

RADIATION DOSIMETRY IN CT

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INTRODUCTION

It is the responsibility of each imaging professional to understand the benefit versus the risks of any procedure and attempt to maximize the positive and minimize the negative. The management of radiation dose and image quality in computed tomography (CT) have been matters of concern since the introduction of the first scanners into clinical practice in the early 1970s. However, they are especially important now in view of the increased number of clinical applications,¹ implementation of modern multidetector row CT (MDCT) technology,² proliferation of CT-guided procedures, early clinical trends toward screening studies,³ and the recent controversy concerning the connection between pediatric CT studies and an increased incidence of cancer.⁴

CT scanning is a relatively high-dose procedure that contributes disproportionately to the overall radiation dose from radiologic sources.⁵ According to the estimates of Mettler and coworkers, CT examinations represented approximately 11% of all diagnostic radiologic procedures but accounted for 67% of the effective dose from diagnostic radiology.⁵

The rational use of CT relative to patient care involves two components: appropriate patient selection and minimization of the radiation dose without compromising diagnostic image quality.⁶ During a recent panel discussion that included radiobiologists, physicists, and pediatric radiologists, it was estimated that 10% to 30% of studies ordered on pediatric patients were not necessary.⁷ In an effort to address the need for appropriate patient selection, the American College of Radiology has created guidelines that are widely available. My focus in this article will be on the second component of the rational use of CT, that is, strategies to minimize dose while maintaining image quality.

To understand how radiation dose to the patient can be reduced without sacrificing image quality, knowledge of the basic physics of CT is essential. Recent literature has

demonstrated the need for additional education for both technologists and radiologists regarding the basic physics associated with radiation dose.⁷⁻⁹ These researchers have outlined the general lack of understanding about the relationship between radiation dose and CT image quality, particularly the *uncoupling effect*. This effect makes CT physics somewhat different than that of conventional radiography. In conventional radiography, when the radiation dose is too high, the image obtained is too dark; therefore, the technique (mA or kVp) is adjusted. With digital technology, the image is *uncoupled* from the dose, so even when an mA or kVp setting that is too high is used, a good image results. This effect can make it difficult to identify when a dose that is higher than necessary is used. Another barrier to industry-wide understanding is that there is no consensus regarding a single expression of dose. Effective dose, organ dose, absorbed dose, multiple scan average dose, and CT dose index, among other measurements, have been discussed.

First, I will review the basic radiation dose concepts as they relate to CT. I will start with definitions of commonly used terms and then progress to a discussion of how dose is calculated in traditional axial studies. Using this knowledge as a background, I will discuss the effects of various technical CT factors on radiation dose. I will then conclude with a discussion of strategies for reducing dose while maintaining adequate image quality.

RADIATION DOSE CONCEPTS

A combination of factors unique to pediatric imaging has resulted in particular concern regarding the radiation dose delivered to infants and children during CT examinations. These special factors include the relative increased lifetime cancer risk of children compared with that of adults and higher organ doses due to their small sizes.¹⁰ A followup article specific to the radiation exposure in pediatric CT appears in the article, *Radiation Exposure to Pediatric Patients*, an article that can be found at CEWebSource.com.

MEASUREMENT TERMINOLOGY (BOX 1)

The ionizing radiation used in CT is an x-ray with maximum energy from 120 to 140 keV and an average energy near 70 keV. (Physicists measure the energies of

fast-moving particles like those in x-ray, cosmic rays and particle accelerators in units called electron volts (eV). An eV is the amount of energy that one electron gains when it is accelerated by an electrical potential of one volt. [A flashlight battery has about 1.5 volts.] $1\text{keV} = 1,000\text{ eV}$. The unit of x-ray exposure in air is the *roentgen* (R). When the x-rays from a CT scanner strike a patient and interact with tissue, most of the energy is absorbed, and some of it passes through to the detector.

The unit of absorbed dose is called the *radiation absorbed dose*, or *rad*. This unit describes the amount of energy absorbed per unit mass at a specific point. The *Système International* (SI) is a newer system that is used internationally. The SI unit of absorbed dose is the *gray* (Gy). There are 100 rad in 1 Gy. A centigray (cGy) equals 1 rad. In recognition of the health effects of x-ray, another conversion factor, called the *quality factor* (Q), is applied to the absorbed dose. This factor accounts for the different health effects produced from different types of ionizing radiation. The quality factor is 1 for the diagnostic x-rays that are used in CT. When the quality factor has been applied to the radiation absorbed dose, the new unit is the *rem*, or *radiation equivalent man*. The *Système International* equivalent unit is the *sievert* (Sv). There are 100 rem in 1 Sv. The rem and the Sv are terms used for radiation protection purposes and are typically used when discussing occupational exposure of the CT staff.

Another measurement, referred to as *effective dose*, or *effective dose equivalent*, attempts to account for the effects particular to the tissue that has absorbed the radiation dose. This unit is a weighted average of organ doses. The weighting factors are set for each radiosensitive organ in Publication 60 of the International Commission on Radiological Protection.¹¹ Effective dose is reported in Sv or rem. Although methods to calculate the effective dose have been established, they depend on the ability to estimate the dose to radiosensitive organs from the CT procedure. Unfortunately, determining the radiation dose to these organs is problematic and is a barrier to accurate calculation of the effective dose.¹²

Box 1. Radiation Dose Measurements

Roentgen (R): exposure in air

Radiation absorbed dose (rad): unit of absorbed dose

Gray (Gy): *Système International* (SI) $1\text{ cGy} = 1\text{ rad}$

Quality factor (Q): Accounts for different types of radiation

Radiation equivalent man (rem): Unit that represents quality factor being applied to rad

Sievert (Sv): SI unit for the rem

DOSE GEOMETRY



FIGURE 1. In conventional radiography the exit dose may be only 1% of the entrance dose.

In conventional film/screen radiography, the skin of the entrance plane receives 100% of the radiation, and the percentage falls rapidly as the x-ray beam is attenuated by the patient's tissue. By the time the beam exits the patient, most of the radiation has been absorbed or scattered (Figure 1). In conventional radiography, it is common for the exit dose to be only 1% (or 1/100th) that of the entrance dose.



FIGURE 2. Rotational Nature of CT Beam

In CT, the difference between the dose at the center and the dose at the periphery is not nearly as great as that of conventional radiography. In fact, in CT studies of the head, the dose to the skin is close to that in the center of the slice. The dose is more uniform in CT than in general radiography for two reasons. First, in CT, the beam is heavily filtered as it exits the x-ray tube. This means that fewer low-energy (or "soft") photons remain. Because the beam is "harder" than that used in conventional radiography, a lower percentage of the beam will be absorbed or scattered as it passes through patient tissue. In addition, the CT exposure comes from all directions, creating a more uniform exposure (Figure 2).

The uniformity of the dose decreases as the scan field of view and patient thickness increase. Therefore, body scans are less uniform than head scans. The central dose for a body scan is usually approximately one-third that of the peripheral dose. To a great degree, this phenomenon accounts for the fact that, for a given set of machine parameters (mAs, slice thickness, pitch), organ doses are clearly higher for children compared to (larger) adults. To elaborate, consider an organ located on the proximal side of the body relative to the x-ray source. This organ will get roughly the same dose in both adult and child. As the x-ray source rotates, that

same organ will be on the distal side of the body relative to the x-ray source; now that organ is partly shielded by the body tissue proximal to it, reducing the organ dose. But this dose-reducing, partial shielding will be much less for a thin individual, such as a child, compared to a thicker adult. Thus, organ doses for children are larger than those for adults.¹⁰

Z AXIS VARIATIONS

In addition to the variations within the scan plane, variations along the length, or *Z axis*, of the patient, are described by the *Z axis dose distribution* (or *radiation profile*). To understand this concept, let us first look at a traditional axial scan sequence (a full gantry rotation at one table position) with contiguous slices (slice thickness is equal to the table increment; therefore, no overlapping slices, no gapped slices). If there were no scatter radiation, the exposure would be equal throughout the study. For the sake of illustration, let's assume that there is no scatter inherent in CT. In this case, if a single CT slice delivered a dose of 1 cGy, then the total exposure from a 30-slice CT examination that was performed with contiguous slices would also deliver 1 cGy. This would be true because no area of the patient is exposed more than once.

In reality, there is some scatter inherent in CT. However, it is important to recognize that, although there is some radiation that is scattered, the overall amount is very low, and the distance it travels is quite short, particularly when compared to conventional radiography. In this discussion of scatter, we are considering scatter that affects adjacent slices. Therefore, we are referring to a distance of only 1 to 10 millimeters.¹³ In CT, the amount of scatter that travels greater distances, such as to the door of the scan room, is almost non-existent. However, to accurately assess the *z axis* dose distribution, the dose to a single slice must be added to the radiation that scatters into adjacent slices.

Figure 3 represents an ideal slice with no scatter. In this ideal situation, all the radiation falls within the designated slice. However, this is not the case in reality, because there is some scatter in CT. Because of this scatter, some of the radiation spreads to tissue outside the designated slice. Figure 4 represents a true slice profile. The areas of scatter into adjacent tissue are sometimes called *tails*. Figure 5 represents a slice profile that results from multiple scans.

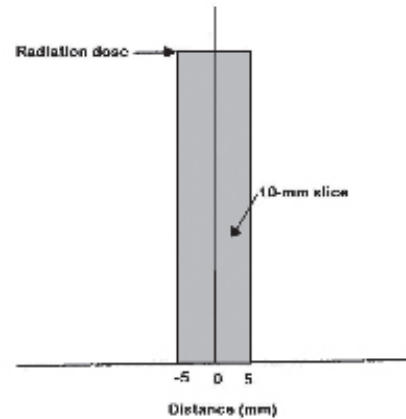


FIGURE 3. Ideal radiation profile, if no scatter radiation existed.

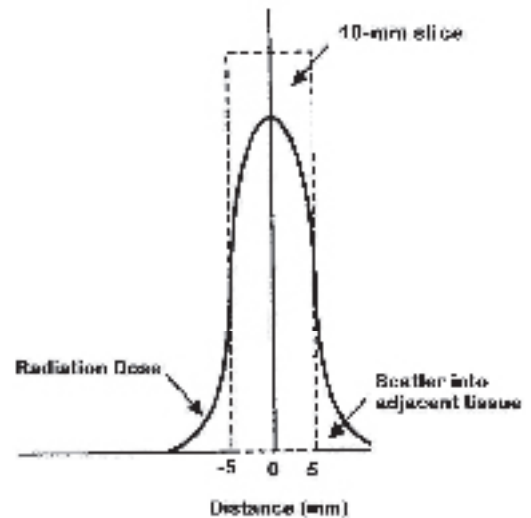


FIGURE 4. Actual profile since radiation spreads to tissue outside the designated slice due to scatter.

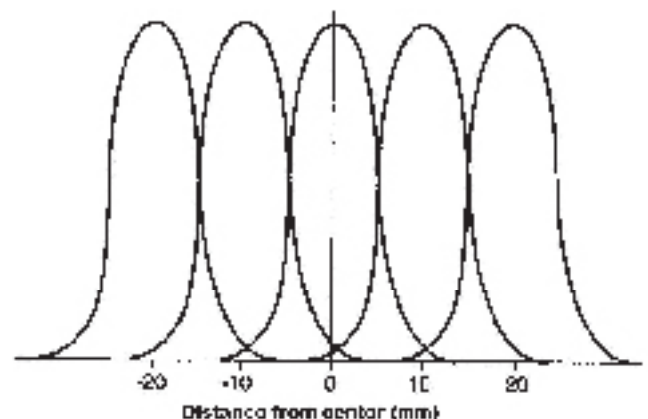


FIGURE 5. The radiation dose from multiple scans accounts for scatter overlap from each neighboring slice to the radiation dose of the central slice.

As illustrated, the total dose will be higher when multiple scans are performed. How much the scatter will contribute to the dose depends on factors such as patient size and physical makeup and the kVp used. In general, the tails will contribute approximately 25% additional dose to the entire study. Therefore, if a single slice of the chest delivered a dose of 4 cGy, the entire dose from 30 contiguous slices is approximately 5 cGy (ie, 4 cGy + 1 cGy). As compared with the dose from a single slice, the overall radiation dose will be higher when multiple scans are performed.

Box 2. Calculating Exposure from Multiple Slices

Single slice dose + amount scattered = total exposure

Multiple scan average dose (MSAD): dose calculated from multiple scans

Computed tomography dose index (CTDI): dose reported to the FDA; slices must be contiguous

When there is no overlap or gap between slices, the MSAD equals the CTDI

Because most CT applications involve multiple scans with adjacent slices, dose is usually calculated from multiple scans. Measurements are made at the center of the slice and several points around the periphery with plastic phantoms. This procedure accounts for the effect of scatter from the tails of each slice into the neighboring slices. Again, total dose is the central slice radiation dose, plus the scatter overlap (or tails). This is called the multiple scan average dose (MSAD). The MSAD will increase if slices overlap and decrease if there are gaps between slices (Box 2).

Another type of radiation dose measurement in CT is the computed tomography dose index (CTDI). The CTDI is what manufacturers report to the Food and Drug Administration (FDA) and prospective customers regarding the doses typically delivered for their machines. The CTDI can only be calculated if slices are contiguous, that is, there is no overlapping or gapped slices. If there is slice overlap or gaps, the CTDI is multiplied by the ratio of slice thickness to slice increment. This would technically be the MSAD, because the CTDI conditions would no longer exist. Equipment manufacturers report CTDI doses for typical head and body imaging techniques. These are equivalent to the dose a patient receives if multiple scans are taken.

In an effort to expand the use of CTDI to scans with variable parameters, such as slice thickness and pitch, other indices were created. The $CTDI_{100}$ allows for a scan sequence longer along the Z axis than the original CTDI permitted, whereas the $CTDI_{vol}$ accounts for the variable pitches commonly used in helical scan sequences.

COMPARISON OF DOSE FROM CT WITH DOSE FROM CONVENTIONAL RADIOGRAPHIC STUDIES

Because the modalities are significantly different, a simple comparison between doses delivered from CT and film/screen radiography cannot be conducted. These two imaging modalities are significantly different in principle and purpose and also have different imaging requirements. However, it is important for technologists to have a general idea of the dose being delivered to the patient and how it relates to other modalities.

CT is an excellent low-contrast discriminator because of detector dynamics and the precision in calculating the linear attenuation of each pixel. Film/screen systems are inferior in their low-contrast sensitivity. Film is unable to discriminate objects that have less than 10% contrast with their background material. Conversely, CT can typically resolve and display visual differences between small objects that have only a minimal difference in density, as little as 0.1% to 0.5%. This capability allows visualization of soft tissue masses that are not seen with film/screen systems. However, there is a price to be paid to produce good low-contrast images. An adequate radiation dose, or photons per pixel, must be provided to suppress image noise. As a result, the radiation dose for CT examinations is substantially higher when compared with film/screen radiography (Table 1).

Table 1. Approximate Dose Comparison Between General Radiography and CT

General Radiography	Computed Tomography
AP abdomen	Abdominal study
Surface dose = 0.3-0.6 cGy	Surface dose = 2-4 cGy
Central dose = 0.03-0.01 cGy	Central dose = 1-2 cGy

In this example given in Table 1, the skin (surface) dose is approximately 10 times higher in CT, and the average absorbed dose (ie, central dose) is approximately 100 times higher. Special procedures such as angiography and interventional radiography may produce radiation doses near or exceeding those from CT. Actual doses are highly variable and are affected by many factors, including type and manufacturer of scanner.

FACTORS AFFECTING DOSE

Radiation Beam Geometry. Theoretically, a rotation arc of only 180 degrees is all that is required to satisfy most construction algorithms. Most scanners employ a 360-degree tube arc to compensate for radiation beam divergence and patient motion. The extra scanning information improves image quality but increases radiation dose.

Additionally, *overscanning*, which is the process of using more than a 360-degree tube arc, is sometimes used—particularly in fourth-generation CT systems. Overscans will increase the radiation dose.

Filtration. Filtration affects the radiation dose by removing some of the soft (ie, low-energy)

X-rays. These low-energy x-rays are quickly absorbed by the patient. Photons are needed to penetrate the patient and strike the detectors, but some of them must be absorbed to produce radiographic contrast. Adding metal filters to the beam permits selective removal of x-rays with low-energy and reduces the radiation dose while maintaining contrast at an acceptable level.

Detector Efficiency. Detector efficiency affects radiation dose to the patient. Less efficient detectors will require a higher radiation exposure to produce an adequate image. Solid-state detectors are from 90% to 100% efficient, while the xenon gas detectors used in older model scanners are significantly less efficient.

Slice Width and Spacing. As slice thickness increases, the volume of tissue irradiated increases, and the dose may increase slightly in the slice. However, for multiple slice examinations, decreasing slice thickness and using contiguous slices will increase the MSAD because of the increased amount of scatter radiation to adjacent slices. Also, to maintain image quality at the same level, additional radiation is needed for thinner slices. Multiple slice examinations using overlapping slices will produce a higher overall dose, whereas gapped slices will produce a lower overall dose.

Although the effects of beam collimation are small for single-detector row scanners, that is not the case with MDCT. Reports from studies of early versions of MDCT systems revealed a significant dependence on x-ray beam collimation.¹⁴ These effects result from differences in x-ray beam collimation—even when the same reconstructed section thickness is used.

Pitch. The spacing of CT slices obtained with a helical (or spiral) scan process is called pitch. The pitch is defined as the table distance traveled in one 360-degree rotation divided by the collimated width of the x-ray beam. For a single-slice helical CT, a pitch of 1:0 means that the slices are adjacent and not overlapped. Helical scans performed with a pitch of 1 deliver approximately the same dose as that of conventional axial CT studies—provided the kVp and mAs values are the same for each mode. Selecting a pitch greater than 1:0 will spread the radiation more thinly over the slices. That is, although there are no areas along the Z axis that are skipped completely, the gantry will not make a full rotation in a given slice location. The pitch has a direct influence on patient radiation dose because as pitch increases, the time that any one point in space spends in the x-ray beam is decreased. Table 2 shows the relationship between radiation dose and various pitch selections. The values presented in Table 2 represent variations in pitch with all other technical parameters held constant

on a single-detector row CT scanner.

TABLE 2. ^{*†} *Changes in CTDI_{vol} in Head and Body Phantoms as a Function of Pitch*

Pitch	CTDI _{vol} in Head Phantom (mGy)	CTDI _{vol} in Body Phantom (mGy)
0.5	80	36
0.75	53	24
1.0	40	18
1.5	27	12
2.0	20	9

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†Note: All other factors were held constant at 120 kVp, 300 mA, 1 sec, and 10 mm. Results are from a single-detector row CT scanner.

For MDCT scanners, the pitch values must be interpreted differently.¹⁴ For example, the table may be incremented 30.0 mm to image several simultaneous 10-mm slices; though, if the CT system collimates the x-ray beam for four 10-mm slices simultaneously (effective pitch, 0.75), there is an overlap of irradiated tissue. However, MDCT scanners typically have several modes that allow the technologist to select whether to overlap slices or extend the pitch. Generally, the radiation doses to patients are approximately 30% to 50% greater with earlier models of MDCT, primarily as a result of scan overlap, positioning of the x-ray tube closer to the patient, and possible increased scattered radiation with wider x-ray beams.¹⁵ Table 3 shows the results when the collimation is changed while all other parameters are held constant.

Table 3. ^{*†} *Changes in CTDI_{vol} in Head and Body Phantoms as a Function of Collimation for an MDCT Scanner*

Collimation (mm)	Total Beam Width (mm)	CTDI _{vol} in Head Phantom (mGy)	CTDI _{vol} in Body Phantom (mGy)
4 x 1.25	5	62	33
2 x 2.5	5	62	33
1 x 5	5	62	33
4 x 2.5	10	46	24
2 x 5	10	46	24
4 x 5	20	40	20

*Reprinted with permission from McNitt-Gray MF. AAPM/RSNA physics tutorial for residents: Topics in CT. Radiation dose in CT. *RadioGraphics*. 2002;22:1541-53.

†Note: All other factors were held constant at 120 kVp, 300 mA, 1 sec, and 10 mm. Results are from a multidetector row CT scanner.

Scan Field Diameter. As mentioned earlier, the scan field diameter affects the dose. Phantoms are frequently used to measure radiation dose. Phantoms of two diameters—16 and 32 cm—are used to simulate head and body scans, respectively. Each of the phantoms is created from the same material that is designed to simulate soft tissue. Holding all technical factors constant, a scan of the head phantom will result in a higher radiation dose than that of the body phantom. This is demonstrated by the data in Tables 2 and 3, wherein the same technical factors were used for each phantom. Therefore, the primary difference in results between the head and body phantoms is size. Each of the tables shows that the smaller object always absorbs the higher dose and that the difference is at least a factor of two. Thus, smaller patients would be expected to absorb much higher amounts of radiation than larger patients.

This effect is primarily attributed to the fact that total exposure is made up of both entrance radiation and exit radiation. For smaller patients, the patient has less tissue to attenuate the beam, which results in a much more uniform dose distribution. Conversely, for a larger patient, the exit radiation is much less intense due to its attenuation through more tissue.

Radiographic technique. As in general radiography, the technique used to create the CT image affects radiation exposure to the patient. The higher the mAs and kVp settings used to create the image, the higher the dose to the patient.

The relationship between mAs and dose is linear. That is, if the mAs settings were doubled, the doses and risks would be doubled. Likewise, if the mAs settings were halved, the doses—and therefore the risks—would be halved. However, a reduction in dose is associated with a subsequent increase in image noise. For example, first assume that the minimum dose to obtain acceptable image quality has been determined. If this dose is halved by halving the mAs, a noise increase of 41% can be expected.¹²

X-ray tube potential (or kVp) also affects the radiation dose, although the affect is not linear. With the mAs kept constant, changing from 120 kVp to 140 kVp increases the radiation dose approximately 30% to 45%.

Patient Size and Body Part Thickness. Large patients or thick body parts require radiographic techniques that increase the radiation dose in order to avoid an unacceptable level of image noise. In addition, the patient size and body composition may affect the degree of scatter radiation.

Repeat Scans. Areas of the patient that are rescanned to visualize various stages of intravenous contrast enhancement or for other technical or clinical reasons receive additional radiation. The effect is cumulative.

Collimation. Lead collimators are used near the x-ray tube to control the size of the beam striking the patient. If the beam were not controlled to match the detector size, there would be additional scatter radiation to degrade the

image; this scenario would result in a higher radiation dose to the patient. Collimators may also be used near the detectors for scatter rejection and aperture use.

Localization Scans. The localization scan performed before scanning, which is often referred to as the *scout image*, delivers a very low dose. The radiation dose for the scout image is much lower than that used to produce cross-sectional slices.

STRATEGIES FOR REDUCING DOSE

In 2001, Brenner and coworkers⁴ created quite a stir in the field by reporting on the potential implications of radiation doses received by children undergoing CT. Since that time, strategies have been suggested for reducing the dose to pediatric patients, and many practices have incorporated these recommendations into their pediatric CT protocols.

More and more evidence has appeared in the radiology literature that concludes that, in many circumstances, CT exposure doses could also be significantly reduced in adults.^{3,16,17} Because a combination of factors is responsible for the total radiation dose delivered to the patient during a CT examination, a variety of methods for reducing dose are available. The following options can be used in any combination according to the specific clinical situation. Ideally, appropriate strategies are chosen and used in conjunction to reduce the dose as much as possible without sacrificing the image quality necessary to answer the clinical questions posed.

ADJUSTING mAs

At this point in the discussion of radiation dose, the need to adjust mAs to suit individual patient size should be apparent. Small bodies require a lesser dose, and large bodies require a greater dose. Numerous authors have documented the ability to adjust mAs, and therefore dose, without compromising image quality.¹⁸⁻²⁰ Although some researchers have used the patient's weight to adjust mAs,¹⁸⁻²⁰ others prefer using the diameter of the patient to determine optimal mAs setting.⁷ Both approaches have proved successful.

AVOID INCREASING kVp

Increasing the x-ray tube potential increases both the radiation dose and penetration of the x-rays through the body. In general, increases beyond 120 kVp should be avoided.¹⁵ However, an increase in kVp could be accompanied by a reduction in tube current to offset the increased dose.

INCREASED PITCH

Another useful method for reducing radiation dose with helical scanning is to increase the pitch of the examination. Vade and coworkers²¹ showed that increasing the pitch from 1.0 to 1.5 decreased the dose by 33% without any apparent loss of diagnostic information.

LIMIT THE USE OF THIN SLICES

Using a large number of thin adjacent CT slices results in 30% to 50% more radiation dose to the patient than using fewer thicker slices to scan the same anatomy.^{15,22} Although it is not always possible to avoid using thin slices, technologists and radiologists should be aware of the consequences.

LIMIT REPEAT SCANS

Because the effects of repeat scans of the same area are cumulative, redundant or multiphase studies should be performed only when clinically indicated. Numerous authors have shown that detection of liver lesions can be improved by multiple scans taken during different phases of contrast injection. Although multiphase studies are clearly indicated to evaluate for liver abnormalities, they should not be done in all circumstances.⁷ Additionally, it has been recommended that triple-phase studies for the evaluation of kidney lesions be reserved for patients in whom a question arises on a routine study or other examination rather than as a standard protocol.⁷

EQUIPMENT OPTIONS

Manufacturers have recently provided users with another method to reduce patient dose. Newer systems may have an option that will make changes in tube current (mA) based on the estimated attenuation of the patient at a specific location. The estimations are derived from scout views done in both the anteroposterior and lateral projections. From these views, the mA will be programmed to vary by location along the length of the patient. The exact details of the option vary by manufacturer.

CONCLUSION

CT technology has revolutionized healthcare. The role and use of CT continue to expand, reinforcing the need for technologists to stay current in methods that will reduce potential risk to the patient. Understanding the terminology associated with radiation exposure as well as the factors that contribute to dose will allow technologists and radiologists to make wise choices in their clinical practices.

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RADIATION DOSIMETRY IN CT POST TEST

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1. **When looking at the overall radiation dose from radiologic sources, CT contributes**
 - a. a very low percentage of the total.
 - b. a proportional amount—that is, CT examinations represent approximately 11% of all diagnostic procedures and account for approximately 11% of the total dose.
 - c. a disproportionately high percentage of the total.
 - d. nearly 95% of the total.
2. **The rational use of CT involves which two key components?**
 - a. Halving the mAs and doubling the kVp
 - b. Eliminating most pediatric examinations and requiring a second physician's opinion to order adult examinations
 - c. Reducing the use of spiral scanning and increasing the frequency of visits by physicists to assess radiation dose delivered
 - d. Appropriate selection of patients and the minimization of the radiation dose without compromising diagnostic quality
3. **The uncoupling effect**
 - a. occurs with CT digital technology and refers to the fact that the relationship between dose and image quality is less direct than in conventional radiography.
 - b. occurs only in CT and refers to the process of changing pitch.
 - c. refers to the process in conventional radiography in which the appropriate dose creates the proper film darkening; that is, too high a dose will create an image that is too dark, whereas too low a dose will result in an image that is too light.
 - d. refers to the lack of a relationship, in CT, between patient size and radiation dose.
4. **Which unit universally expresses dose?**
 - a. Effective dose
 - b. Organ dose
 - c. computed tomography dose index (CTDI).
 - d. there is no consensus regarding an expression of dose, and many units have been used.
5. **The unit of exposure in air is the**
 - a. roentgen (R).
 - b. radiation absorbed dose (rad).
 - c. gray (Gy).
 - d. sievert (Sv).
6. **The unit of absorbed dose is the**
 - a. roentgen (R).
 - b. radiation absorbed dose (rad) or gray (Gy).
 - c. computed tomography dose index (CTDI).
 - d. multiple scan average dose (MSAD).
7. **The Système International (SI)**
 1. is used internationally.
 2. replaces the unit known as the rad
 3. replaces the unit known as the rem.
 - a. 1 only
 - b. 1 and 2
 - c. 1 and 3
 - d. 1, 2, and 3
8. **The quality factor (Q) is used to**
 - a. account for the different health effects produced from different types of ionizing radiation.
 - b. account for the pitch in helical CT.
 - c. describe exposure from scatter radiation.
 - d. convert older units to SI units.
9. **The term often used when describing the occupational exposure of the CT staff is the**
 - a. roentgen (R).
 - b. radiation absorbed dose (rad).
 - c. sievert (Sv).
 - d. multiple scan average dose (MSAD).
10. **Which of the following statements is TRUE concerning the measurement referred to as effective dose?**
 - a. It is measured in rad or Gy.
 - b. It is a weighted average of organ doses.
 - c. There is no agreement on the weighting factors to be applied to each radiosensitive organ.
 - d. It is relatively easy to calculate accurately and is therefore used universally.
11. **Which is of the following is TRUE concerning CT dose uniformity?**
 - a. Uniformity of dose increases as the scan field of view and patient thickness increase.
 - b. The dose in body scans is more uniform than that of head scans.
 - c. The peripheral dose, or skin dose, of a body scan is approximately three times higher than the central dose.
 - d. Compared with children, adults can be expected to receive a more uniform dose.
12. **The areas of scatter into adjacent tissue are sometimes called**
 - a. tails.
 - b. overflow.
 - c. excess.
 - d. collimation.
13. **Which units of dose account for that fact that most applications of CT involve multiple scans?**
 - a. MSAD or CTDI
 - b. Sv or rem
 - c. mAs and kVp
 - d. R
14. **Radiation dose is higher in CT than conventional radiography due to the**
 - a. goal of producing images with good high-contrast detectability.

- b. goal of producing images with good low-contrast sensitivity.
 - c. fact that the distance between the x-ray tube and the detectors is much greater than between the x-ray tube and the film.
 - d. lower kVp setting used in CT.
- 15. The spacing of CT slices with a helical scan process is known as**
- a. filtration.
 - b. algorithm.
 - c. reconstruction.
 - d. pitch.
- 16. The relationship between mAs and dose is**
- a. inversely proportional: the higher the mAs, the lower the dose.
 - b. linear; the higher the mAs, the higher the dose.
 - c. represented by the equation: $\text{dose} = 1/\sqrt{\text{mAs}}$
 - d. highly variable and impossible to quantify.
- 17. Increasing the pitch from 1.0 to 1.5 will have what effect on the dose?**
- a. An increase in dose of approximately 20%
 - b. No effect
 - c. A decrease in dose of approximately 8%
 - d. A decrease in dose of approximately 33%
- 18. Compared to using wider slices, using a large number of thin adjacent slices results in**
- a. 5-10% less radiation dose to the patient.
 - b. 15-20% less radiation dose to the patient.
 - c. decreased image quality due to the partial volume effect.
 - d. 30-50% percent more radiation dose to the patient.
- 19. Some newer CT systems may have an option that will adjust tube current based on**
- a. the operator's selection of desired dose.
 - b. published tables of the average dose necessary to examine a specific anatomic area.
 - c. the estimated attenuation of the patient at a specific location.
 - d. previous scans of the patient.
- 20. Which of the following are strategies that may reduce the radiation dose to the patient?**
- 1. Adjusting mAs to suit individual patient size
 - 2. Avoiding increased kVp beyond 120
 - 3. Increasing pitch
 - 4. Performing multiphase studies only when clinical indications exist
- a. 1 and 2
 - b. 1 and 3
 - c. 2 and 4
 - d. 1, 2, 3, and 4



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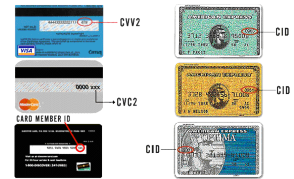
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