HHS Public Access

Author manuscript

Radiology. Author manuscript; available in PMC 2024 April 01.

Published in final edited form as:

Radiology. 2023 April ; 307(1): e221263. doi:10.1148/radiol.221263.

Patient Exposure from Radiologic and Nuclear Medicine Procedures in the United States and Worldwide: 2009–2018

Mahadevappa Mahesh, MS, PhD,
Russell H. Morgan Department of Radiology and Radiological Science, The Johns Hopkins University School of Medicine, 601 N Caroline St, Baltimore, MD 21287-0856

Armin J. Ansari, PhD,
Radiation Studies Section, U.S. Centers for Disease Control and Prevention, Atlanta, Ga

Fred A. Mettler Jr, MD
Department of Radiology, University of New Mexico, Albuquerque NM

Abstract

The U.S. National Council on Radiation Protection and Measurements (NCRP) conducted a retrospective assessment of the U.S. data, and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) performed a similar worldwide assessment for 2009–2018 (with most data from 2014 to 2017). Using the data from those reports, the frequency of radiologic and nuclear medicine studies, annual collective, and per capita effective dose in the United States for 2016 were compared with worldwide estimates from 2009 to 2018. There were an estimated 691 million radiologic, CT, dental, and nuclear medicine studies performed in the United States in 2016, which represented 16.5% of the 4.2 billion performed worldwide. The United States also accounted for 74 million CT procedures (18% of the world's estimated total), 275 million conventional radiology procedures (11% of the world's total), 8.1 million interventional radiologic procedures (34% of the world's total), 320 million dental radiography procedures (29% of the world's total), and 13.5 million nuclear medicine procedures (34% of the world's total). The U.S. collective effective dose was 717 000 person-sieverts (17.6% of the world's total). The average annual individual effective dose in the United States was 2.2 mSv compared with 0.56 mSv worldwide. The United States accounts for a large and disproportionate share of global medical radiation procedures and collective effective dose, but use of CT has increased more in other countries compared with the United States.

Summary

Address correspondence to M.M. (mmahesh@jhmi.edu and mmahesh@mmahesh1).

Author contributions: Guarantors of integrity of entire study, all authors; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; agrees to ensure any questions related to the work are appropriately resolved, all authors; literature research, all authors; and manuscript editing, all authors

Disclosures of conflicts of interest: M.M. Board member, chair of Physics Commission at the American College of Radiology. **A.J.A.** No relevant relationships. **F.A.M.** Travel expenses from the National Council on Radiation Protection; lecture fees from the Society on Birth Defects.

There are no conflicts of interest nor industry support. The findings, conclusions, or statements in this manuscript are those of the authors and do not necessarily represent the official position of the U.S. Centers for Disease Control and Prevention.

The United States accounts for a large and disproportionate share of global medical radiation procedures and collective effective dose, but use of CT increased more in other countries than in the United States.

Sources of radiation exposure to the U.S. population are derived from five broad categories: ubiquitous back-ground radiation (including radon); medical procedures in patients; consumer products or activities involving radiation sources; industrial, security, medical, educational, and research radiation sources; and occupational sources in specific categories of workers. Whereas radiation exposures from medical procedures in patients constitute a substantial fraction of total population exposures, comprehensive assessments of the frequency and associated doses from radiology and nuclear medicine procedures are conducted only rarely.

In 2017, the U.S. National Council on Radiation Protection and Measurements (NCRP) convened a committee to reassess medical exposures; determine the changes that occurred in trends, frequency, and doses as well as the associated uncertainties resulting from radiologic, dental, and nuclear medicine exposure of patients; and produce a comprehensive report on the subject (1). The previous comprehensive estimate of the uses of medical radiation in the United States was performed more than 10 years ago and was published in 2009 by the NCRP in its Report 160 (2). The United Nations (UN) Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) recently published a similar report using data obtained from the literature and a global survey of UN Member States (3).

The last comprehensive estimate of uses of medical radiation in the United States compared with the worldwide estimate was performed more than 10 years ago and published in 2009 by Mettler et al (4). That analysis showed that the United States accounted for a disproportionally large percentage of worldwide radiologic and nuclear medicine procedures.

In our report, we compare highlights from the 2019 NCRP Report 184 on Medical Radiation Exposure of Patients in the United States (1,5) with those from the UNSCEAR survey (3). The information has many potential uses, including following and possibly predicting trends, observing the effects of health planning policies, and comparing radiation doses from various practices. Specifically excluded from both the NCRP and UNSCEAR reports were discussions about occupational doses and estimation of potential benefits or risks associated with medical exposure. Furthermore, both the NCRP and UNSCEAR reports represent population averages and do not address the distribution of medical exposures or any sources of disparity in access to such medical services. Therefore, the goal of our report is to compare the frequency of radiologic and nuclear medicine studies, annual collective, and per capita effective dose in the United States for 2016 with worldwide estimates from 2009 to 2018.

Background

We compared two extensive and detailed reports that analyzed the frequency and radiation doses from medical radiation patient exposure in the United States and worldwide: the

NCRP Report 184 (1,4) and the 2022 UNSCEAR report (3). We estimated several metrics from these reports. In particular, the per capita effective dose per 1000 people is a calculated dose based on the type of radiation and the detriment (primarily cancer risk) to tissues exposed. This quantity allows a comparison of the magnitude of medical radiation exposure to that from various nonmedical radiation sources. The collective effective dose is the number of procedures multiplied by the effective dose per procedure. The annual average individual effective dose is the collective effective dose divided by the total population, whether the persons were exposed or not.

Data regarding medical radiation use and radiation doses in the United States were gathered from more than 150 scientific publications, Medicare data, commercial surveys, and professional organizations. Estimates were provided for the year 2016 for the general categories of conventional projection radiography, CT, cardiac interventional, noncardiac interventional, nuclear medicine, dental, and radiation oncology. Uncertainties are the result of estimation of procedure numbers and effective dose per procedure. Other factors leading to uncertainties include but are not limited to survey design, data collection methods, extrapolations, dosimetry, and systemic or random errors. Uncertainties were presented in the NCRP report (1) as subjective uncertainty intervals and characterized as low (<30%), medium (30%–90%), or high (≥90%).

UNSCEAR conducted periodic assessments regarding radiation sources worldwide including medical radiation. These assessments appeared in reports to the UN General Assembly in 1988 (6), 1993 (7), 2000 (8), and 2008 (9–11). Detailed data were obtained from many UN Member States and other national and international organizations, and from the published literature. In previous reports, for countries in which no data were available, extrapolation was performed using population-weighted average frequencies for procedures and effective dose per procedure in a model with four discrete levels of health care on the basis of the number of physicians per 1000 people in each level of health care. Details from the UNSCEAR report (3) are in Appendix E1 (online).

Collective and per capita effective doses were calculated in both reports. Effective dose is a robust measure of detriment and calculation requires the use of tissue weighting factor. The International Commission on Radiological Protection (ICRP) described tissue weighting factors in 1990 (12) and redefined them in 2007 (13). NCRP Report 184 estimated effective doses using both sets of tissue weighting factors. The UNSCEAR report used ICRP 60 (12) factors for most tables where specific procedures were assessed. However, for the overall categories, ICRP 103 (13) collective dose was also estimated. The ICRP publication 103 values were used for our comparison because they are used currently and would likely be the baseline for future studies. Both NCRP and UNSCEAR showed that for overall estimates, the use of one versus the other set of tissue weighting factors only resulted in a difference in the collective effective dose of less than a few percent.

Data from United States and Worldwide Regarding the Frequency of Procedures and Collective and Per Capita Doses

The results of the global survey expressed in percentages of frequency of examinations or procedures and the collective doses for various modalities worldwide are shown in Figure 1. An estimated total of 691 million radiologic, CT, dental, and nuclear medicine examinations were performed in the United States in 2016, which represented about 16.5% of the 4.2 billion examinations performed worldwide. The United States also accounted for 74 million CT procedures (18% of the world's estimated total), 275 million conventional radiology procedures (11% of the world total), 8.1 million interventional radiologic procedures (34% of the world total), 320 million dental radiographic examinations (29% of the world total), and 13.5 million nuclear medicine procedures (34% of the world's total). The annual collective effective dose was 717 000 person-sieverts (17.6% of the world total). The annual average individual effective dose computed using both ICRP 60 (12) and ICRP 103 (13) weighting factors for both U.S. and worldwide data are shown in Table 1. Overall, the annual average individual effective dose in the United States was 2.2 mSv compared with 0.56 mSv worldwide. A comparison of procedures per 1000 people and annual average individual effective dose for various categories between global data and the United States are shown in Figure 2.

Trends in the global use of medical radiologic and nuclear medicine have been summarized in the UNSCEAR 2022 Report (3) and are shown in Table 2. Although the world population increased substantially from the 1980s to 2006 (UNSCEAR 2008), the increase in use of medical radiologic and nuclear medicine during that time increased even faster, as evidenced by the increase in annual frequency per 1000 people over the same time. The global annual per capita effective dose had increased from 0.33 to 0.65 mSv. Since 2006, the usage rate slowed, with annual frequency remaining essentially the same per 1000 people, and whereas the number of total procedures has increased, the annual collective dose has decreased.

Conventional Projection Radiography

NCRP publication 184 (1,4) revealed major shifts in the frequency of some conventional radiographic examinations in the United States. Since the 2010s, radiographic intravenous urography had been almost completely replaced by CT and MR urography. Fluoroscopic examinations of the gastrointestinal tract declined substantially, likely because of replacement with fiberoptic procedures.

In 2006 there were an estimated 281 million radiographic and diagnostic fluoroscopic procedures in the United States. This decreased to approximately 275 million in 2016 even though the population increased from approximately 300 to approximately 323 million. There was an incremental decrease in chest, abdomen and pelvis, and urologic radiography, and an increase in hip and extremity radiographic and mammographic examinations.

In the United States and worldwide since 2006, there were fundamental changes in the type of image receptors used, with essentially complete replacement of screen-film units by digital detectors. Despite this, the effective dose per procedure appears to have changed little. The decrease in procedures (particularly abdomen and pelvis) resulted in a reduction in collective effective dose calculated with ICRP 60 weighting factors, or S_{60}, from radiography and diagnostic fluoroscopy.

The UNSCEAR 2022 global estimate of conventional projection radiography use for the years 2009–2018, categorized by income level of country (Table 3), was 2626 million examinations (359 per 1000 people) or about 17% less than the 3143 million estimated for 2006 (10).

The worldwide use of conventional projection radiography, as documented in the UNSCEAR global survey (3), mirrors the same changes observed in the United States over the last decade (1,5). The total number of procedures has decreased slightly despite an increasing population, mammography has increased, and gastrointestinal fluoroscopy and intravenous urography have declined.

Use of CT

In the United States, CT grew very rapidly beginning in the mid-1970s. By 1998 there were an estimated 26 million procedures and, with the introduction of multidetector CT, by 2006 the number of CT procedures increased to 62 million (2), peaking at 85 million in 2010. After this, the trend leveled off at approximately 74 million through 2016. In 2016, there were an estimated 230 CT procedures per 1000 people, with the largest categories for abdomen and pelvis (20.1 million procedures), brain (15.3 million), and chest (12.7 million) (1,5) (Table 4).

The UNSCEAR 2022 global estimate of CT use for the years 2009–2018, categorized by income level of country (Table 3), was 403 million examinations (55 per 1000 people) or almost double that compared with the 220 million estimated for 2006 (3). In terms of frequency, head CT (skull and facial bones and soft tissue and brain altogether) made the highest contribution (26.3%) followed by chest CT (12.2%) and abdominal CT (11.9%).

The variation of CT examinations per 1000 people between high- and low-income countries is a factor of more than 13. There is substantial variation in CT scanners per 1000 people, even among similar high-income countries. For example, among European high-income countries in 2015, the number of CT scanners per million people was at least a four-fold difference (eg, Denmark, 42; Germany, 32.8; Sweden, 24.5; and the United Kingdom, 11.6 [14]).

Data regarding use of CT can be arduous due to the ambiguity and various use of the terms “examination, procedure, and scan.” There are protocols that require multiple scan sequences per examination or procedure. This may cause uncertainty of about 10%–13% in estimated CT procedure numbers.

Nuclear Medicine

In the United States until 2005 there was rapid growth in diagnostic nuclear medicine, peaking at about 17.2 million. The number of procedures decreased substantially. From 2006 to 2016 the annual number of procedures decreased more than 20%, from approximately

17 to 13.5 million. The decrease was largely because of a sizeable decrease in cardiac studies, partially replaced with stress echocardiography and cardiac CT. There was an increase in hybrid nuclear medicine and CT examinations representing about 16% of the total procedures in 2016. PET/CT for tumor imaging increased from 1.3 million in 2006 to approximately 1.9 million in 2016, and SPECT/CT examinations were estimated to be about 315 000 in 2016. Using ICRP 1990 tissue weighting factors for both 2006 and 2016 data, the value of collective effective dose (S_{60}) from nuclear medicine decreased by 40% and the average individual effective dose from nuclear medicine decreased by 44% in the United States.

UNSCEAR derived estimates for both diagnostic nuclear medicine (Table 3) and radionuclide therapy. The global estimated annual total number of diagnostic nuclear medicine procedures was only 40 million with a frequency of 5.5 per 1000 people, whereas for the United States, the total number was about 14 million with a frequency of 42 per 1000 people. The global frequency of radionuclide therapy was estimated to have increased from 0.07 per 1000 people in the 2000 UNSCEAR report (8) to 0.14 per 1000 in the 2008 report (10) and 0.20 per 1000 in the 2022 report (3). The total number was estimated to be 1.4 million. NCRP did not estimate the number of radionuclide therapy procedures for 2016.

Interventional Radiologic Procedures

Summary estimates of interventional procedures is difficult because of fragmentary data and disparate classifications and types of procedures. Procedures range from embolization of brain aneurysms to replacement of aortic vales and even treatment of pelvic tumors. There are procedures that are initially diagnostic but then may require therapeutic intervention based on the findings. The procedures also range from low to high doses. There is uncertainty about the frequency of specific procedures and the doses.

The NCRP publication 184 (1) divided the 2016 information and estimates based on cardiac and noncardiac procedures. As of 2016, the estimated total number of interventional cardiac procedures performed in the United States in catheterization or angiography laboratories has remained at approximately 4.1 million cases annually. Many coronary diagnostic and percutaneous interventions were combined in a single procedure.

Many noncardiac interventional procedures (eg, tissue biopsy, aspiration, arthrography, and central venous catheter insertions) for which fluoroscopy was previously the main modality now use minimal or no fluoroscopic guidance, and diagnostic imaging is often performed at CT, US, or MRI. In the United States this resulted in a substantial reduction (from 12 million to 4 million) in the number of what were classified in NCRP report 160 as noncardiac interventional fluoroscopy procedures. It was estimated broadly that the total collective effective dose (S_{103}, which means that the collective effective dose was estimated using tissue-weighting factors from ICRP 103) was 40 000 person-sieverts. In 2016, the estimated frequency of both cardiac and noncardiac procedures together was 25.1 per 1000 people.

The UNSCEAR global estimates (3) for interventional radiologic procedures by income level of country are shown in Table 3, for a total of 23.6 million estimated procedures and a frequency of 3.2 per 1000 people. This indicates that about 34% of the global interventional procedures in 2016 were in the United States.

Dental Radiography

Dental radiography accounts for a large number of procedures among all the procedures, but has a low collective effective dose. Care must be taken when evaluating and comparing the number and frequency of radiologic examinations to determine whether dental data are included or had been excluded. The estimates for dental radiography in the United States in NCRP report 160 (2) were based on estimates of images acquired and not on examinations performed. The 2016 estimates (1,5) were based on better data from examinations and therefore the total number and frequencies from 2006 to 2016 could not be compared. The 2016 U.S. estimates for the number of dental procedures were as follows: intraoral, 296 million; panoramic, 21 million; cephalometric (<1%) and cone-beam CT, 5.2 million. The rounded total was 320 million procedures. The frequency was about 991 per 1000 people.

UNSCEAR global estimates for dental radiographic examinations are shown in Table 5 and indicate a total of 1101 million examinations and a frequency of 151 examinations per 1000 people. The United States accounts for about 29% of the global dental radiographic examinations (Table 1).

Radiation Oncology

Both the NCRP and UNSCEAR reports included some information on the estimated use of radiation oncology. The available published and survey data are more limited than those for other medical uses of radiation. The estimates of the frequency of procedures are often based on cancer incidence data, the estimates of the percentage of patients with a specific cancer being treated using radiation oncology alone but more often in combination with other therapies. The use of terminology can be challenging when survey responses may variably identify patients treated, courses of radiation therapy, and whether the modality is brachytherapy, radionuclide radiation therapy, or one of several external beam techniques.

The NCRP did not estimate the number of courses of radiation therapy in 2006 (2) or earlier. The NCRP did estimate that for the United States in 2016 there were just over 1 million courses of radiation therapy performed annually in about 800 000 patients (1,5). About 60% of these examinations were for treatment of breast, lung, and prostate cancer. It was also pointed out that imaging is an integral part of radiation therapy and may contribute several percent to the tissue dose (15).

Before the most recent UNSCEAR report (3), global estimates regarding the use of radiation therapy were limited to using data from only a few countries. To overcome this limitation, UNSCEAR frequently used the number of therapy machines in a country and estimated the number of patients treated per day in various countries. UNSCEAR has indicated that the worldwide frequency of radiation therapy has not changed during the last several decades, with 0.9 courses of treatment per 1000 people in the 1988 UNSCEAR survey (6), 0.9 in the 2000 survey (8), and 0.85 in the current survey (3). It appears that the use of radiation therapy has remained almost exclusively (95%) in high-income countries. UNSCEAR estimates for 2009–2018 are shown in Table 5; there is an estimated total of 6.2

million treatment courses worldwide (uncertainty of 30%). This suggests that the percentage performed in the United States is about 16% of the global total.

Neither NCRP nor UNSCEAR attempted to estimate population radiation dose from radiation therapy because it was complicated by the high localized tumor doses and high doses to surrounding normal tissue, which precluded the defined use of effective dose.

Discussion

Comparisons of U.S. and global data regarding medical exposure to ionizing radiation from 2006 to 2016 were affected by the number and types of procedures, dose per procedure, and population size. The United States has continued to perform procedures that are in frequency and number disproportionately greater than other high-income countries.

Many interesting trends occurred that are not solely accounted for by population growth. The number of estimated conventional radiography (excluding dental) procedures decreased both globally and in the United States. The number of nuclear medicine procedures showed a small increase globally but decreased markedly in the United States (5). Mammography substantially increased both in the United States and globally. The largest change related to radiation dose and procedure numbers occurred in the use of CT scanning. Whereas the United States estimated number of CT examinations went up by about 20% between 2006 and 2016, the estimated number of CT examinations globally almost doubled. Only a small increase was estimated for radiation therapy. The causes for these changes are almost certainly multifactorial, but it seems unlikely to be from changes in disease type or prevalence during the last decade and instead due to the proliferation of CT scanners worldwide. Current global data (3) show that individuals aged 65–74 years have the highest percentage of medical radiation use.

Overall, the estimated total collective effective dose in the U.S. population decreased since 2006: from 885 000 person-sieverts in 2006 to 717 000 person-sieverts in 2016 (1). We did not analyze the reasons for this decline, but they are likely multifactorial, including awareness of radiation dose, education, attempts to optimize doses, newer technologies, changes in practices, and reduction in reimbursement.

There were limitations in the data for the United States and the UNSCEAR global analyses. Evaluation of nationwide doses was difficult for many reasons, such as reconciling diverse data sources that were collected for disparate reasons. For example, use of billing data for frequency of procedures is affected by changes in data collection methods and definitions of procedures. There was also a wide range of reported doses for a single specific procedure (1,3). The change in ICRP tissue-weighting factors in 2007 required careful analysis of doses for coherence of estimated effective doses. This was important for mammography and head and neck procedures. Additional limitations also included the need for various assumptions and judgments for coherence from divergent data sources and literature and timeliness of the data. It would be interesting to have had more recent data. For example, usage data from 2016 frequently were not available until the end of 2017, and subsequent analysis and compilation took an additional 18–36 months. Little effort is typically devoted to collecting data from either rare or low-dose procedures.

Evaluation of uncertainties is an important issue. Much of the literature and data sources do not contain sufficient information for a precise mathematical analysis. Subjective uncertainty intervals or other methods are used. For the modalities that account for more than 90% of collective effective dose (ie, CT, nuclear medicine, and radiography), uncertainties in frequency and dose can be 30% or less, although the uncertainty can be higher for some high-dose, rare, complex interventional procedures.

The estimated effective doses per procedure in a population should be used to compare with other radiation sources in the same population. The values of dose per procedure are averages and do not apply to a specific individual. Estimation of radiation detriment should be based on organ dose. The estimated effective dose per person in the United States is an average and does not represent a specific individual. The range of radiation exposures to an individual patient may vary substantially from the average. Interpret the potential risk of radiation dose in the context of the greater medical benefits of the procedure.

We recognize that the average number of procedures per 1000 people or the average individual effective dose for the global population is by no means evenly distributed among the countries or among the population within each country. The UNSCEAR 2022 report indicated that the use of radiation for diagnosis and therapy continues to be strongly weighted to high-income and upper-middle–income countries, as defined by the World Bank (3). The UNSCEAR global survey showed substantial variation, by a factor of 15 or more, in number, frequency, and radiation dose across countries of varying income levels. High- and middle-income–level countries with 51% of the world population account for about 70% of medical radiation imaging examinations, 90% of nuclear medicine examinations, more than 95% of the collective effective dose, and about 95% of radiation therapy treatments. It is also clear that even among the United States and Western European high-income neighboring countries, there is variation by up to a factor of four or more in frequency of examinations per 1000 people.

In conclusion, the United States continues to have a large and disproportionate share of global medical radiation procedures and associated collective effective dose. During 2006–2016, use of CT continued to increase in the United States but much more in other countries. The trends in other modalities were variable but often decreased relative to the population increase.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments:

The authors thank the members of National Council on Radiation Protection and Measurements (NCRP) Program Area Committee 4.9 who drafted NCRP report 184 and committee members of United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) who drafted UNSCEAR 2022.

Abbreviations

ICRP	International Commission on Radiological Protection
NCRP	National Council on Radiation Protection and Measurements
UN	United Nations
UNSCEAR	UN Scientific Committee on the Effects of Atomic Radiation

References

1. National Council on Radiation Protection and Measurements. Medical Radiation Exposure of patients in the United States, NCRP Report 184. Bethesda, Md: National Council on Radiation Protection and Measurements, 2019.
2. National Council on Radiation Protection and Measurements. Ionizing Radiation Exposure of the Population of the United States, NCRP Report 160. Bethesda, Md: National Council on Radiation Protection and Measurements, 2009.
3. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources, effects, and risks of ionizing radiation. Evaluation of medical exposure to ionizing radiation. Vol 1, Scientific Annex A. 2020/2021 Report to the General Assembly with annexes. New York, NY: United Nations, 2022.
4. Mettler FA Jr, Bhargavan M, Faulkner K, et al. Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources--1950–2007. Radiology 2009;253(2):520–531. [PubMed: 19789227]
5. Mettler FA Jr, Mahesh M, Bhargavan-Chatfield M, et al. Patient Exposure from Radiologic and Nuclear Medicine Procedures in the United States: Procedure Volume and Effective Dose for the Period 2006–2016. Radiology 2020;295(2):418–427. [PubMed: 32181730]
6. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources, effects, and risks of ionizing radiation. Exposures from medical uses of radiation, annex C. 1988 Report to the General Assembly with annexes New York, NY: United Nations, 1988.
7. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation. Medical radiation exposure, annex C. 1993 Report to the General Assembly with annexes. New York, NY: United Nations, 1993.
8. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effects of ionizing radiation. Medical radiation exposures, annex D. 2000 Report to the General Assembly, with annexes. New York, NY: United Nations, 2000.
9. United Nations Scientific Committee on the Effects of Atomic Radiation. Effects of Ionizing Radiation. Vol 1. 2006 Report to the General Assembly, Scientific Annexes A and B. New York, NY: United Nations, 2008.
10. United Nations Scientific Committee on the Effects of Atomic Radiation. Effects of Ionizing Radiation. Vol 1: Sources. 2008 Report to the General Assembly, Scientific Annexes A and B. New York, NY: United Nations, 2010.
11. United Nations Scientific Committee on the Effects of Atomic Radiation. Effects of Ionizing Radiation. Vol 2: Effects. 2008 Report to the General Assembly, Scientific Annexes C, D and E. New York, NY: United Nations, 2011.
12. 1990 Recommendations of the International Commission on Radiological Protection. Ann ICRP 1991;21(1–3):1–201.
13. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. Ann ICRP 2007;37(2–4):1–332.
14. European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry (COCIR). Medical Imaging Equipment Age Profile and Density, 2016 Edition. https://www.cocir.org/uploads/media/16052_COC_AGE_PROFILE_web_01.pdf. Accessed April 18, 2022.

15. Milano MT, Mahesh M, Mettler FA, Elee J, Vetter RJ. Patient Radiation Exposure: Imaging During Radiation Oncology Procedures: Executive Summary of NCRP Report No. 184. J Am Coll Radiol 2020;17(9):1176–1182. [PubMed: 32105647]

Essentials

- The United States consists of 4.4% of the world's population but accounts for a large and disproportionate share (15%–30%) of global medical radiation procedures depending on the modality.
- The estimated number of CT examinations in the United States went up about 20% between 2006 and 2016, whereas the global number almost doubled.
- From 2006 to 2016, the annual average effective dose per person decreased worldwide from 0.65 to 0.56 mSv and decreased from 3.0 to 2.2 mSv in the United States in the same period.

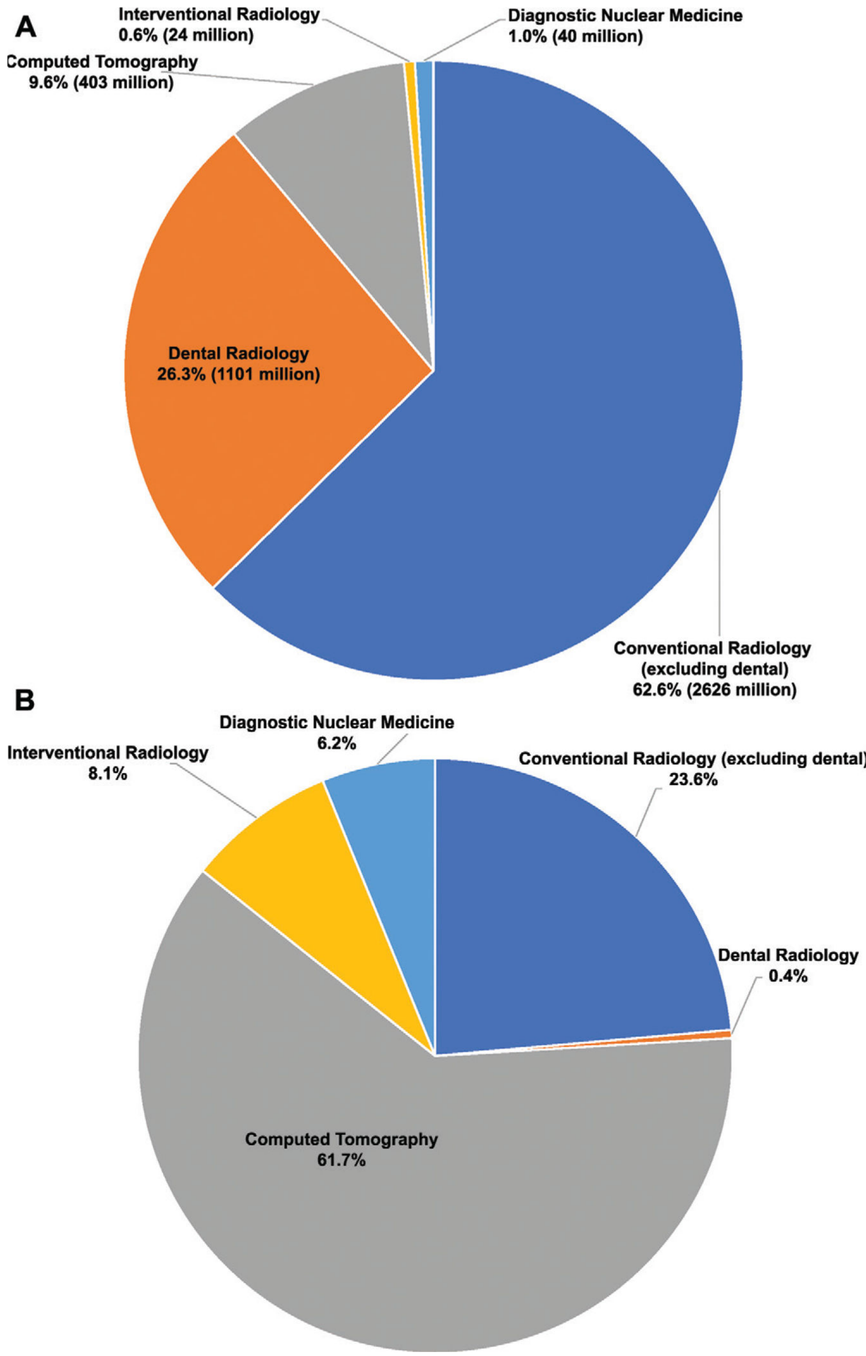

Figure 1:
Relative contributions by modality category to **(A)** estimated global annual number of examinations and/ or procedures (2009–2018) and **(B)** estimated annual collective effective dose (based on International Commission on Radiological Protection 103 tissue weighting factors).

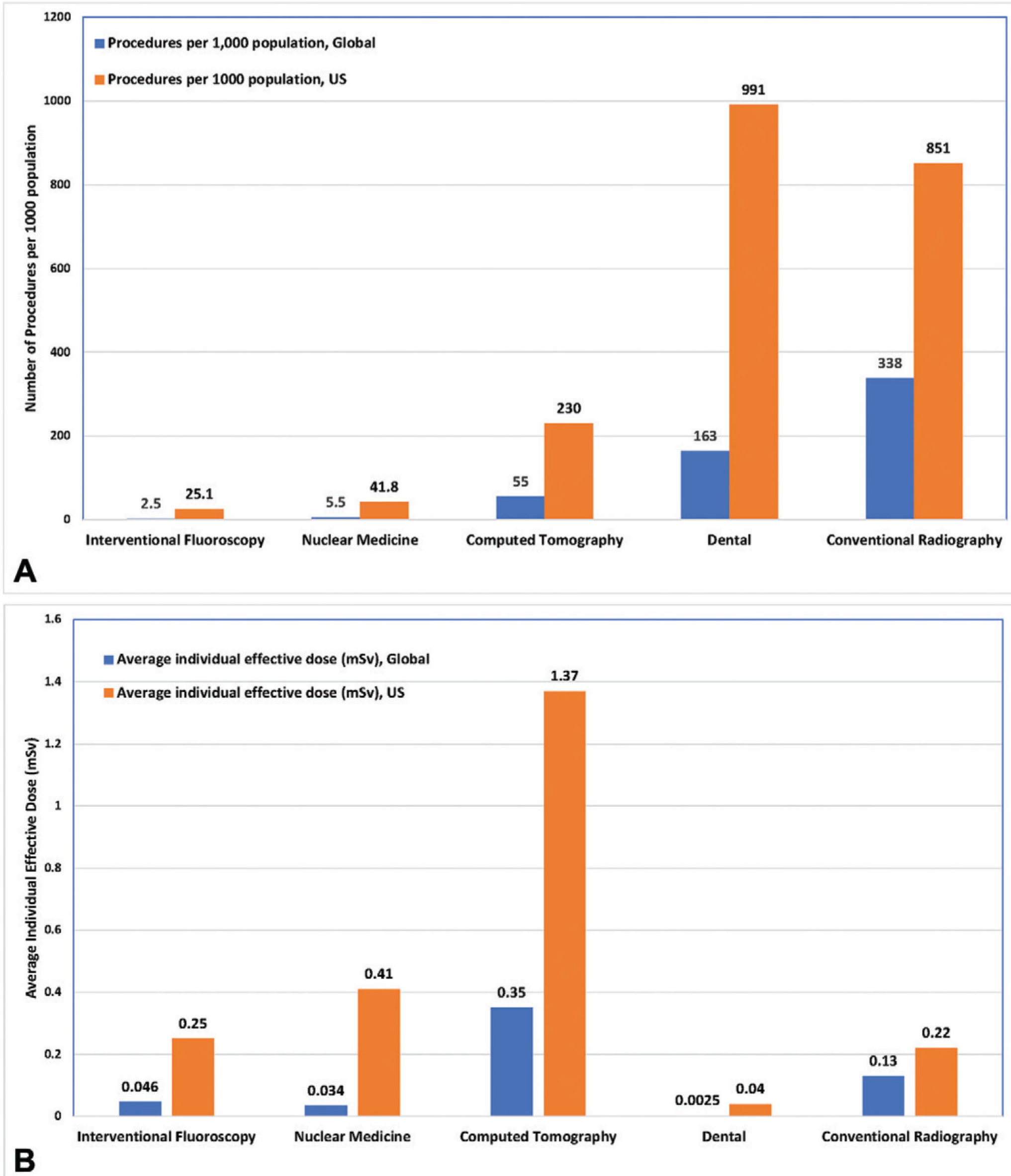

Figure 2:

Comparison of **(A)** procedures per 1000 people and **(B)** annual average individual effective dose for various categories between worldwide and United States (1,3). The average individual effective dose was estimated using International Commission on Radiological Protection 103 tissue weighting factors (13).

Author Manuscript

Author Manuscript

Author Manuscript

Table 1:

Comparison of Estimated World Total Values for Various Frequency and Dose Metrics with those of the United States

Analysis Metric	CT Examinations*	Conventional Radiography†	Interventional Fluoroscopy‡	Nuclear Medicine	Dental Radiography	Rounded Total§
World UNSCEAR summary 2014–2017						
No. of procedures	403 000 000	262 600 000	23 600 000	41 300 000//	1 101 000 000	4 195 000 000
Procedures per 1000 people	55	338	2.5	5.5	163	574
Collective effective dose ICRP 1990 w_T ($S_{w\ 60}$) (person-Sv)	2 556 000	955 000	334 000	297 000	9700	4 152 000
Average individual effective dose ICRP 1990 W_T ($E_{w\ 60}$) (mSv)	0.35	0.13	0.046	0.041	0.0013	0.58
Collective effective dose ICRP 2003 W_T ($S_{W\ 103}$) (person-Sv)	2 519 000	964 000	332 000	252 000	18 200	4 085 000
Average individual effective dose ICRP 2003 w_T ($E_{W\ 103}$) (mSv)	0.35	0.13	0.046	0.034	0.0025	0.56
U.S. summary NCRP 2016						
No. of procedures	74 000 000 (18.4)	275 000 000 (10.5)	8 100 000 (34.3)	13 500 000 (32.7)	320 000 000 (29.1)	691 000 000 (16.5)
Procedures per 1000 people	230	851	25.1	41.8	991	2139
Collective effective dose ICRP 1990 W_T ($S_{US\ 60}$) (person-Sv)	469 000 (18.3)	71 000 (7.4)	82 000 (24.6)	133 000 (44.8)	NA#	755 000 (18.1)
Average individual effective dose ICRP 1990 W_T ($Eu_{S\ 60}$) (mSv)	1.45	0.22	0.12	0.41	NA#	2.3
Collective effective dose ICRP 2003 W_T ($S_{US\ 103}$) (person-Sv)	444 000 (17.6)	71 000 (7.4)	82 000 (24.7)	106 000 (42.1)	14 000 (76.9)	717 000 (17.6)
Average individual effective dose ICRP 2003 W_T ($E_{US\ 103}$) (mSv)	1.37	0.22	0.25	0.41	0.04	2.2

Note.—The U.S. percentage of the worldwide total is in parentheses. International Commission on Radiological Protection (ICRP) 2007 w_T represents tissue-weighting factors from the ICRP (13). $S_{US\ 103}$ and $S_{US\ 60}$ are collective effective doses for the United States using tissueweighting factors (w_T) from reference 1. $S_{W\ 103}$ and $S_{W\ 60}$ are collective effective doses worldwide using tissue-weighting factors from reference 3. $E_{US\ 60}$ and $E_{US\ 103}$ are average individual effective doses for the U.S. population using tissue-weighting factors from reference 1. $E_{W\ 60}$ and $E_{W\ 103}$ are average individual effective doses for the U.S. population using tissue-weighting factors from reference 3. NA = not applicable, NCRP = National Council on Radiation Protection and Measurements, UNSCEAR = United Nations Scientific Committee on the Effects of Atomic Radiation.

*The values are for procedures. The estimated number of CT examinations performed in the United States in 2016 was 84 million.

†Excludes dental radiography.

[‡] Includes cardiac and noncardiac interventional fluoroscopy.

[§] Does not include radiation therapy procedures, estimated to be 6.2 million worldwide.

[//] Includes radionuclide therapy.

[#] NCRP did not estimate ICRP 60 effective dose for dental radiography; however, it is less than 1% of the total.

Table 2:

Trends in Global Medical Exposures

Source	Annual No. of Procedures*	Annual Frequency of Procedures per 1000 People	Annual Collective Effective Dose (per 1000 Person-Sv)*	Annual per Capita Dose (mSv)†
UNSCEAR 1988	1 740 000 000	355	1890	0.37
UNSCEAR 1993	1 620 000 000	305	1780	0.33
UNSCEAR 2000	2 460 000 000	426	2460	0.43
UNSCEAR 2008	3 660 000 000	561	4210	0.65
UNSCEAR 2022	4 190 000 000	574	4210	0.58

Source.—Reference 3.

* Values were rounded.

† For the effective dose determination, International Commission on Radiological Protection 60 tissue weighting factors were applied (12).

Table 3:

Global Estimate of Number of Conventional Radiology, CT, Nuclear Medicine, and Interventional Radiology Procedures

		Conventional Radiology		CT Examinations		Nuclear Medicine		Interventional Radiology	
Income Level	**Population**	**Total No. of Examinations**	**Mean No. of Examinations per 1000 People**	**Total No. of Examinations**	**Mean No. of Examinations per 1000 People**	**Total No. of Examinations**	**Mean No. of Examinations per 1000 People**	**Total No. of Examinations**	**Mean No. of Examinations per 1000 People**
High	1 149 000 000	983 000 000	855	183 000 000	159	28 500 000	25	13 900 000	12
Upper middle	2 619 000 000	764 000 000	292	131 000 000	50	8 100 000	3.1	4 970 000	1.9
Lower middle	2 882 000 000	801 000 000	278	81 000 000	28	2 800 000	1	4 350 000	1.5
Low	662 000 000	78 000 000	118	7 800 000	12	39 000 000	0.6	44 000 000	0.7
All	7 312 000 000	2 626 000 000	359	403 000 000	55	39 900 000	5.5	23 600 000	3.2

Note.—Values for total number of examinations were rounded. Data are per annum and derived from assessed data (2009–2018) and categorized based on income level (3).

Table 4:

Number and Type of CT Procedures and Scans for 2016 in United States according to NCRP 184

Type of CT Examination	No. of CT Procedures	No. of CT Scans Accounting for Multiple Scans in Certain Examinations	Effective Dose Based on E_{60} (mSv per Scan)	E_{103}-to-E_{60} Ratio	Effective Dose Based on E_{103} (mSv per Scan)	Collective Effective Dose Based on S_{60} (Person-Sv)	Collective Effective Dose Based on S_{103} (Person-Sv)
Brain	15 300 000	15 891 371	1.9	0.84	1.6	30 193	25 426
Head and neck	7 200 000	7 700 481	1.4	0.87	1.2	10 780	9240
Chest	12 700 000	13 250 657	5.4	1.14	6.2	71 553	82 154
Calcium scoring*	57 492	57 492	1.5	1.14	1.7	86	97
Cardiac*	281 920	281 920	7.6	1.14	8.7	2142	2452
Abdomen and pelvis	20 100 000	22 137 153	8.7	0.88	7.7	192 593	170 456
CT colonography	200 000	200 000	7.5	0.88	6.6	1500	1320
Spine	6 400 000	6 457 522	9.2	0.96	8.8	59 409	56 826
CT angiography (noncardiac)	6 600 000	13 027 708	5.4	0.94	5.1	70 349	66 441
Interventional*	863 280	863 280	5.2	0.96	5	4489	4316
Extremity: upper*	471 100	479 228	2	0.87	1.7	958	814
Extremity: lower*	1 203 716	1 223 064	3.2†	1	3.2	3913	3913
Miscellaneous (bone densitometry, follow-up scans, etc)	300 000	300 000	5.2	0.96	5	1560	1500
PET/CT	1 821 610	1 821 610	10	1	10	18 216	18 216
SPECT/CT	314 206	314 206	3	1	3	942	942
Total (including PET/CT, SPECT/CT)	73 813 324	84 005 692				468 688	444 118

Note.—Adapted, with permission, from reference 5. PET/CT is a category assuming all procedures are for localization of whole-body PET/CT procedures. Miscellaneous includes whole-body screening, bone densitometry, follow-up, and others. E_{60} = collective effective dose based on International Commission on Radiological Protection (ICRP) publication 60 (12), E_{103} = effective dose based on the ICRP 103 (13), NCRP = National Council on Radiation Protection and Measurements, S_{60} = collective effective dose based on the ICRP publication 60 (12), S_{103} = collective effective dose based on the ICRP publication 103 (13).

*Cardiac CT, calcium scoring, interventional, extremity (upper and lower) scans: scaled Medicare counts by factor of 4 to obtain the numbers because IMV numbers (IMV Medical Information Division, www.imvinfo.com) did not correlate with Medicare or Veterans Affairs data.

†Value is for hip CT. Lower values can be applied for knee and ankle CT.

Table 5:

Global Estimate of Number of Dental Radiology and Radiation Therapy Per Annum

		Dental Radiology		Radiation Therapy	
Income Level of Country	**Population**	**Total No. of Examinations**	**Mean No. of Examinations per 1000 People**	**Total No. of Examinations**	**Mean No. of Examinations per 1000 People**
High	1 149 000 000	644 000 000	561	3 010 000	2.62
Upper middle	2 619 000 000	289 000 000	110	2 630 000	1
Lower middle	2 882 000 000	154 000 000	53	500 000	0.17
Low	6 620 000 000	140 00 000	21	100 000	0.15
All	7 312 000 000	1 101 000 000	151	6 200 000	0.85

Note.—Data are from 2009–2018 and are categorized based on income level (3). High income is a gross national income of 16%, upper middle income is gross national income of 36%, lower middle income is gross national income of 39%, and low income is gross national income of 9%.