3	NA	2.7	NA	2.3	NA
Shiralkar[19]		3.8	NA	3.8	NA	1.0	NA
Soye[20]		22.0	NA	41.0	NA	0.5	NA

Abbreviations: Avg, average; CT, computed tomography; NA, not available; NM, nuclear medicine; Underest, underestimate.

[a] The practitioner group is required to justify utilization of radiologic services under IR(ME)R.[16]

[b] Participants were asked to estimate exposures for fetuses and adults.

and 43% (21.5%). **Table 3** shows the average same-group or same-study percent correct estimates and underestimates for nuclear medicine and CT, as well as ratios comparing these. **Figure 2** shows the average percentage of underestimates provided from the studies. **Figures 3** and **4** separate studies or groups according to their position above or below the median line. The above- or below-line status of the studies and groups is based on the position of either nuclear medicine or CT estimates (or both) and were not separated according to modality.

Participant patient radiation exposure estimations for 27 types of other radiologic procedures using radiographs also were included. Summaries of procedure types investigated in review studies appear in **Table 4**. One of the 14 studies did not include participant estimates of patient radiation exposure for radiograph-based procedures other than CT.[15] The lowest correct estimate percentage for a radiograph was 0%, which occurred in 4 studies.[18,19,21,24] Three of these studies provided percentages of participant underestimations for these same procedures ranging between 96% and 100%.[18,21,24] Conversely, the study by Zhou et al provided the highest percentage of correct participant estimates for a radiograph, with 87% correctly estimating the radiation exposure a patient would receive from an ankle radiograph.[27] As with nuclear medicine and CT procedures, the tendency leaned (although less substantially) toward underestimation rather than overestimation for radiographs. In the 5 studies providing both under- and overestimations for radiographs,[18,22,25-27] the proportion of participant overestimates exceeded underestimates in 5 situations.[25,27] For the remaining 54 radiographs mentioned in these 5 studies, underestimates exceeded overestimates.

All but 4 review studies required participants to estimate patient exposure to ionizing radiation from ultrasonography, magnetic resonance (MR) imaging procedures, which do not emit ionizing radiation,[15,17,18,23] or both. Lee et al reported that 34% of nonradiologists thought that MR procedures exposed patients to ionizing

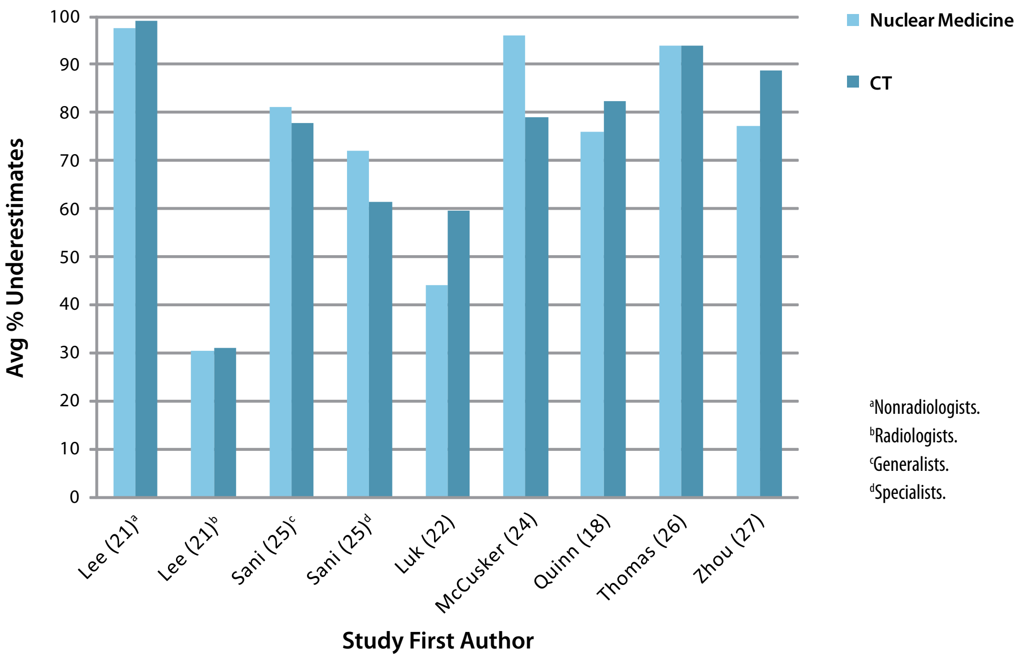

Figure 2. *Participant average percent underestimates of patient radiation exposure from nuclear medicine and CT procedures by study first author (reference number in parentheses).*

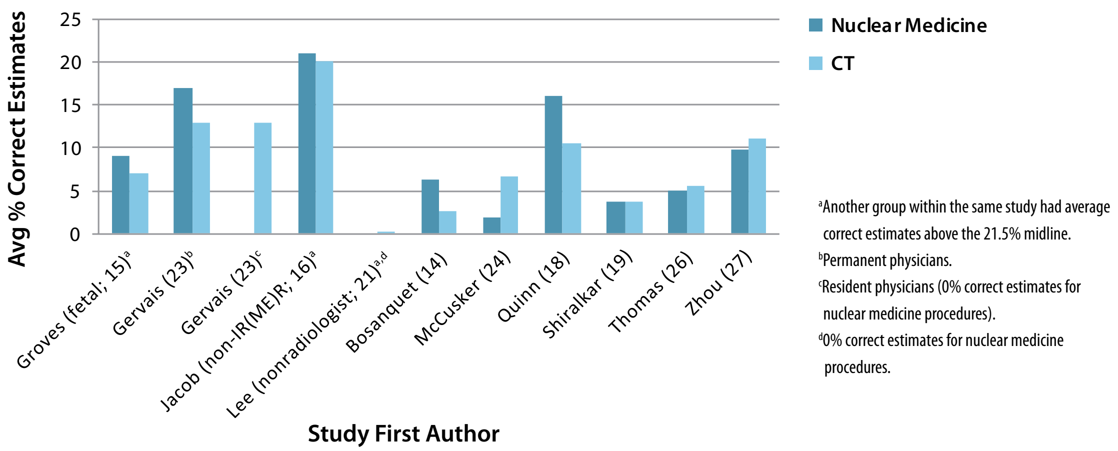

Figure 3. *Participant average percent correct estimates of patient radiation exposure from nuclear medicine and CT procedures — below 21.5% midline by study first author (reference number in parentheses).*

radiation.[21] Another study by Sani et al revealed that 11% to 12% of general practice physicians thought that ultrasonography and MR imaging exposed patients to radiation.[25] In the remaining studies that asked for ultrasonography or MR imaging radiation exposure estimates, no study-categorized group of participants completely correctly recognized that these 2 procedures do not emit ionizing radiation. For these 8 studies, 4%[26] to 33%[20] of study or group participants thought that ultrasonography or MR imaging studies exposed patients to ionizing radiation.[14,16,19,20,22,24,26,27]

Outcomes: Cancer Risk Estimates

Six studies presented physician or physician trainee estimates of patient lifetime cancer risk from medical radiation exposure.[16,17,20,22,26,27] Jacob et al reported that when asked to predict the risk of lifetime cancer from a single CT scan of the abdomen, 12.5% of participants correctly placed the risk at 1 in 2000.[16] Ninety-eight percent of participants underestimated the cancer risk from an abdominal CT scan in the study by Luk et al.[22] In the study by Soye and Paterson, only 19% correctly identified the cancer risk from an abdominal CT scan (also cited as 1 in 2000).[20] Thomas et al revealed largely underestimated cancer risk by participants for a child aged 1 year having a CT procedure (defined as 1 in 1000), with only 6% of pediatricians correctly identifying the risk.[26] Zhou et al disclosed that nearly 59% of participants in their study underestimated the cancer risk from 1 abdominal CT scan.[27] Roughly half of the participants underestimated the risk of cancer for a variety of radiation-emitting procedures (including nuclear medicine myocardial perfusion imaging) in the study by Nicol et al.[17]

Study Quality

Only a few of the review studies addressed randomization when it came to selecting subjects. One study mentioned that subjects were personally approached at random,[14] and another indicated that the study relied on subject volunteerism.[23] One study self-identified its convenience sampling method.[19] The study by Soye and Paterson employed a random generator for selecting its subjects.[20] Two studies identified their questionnaires as being completed by subjects in anonymity, but other than that, no blinding techniques were identified by any studies.[18,20]

Outcome reporting was ranked using a number system adapted from the Cochrane Collaboration's Tool for Assessing Risk of Bias from the *Cochrane Handbook* (see **Box 3**).[13] The study by Nicol et al received a rank of 3.[17] Six studies received a rank of 2.[16,18,21,25-27] The remaining 7 studies received a rank of 1 (see **Table 5**).

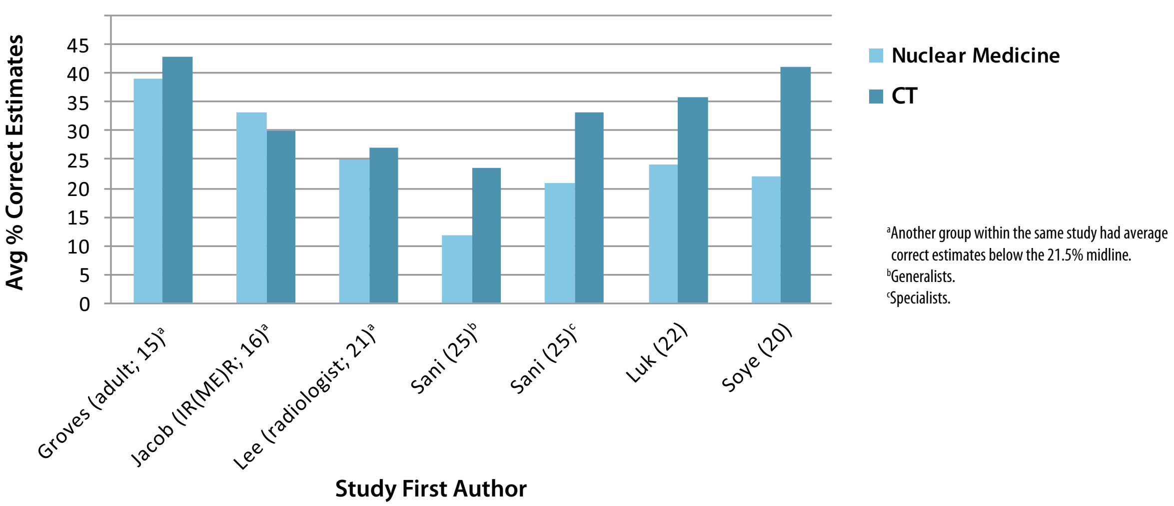

Figure 4. *Participant average percent correct estimates of patient radiation exposure from nuclear medicine and CT procedures — above 21.5% by first author (reference number in parentheses).*

Table 4

Procedures Appearing in Systematic Review Articles by First Author

1st Author	NM Procedure	CT Procedure	Radiographic Procedure	Nonionizing Procedure
Bosanquet[14]	Thyroid scan, WBC scan	Spiral abdomen	Abdomen, lumbar spine, thoracic spine, barium swallow, cholangiogram, arteriogram leg	Ultrasound, MR
Gervais[23]	V/Q scan	Pulmonary	Chest	
Groves[15]	V/Q scan	CT pulmonary angiogram		
Jacob[16]	V/Q scan, bone scan	Abdomen	Barium enema, IVU, lumbar spine	Ultrasound, MR angiogram
Lee[21]	Thyroid scan, PET scan	Head, thorax, abdomen	Abdomen, thoracic spine, lumbar spine, pelvis, hip, IVU, barium enema, barium swallow, arteriogram leg	Ultrasound abdomen, abdomen, MR brain, MR limbs
Luk[22]	Bone scan	Abdomen or pelvis, brain	Barium enema, IVU	Ultrasound abdomen, MR abdomen
McCusker[24]	Thyroid scan, PET-CT scan	TAP, brain	Abdomen, lumbar spine, barium enema, mammogram, renal artery embolization, biliary stent	MR
Nicol[17]	Myocardial perfusion	CT angiogram	Coronary angiogram, PTCA	
Quinn[18]	Bone scan	Abdomen, lumbar spine	Lumbar spine, IVU, barium meal, barium enema	
Sani[25]	Renal scan, thyroid scan	Skull, chest, abdomen	Chest, skull, thoracic spine, lumbar spine, KUB, lumbar-lateral, lumbar/spine-lateral, barium swallow, barium follow, IVP, barium enema, mammogram, angio-cerebral, angio-abdomen	MR, ultrasound
Shiralkar[19]	Thyroid scan, WBC scan	Abdomen, spiral abdomen	Abdomen, lumbar spine, thoracic spine, barium swallow, cholangiogram, fixation of fractured neck of femur, arteriogram leg, arteriogram renal	Ultrasound abdomen, MR abdomen, MR knee, MR spine
Soye[20]	V/Q scan	Abdomen	Abdomen, IVU, barium enema	Ultrasound abdomen, MR brain without contrast, MR brain with contrast
Thomas[26]	DMSA renal	Abdomen, head, chest, neck-pelvis	Pelvis, VCUG	Ultrasound abdomen
Zhou[27]	V/Q scan, bone scan, myocardial perfusion, PET scan	Abdomen	Chest, ankle, abdomen, barium meal, arteriogram leg	Ultrasound abdomen, MR spine

Abbreviations: CT, computed tomography; DMSA, dimercaptosuccinic acid; IVP, intravenous pyelogram; IVU, intravenous urogram; KUB, kidneys, ureters, bladder; MR, magnetic resonance; PET, positron emission tomography; PTCA, percutaneous transluminal coronary angioplasty; TAP, thorax, abdomen, and pelvis; V/Q, ventilation/perfusion; VCUG, voiding cystourethrogram; WBC, white blood cell.

All studies in the review carried some potential sources of bias. Because explanations of blinding techniques were either absent or limited in all studies, all review studies could be at risk of bias from researcher intervention. Limited information on the means by which subjects were selected might suggest that all studies except for Soye and Paterson carried the risk of selection bias.[20] Six studies relied on face-to-face interviews with subjects and provided limited details concerning conduction of the interviews, suggesting a risk of interviewer bias.[14,15,17,19,23,27] The risk of institutional bias appeared in 5 studies.[14,19,21,22,24] Because a number of surveys and questionnaires were answered through postal mail or e-mail, which would have enabled some subjects to acquire informational assistance, the potential for performance bias was present in 4 studies.[16,20,21,26]

Subjects worked in a variety of clinical settings such as university teaching hospitals, community hospitals, and clinics. Three studies did not specify the clinical settings associated with its subjects but sampled across the researchers' respective countries or at profession-related meetings.[17,20,27] The quality of each study's site locations was assigned a numeric ranking (see **Box 4**). Rankings could not be determined for 2 of the studies.[25,27]

Seven studies identified limitations. Three studies reported a concern about subject access to information for self-completed questionnaires and surveys.[16,21,20] Two studies identified limited institutional sampling.[19,22] The study by Groves et al acknowledged the possibility of selection bias and the arbitrary designation of the ±10% acceptance window for correct physician dose estimates.[15]

Other items regarding study quality among those included in this review were author-identified funding sources and the provision of key conclusions. Only 5 studies specifically included a statement denying conflicts of interest or funding.[15,17,19,21,23] Regarding key conclusions, the study by Bosanquet et al[14] was a follow-up comparison study to that conducted by Shiralkar et al[19] and recognized only limited generalizability. The study by Soye and Paterson did not seem to indicate any generalization of findings in their conclusion.[20] All other studies hinted that results were at least partially generalizable.

Comparisons Within Studies

All but 4 studies searched for statistically significant differences between groups of study participants.[14,19,21,25]

Box 3

Outcomes Ranking[13]

1. Prespecified outcomes consistent with objectives and methods (protocol).
2. Unclear methods (protocol) but outcomes relevant to aim of study.
3. Prespecified outcomes omitted.
4. Outcomes not consistent with methods (protocol).
5. Incomplete reporting of outcomes.
6. Study missing key outcome expected for study purpose.

Table 5

Review Outcomes and Site Rankings[a]

First Author		
Bosanquet[14]	1	2
Gervais[23]	1	1
Groves[15]	1	1
Jacob[16]	2	1
Lee[21]	2	6
Luk[22]	1	6
McCusker[24]	1	5
Nicol[17]	3	1
Quinn[18]	2	1
Sani[25]	2	Indeterminate
Shiralkar[19]	1	2
Soye[20]	1	1
Thomas[26]	2	3
Zhou[27]	2	Indeterminate

[a] *See Boxes 3 and 4 for definitions of rankings.*

Fischer's Exact test and Chi-square testing were the most common means used to compare results between groups. Of the 10 studies seeking differences between participant groups, 3 did not find any statistically significant differences.[23,15,17] The study by Jacob et al found that practitioners who practice under radiation protection regulations such as IR(ME)R, which require justification for conducting radiologic procedures, performed better than referring physicians as did

Box 4

Participant Site Rankings

1. Multiple diverse locations and institution types.
2. Multiple diverse locations, same institution type.
3. Multiple institution type, same general area.
4. Multiple institutions of same type, same general area.
5. Multiple institutions in same location (eg, city).
6. One institution.
7. Not provided.

participants with more experience and those who had attended a radiation safety course.[16] Luk et al found that participants with more years of experience answered more accurately than those with less.[22] McCusker et al noted that medical students performed significantly worse than interns and those who were practicing doctors.[24] No significant difference was noted between groups in the study by Quinn et al, but the authors found that participants were significantly more likely to underestimate radiation exposures.[18] Soye and Paterson found that participants with more training performed better than those with less.[20] The study by Thomas et al did not find significant performance differences according to a variety of variables, such as years of clinical experience and institutional setting, but discovered that fellows scored better than practicing pediatricians.[21] Zhou et al found that interns performed significantly better on their estimations than medical students.[27]

Discussion

This systematic review produced 14 published peer-reviewed articles, each representing an individual research study on physician or physician trainee knowledge of patient exposure to ionizing radiation from nuclear medicine and CT procedures. Because of considerable variation in survey instrument design, radiation exposure reference sources, types of comparisons made, subject types, and sample sizes, a meta-analysis was not attempted as part of this review. The inability to perform a meta-analysis was anticipated as a strong possibility, particularly seeing that Krille et al also could not justify a meta-analysis in their review.[11] To develop the aim of this review with this possibility in mind, a comparison between knowledge of nuclear medicine exposures and CT exposures could be made on a study-by-study basis to demonstrate that physician knowledge of exposures from both modalities was comparable. Because CT is a source of concern regarding public radiation exposure, and since Krill et al[11] found physician awareness of patient radiation exposure from CT lacking, such a study-by-study comparison could add validity to a qualitative analysis of this review's results.

All studies except one produced a proportional representation — whether by frequencies, percentages, or graphs — of physician or physician trainee correct estimations of patient exposure to ionizing radiation from procedures. The study by Nicol et al presented interquartile medians to demonstrate the general degree of error among cardiologists and some other physicians regarding estimating patient exposure from procedures emitting ionizing radiation.[17] Nevertheless, because the proportion of correct answers was not an a priori criterion for inclusion in this review, the study was not excluded despite its problematic representation of results.

Although this review did not include any articles originating in the United States, similar studies do exist. For example, Lee et al tested awareness of physicians and radiologists about patient radiation exposures from CT,[10] and Ratnapalan et al assessed family physician and obstetrician awareness of teratogenic effects from radiographic and CT procedures.[32] No United States studies, however, met the inclusion criteria for this review. Six of the studies originated in the United Kingdom, suggesting that this issue has received more attention in that region of the world. Exploring motives behind this tendency is beyond the scope of this review.

It was possible in this review to at least approximate the percent correct participant exposure estimations for nuclear medicine and CT procedures in all studies except that by Nicol et al.[17] Because of the available percentages, a simple ratio was used to quantitatively describe the homogeneity or heterogeneity between these 2 modalities for each study (or groups within a study), with nuclear medicine procedures and CT procedures represented by the numerator and denominator, respectively. Any ratios near unity would suggest homogeneity between physician radiation exposure estimations for nuclear medicine and CT procedures.

The study by Bosanquet et al had the highest correct estimation ratio of nuclear medicine to CT (2.3), meaning that participants more than twice as often correctly estimated nuclear medicine patient exposures over CT exposures.[14] The lowest ratio (0.3) was derived from the information provided by McCusker et al and indicated that participants correctly estimated nuclear medicine exposures only one-third as often as those for CT.[24] The range of correct estimation ratios for all remaining studies (except for Nicol et al[17]) was 0.5 to 1.5. The studies generally revealed that participant estimations were mostly incorrect, and this range of ratios suggested that estimations were off similarly whether the procedure estimated was nuclear medicine or CT.

When available, a same-study or same-group-within-a-study ratio was applied comparing average nuclear medicine exposure percent underestimates with average CT underestimates (see Table 3).[18,21,22,24-27] The range of this nuclear medicine to CT underestimation ratio was 0.7 to 1.2, which suggested that participants underestimated the exposure from nuclear medicine procedures similarly to CT procedures.

To reinforce the projected finding of the lack of physician knowledge concerning patient radiation exposure from nuclear medicine procedures, a comparison between physician knowledge of exposure from nuclear medicine procedures and radiographs (when available) was included in the objectives for this review. The percentage of correct participant estimates for patient exposure from radiologic procedures ranged from 0% to 87%, while the range for correct percent estimates for nuclear medicine procedures was 0% to 39%. For those radiologic procedures presenting percent underestimations of patient exposure doses, the range of percent underestimations was 0% to 100%, with the stronger tendency toward underestimations.[18,21,22,24-27] Underestimation percentages for nuclear medicine were less broad (31-99%).

It was noted from the 8 core articles that researchers also requested estimations of patient exposure from modalities that do not emit ionizing radiation, so these observations were included in the review objectives. The percent range for participants correctly identifying these modalities as giving 0 exposure to patients was 65% to 100%. For ultrasonography and MR imaging, any estimation other than 0 exposure would be an overestimation, so this does not reveal any similarity with the nuclear medicine estimation trends; yet it is interesting to note that all studies that requested these estimations had at least a small degree of participants who thought these procedures exposed patients to ionizing radiation.[14,16,19-22,24-27] This demonstrated a very modest confirmation of the lack of understanding among physicians and trainees regarding the use of ionizing radiation in imaging procedures.

The variation among the average percent correct estimations for both nuclear medicine and CT exposures was considerable and ranged from 0% for nuclear medicine procedures in the studies by Lee et al[21] and Gervais et al[23] (resident physicians' subgroup) to 43% for the dose estimate from adult CT pulmonary angiography in the study by Groves et al.[15] This range was divided by a theoretical median line at 21.5%, and studies with estimates above and below this line were examined for possible characteristics that might be associated with the above and below median results.

Three studies had same-study group averages both above and below the line.[15,16,21] Seven studies[14,18,19,23,24,26,27] fell below the line regarding correct estimates, and 3 other studies[20,22,25] had percent correct estimates above the line. The higher scores could be explained among the above-line averages for the 3 studies that featured within-study group averages.[15,16,21] The Groves et al study had the highest percent correct estimate for adult exposure from CT pulmonary angiography, which was in contrast to the same-study estimates (7% correct) for fetal exposure from the same procedure.[15] The authors of the study concluded that there was more familiarity with adult doses. The groups that scored above the line for the 2 other studies featuring same-study group averages were radiologists[21] and physicians who were familiar with newer regulations on ordering diagnostic procedures.[16] Both of these situations suggested that specialized training enabled physicians to estimate patient radiation exposure more accurately.

The remaining 3 of the above-line studies offered no particular characteristic that might have explained more accurate estimations except that all 3 featured self-written responses to questionnaires submitted via e-mail or postal mail.[20,22,25] In such cases, participants could refer to information sources to estimate doses more correctly. It is important to note that 3 of the 7 below-line studies with singular average correct estimates also featured self-written surveys or questionnaires. Therefore, a conclusion cannot be drawn concerning the association between self-written responses and above- or below-line position. Nevertheless, the ability of participants to use sources for information cannot be ruled out as an advantage that could have resulted in the 3 studies having average percent correct estimates above the line.[20,22,25]

The method of estimation (ie, by direct dose estimation or chest radiograph equivalents) did not appear to affect study position on either side of the line. The studies or groups on the lower side of correct estimates featured physicians from a variety of specialties and backgrounds. Two studies sampled interns and medical students as participants, and both of these scored on the lower side of the theoretical median line, suggesting that the inexperienced individuals might have exerted a downward influence regarding correct estimates.[24,27]

It was considered that improved physician awareness of increased public medical radiation exposure would be reflected in the more recently published studies. All review studies were published between 1997 and 2011, and indeed the oldest study by Quinn et al appears in the below-the-line category.[18] Other than this, however, year of publication did not seem to predict where the average percent correct estimates for a study would fall.

Nine studies[15,16,18,20,22,24-27] provided readers with a copy of the questionnaire or survey instrument used, and 6 of these[16,18,20,22,26,27] presented multiple choices (ranging from 4 to 8 choices) for estimating patient radiation exposure from various procedures. Based on this, participants would have performed better by randomly selecting their exposure estimate choice for nuclear medicine procedures in the studies by Luk et al[22] and Thomas et al.[26] Participants probably would have had more correct answers had they randomly selected their exposure estimate choice for CT procedures in studies by Quinn et al,[18] Thomas et al,[26] and Zhou et al.[27] This poorer-than-random result outcome was not the case for all studies offering choices; therefore, an overarching conclusion regarding the poorer-than-random result outcome cannot be made. However, in the studies demonstrating this phenomenon, underestimations for the same procedures ranged from 44% to 99%, suggesting a stronger tendency toward underestimating patient radiation and obviously subduing the random influence in the estimation process.

Many of these studies used the effective dose equivalent of a chest radiograph as a standard for participants to estimate patient radiation exposure levels for procedures. However, there was disagreement with defining the amount of radiation exposure a patient receives from a typical chest radiograph. In addition, the answers varied so much between studies and groups within a study that it was unclear that directly estimating the doses in millisieverts, either by error margin or choice selection, produced better or worse results than using chest radiograph equivalents.

The quality of the review studies could have been limited by their cross-sectional design and lack of resources to fully exercise measures, such as randomization and blinding, to avoid bias risk. Some studies were more forthright than others with information. Most studies did not disclose frequencies, and some did not provide actual percentages (these had to be interpolated from graphs). These restrictions might have been because of editing constraints encountered through the studies' respective publications. A chief concern that appeared in multiple studies was the inability to restrict participants from seeking information to assist in answering the survey or questionnaire. This situation is inherent with surveys distributed by e-mail or postal mail. Conversely, face-to-face interviewing poses the risk of interviewer bias, and for this review, none of the studies gave sufficient detail as to the personnel conducting the interviews or any training they might have received to avoid bias.

During the hand search through the literature for this review, it was apparent that many were addressing this topic, and the presumption expressed was that more scrutiny be used in prescribing and performing these procedures. For example, the Image Gently campaign is a direct response of the radiologic imaging community to encourage increased awareness of the need to reduce radiation exposure from CT scans to pediatric patients.[33] This could imply that those in leadership roles in the United States are aware that not enough care has been applied in justifying the risks vs benefits of such procedures. Thus, the relative lack of U.S. studies that assess physician awareness of patient radiation exposure would not be a surprise to them. However, there could be other explanations, perhaps deserving further research, for the relative paucity of similar studies conducted in the United States.

Efforts were made to follow as close as possible the guidelines set forth by the *Cochrane Handbook* and the PRISMA statement for systematic reviews, but many recommendations could not be followed because of limited resources. For example, this review was never registered with the Cochrane Library as required of a true Cochrane Systematic Review. In addition, the review was conducted principally by 1 investigator within a shorter time frame than recommended for a systematic review. With a single researcher, this review carries a high risk of researcher and perhaps selection bias. Ideally, as part of this review, volunteers or other researchers should have followed the same search strategy to see if they obtained similar results. Also, some of the decisions regarding databases and the stopping point for Google Scholar searches were substantially arbitrary. The decision to include gray literature, such as unpublished dissertations or conference proceedings, was discussed with an advising systematic review specialist, but the principle investigator decided against this, again because of limited resources.

Conclusion

This systematic review suggests a worldwide knowledge deficit among physicians and physician trainees regarding patient exposure to ionizing radiation from nuclear medicine procedures. Based on same-study comparisons, this lack of knowledge seems consistent with physician and physician trainee knowledge of patient exposure from CT procedures, which was identified in the systematic review by Krille et al.[11] Because physicians order such procedures for their patients, their tendency to underestimate patient exposures — and the cancer risk from them — could be a contributing factor in the overall increase in public radiation exposure over the past few decades, particularly as nuclear medicine myocardial perfusion imaging and CT became more available over the same period.

To reduce radiation exposure to the population, those ordering these procedures need to be more aware of the radiation exposure levels these procedures deliver to patients as well as the resulting effect on public health. More research must be conducted regarding improving physician and other health care personnel awareness of the health risk these procedures pose, as well as finding more knowledgeable ways to weigh the benefits of these procedures against their risks. This might involve formulating new algorithms to aid in the physician's decision process in authorizing ionizing radiation for diagnostic purposes. Although most procedures appearing in the articles included in this review do not require the informed consent of patients, there is an ethical obligation to reasonably inform patients of risks involved with procedures.[34] Enhancing an atmosphere of professional conscientiousness concerning patient radiation exposure among all health care providers — referring physicians, nuclear medicine physicians, and nuclear medicine technologists — also could result in reduced exposure rates to the public.

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