Radiology

Effective Doses in Radiology and Diagnostic Nuclear Medicine: A Catalog[1]

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Medical uses of radiation have grown very rapidly over the past decade, and, as of 2007, medical uses represent the largest source of exposure to the U.S. population. Most physicians have difficulty assessing the magnitude of exposure or potential risk. Effective dose provides an approximate indicator of potential detriment from ionizing radiation and should be used as one parameter in evaluating the appropriateness of examinations involving ionizing radiation. The purpose of this review is to provide a compilation of effective doses for radiologic and nuclear medicine procedures. Standard radiographic examinations have average effective doses that vary by over a factor of 1000 (0.01–10 mSv). Computed tomographic examinations tend to be in a more narrow range but have relatively high average effective doses (approximately 2–20 mSv), and average effective doses for interventional procedures usually range from 5–70 mSv. Average effective dose for most nuclear medicine procedures varies between 0.3 and 20 mSv. These doses can be compared with the average annual effective dose from background radiation of about 3 mSv.

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Over the past 2 decades, there has been marked growth in the absolute number of diagnostic medical procedures that utilize ionizing radiation. In addition, there has been an increasing frequency of relatively high-dose procedures including computed tomographic (CT) scanning, interventional procedures, and cardiac nuclear medicine. As of 2007, medicine represented the largest source of ionizing radiation exposure to the U.S. population.

Although most of these procedures undoubtedly have benefit, there are others for which the benefit is not clear or has not been quantified. It is the duty of the referring clinician and the radiologist, cardiologist, and others to assess the potential benefit-risk ratio for various procedures. To do this, one needs to have some idea of the magnitude of the radiation dose associated with the procedures. This has recently been emphasized by the American College of Radiology (1). Although there are many articles and surveys in the literature concerning dosimetry for a specific examination or procedure, there are few places in which the recent literature has been reviewed and summarized in a concise form.

There are a number of ways in which radiation exposure and dose in medicine are quantitated. Measured quantities include air kerma, entrance surface dose, dose-area product, dose-length product, and administered activity. Organ absorbed doses can be estimated by using either clinically validated anthropomorphic phantoms with internal dosimeters or Monte Carlo computer programs. These phantoms and programs represent a "typical patient" and are useful ways to collect data over time.

When organ doses are adjusted by International Commission on Radiological Protection (ICRP) radiation weighting factors (1.0 for photons), the equivalent dose is obtained (2,3). To estimate detriment from cancer and hereditary effects, effective dose is used. This is a calculated quantity and cannot be measured. Multiplying the average organ equivalent dose by the ICRP tissue-weighting factor and summing the results over the whole body yields the effective dose. Effective dose is expressed in sieverts and is a single dose parameter that reflects the risk of a nonuniform exposure in terms of whole-body exposure. Effective dose is age and sex averaged, and, although it can be used to enable comparison of relative detriment between procedures that utilize ionizing radiation, it should not be used retrospectively to determine individual risk. Individual risk is best evaluated by determining the mean doses to all radiosensitive tissues of the individual and combining these with age-, sex-, and organ-specific risk coefficients.

The purpose of this article is to present effective doses from various procedures because effective dose is a measure of potential detriment. It is hoped that this information will be of value to those performing procedures involving ionizing radiation, as well as to referring physicians and other entities such as institutional research committees. Although limited information on organ doses is given, inclusion of organ doses for all procedures is unmanageable in one article. However, a large amount of information on organ doses is included in the references.

Materials and Methods

Peer-reviewed scientific literature on radiation dosimetry in radiology and diagnostic nuclear medicine published between 1980 and 2007 was reviewed (4–161). The review included data from the United States, Canada, Japan, Australia, and Western Europe. Additionally, periodic surveys and literature reviews of the United Nations Scientific Committee on Atomic Radiation and material from Web sites of the U.S. Food and Drug Administration (Nationwide Evaluation of X-ray Trends survey program), several states, and the Conference of Radiation Control Program Directors were also reviewed.

Reported values and ranges of effective dose were compiled for common procedures. For some procedures (such as abdominal CT) there were more than 20 publications with the required information. In cases where there was substantial material, it was possible to derive an arithmetic mean. This in itself was not very helpful, as it was clear that some of the publications represented large international surveys, others were national surveys, some represented data from a single hospital, and others reported measurements in phantoms. Some of the articles included some new data, but some other portions of the data presented were from previous publications of other authors. The latter were not counted twice. Only a few publications provided detailed data about radiologic techniques or protocols.

Additionally, for some procedures, the mean was not useful if it was clear that the temporal trend in dose had been decreasing or increasing. Finally, for some procedures, there were only a few references. As a result, it was necessary to make an informed judgment as to what would be a current representative value for effective dose per examination. These usually were central values from the literature rounded to one decimal point; however, in cases where there were repeated periodic surveys and reported doses had decreased substantially over time, only newer values were considered.

Much of the literature contained additional quantities such as entrance skin dose, imparted energy, and dose-length product. For CT and mammography, we believed that it was important to include some limited information on dose to organs in the direct beam.

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Abbreviation:
ICRP = International Commission on Radiological Protection

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Results

Representative values and ranges of effective doses reported in the literature for various examinations and procedures are presented in Tables 1–5.

In addition to effective dose, absorbed organ doses are important for some procedures that either involve high doses or include sensitive tissues in the primary radiation beam. For CT scanning, organs in the beam can receive doses that are 10–100 mGy but are usually in the range of 15–30 mGy per single CT sequence (162–169).

Doses to the lens of the eye during CT scanning of the head have been reported to be 30–50 mGy (170–174). Values depend on whether the lens is in the direct beam or out of the beam when the gantry is angled. Angulation of the gantry for head CT studies can reduce the eye dose by 90%, to about 3–4 mGy. For many new scanners, such as portable intensive care unit scanners, positron emission tomography/CT scanners, and dual-tube multidetector CT scanners, the gantry cannot be angled, which will result in higher eye doses when head CT examinations are performed.

Radiation dose to the breast tissue is of critical importance, especially in girls and young women. Chest CT scanning results in relatively high doses to breast tissue. Doses have been estimated to be 20–60 mGy for a CT examination performed for pulmonary embolism, 50–80 mGy for a CT coronary angiography examination, and even 10–20 mGy to the inferior part of the breast for an abdominal CT examination (175–177). Even though lower x-ray energies are used, as a comparison, for mammography, the American College of Radiology and the Mammography Quality Standards Act of 1992 regulations require that the mean glandular dose for a single mammogram to a normal-sized breast with 50% glandularity be less than 3 mGy.

Discussion

As mentioned earlier, effective dose is a calculated age- and sex-averaged value that is used as a robust measure to compare detriment from cancer and hereditary effects due to various procedures involving ionizing radiation. Martin (178) has pointed out a number of limitations in its use, including about ±40% uncertainty for a reference patient. Often, effective dose is calculated and expressed to a much greater precision than is warranted, and we have expressed values to only one significant digit. There clearly are additional problems in trying to apply the sex-averaged effective dose to procedures that predominantly involve one sex (such as mammography).

The sources of information reviewed were variable in quantity, qual-

Table 1

Adult Effective Doses for Various Diagnostic Radiology Procedures

Examination	Average Effective Dose (mSv)	Values Reported in Literature (mSv)
Skull	0.1	0.03–0.22
Cervical spine	0.2	0.07–0.3
Thoracic spine	1.0	0.6–1.4
Lumbar spine	1.5	0.5–1.8
Posteroanterior and lateral study of chest	0.1	0.05–0.24
Posteroanterior study of chest	0.02	0.007–0.050
Mammography	0.4	0.10–0.60
Abdomen	0.7	0.04–1.1
Pelvis	0.6	0.2–1.2
Hip	0.7	0.18–2.71
Shoulder	0.01	. . .
Knee	0.005	. . .
Other extremities	0.001	0.0002–0.1
Dual x-ray absorptiometry (without CT)	0.001	0.001–0.035
Dual x-ray absorptiometry (with CT)	0.04	0.003–0.06
Intravenous urography	3	0.7–3.7
Upper gastrointestinal series	6*	1.5–12
Small-bowel series	5	3.0–7.8
Barium enema	8*	2.0–18.0
Endoscopic retrograde cholangiopancreatography	4.0	. . .

* Includes fluoroscopy.

Table 2

Adult Effective Doses for Various CT Procedures

Examination	Average Effective Dose (mSv)	Values Reported in Literature (mSv)
Head	2	0.9–4.0
Neck	3	. . .
Chest	7	4.0–18.0
Chest for pulmonary embolism	15	13–40
Abdomen	8	3.5–25
Pelvis	6	3.3–10
Three-phase liver study	15	. . .
Spine	6	1.5–10
Coronary angiography	16	5.0–32
Calcium scoring	3	1.0–12
Virtual colonoscopy	10	4.0–13.2

Table 3

Adult Effective Doses for Various Interventional Radiology Procedures

Examination	Average Effective Dose (mSv)*	Values Reported in Literature (mSv)
Head and/or neck angiography	5	0.8–19.6
Coronary angiography (diagnostic)	7	2.0–15.8
Coronary percutaneous transluminal angioplasty, stent placement, or radiofrequency ablation	15	6.9–57
Thoracic angiography of pulmonary artery or aorta	5	4.1–9.0
Abdominal angiography or aortography	12	4.0–48.0
Transjugular intrahepatic portosystemic shunt placement	70	20–180
Pelvic vein embolization	60	44–78

* Values can vary markedly on the basis of the skill of the operator and the difficulty of the procedure.

Table 4

Adult Effective Dose for Various Dental Radiology Procedures

Examination	Average Effective Dose (mSv)	Values Reported in Literature (mSv)
Intraoral radiography	0.005	0.0002–0.010
Panoramic radiography	0.01	0.007–0.090
Dental CT	0.2	. . .

Table 5

Effective Doses for Adults from Various Nuclear Medicine Examinations

Examination*	Effective Dose (mSv)	Administered Activity (MBq)†	Effective Dose (mSv/MBq)‡
Brain (^{99m}Tc-HMPAO–exametazime)	6.9	740	0.0093
Brain (^{99m}Tc-ECD–Neurolite)	5.7	740	0.0077
Brain (^{18}F-FDG)	14.1	740	0.019
Thyroid scan (sodium iodine 123)	1.9	25	0.075 (15% uptake)
Thyroid scan (^{99m}Tc-pertechnetate)	4.8	370	0.013
Parathyroid scan (^{99m}Tc-sestamibi)	6.7	740	0.009
Cardiac stress-rest test (thallium 201 chloride)	40.7	185	0.22
Cardiac rest-stress test (^{99m}Tc-sestamibi 1-day protocol)	9.4	1100	0.0085 (0.0079 stress, 0.0090 rest)
Cardiac rest-stress test (^{99m}Tc-sestamibi 2-day protocol)	12.8	1500	0.0085 (0.0079 stress, 0.0090 rest)
Cardiac rest-stress test (Tc-tetrofosmin)	11.4	1500	0.0076
Cardiac ventriculography (^{99m}Tc-labeled red blood cells)	7.8	1110	0.007
Cardiac (^{18}F-FDG)	14.1	740	0.019
Lung perfusion (^{99m}Tc-MAA)	2.0	185	0.011
Lung ventilation (xenon 133)	0.5	740	0.00074
Lung ventilation (^{99m}Tc-DTPA)	0.2	1300 (40 actually inhaled)	0.0049
Liver-spleen (^{99m}Tc–sulfur colloid)	2.1	222	0.0094
Biliary tract (^{99m}Tc-disofenin)	3.1	185	0.017
Gastrointestinal bleeding (^{99m}Tc-labeled red blood cells)	7.8	1110	0.007
Gastrointestinal emptying (^{99m}Tc-labeled solids)	0.4	14.8	0.024
Renal (^{99m}Tc-DTPA)	1.8	370	0.0049
Renal (^{99m}Tc-MAG3)	2.6	370	0.007
Renal (^{99m}Tc-DMSA)	3.3	370	0.0088
Renal (^{99m}Tc-glucoheptonate)	2.0	370	0.0054
Bone (^{99m}Tc-MDP)	6.3	1110	0.0057
Gallium 67 citrate	15	150	0.100
Pentreotide (^{111}In)	12	222	0.054
White blood cells (^{99m}Tc)	8.1	740	0.011
White blood cells (^{111}In)	6.7	18.5	0.360
Tumor (^{18}F-FDG)	14.1	740	0.019

* DMSA = dimercaptosuccinic acid, DTPA = diethylenetriaminepentaacetic acid, ECD = ethyl cysteinate dimer, ^{18}F = fluorine 18, FDG = fluorodeoxyglucose, HMPAO = hexamethylpropyleneamine oxime, ^{111}In = indium 111, MAA = macroaggregated albumin, MAG3 = mercaptoacetyltriglycine, MDP = methylene diphosphonate, ^{99m}Tc = technetium 99m.

† Recommended ranges vary, although most laboratories tend to use the upper end of suggested ranges.

‡ From reference 74.

ity, and methodology. In spite of this, for many procedures there was a relatively narrow band of reported effective doses (usually with ±50% variation). There was more variation involving procedures that were interventional or that involved fluoroscopy. The effective doses presented here should be used with caution when evaluating an individual procedure. In addition, the values presented above for various examinations are averages given with the realization that for any examination, actual doses in practice may vary by an order of magnitude.

In 2007, the ICRP approved new tissue-weighting factors that will change effective doses slightly for most examinations. There has been a decrease in the weighting factor applied for hereditary effects and an increase in values for other tissues (notably the female breast). Thus, effective doses for abdominal and pelvic examinations will decrease about 5%–20% from those reported here, and effective doses for procedures involving the chest will increase about 5%–20% (160). However, any such changes will be small compared with other uncertainties involved in estimating effective doses. A few exceptions to this are cardiac CT, where the new ICRP tissue-weighting factors may increase the effective doses (for the same x-ray technique and scan geometry) (170), and mammography, where effective doses will be increased by a factor of 2.4 because of the increase in the breast weighting factor from 0.05 to 0.12.

The transition in imaging technology from screen-film radiography to computed or direct digital radiography does have some effect on both absorbed and effective doses (179–181). The limited literature to date indicates that even though both computed radiography and direct digital radiography have the potential to reduce doses compared with screen-film combinations, effective doses are somewhat higher (10%–50%) with computed radiography and somewhat lower (30%–40%) with direct digital radiography than with screen-film combinations (37,182). Even for the same examination (chest), when different digital systems are compared, the effective dose varies by about a factor of three, depending on the detector type (183–185).

In mammography, digital techniques result in slightly lower doses than do screen-film techniques (186–189). Reported mean glandular dose in digital mammography is about 1.6 mGy, which is lower than typical breast doses in screen-film mammography, which are currently estimated to be about 2 mGy. Reductions in breast dose are generally a result of the use of x-ray beams with higher quality (ie, half-value layer), achieved by the use of higher x-ray tube voltages and higher Z targets and/or filters.

The introduction of four-section CT scanners resulted in relatively large dose increases compared with doses from single-section scanners. Improvements in CT scanner design, together with the use of much wider CT beams, has reduced current CT dose levels to be generally comparable to those of single-section scanners (190–193). For comparable image quality, there is no intrinsic reason for patient doses with 64- or 256-section scanners to substantially increase. The dominant contributor to CT dose is increased usage, not CT scanner type.

The values of effective doses presented here are related to adults. There are some publications that concern effective doses to children (particularly from CT) (194–197). Effective doses to the neonate for a head CT examination are markedly higher than for adults, whereas for body CT, the effective doses are usually within 50% of the adult dose. In part, this is a result of the fact that technique factors (voltage and/or tube current–time product) can be substantially lowered in body CT, but only very modest reductions in technique are made when performing pediatric head CT examinations. The use of reduced techniques in pediatric scanning has substantially reduced pediatric patient doses, with no apparent loss of diagnostic imaging performance (165).

Radiologists and other physicians have an obligation to balance the risks and benefits of various medical procedures and to inform the patient. Effective dose provides a general idea of detriment from ionizing radiation to allow comparison of different procedures or to justify or optimize procedures. Values of effective dose presented here are representative, and actual values will vary on the basis of a number of factors discussed above.

Standard radiographic examinations have effective doses (and potential detriment) that vary widely by over a factor of 1000 (0.01–10 mSv). CT examinations tend to be in a more narrow dose range but have relatively high effective doses (approximately 2–20 mSv), and doses for interventional procedures usually range from 5 to 70 mSv. Most nuclear medicine procedures vary in effective dose between 0.3 and 20 mSv. This can be compared with an annual effective dose from natural background radiation of about 3 mSv.

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