RadioGraphics

Quality Initiatives

Radiation Risk: What You Should Know to Tell Your Patient[1]

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TEACHING POINTS
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The steady increase in the number of radiologic procedures being performed is undeniably having a beneficial impact on healthcare. However, it is also becoming common practice to quantify the health detriment from radiation exposure by calculating the number of cancer-related deaths inferred from the effective dose delivered to a given patient population. The inference of a certain number of expected deaths from the effective dose is to be discouraged, but it remains important as a means of raising professional awareness of the danger associated with ionizing radiation. The risk associated with a radiologic examination appears to be rather low compared with the natural risk. However, any added risk, no matter how small, is unacceptable if it does not benefit the patient. The concept of diagnostic reference levels should be used to reduce variations in practice among institutions and to promote optimal dose indicator ranges for specific imaging protocols. In general, the basic principles of radiation protection (eg, justification and optimization of a procedure) need to be respected to help counteract the unjustified explosion in the number of procedures being performed.

Abbreviations: CTDI = CT dose index, ERR = excess relative risk, ICRP = International Commission on Radiation Protection

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Introduction

Rapid technologic developments in radiology have had a direct positive impact on patient care. For instance, multitrauma patients can undergo a complete examination within a few seconds, or previously invasive diagnostic examinations such as angiography can be replaced with noninvasive computed tomography (CT). However, this evolution has also led to a noticeable increase in the radiologic procedure–based radiation dose delivered to the patient population, a fact that has made headlines in the general press (see, for example, the June 19, 2007 issue of the *New York Times*).

The use of ionizing radiation has inherent risks. General practitioners and radiologists need to balance these risks with the potential outcome of the diagnostic procedure. This standard radiation protection requirement necessitates having the right tools. In addition, modern medicine tacitly assumes a shared decision between patient and physician that requires radiologists to discuss with their patients the known risks associated with a procedure to obtain informed consent (1,2). Finally, many insurance companies in the United States, as part of emerging pay-for-performance requirements, are now expecting cumulative doses to be measured and recorded. With some procedures (eg, fluoroscopy), this information needs to be included in the radiology report, a practice that is also being introduced in Europe.

A few years ago, a survey was conducted in an emergency department and an academic medical center and showed that patients were not able to give informed consent due to a lack of knowledge among all parties (radiologists, physicians, and patients) concerning the matter in question (3). In addition to this overall unawareness of the risks associated with the use of ionizing radiation, some groups base their research on thorough studies such as the ones published in the seventh National Academy of Science BEIR (Biological Effects of Ionizing Radiation) report (4) and then infer deaths from the use of a given technology by multiplying very small risk factors times large populations without giving the range of uncertainties associated with the procedure in question (5). In this context, it becomes necessary to reiterate the fundamentals of radiation protection.

In this article, we summarize the biologic effects of low-dose ionizing radiation; even if risks have been demonstrated above a certain dose threshold, because of insufficient statistics, hypothetic risks in the low-dose range must be postulated to assure the protection of professionals and patients. In addition, we discuss and illustrate the concept, determination, and limitations of effective dose. We also discuss radiologic risk versus natural cancer risk and what to tell a patient concerning radiologic risk.

Biologic Effects of Low-Dose Radiation

X-rays ionize atoms and molecules in tissues through the deposition of energy. This ionization is the first step in a series of events that may have a biologic effect. Absorbed dose is a measure of the energy deposited per unit mass and provides a means of predicting the potential for biologic effects. Absorbed dose is measured in grays or milligrays. One gray is equivalent to an energy deposition of 1 joule per kilogram of tissue. To take into account the fact that not all types of radiation produce the same effect in humans, the concept of dose equivalent has been introduced. Dose equivalent is the product of the absorbed dose and a radiation weighting factor and is expressed in sieverts. For x- or gamma rays, the radiation weighting factor is 1.0. Thus, an absorbed dose of 1 Gy is equivalent to 1 Sv (1,6).

The biologic effects of ionizing radiation have been studied widely for more than a century and, in spite of being well documented, are still the subject of controversy (4,7–9). Although there is now no doubt that a dose above 100 mSv can produce deleterious consequences such as cancer in humans, the situation is less clear for low doses. One of the main difficulties in assessing radiation risks in the low-dose range is that human beings already run a quite high natural cancer risk (25%–33%). Even if it is obvious that the risks of low doses of radiation are lower than those of high doses, large epidemiologic studies are required to quantify the risk with a reasonable statistical power.

For example, if the excess risk of cancer induction due to ionizing radiation were directly proportional to radiation dose, and if a sample size of 1000 persons were needed to quantify the effect of a 1.0-Sv dose, 100,000 persons would be needed to quantify the effect of a 100-mSv dose and 10 million persons for a 10-mSv dose (10). To maintain statistical precision and power when assessing the risks associated with ionizing radiation, the required sample size should increase proportionately with the inverse square of the dose (7,10). This relationship is similar to a "signal-to-noise" (signal representing radiation risk and noise representing natural background risk) ratio reduction as dose decreases. Thus, there is a range of low doses in which even large epidemiologic studies will fail to provide reliable excess risk factors. In this range of doses, current irradiation practices make use of the notion of hypothetic risk to help determine the risk below the background radiation level (3) by extrapolation from the risk evidenced in the high-dose

Teaching Point

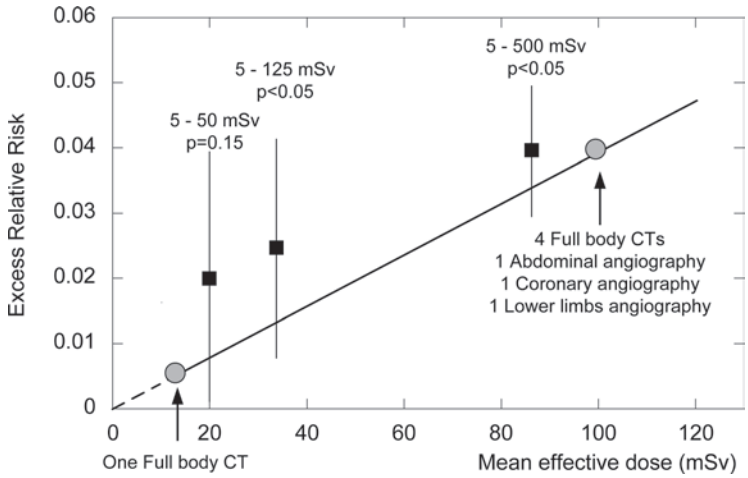

Figure 1. Graph illustrates the estimated ERRs (± 1 SD) of death (1950–1997) from solid cancer among groups in the cohort of Japanese atomic bomb survivors who were exposed to low doses (<500 mSv) of radiation. Doses delivered with one full-body CT examination (15 mSv) (gray dot, left) and with a series of radiologic examinations (gray dot, right) have been indicated to show where standard radiologic examinations lie within the range of ERRs. The linear no-threshold principle linking effective dose to ERR is illustrated with a dashed line. (Adapted, with permission, from reference 12.)

range (>500 mSv). This is called the linear no-threshold hypothesis (1,10,11). However, even if the linear no-threshold hypothesis were valid and a study were conducted with a very large cohort, odds are that the result would be inconclusive because of the inherently large fluctuation in the control population.

For acute low-dose exposure, the cohort of Japanese atomic bomb survivors (exposed to a dose <500 mSv) provides the most reliable statistics on excess relative risk (ERR, expressed as a percentage) of mortality from solid cancers. This cohort has been studied since 1957, and results are regularly updated to improve the state of knowledge. Individuals in the low-dose category (5–50 mSv; mean, 20 mSv) showed a marginal increase in cancer mortality risk (ERR = 0.02, $P = .15$). It is significant that this dose range includes common radiologic examinations such as whole-body CT (Fig 1). A study of a wider dose range such as 5–125 mSv (mean, 34 mSv) yields a significant increase in solid cancer–related mortality (ERR = 0.025, $P = .025$) (1,7,10,11,13). It is obvious that these results must be interpreted with caution, however, since they were obtained in a population in which subpopulations (related to age in particular) are undoubtedly at greater or lesser risk than the average. For example, Doll and Wakeford (14) concluded that exposure of an embryo or fetus to a 10-mSv dose translated into a significant and quantifiable increase in the risk of childhood cancer of about 6% per sievert.

In addition to the study of Japanese atomic bomb survivors, other cohort analyses, including the U.S. scoliosis cohort study (15) and a study of nuclear plant workers (16), have been used to estimate ERR. Current results can be summarized as follows (7):

1. Significant excess risks of mortality from solid cancers have been demonstrated in humans exposed to low doses of radiation from x-rays or gamma rays such as those used in radiology. Between 10 and 50 mSv (acute exposure) can be delivered to the lung or breast during certain radiologic examinations such as *(a)* retrospective cardiac CT in adults (with which partially overlapping helical multidetector CT data are continuously acquired throughout the cardiac cycle while simultaneously recording the electrocardiographic data) or *(b)* standard abdominal CT in the pediatric population. Between 50 and 100 mSv (protracted exposure) might be received by a radiologist performing a large number of interventional procedures with fluoroscopic or CT guidance over his or her career.

2. Epidemiologic studies are unlikely to help quantify risks of mortality from solid cancers at exposures of less than 10 mSv. Thus, below this level, the risk of mortality remains hypothetic and the linear no-threshold relationship between dose and risk is considered the best practical criterion.

Teaching Point

Effective Dose

Concept

To assess the probability of health detriment from low doses of ionizing radiation (defined as the stochastic effects, in which the probability but not the severity of the effect depends on the dose), the International Commission on Radiation Protection (ICRP) proposed a theoretic quantity in 1975 that was first named effective dose equivalent and became known as effective dose in 1990 (1,17). This quantity takes the health risk (fatal and nonfatal cancers, taking into account the latency period as well as severe hereditary disorders) of a "standard" patient who is nonuniformly exposed to ionizing radiation and transposes it into a situation in which this patient would be uniformly exposed to a radiation field. This methodology is used for monitoring workers exposed to ionizing radiation.

The estimation of effective dose relies on data based on health detriments established for a population averaged over all ages and both genders. It is of note that effective dose cannot be measured and is obtained by computation whereby equivalent doses delivered to a defined number of organs are multiplied by tissue weighting factors that are regularly reassessed.

Determination

To simplify the assessment of effective dose in radiology (although its appropriateness might be questioned), easily measurable operational quantities have been defined over time for each radiologic technique. These quantities are initially very useful for optimizing procedures for a given modality. Moreover, they are representative of the dose delivered to the patient and can be used to estimate effective dose by means of specific conversion factors with the equation $E = OQ \times CF$, where E = effective dose, OQ = operational quantity, and CF = conversion factor.

Sets of conversion factors are also available for estimating individual organ doses from these operational quantities.

The assessment of conversion factors began more than 30 years ago. Methodologies for defining standard patients and ways of assessing organ doses have evolved from the use of tissue-equivalent plastic body phantoms containing organs, into which dosimeters could be inserted, to mathematic phantoms, for which Monte Carlo simulations are applied (18,19). The most common available standard includes an adult with a body mass of 70 kg; children aged 15, 10, and 5 years and 1 year; and newborns (both genders for all ages).

More realistic voxel phantoms are also being used. Nevertheless, it is important to always remember that the use of phantoms with patient-similar anatomy yields effective dose, not for a given patient, but for a phantom whose anatomy is representative of a "general" patient. In the future, this situation might improve with use of data obtained in the patient him- or herself, although uncertainty regarding the conversion factors, which take into account the radiosensitivity of individual organs, will remain high (20–23).

Conventional radiography is well standardized and, when an examination (eg, posteroanterior chest radiography, lateral lumbar spine radiography) is indicated, the geometry and the mean energy of exposure are quite precisely known. In such cases, a dose measurement at one particular point in the beam is sufficient to allow estimation of the dose to each organ and of the effective dose. The most common operational quantity,

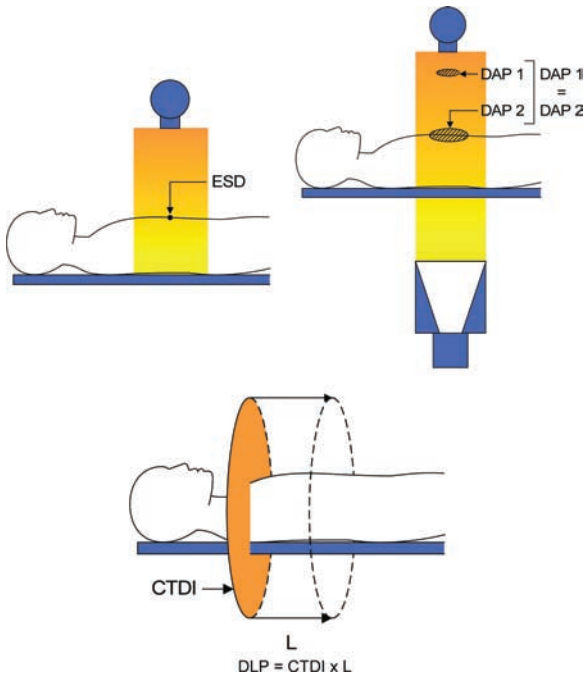

Figure 2. Drawings illustrate the dose indicators used in radiography (top left), fluoroscopy (top right), and CT (bottom). *CTDI* = CT dose index, *DAP* = dose-area product, *DLP* = dose-length product, *L* = scan length.

or dose indicator, for radiography is the entrance skin dose (Fig 2). It represents the absorbed dose to the skin at the point of entry of the x-ray beam and can easily be measured or estimated with a simple equation such as

$$\mathrm{ESD(mGy)} = 0.13\left(\frac{U}{100}\right)^2 Q\frac{1}{DFS^2},$$

where ESD = entrance skin dose, U = x-ray tube peak voltage (in kilovolts), Q = x-ray tube charge (in milliamperes), and DFS = distance from the focal spot of the x-ray tube to the point of entry of the x-ray beam.

With fluoroscopic examinations, the geometry of patient exposure is less predictable and varies during the procedure. Under such conditions, uncertainty as to effective dose will be higher than with conventional radiography. Patient dose in fluoroscopy is estimated with use of another operational quantity that measures the product of the dose, or preferably air kerma, and the surface of the beam at the point where the dose is measured. This dose indicator is the dose-area product (Fig 2). One advantage of this operational quantity is that it does not vary with the distance from the tube to the patient. Dose-area product is also sometimes referred to as kerma-area product, which (unfortunately) is expressed in various units such as gray–square centimeters or micro-

Table 1
Generic Entrance Skin Doses, Conversion Factors, and Effective Doses at Radiography in a Standard Adult Patient

Examination	Projection	Entrance Skin Dose (mGy)	Conversion Factor (mSv/mGy)	Effective Dose (mSv)
Chest	Posteroanterior	0.1	0.20	0.02
Abdomen	Anteroposterior	6.0	0.30	1.8
Abdomen	Posteroanterior	6.0	0.15	0.9
Lumbar spine	Posteroanterior	6.0	0.15	0.9
Lumbar spine	Lateral	20.0	0.03	0.6
Extremities	. . .	1.0	0.005	0.005

Source.—Adapted from reference 27.

Table 2
Generic Dose-Area Products, Conversion Factors, and Effective Doses at Angiography in a Standard Adult Patient

Examination*	Fluoroscopy time (min)	Dose-Area Product (Gy • cm^2)	Conversion Factor (mSv/Gy • cm^2)	Effective Dose (mSv)
Cerebrum	12	75	0.04	3.0
Coronary arteries	4	75	0.20	15.0
Abdomen	8	80	0.25	20.0
Lower limbs	6	50	0.10	5.0

Source.—Adapted from reference 27.
*Including image acquisition.

Table 3
Generic Dose-Length Products, Conversion Factors, and Effective Doses at CT in a Standard Adult Patient

Examination	Dose-Length Product (mGy • cm)	Conversion Factor (mSv/mGy • cm)	Effective Dose (mSv)
Head	1000	0.0023	2.3
Neck	400	0.0054	2.2
Chest	300	0.017	5.1
Abdomen-pelvis	500	0.015	8.0
Lower limbs (excluding pelvis)	500	0.0012	0.6

Sources.—References 21 and 32.

gray–square meters, so that care is required when comparing data. This dose indicator is easily measured by means of a transmission ion chamber located at the exit of the x-ray tube collimators. Some manufacturers prefer the estimation of dose-area product by means of computations based on the beam size and known exposure parameters of the fluoroscopy unit. Modern units indicate this quantity continuously during the procedure to provide radiologists a hint concerning the stochastic risks.

The fundamental radiation dose parameter in CT is the CT dose index (CTDI). It can be measured in air or in simple cylindric phantoms to be more representative of the average dose delivered to an area within the patient ($CTDI_{vol}$). To assess patient dose exposure after scanning a certain distance, one uses the dose-length product ($CTDI_{vol} \times$ scan length) (Fig 2). The dose-length product is indicated by the CT unit and is given in milligray–centimeters. This concept is very convenient for optimization purposes. However, as shown by several authors, it has serious limitations that might lead to the over- or underestimation of dose (24–26).

To help the reader estimate patient dose from standard examinations, Tables 1–3 provide sets of

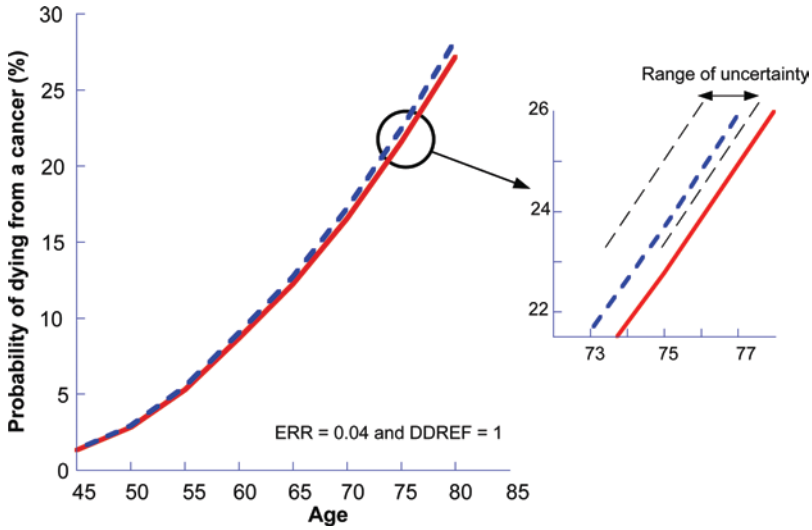

Figure 3. Graph (left) illustrates the natural risk (solid red line) of dying from cancer for a Caucasian male as a function of age. To this risk has been added the excess risk associated with radiologic examinations performed at age 40 years and delivering a total dose of 100 mSv (dashed blue line represents natural risk plus radiologic risk). Magnified view (right) more clearly depicts the impact of the radiologic examinations at age 75 years. An uncertainty of a factor of two has been applied in either direction to the radiation risk estimate, since the dose range involved is higher than that for a single examination. An additional risk can be observed by the age of 75 years (from 22.8% to 23.3–24.6%, representing an additional risk of 0.9%), but radiologic risk remains low compared with the natural risk of dying from cancer. (In this calculation, a dose and dose rate effectiveness factor [*DDREF*] of 1 has been assumed, corresponding to a conservative approach in which the absolute risk factor of dying from cancer is equal to 10% Sv^{-1}.)

generic conversion factors with average dose indicators applied to a standard adult patient. Many studies have focused on improving these conversion factors, but the sets of data shown in Tables 1–3 allow the reader to at least get an idea of the range of effective doses associated with a given examination.

Limitations

In 1990, a first revision of the organ weighting factors was made and led to a change from effective dose equivalent to effective dose (1,17).

In 2007, the ICRP recommended a new set of conversion factors based on continuing analysis of data mainly from the study of the cohort of Japanese atomic bomb survivors. With this new recommendation, the ICRP proposes the use of other tissue weighting factors that will modify the result of effective dose estimates (11,22).

Because of the continuous evolution of the conversion factors, the effective dose used to optimize a radiologic examination may fluctuate considerably. Therefore, it may be more appropriate to use the operational quantities rather than a quantity that is regularly updated.

Moreover, the definition of detriment assessment with the effective dose has been changed since 1990 (1) to the current recommendation (11). For example, the probability of radiation-induced cancer is now expressed in terms of prevalence rather than mortality rate per cancer. Other parameters such as lethality and nonlethal detriment, together with years of life lost, are also taken into account in the estimation of effective dose.

In addition to the aforementioned limitations of effective dose, there are known differences in

risk factors related to corpulence, age, and gender. Thus, it is clear that effective dose should not be used to infer the ERR of harm for a particular individual. According to the ICRP, effective dose is intended for use in the assessment of risks in general terms for radiation protection purposes. For instance, its use has been very efficient in optimizing the exposure doses received by workers at nuclear plants in France (28).

Nevertheless, within the framework of patient dose optimization, effective dose is increasingly being used in dealing with radiation exposure to patients. The basic concept of effective dose might be convenient for comparing the health detriments to a standard patient (body weight of 70 kg) associated with various radiologic procedures, to help balance the radiation-associated risks with the diagnostic information that can be obtained. But effective dose should not be given for a specific individual of known gender and age. This was recently reemphasized by C.J. Martin in an article showing that, even for a standard adult patient, the assessment of effective dose was associated with an uncertainty of ±40% for an 80%–90% confidence limit (22). When a specific patient is being considered, this uncertainty can increase drastically due to gender, age, size, and organ position (22).

Teaching Point

Radiologic Risk

Radiologic Risk versus Natural Cancer Risk

The main goal of assessing effective doses in radiology is to compare the radiologic risk of different modalities for a standard patient to balance patient dose with optimal image quality. Nevertheless, it is possible to infer from an effective dose an ERR for a hypothetic fatal cancer induction for a standard adult patient when effective doses are lower than 10 mSv or to infer a fatal cancer induction when effective doses are higher than, say, 10–50 mSv.

To do this, one can use the ERR for fatal cancer as a function of sex and age of the exposure data from the studies of the Japanese atomic bomb survivors reported by BEIR and UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) (1,4,29). When making the inference from the effective dose to cancer death, remember that cancer risk estimates have an uncertainty of a factor of two to three for an adult patient (the higher the dose, the lower the uncertainty). This means that the risk estimate might be two to three times higher or lower than expected. This uncertainty can be as high as a factor of five for a given patient (22).

Teaching Point

With this in mind, it might be interesting at this stage to estimate the total risk for fatal cancer (natural risk plus risk induced by radiologic examinations) of a standard patient who receives 100 mSv of radiation at age 40 years. This effective dose can be delivered with (for example) a combination of four whole-body CT scans (four 15-mSv doses), an abdominal angiogram (20 mSv), an angiogram of the coronary arteries (coronary angiography) (15 mSv), and an angiogram of the lower limbs (5 mSv). As shown in Figure 1, the ERR for fatal cancer is 0.04 for an exposure of 100 mSv. The corresponding absolute risk is calculated by multiplying this number by the natural risk of dying from cancer. The total risk of fatal cancer is then obtained by adding the absolute radiologic risk to the absolute natural risk. The results of these calculations are shown in Figure 3, in which the natural risk of death from cancer for an average white Caucasian adult male (30) is given as a function of age both without and with the radiologic exposures mentioned earlier. Over a lifetime, assuming the natural risk of dying from cancer to be 25%, the additional risk associated with an acute exposure of 100 mSv is 0.01 (0.04×0.25). This is a 1% risk, or 10% Sv^{-1}. In cases of low exposure, this is reduced by two dose and dose rate effectiveness factors, yielding the well-known absolute risk factor of 5% Sv^{-1}. Interestingly, during these examinations the absorbed dose delivered to the lung is roughly 70 mGy, a level that is clearly related to stochastic risks and no longer to a simple hypothetic risk. Indeed, considering the cancer risk factor for lung tissue at the age of 40 years (0.03% per 10 mGy), the risk of lung cancer induction is 0.2%.

Teaching Point

Very young children are three to four times more sensitive to ionizing radiation than are adults. To put their relative radiologic risks in perspective, an approach similar to that described earlier has been chosen for various levels of acute

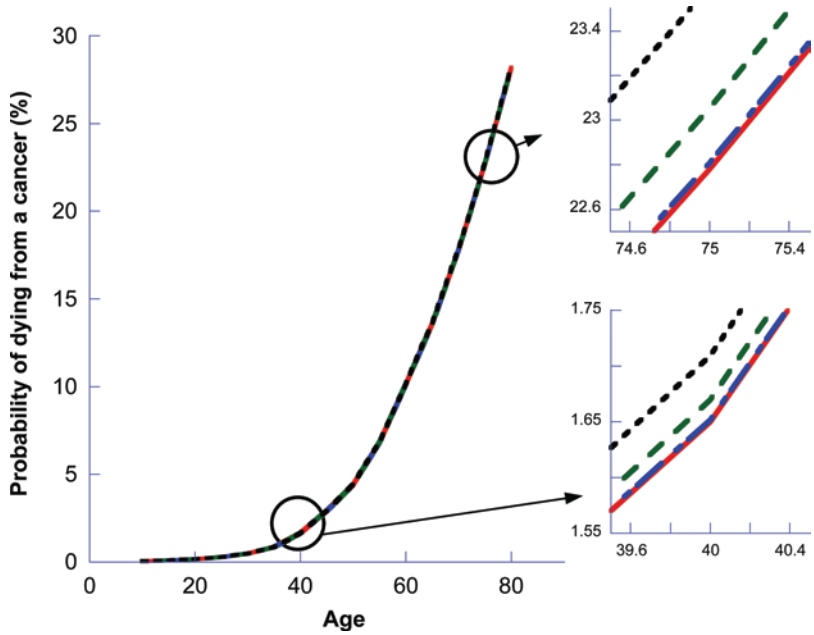

Figure 4. Graph (left) illustrates the natural risk (solid red line) of dying from cancer for a Caucasian male as a function of age. To this risk have been added the excess risks associated with radiologic examinations performed at age 5 years and delivering an effective dose of either 1, 10, or 30 mSv (dashed blue line represents natural risk plus risk at 1 mSv, dashed green line represents natural risk plus risk at 10 mSv, dashed black line represents natural risk plus risk at 30 mSv). Magnified views more clearly depict the impact of the radiologic examinations at ages 40 years (bottom right) and 75 years (top right).

Table 4
What to Tell Your Patients concerning Additional Risk of Death from Cancer

Effective Dose (mSv)	Risk	Quantification	Examination
<0.1	$<10^{-6}$	Negligible	Radiography of the chest (postero-anterior), extremities, or teeth
0.1–1.0	10^{-5}	Minimal or extremely low	Abdomen, lumbar spine
1.0–10	10^{-4}	Very low	CT of the brain, chest, or abdomen
10–100	10^{-3}	Low	Multiphase CT
>100	$>10^{-2}$	Moderate	Interventional procedures,* repeat CT

Sources.—References 10 and 22.
*Including the determinist effects of ionizing radiation (skin burns).

exposures assuming an absolute risk factor of 20% Sv^{-1} over a lifetime. We considered the following examinations performed at the age of 5 years: one abdominal radiograph (effective dose = 1.0 mSv) and two representative CT examinations (effective dose = 10 and 30 mSv, respectively). The results are shown in Figure 4, in which the impact of these examinations at ages 40 and 75 years are reported. Figure 4 helps confirm the fact that radiologic examinations add an almost negligible risk at age 40 years and a small risk at age 75 years (about 0.8% versus 22.8% for an effective dose of 30 mSv) to the natural risk of dying from cancer. In spite of this small additional risk, one should always remember the first two principles of radiation protection: The examination needs to be justified and then optimized. Because children have a long life expectancy, they may still benefit from radiologic examinations that will increase their risk. However, exposure of children to radiation without any clear benefit should be banned.

What to Tell a Patient concerning Radiologic Risk

Several studies have demonstrated the uncertainty associated with both the evaluation of effective dose and the inference from the effective dose to cancer risk (7,12,22,31). Furthermore, the use of values when discussing radiologic risk with a patient should be discouraged. Operational quantities and effective doses should be used only by professionals in the optimization of patient dose and image quality. Moreover, it seems rather

unwise to project a number of expected deaths from a radiologic examination applied to a given subset of the population, since this regularly and unnecessarily alerts the public to radiation risks. Thus, caution needs to be exercised. With regard to informing patients of the risk associated with a radiologic procedure, several groups propose simply using categories that would reflect the uncertainty associated with current knowledge and natural cancer prevalence. Table 4 summarizes the categories usually proposed. To aid in the understanding of risks mentioned in Table 4, it might be worth comparing them with the natural effective dose received by the general population (3–4 mSv/y) or with some common activities of everyday life that are generally considered to be acceptable. For instance, the risk of death associated with a flight of about 4500 miles (7200 km) falls in the "minimal risk" category ($\sim 4 \times 10^{-6}$), whereas the risk of death associated with a car drive of 2000 miles (3200 km) is in the "very low" category ($\sim 3 \times 10^{-5}$) (33).

Conclusions

From the data presented in Figures 3 and 4 and Table 4, it appears that the risk associated with a radiologic examination is rather low compared with the natural risk. However, it is important to remember that any added risk, however small, is not acceptable if it does not benefit the patient. Justification and optimization of a procedure are absolutely essential. Moreover, the concept of diagnostic reference levels should be used to reduce variations in practice from one center to another and to promote optimal dose indicator ranges for specific medical imaging protocols. Even if inferring a number of expected deaths from the effective dose is to be discouraged, it remains important to raise professional awareness of the danger associated with ionizing radiation. The basic principles of radiation protection need to be respected to help counteract the unjustified explosion in the number of procedures now being performed.

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Radiation Risk: What You Should Know to Tell Your Patient

Francis R. Verdun, PhD, et al

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Page 1808
To maintain statistical precision and power when assessing the risks associated with ionizing radiation, the required sample size should increase proportionately with the inverse square of the dose (7,10).

Page 1809
Epidemiologic studies are unlikely to help quantify risks of mortality from solid cancers at exposures of less than 10 mSv. Thus, below this level, the risk of mortality remains hypothetic and the linear no-threshold relationship between dose and risk is considered the best practical criterion.

Page 1813
But effective dose should not be given for a specific individual of known gender and age.

Page 1813
This means that the risk estimate might be two to three times higher or lower than expected. This uncertainty can be as high as a factor of five for a given patient (22).

Page 1813
In cases of low exposure, this is reduced by two dose and dose rate effectiveness factors, yielding the well-known absolute risk factor of 5% $Sv^{[-]1}$.

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