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Exposure to Low-Dose Ionizing Radiation from Medical Imaging Procedures in the United States

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Abstract

Background—Growing use of imaging procedures in the United States has raised concerns about exposure to low-dose ionizing radiation in the general population.

Methods—We identified 952,420 non-elderly adults in 5 healthcare markets across the United States between July 1, 2005 and December 31, 2007. Utilization data were used to determine cumulative effective doses of radiation from imaging procedures in millisieverts (mSv) and to calculate population-based rates of “moderate” (>3 to 20 mSv per year), “high” (>20 to 50 mSv per year) and “very-high” (>50 mSv per year) doses.

Results—During the study period, 655,613 (68.8%) individuals underwent at least 1 imaging procedure associated with radiation exposure. The mean effective dose from imaging procedures was 2.4 mSv per person per year (std dev, 6.0 mSv); however, a wide distribution was noted with a median effective dose of 0.1 mSv per person per year (interquartile range, 0.0 to 1.7). Overall, the annual rate for moderate effective doses in the study population was 193.8 per 1000 enrollees, while high and very-high doses occurred at annual rates of 18.6 per 1000 enrollees and 1.9 per 1000 enrollees, respectively. In general, effective doses of radiation from imaging procedures increased with advancing age and were higher in women. Computed tomography and nuclear

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medicine scans accounted for 75.4% of the total effective dose and 81.8% occurred in non-hospitalized settings.

Conclusions—Imaging procedures are an important source of ionizing radiation in the United States and can lead to high radiation doses in patients.

Experimental and epidemiological evidence has linked exposure to low-dose, ionizing radiation with the development of solid cancers and leukemia.[1] As a result, individuals at-risk for repeated radiation exposure, such as healthcare and nuclear industry workers, are typically monitored and restricted to effective doses of 100 millisieverts (mSv) every 5 years (i.e., 20 mSv per year) with a maximum of 50 mSv allowed in any given year.[2, 3] In contrast, radiation exposures among patients related to medical imaging procedures are not typically monitored and patient data on longitudinal radiation exposure from them are scant, although in clinical practice these procedures are frequently repeated or clustered together within the same individual.

Accordingly, we used recent data on utilization from five healthcare markets across the United States to estimate the total effective dose of radiation from medical imaging procedures in a large, non-elderly adult population. In addition to determining cumulative effective dose by age and gender, these data presented a unique opportunity to expand on earlier work by calculating population-based rates of moderate, high, and very-high doses from imaging procedures and describing the types and locations of these procedures among non-elderly adults – in whom the long-term risks of radiation exposure are most relevant. Our findings have important implications for the general population's health given the growing use of imaging procedures.[4, 5]

Methods

Data Sources and Study Population

We conducted an investigator-initiated, retrospective cohort study using claims data from United Healthcare, a large healthcare organization that insures and/or administers medical benefits for over 26 million individuals across the United States. We focused on 5 healthcare markets: Dallas, Orlando, South Florida, Arizona, and Wisconsin. From these markets, all individuals between the ages of 18 and <65 who were alive *and* continuously enrolled in its programs between January 1, 2005 and December 31, 2007 were identified.

After removing all personal identifiers, data were provided to us for independent statistical analysis. No external funds were provided for this study. The Institutional Review Board of the University of Michigan evaluated this study prior to its initiation and determined it to be exempt from further review.

Data Elements

All claims from hospitals, outpatient facilities and physician offices submitted during the study period above were queried for Current Procedural Terminology (CPT)-4 codes that identified imaging procedures with radiation exposure (under Radiology Schedule – Diagnostic Imaging and Nuclear Medicine: 70010 through 76499 and 78000 through 79999; and under Medicine Schedule – Cardiovascular and Non-invasive Vascular Diagnostic Studies: 92950 through 93799 and 93875 through 94005), regardless of whether it was performed for diagnostic or therapeutic indications like fluoroscopy for interventional cardiovascular or radiological procedures.[6] However, all procedures in which radiation was specifically delivered for a therapeutic purpose (e.g., high-dose radiation therapy for breast cancer) were excluded. In cases where the CPT code designation for a procedure changed during the study period, all versions of the procedure codes were included.

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For the analysis, we obtained information from each claim on the patient's: (1) age, (2) gender, (3) home address Zip code, and (4) the location of service. We then categorized procedures into mutually exclusive categories based on the technology (plain radiography, CT scans, fluoroscopy [including angiography], and nuclear medicine scans) and anatomic area of focus (chest [including cardiac imaging], abdomen, pelvis, extremity, head and neck [including brain imaging], multiple areas [including whole body scans], and non-specified). We considered the potential of over-estimating radiation dose from procedures that could overlap when performed during the same setting. For example, a patient who underwent coronary stent placement in addition to left heart catheterization would have 2 claims made separately for each procedure even if both were done during the same setting. To address this issue, we limited individuals to 1 procedure per day that used the same type of technology (e.g., fluoroscopy) and was performed on the same anatomic area (e.g., chest), taking the highest dose when applicable.

We excluded claims with the non-specific CPT code 76499 for “unlisted radiographic procedure”, since we could not link it to a particular type of technology associated with ionizing radiation. In contrast, for the rare instances when we identified non-specific CPT codes related to CT scans (e.g., CPT 76497, “unlisted CT procedure”; n=159 [0.0024%]), fluoroscopy (eg, CPT 76496, “unlisted fluoroscopy procedure”; n=25 [0.0004%]), and nuclear medicine scans (eg, CPT 78499, “unlisted cardiovascular diagnostic nuclear medicine procedure”; n=14 [0.0002%]), we used the lowest dose reported in each category.

Estimates of Radiation Dose

To approximate radiation exposure for each imaging procedure, we obtained estimates from published literature based on *effective dose*, assessed in millisieverts (mSv). Effective dose is a quantity designed to represent the overall detrimental biological effect of a radiation exposure. It is calculated by weighting the concentrations of energy deposited in each organ from a radiation exposure using parameters that reflect the type of radiation and the potential for radiation-related mutagenic changes in each organ in a reference individual.[7, 8] Thus, it allows for useful population-level comparisons across different types of radiation exposure.[2, 9] For common procedures, we relied primarily on data summarized in a recent review.[10] In instances where this source was insufficient, we obtained estimates from other published literature or extrapolated from doses reported for similar procedures.[11-17]

Study Oversight

This study was investigator-initiated and the authors were responsible for its design and wrote the manuscript. No external funding was provided for this study and there was no need to gain approval from UnitedHealthcare prior to its submission for publication. The authors had complete control of the data and Mr. Wang conducted the analysis.

Statistical Analysis

Procedural frequencies and cumulative radiation exposures were calculated for the entire study population over the 3-year study period. Patients were then categorized based on their age at the beginning of the study period (≥18 to 34, 35 to 39, 40 to 44, 45 to 49, 50 to 54, 55 to 59, and 60 to <65) and gender. We calculated population-based rates of low, moderate, high and very-high effective doses in the study population and for each age and gender group based on the following thresholds: ≤3 mSv per year (background level of radiation from natural sources in the United States),[18] >3 to 20 mSv per year (upper annual limit for occupational exposure for at-risk workers averaged over 5 years),[2] >20 to 50 mSv per year (upper annual limit for occupational exposure for at-risk workers in any given year),[2] and >50 mSv per year. Numerators for rates were the number of individuals with cumulative effective doses within these thresholds while denominators included the total number of

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eligible individuals enrolled throughout the study period. All statistical analyses were carried out with the use of SAS software, version 9.1 (SAS Institute Inc., NC), and STATA software, version 10 (College Station, TX).

Results

We identified 952,420 individuals in our study population. Mean age was 35.6 (std dev, 23.0) and 499,342 (52.4%) were women. The largest proportion of individuals was located in the Dallas market area (298,747 [31.4%]), while the smallest proportion came from the Orlando market area (133,561 [14.0%]). During the 3-year study period, we identified a total of 3,442,111 imaging procedures associated with radiation exposure performed in 655,613 (68.8%) patients, resulting in an overall mean use of 1.2 procedures per person per year (std dev, 1.8) and median use of 0.7 procedures per person per year (interquartile range, 0.0 to 1.7; 95th percentile, 4.3).

The mean effective dose was 2.4 mSv per person per year (std dev, 6.0) and median effective dose was 0.1 mSv per person per year (interquartile range, 0.0 to 1.7; 95th percentile, 12.3). The proportion of individuals undergoing these procedures and their mean doses varied by age, gender and market. For example, the proportion of individuals undergoing at least 1 procedure during the study period was higher in older age groups, rising from 49.5% of those aged 18 to 34 to 85.9% of those aged 60 to 64. We also found that women underwent procedures significantly more often than men with a total of 78.7% of women undergoing at least 1 procedure during the study period as compared with 57.9% of men. These findings are summarized in Table 1.

Table 2 displays the rates of moderate, high and very-high doses in the study population. The annual rate for moderate doses was 193.8 per 1000 enrollees, while the annual rate for high and very-high doses were 18.6 per 1000 enrollees and 1.9 per 1000 enrollees, respectively. Each of these rates rose with advancing age. For example, the annual rate for high doses increased from 4.9 per 1000 enrollees in those aged 18 to 34 to 52.7 per 1000 enrollees in those aged 60 to 64. When stratified by gender, rates for moderate doses were higher in women up to the age of 60. Similarly, women were more likely to have higher rates of high and very-high doses in younger age groups up to the age of 50. Figure 1 displays the overall distribution of radiation doses in the study population, stratified by gender.

Table 3 displays the 20 procedures with the largest contribution to total radiation dose in the study population. Myocardial perfusion imaging alone was responsible for over 22% of the total effective dose while CT scans of the abdomen, pelvis and chest were responsible for approximately another 38%. CT scans accounted for 16.1% of the total number of procedures and 49.2% of the total dose. In contrast, procedures related to plain radiography were responsible for 71.4% of the total number performed, but only 10.6% of the total radiation dose. When examined by site, procedures of the chest were responsible for 45.3% of the total radiation dose. Finally, over 81.8% of the total radiation dose from procedures occurred in non-hospitalized settings, most commonly in physician offices.

Discussion

In this study, we report estimates of cumulative effective doses of radiation from medical imaging procedures in nearly 1 million non-elderly adults across the United States. Approximately 70% of this study population underwent at least 1 of these procedures during the 3-year period, resulting in mean effective doses that almost doubled what would be expected from natural sources. While most received less than 3 mSv per year, moderate,

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high and very-high effective doses were observed in a sizeable minority – especially if one considers how frequently these procedures are performed. For example, generalizing our findings to the non-elderly adult population of the United States suggests that these procedures lead to cumulative effective doses that exceed 20 mSv per year in approximately 4 million Americans.

Our finding that worrisome radiation doses from imaging procedures can accumulate over time in some individuals emphasizes the need to improve their use. In contrast to occupational exposures to radiation, restricting doses for patients undergoing procedures may not be possible.[2, 21] This is largely due to the inherent difficulty in balancing the immediate clinical necessity for these procedures, which is frequently substantial, against stochastic risks of cancer that will not be evident for years, if at all. Prior recommendations related to medical exposures therefore have focused on justifying the clinical need for a procedure and optimizing their use to ensure exposure is *as low as reasonably achievable* (ALARA) without sacrificing quality of care.[22, 23]

By necessity, such approaches rely on healthcare providers to recognize and inform patients about risks of radiation, an area of potential concern.[24-26] In one study of providers in the United States caring for patients undergoing CT scans for abdominal and flank pain, less than half of radiologists and only 9% of emergency department physicians reported even being aware that CT scans were associated with an increased cancer risk.[27] An improved understanding of radiation risks is clearly needed and raising such awareness among providers has been the focus of recent efforts.[28, 29] With technological advances, estimation of patient-specific doses and their inclusion in the medical record to inform individuals at-risk for high cumulative dose may also become feasible.

The National Council on Radiation Protection recently reported a nearly six-fold increase in per capita radiation dose from medical imaging in the U.S. since the early 1980s.[30, 31] Several unique aspects of our study complement these data. First, we described rates of moderate, high and very-high annual effective doses, not simply the overall population average. This is important since many of these procedures are frequently repeated or may cluster together in the same individual. Second, we focused on non-elderly adults, in whom growing utilization of imaging procedures is a great concern and for whom the long-term risks of radiation are most relevant.[32] For similar reasons, we also only included those who remained alive throughout the study period. This excluded patients who may have undergone multiple procedures near the time of death – when healthcare utilization could rise,[33] but is not germane for discussions about long-term risks.

Several of our findings deserve further mention. We found higher cumulative effective doses more frequently with advancing age and in women. However, we should emphasize that while younger individuals were less likely to receive large cumulative effective doses, rates for high and very-high doses were not trivial in these groups. In fact, over 30% of men and 40% of women in this study population who received doses exceeding 20 mSv per year were under the age of 50. Understanding the age and gender distribution of effective doses from imaging procedures is critical because its risks accrue over a lifetime[33] and women may have a higher likelihood of developing cancer following similar levels of exposure.[34] Finally, we found that the largest contribution to total effective doses was from CT and nuclear medicine scans and that most radiation exposure occurred in non-hospitalized settings.

This study should be interpreted in the context of the following limitations. First and most importantly, we used claims data. While this allowed us to comprehensively examine the utilization of imaging procedures, it did not allow us to evaluate their appropriateness. A

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large reason for their growing use stems from their ability to radically improve the care of patients. While others have raised concerns that imaging procedures may be over-utilized,[35] this cannot be directly determined from our data. Use of claims data also prevented us from including procedures that were not covered (e.g., dental radiography), which implies an underestimation of rates.

Second, we did not directly assess measures of radiation dose specific to the patients studied, but instead relied on estimates of effective doses, which are neither precisely measured nor patient-specific. Rather, effective dose is a calculated estimate designed not to provide a dose for a specific individual but that for a gender-averaged reference individual under a given exposure situation.[2] It relies on assumptions regarding the radiation sensitivity of organs and tissues, imaging technique and protocols, and, in the case of nuclear medicine scans, radiopharmaceutical activity, half-life, distribution, and elimination kinetics.[29] Although these assumptions have raised controversy regarding the use of effective dose,[36] it remains the only parameter currently available that reflects an overall measure of potential biological detriment across different types of radiation exposure,[37, 38] which is why we used it as our primary metric.

A specific limitation in regards to our use of effective dose is that it was originally designed for use in a population with age and sex distribution similar to that of a reference population of all ages and both sexes, given that risks of stochastic effects of ionizing radiation are dependent on age and sex.[9] As such, our characterization of the effective dose of patient subgroups (e.g. 18-34 year old women) represents an application of this quantity beyond its formal definition.

Third, doses received from these procedures are likely to vary across, and even within, institutions[39] – particularly for studies like CT and fluoroscopy that can differ substantially in equipment, protocols and length of time – and ongoing technological advances continue to lower doses.[40, 41] Finally, this study population was restricted to 5 healthcare markets and those with insurance. Although we included nearly 1 million non-elderly adults, the extent to which our findings can be extrapolated to broader populations or the uninsured is unknown.

In conclusion, our findings indicate that the pattern of medical imaging in the United States among the non-elderly is resulting in substantial exposures to ionizing radiation for many individuals. Developing new approaches to optimize and ensure appropriate use of these procedures in the general population should be encouraged.

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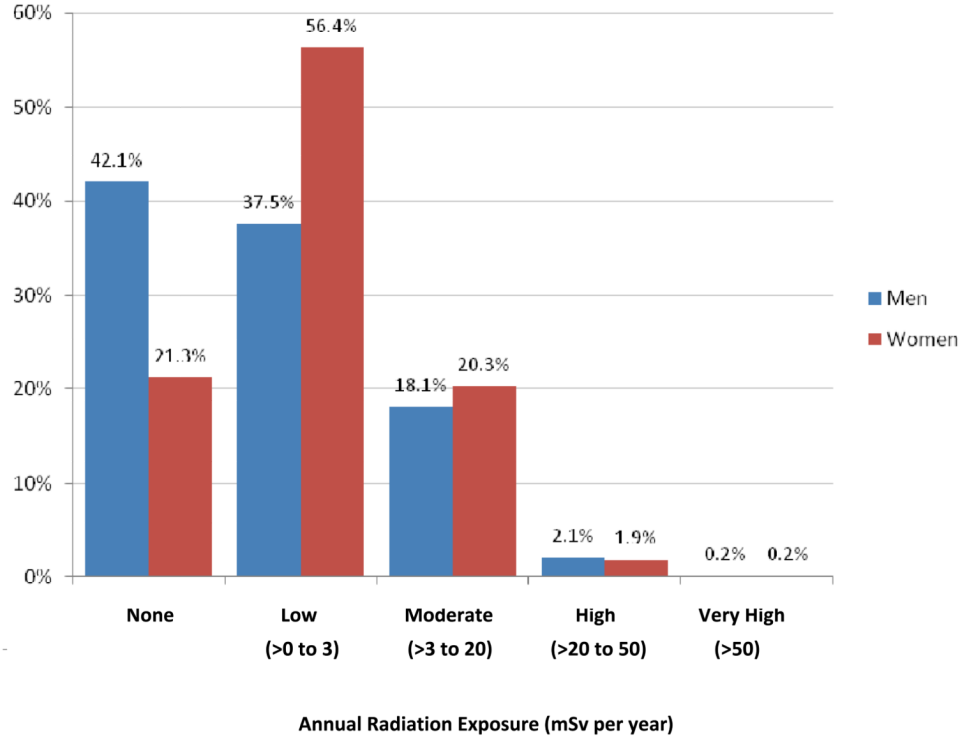

Figure 1. Distribution of Annual Radiation Exposure in Men and Women

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Table 1

Effective Doses of Radiation from Medical Imaging Procedures

	Overall Study Population	Individuals With 1 or More Imaging Procedures Using Ionizing Radiation		Annual Effective Dose from Medical Imaging Procedures (mSv)			
	No	*No.*	*(%)*	Mean (±SD)		Median (IQR)	
All individuals	952420	655613	(68.8)	2.4	(±6.0)	0.1	(0.0 - 1.7)
Age groups							
18-34	233586	115696	(49.5)	1.0	(±3.5)	0.0	(0.0 - 0.4)
35-39	118365	77746	(65.7)	1.6	(±4.5)	0.1	(0.0 - 0.8)
40-44	144728	104398	(72.1)	2.0	(±5.1)	0.2	(0.0 - 1.2)
45-49	146703	109827	(74.9)	2.6	(±6.0)	0.3	(0.0 - 2.3)
50-54	131209	102559	(78.2)	3.3	(±6.9)	0.4	(0.0 - 4.7)
55-59	115520	91870	(79.5)	4.1	(±7.9)	0.5	(0.0 - 5.3)
60-64	62309	53517	(85.9)	5.2	(±9.1)	0.9	(0.1 - 6.4)
Gender							
Men	453078	262552	(57.9)	2.3	(±6.1)	0.0	(0.0 - 1.2)
Women	499342	393061	(78.7)	2.6	(±5.9)	0.3	(0.0 - 2.2)
Age groups, men							
18-34	110062	49747	(45.2)	0.9	(±3.2)	0.0	(0.0 - 0.1)
35-39	56636	30547	(53.9)	1.3	(±3.9)	0.0	(0.0 - 0.5)
40-44	69178	39265	(56.8)	1.8	(±4.7)	0.0	(0.0 - 0.7)
45-49	70141	42207	(60.2)	2.3	(±6.0)	0.0	(0.0 - 1.5)
50-54	61426	39808	(64.8)	3.1	(±7.0)	0.0	(0.0 - 4.7)
55-59	54407	37207	(68.4)	4.2	(±8.4)	0.1	(0.0 - 5.2)
60-64	31228	23771	(76.1)	5.5	(±9.7)	0.7	(0.0 - 7.1)
Age groups, women							
18-34	123524	65949	(53.4)	1.2	(±3.8)	0.0	(0.0 - 0.5)
35-39	61729	47199	(76.5)	1.8	(±4.9)	0.2	(0.0 - 1.0)
40-44	75550	65133	(86.2)	2.3	(±5.5)	0.4	(0.1 - 1.7)
45-49	76562	67620	(88.3)	2.8	(±6.1)	0.4	(0.1 - 2.8)
50-54	69783	62751	(89.9)	3.4	(±6.7)	0.5	(0.2 - 4.9)
55-59	61113	54663	(89.4)	3.9	(±7.3)	0.7	(0.3 - 5.4)

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	Overall Study Population	Individuals With 1 or More Imaging Procedures Using Ionizing Radiation		Annual Effective Dose from Medical Imaging Procedures (mSv)			
	No	*No.*	*(%)*	Mean (±SD)		Median (IQR)	
60-64	31081	29746	(95.7)	4.9	(±8.3)	1.0	(0.3 - 6.1)
Markets							
Arizona	180050	127106	(70.6)	2.5	(±6.0)	0.2	(0.0 - 1.9)
Dallas	298747	204953	(68.6)	2.3	(±6.0)	0.1	(0.0 – 1.3)
Orlando	133561	90206	(67.5)	2.8	(±6.5)	0.2	(0.0 – 2.8)
South Florida	170466	124261	(72.9)	2.8	(±6.2)	0.3	(0.0 – 3.4)
Wisconsin	169600	109087	(64.3)	2.0	(±5.3)	0.1	(0.0 – 0.9)

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Table 2

Rates of Low, Moderate, High and Very High Annual Effective Doses From Medical Imaging Procedures

	Rates of Low, Moderate, High, and Very High Annual Effective Doses per 1000			
	Low ≤3 mSv/year	**Moderate >3 to 20 mSv/year**	**High >20 to 50 mSv/year**	**Very High >50 mSv/year**
All individuals	785.7	193.8	18.6	1.9
Age groups				
18-34	895.9	98.7	4.9	0.5
35-39	845.5	145.2	8.5	0.8
40-44	809.3	177.5	12.0	1.2
45-49	770.4	209.2	18.4	2.0
50-54	719.0	252.2	26.2	2.7
55-59	668.4	289.7	38.4	3.5
60-64	598.2	343.4	52.7	5.7
Gender				
Men	796.0	182.8	19.4	1.8
Women	776.4	203.8	17.9	1.9
Age groups, men				
18-34	912.2	83.4	3.9	0.4
35-39	860.1	133.1	6.3	0.6
40-44	826.2	161.9	11.1	0.8
45-49	786.3	194.1	17.8	1.8
50-54	728.0	242.0	27.3	2.7
55-59	664.7	287.2	44.1	4.0
60-64	587.0	346.0	60.6	6.4
Age groups, women				
18-34	881.4	112.4	5.7	0.6
35-39	832.1	156.3	10.6	1.0
40-44	793.8	191.8	12.8	1.6
45-49	755.8	223.0	19.0	2.1
50-54	711.1	261.1	25.1	2.7
55-59	671.7	292.0	33.2	3.1
60-64	609.4	340.9	44.8	4.9
Markets *				
Arizona	853.7	132.3	12.8	1.1
Dallas	860.7	125.2	12.7	1.4
Orlando	836.8	147.6	14.4	1.2
South Florida	814.9	168.5	15.4	1.2
Wisconsin	884.1	105.6	9.4	0.9

*Annual rates reported in markets are age- and gender-adjusted by direct standardization using the entire study population as a reference

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Table 3

Procedures with the Largest Contributions to Radiation Exposure in the Study Population[a]

Procedure	Average Effective Dose (mSv)	Annual Effective Dose (mSv) per person	Proportion of Overall Effective Dose From Medical Imaging Procedures
1. Myocardial perfusion imaging	15.6[b]	0.540	22.1%
2. Computed tomography (CT) of the abdomen	8	0.446	18.3%
3. CT of the pelvis	6	0.297	12.2%
4. CT of the chest	7	0.184	7.5%
5. Diagnostic cardiac catheterization	7	0.113	4.6%
6. X-ray of the lumbar spine	1.5	0.080	3.3%
7. Mammography	0.4	0.076	3.1%
8. CT angiography of the chest (non-coronary)	15	0.075	3.1%
9. Upper GI series	6	0.058	2.4%
10. CT of the head/brain	2	0.049	2.0%
11. Percutaneous coronary intervention	15	0.043	1.8%
12. Bone scan (nuclear)	6.3	0.035	1.4%
13. X-ray of the abdomen	0.7	0.028	1.1%
14. CT of the cervical spine	6	0.020	0.8%
15. CT of the lumbar spine	6	0.018	0.7%
16. Chest x-ray	0.02[c]	0.016	0.7%
17. Thyroid uptake scan	1.9	0.016	0.7%
18. Intravenous urography	3	0.014	0.6%
19. CT of the neck	3	0.014	0.6%
20. Cardiac resting ventriculography	7.8	0.014	0.6%

[c]Average effective doses for these imaging procedures are based on estimates published by Mettler et al.[10]

[b]Calculation of the average dose for single photon emission computed tomography (SPECT) myocardial perfusion imaging also relied on dose coefficients from a more detailed review of radiation dosimetry of specific cardiac radiopharmaceuticals,[17] median injected activities from the American Society of Nuclear Cardiology (ASNC) guidelines,[19] as well as recently reported distributions of use of various protocols in the United States.[20]

[c]Effective dose for a posteroanterior study of the chest