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CT radiation: key concepts for gentle and wise use

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CT Radiation: Key Concepts for Gentle and Wise Use

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Use of computed tomography (CT) in medicine comes with the responsibility of its appropriate (wise) and safe (gentle) application to obtain required diagnostic information with the lowest possible dose of radiation. CT provides useful information that may not be available with other imaging modalities in many clinical situations in children and adults. Inappropriate or excessive use of CT should be avoided, especially if required information can be obtained in an accurate and time-efficient manner with other modalities that require a lower radiation dose, or non–radiation-based imaging modalities such as ultrasonography and magnetic resonance imaging. In addition to appropriate use of CT, the radiology community also must monitor scanning practices and protocols. When appropriate, high-contrast regions and lesions should be scanned with reduced dose, but overly zealous dose reduction should be avoided for assessment of low-contrast lesions. Patients’ cross-sectional body size should be taken into account to deliver lower radiation dose to smaller patients and children. Wise use of CT scanning with gentle application of radiation dose can help maximize the diagnostic value of CT, as well as address concerns about potential risks of radiation. In this article, key concepts in CT radiation dose are reviewed, including CT dose descriptors; radiation doses from CT procedures; and factors and technologies that affect radiation dose and image quality, including their use in creating dose-saving protocols. Also discussed are the contributions of radiation awareness campaigns such as the Image Gently and Image Wisely campaigns and the American College of Radiology Dose Index Registry initiatives.

Introduction

Technologic innovations in computed tomography (CT), including helical and multi–detector row capabilities, have expanded the applications of CT in modern medicine (1–3). Use of CT has increased substantially in recent years, with approximately 70 million CT examinations performed annually in the United States (1). Abdominal, head, and chest CT examinations represent the majority of CT procedures. CT examinations represent about 17% of radiation-based medical procedures but contribute approximately 49% of the medical radiation dose to the population as a whole (2).

Despite concerns about the potential risks of radiation at CT, in appropriate clinical settings CT provides information vital to accurate clinical diagnosis and patient care (1,3). Technologic advances have led to the introduction of many factors that can complicate scanning protocols but are crucial to optimize the technology and tailor examinations to clinical indications, body regions, and body sizes (4–7). Throughout this article, unless specified otherwise, when we mention size we are referring to the cross-sectional area.
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of the patient in the scanned region. Automatic exposure control (AEC), automatic voltage selection, and iterative reconstruction (IR) techniques are examples of factors that affect image quality and associated radiation dose.

In this article, we address key aspects of CT radiation dose as outlined in the American Board of Radiology Core Quality and Safety Study Guide (8). These include CT dose descriptors; radiation doses for CT procedures; and factors and technology that affect radiation dose and image quality, as well as the use of these factors in creating dose-saving protocols. Radiation awareness campaigns including Image Gently and Image Wisely and the American College of Radiology (ACR) Dose Index Registry initiative are discussed.

Radiation Risks

Radiation exposure has received much attention in both the medical literature and the lay media. This attention has focused, in part, on a number of highly publicized events in which radiation exposure from improperly performed CT perfusion examinations led to the deterministic effects of skin erythema and hair loss (9,10). It is important, however, to distinguish medical errors from properly performed examinations with dose levels that are well below these deterministic effect thresholds.

Controversy over the shape of the dose-response curve linking cancer risk to the radiation doses used at diagnostic imaging is ongoing (11,12). Cancer data from the survivors of the atomic bombs at Hiroshima and Nagasaki, Japan, show a statistically significant increase in cancer incidence for one-time acute exposure of 50–100 mSv or greater, yet most diagnostic imaging examinations (including CT) impart patient doses well below 20 mSv (with the possible exception of multiphasic scanning of the torso) (13). There is debate about how best to incorporate the atomic bomb risk data into low-dose risk models. Some practitioners believe that there likely is a threshold dose below which there is no lasting effect (the linear threshold model) or even that low levels of radiation are protective (the hormesis model). In the absence of definitive data linking low-dose radiation to cancer induction, however, most organizations have adopted a linear no-threshold model such as that used in the seventh report of the Biologic Effects of Ionizing Radiation (BEIR) study (BEIR VII), in which doubling the radiation exposure is assumed to double the associated cancer risk (14). As shown in Figure 1, this model shows that for the same x-ray exposure, risks are expected to be higher for young patients, likely because cell division is more active in young people, and their life expectancy after the exposure is longer (14). These facts highlight the need to image gently in younger patients. Female patients are also thought to be at higher risk for a given exposure, due in part to risks of breast, ovarian, and uterine cancer, as well as to an increased risk of lung and thyroid cancer without a clearly understood biologic basis.

A large amount of radiation exposure data linked to eventual cancer outcomes is needed to test the cancer risks of diagnostic imaging directly (13). The fundamental epidemiologic challenge is to detect a small incremental increase in the 42% baseline lifetime rate of cancer in the U.S. population. Large-scale epidemiologic studies to date have been focused primarily on pediatric cancer risks, and in these populations researchers generally have found cancer risks of a magnitude similar to those predicted by downward extrapolation of the atomic bomb data by using linear no-threshold models (15–18). However, fundamental questions remain as to whether the identified risk increases are real or related to issues such as reverse causation, indication bias, or predisposing patient factors (19–21).

Although the absolute risk of performing CT is not definitively known, radiologists, physicists, technologists, and CT technology manufacturers must optimize available technology to reduce the potential risks from ionizing radiation while maintaining the ability to perform high-quality imaging that allows clinical questions to be answered. We believe that it is prudent to adhere to the “as low as reasonably achievable,” or ALARA, principle when performing medical imaging.

**Units of Radiation**

**Dose and Metrics Used at CT**

Absorbed dose (also referred to as organ dose) is the energy absorbed by tissue divided by the tissue mass. It is measured in grays (grays =
joules per kilogram). CT radiation outputs are described by using the volume CT dose index \( (\text{CTDI}_{\text{vol}}) \) expressed in milligrays) and dose-length product \( (\text{DLP}) \) expressed in milligray-centimeters \((22,23)\). \( \text{CTDI}_{\text{vol}} \) is calculated on the basis of measurements made in standard plastic (polymethyl methacrylate) 16-cm head or 32-cm body phantoms to quantify the x-ray tube output emitted by the scanner. \( \text{CTDI}_{\text{vol}} \) is an estimate of average x-ray tube output from an acquired CT image series, and \( \text{DLP} \) is the total x-ray tube output integrated throughout the entire scan, which is obtained by multiplying \( \text{CTDI}_{\text{vol}} \) by the scanned length (in centimeters) of the patient. Both \( \text{CTDI}_{\text{vol}} \) and \( \text{DLP} \) can be used for comparison of different CT protocols and scanners. Anticipated values of these technique descriptors are displayed on the user interface of the scanner before acquisition of the CT data (with more accurate performed values reported after the scan when AEC is used), thus providing to the technologist an estimate of scanner output before the patient undergoes imaging. Recently, a “CT dose alert” feature, which allows users to set certain \( \text{CTDI}_{\text{vol}} \) values to enable the scanner to alert the user if a specified limit is exceeded, has been introduced in scanners.

The dose information page and structured Digital Imaging and Communications in Medicine, or DICOM, report available on most CT scanners tabulate \( \text{CTDI}_{\text{vol}} \) and \( \text{DLP} \) for each acquired CT series, and can be used for quality assurance when reviewing scans on a picture archiving and communication system, or PACS, or for subsequent data capture for large-scale dose monitoring efforts \((24)\). These metrics represent scanner x-ray tube output and not patient dose \((25)\). For example, at any given \( \text{CTDI}_{\text{vol}} \) value for the same diameter phantom, organ doses are substantially larger for small patients than for large patients, in whom many of the incident x-rays are blocked in the peripheral soft tissues and thus do not deposit energy in the centrally positioned, more radiation-sensitive organs \((26)\).

A recent report from the American Association of Physicists in Medicine (AAPM) defined a relatively new metric, the size-specific dose estimate \( (\text{SSDE}) \), which is calculated by adjusting (or normalizing) the \( \text{CTDI}_{\text{vol}} \) to the size of the patient to better estimate patient-specific organ doses \((27–29)\). To calculate \( \text{SSDE} \), \( \text{CTDI}_{\text{vol}} \) is multiplied by a correction factor on the basis of patient size by using tables in the AAPM report. Patient size may be estimated from the anteroposterior or lateral diameters, the sum of the anteroposterior and lateral diameters, or the effective diameter \( (\text{square root of the product of anteroposterior and lateral diameters}) \) of the patient. A subsequent AAPM report \((30)\) identified the patient’s water-equivalent diameter \( (\text{diameter of a cylinder of water that would yield the same overall x-ray attenuation as the cross section through the patient}) \) as the preferred size metric for automated \( \text{SSDE} \) calculation. \( \text{SSDE} \) is not used to estimate effective dose. Effective dose \( (\text{measured in sieverts}) \) is intended to represent the uniform whole-body equivalent dose that would be expected to cause the same overall cancer risk as the nonuniform or partial-body exposure delivered to the patient. It is calculated as a weighted sum of each organ’s dose times that organ’s relative risk of radiation-induced carcinogenesis; it is a single dose value that is commonly used to compare the relative biologic risks of different exposures \( (\text{from the same or different imaging modalities}) \), even if the exposure is to different body regions \((23)\).

Effective dose can be estimated by multiplying the \( \text{DLP} \) by a conversion factor on the basis of the body region scanned in a sex- and age-neutral reference patient, although these methods can be
Benchmarks for CT Radiation Doses

A primary purpose of surveys of radiation dose from CT is to establish diagnostic reference levels (DRLs) for different CT examinations, which help establish benchmark doses for various CT procedures to avoid excess radiation dose (2,33). Although DRLs typically represent radiation dose levels used by 75% of the surveyed CT facilities (recorded as CTDI<sub>vol</sub>), users should use diagnostic reference ranges of 25%–75% levels as one common range. In 2013, the CT scanner accreditation process from the ACR set DRLs of 75 and 35 mGy (both with a 16-cm CTDI phantom size) for adult and pediatric head CT examinations, respectively (34). The DRLs for adult and pediatric (in a 5-year-old child) abdominal CT examinations were set at 25 mGy (32-cm CTDI phantom size) and 15 mGy (16-cm CTDI phantom), respectively. Although there is no chest CT reference dose evaluation in the ACR accreditation process, the American Association of Physicists in Medicine and ACR practice guideline has set an adult DRL of 21 mGy (32-cm phantom) (35).

The National Council on Radiation Protection and Measurements report number 172 (36) states that, for institutions already operating below the DRLs, the next target should be achievable doses, which represent radiation dose levels below which 50% of the institutions are operating without compromising required diagnostic image quality (35–37). These DRLs and achievable doses refer to CTDI<sub>vol</sub> values from a single CT series for a standard-sized patient; smaller patients are expected to need lower doses, and larger patients may need higher radiation doses.

Factors Affecting Radiation Dose and Quality

Several CT parameters and patient factors affect CT radiation dose and image quality. The most important strategy for reducing radiation dose associated with CT is ensuring the appropriateness or justification for CT. These factors should be accounted for in the creation of CT protocols for different body regions and clinical indications.

Patient Factors

A few key concepts are important regarding the effect of patient cross-sectional area on CT radiation dose and image quality. If constant scanning factors such as tube current, tube potential, gantry rotation time, detector configuration, and image reconstruction parameters are maintained, image noise (a general inverse surrogate of image quality in CT) will increase with increasing patient size and will decrease with decreasing patient size. Thus, for the same clinical indication and body region, larger patients generally require higher x-ray tube output, while smaller patients can be scanned at a lower radiation dose to achieve the same image quality. Small children can and should be scanned with substantially lower radiation doses than those used with adults.

Regions with lower x-ray attenuation (eg, the air-containing thorax) should be scanned at lower dose compared with regions with higher x-ray attenuation (eg, the abdomen). Both AEC and automatic tube potential selection techniques accommodate these attenuation differences by modifying scanning parameters appropriate to the size of the patient and the body region (1,38,39).

The clinical indication for CT is an important patient factor, because conspicuity of different findings at CT is influenced differently by changes in image quality or applied radiation dose. Certain inherently high-tissue-contrast tasks such as lung nodule follow-up or kidney stone evaluation can be performed by using lower radiation doses, because image noise is less detrimental to detection of these high-contrast structures. CT examinations performed to detect low-contrast lesions such as mediastinal lymph nodes or liver tumors require less image noise and thus higher doses for accurate detection and characterization. Applied radiation dose affects some attributes of image quality, such as image noise and certain artifacts, which increase with decreasing radiation dose. These attributes can affect lesion conspicuity negatively, although other factors such as lesion size, location, contrast enhancement, and patient cross-sectional area also can have an effect on lesion conspicuity. This complex relationship demands attention to details in CT protocols, which should be designed with consideration of the patient cross-sectional area, body region scanned, and examination indication. Clinical indication also dictates the scanning coverage length and the number of scanning phases.

Scanning Factors

Many scanning factors affect image quality and radiation dose. Although selection of some factors such as tube current (in milliamperes) and tube voltage (in kilovolts) has been automated by some CT vendors, the CT scanners of several other vendors need manual adjustment, such as gantry rotation time, detector configuration, and pitch. Different CT vendors each have their own proprietary nomenclature for similar scanning factors, which can create confusion...
at institutions in which different scanners are used. A good resource to navigate the lexicon for all major CT vendors is now available on the American Association of Physicists in Medicine Web site (40). In addition to nomenclature variability, changes in certain scan factors produce different effects on image quality and radiation dose when equipment from different vendors is used. The terminology and effects have been reviewed in a recent article (1). It is important to work closely with technologists, medical physicists, and industry specialists to understand and optimize the unique and variable functionality of each type of scanner. In implementation of strategies for radiation dose reduction for CT, maintaining the required diagnostic quality and information for which the CT examination was requested is important. A lower-dose CT examination with insufficient visualization of required structures is just as suboptimal as a higher-dose CT examination that provides higher image quality than needed to establish a diagnosis.

**Tube Current and Tube Current–Time Product.**—Some vendors use tube current (in milliamperes) as an independent factor, while others use tube current–time product (in milliamperes-seconds), which is milliamperes multiplied by the gantry rotation time and divided by the helical pitch factor. A change in tube current or tube current–time product is linearly related to the radiation output from the x-ray tube, such that doubling of tube current or tube current–time product doubles the radiation output. Adjustment of tube current or tube current–time product remains the most practical and most commonly used method of adapting radiation output from CT scanners (4,5). Although most multi–detector row CT scanners now use AEC techniques to modulate tube current as appropriate for patient attenuation, older scanners and certain low-dose scanning protocols still operate with fixed tube current or tube current–time product. As a rule of thumb, smaller patients and body regions with lower x-ray attenuation (such as the chest) should be scanned at lower tube current or tube current–time product settings, and larger patients or more higher attenuating body regions (such as the shoulders or abdomen) require higher tube current or tube current–time product settings. Clinical indications for assessment of high-contrast regions or lesions (eg, lung nodules, kidney stones) are less affected by image noise and, therefore, enable a lower tube current or tube current–time product technique compared with organs with lower inherent tissue contrast (eg, liver, pancreas). When AEC techniques are unavailable or not used, scan protocols should allow suitable adjustment of tube current–time product to account for variations in patient size, region scanned, and clinical indications.

**Tube Voltage.**—Tube voltage represents the peak photon energy of an x-ray energy spectrum. A change in voltage has a much greater effect on radiation dose than does a change in fixed tube current or tube current–time product. For example, a 15% reduction in tube current–time product results in 15% dose reduction if all other scanning parameters are held constant, whereas a 15% reduction in voltage results in a 35% dose reduction if other scanning parameters are held constant. Smaller children and smaller adults should be scanned at lower voltage (≤100 kV) to reduce radiation dose. Unlike change in tube current, a change in voltage is associated with a change in CT numbers as well. This is particularly beneficial at contrast material–enhanced examinations such as CT angiography (including CT pulmonary angiography and coronary CT angiography) and CT perfusion, because iodine enhancement increases substantially at lower voltage (41–44). A decrease in voltage reduces radiation dose and substantially improves image contrast, particularly for contrast-enhanced CT examinations. Lower voltage can also help reduce the amount of contrast material required for CT scanning (41–44). Lower voltage is being used increasingly for contrast-enhanced CT in adults and children.

Because a decrease in voltage is associated with an increase in image noise, since fewer of the x-rays in the lower energy spectrum make it through the patient to the detector array, a compensatory increase in tube current–time product is often used to maintain similar image noise. As an alternative, IR techniques that reduce image noise may enable use of lower voltage in adult patients with reduced radiation dose (43,44).

Regions with lower x-ray attenuation (eg, chest, extremities) also can be scanned at lower voltage (≤100 kV) compared with regions with higher x-ray attenuation (abdomen). On scanners with IR techniques, lower voltage is being used increasingly for contrast-enhanced CT studies in adult patients as well.

**Gantry Rotation Time and Pitch.**—Image quality is dependent on adequate x-ray flux passing through the patient and reaching the detector array. As we described previously, x-ray flux may be increased by increasing voltage (when relevant) or by increasing the tube current–time product, which may be achieved by increasing either tube current, effective tube current–time product, or gantry rotation time (expressed in seconds), which refers to the duration of a 360° revolution...
of the x-ray tube around the patient. Gantry rotation time and pitch are the two main parameters that determine the scanning speed. In general, gantry rotation time should be kept low to avoid motion artifacts. This is particularly important in small children or in imaging of mobile structures (eg, the lungs during breath-hold scanning), where motion artifacts may necessitate repeat scanning. However, in large patients in whom the maximum tube current limits of the x-ray tube are readily reached, further increases in x-ray flux may require scanning to be slowed down by using a slower gantry rotation time or a reduced pitch.

The pitch of a helical CT acquisition is defined as the table travel (CT table movement in millimeters per gantry rotation) divided by the collimated beam width (in millimeters). If the table travel in millimeters for one 360° gantry rotation equals the x-ray collimated beam in millimeters, the pitch is 1. If table travel is less than the x-ray collimated beam width, there is overlap at each view angle from one gantry rotation to the next (overlapping pitch < 1). A pitch greater than 1 (nonoverlapping) implies that table travel is greater than the x-ray beam width, and some view angles are not recorded at certain table positions. Generally speaking, pitch selection should be based on the requirement of scanning speed. If all other scanning factors are held constant, higher pitch results in faster scanning (Fig 2). For coverage of longer regions of the body, a nonoverlapping pitch is often used, whereas regions with rapidly changing anatomy (eg, skull base) are scanned with overlapping pitch. Likewise, to minimize scanning times, as in patients with shortness of breath who are undergoing CT pulmonary angiography, a nonoverlapping pitch with fast gantry rotation time is preferred to minimize motion artifacts.

The effect of changes in pitch varies according to CT scanner vendor. On most Siemens Healthcare (Forchheim, Germany) and Philips Healthcare (Andover, Mass) CT scanners, a change in pitch is associated with a compensatory change in the tube current, such that the tube current–time product and radiation dose remain essentially constant. On most scanners from GE Healthcare (Milwaukee, Wis) and Toshiba Medical Systems (Tokyo, Japan), tube current is not automatically changed with pitch; thus, radiation dose decreases as pitch is increased and vice versa.

Detector Configuration.—Detector configuration refers to the number of detector rows and the width of each detector row. The detector configuration determines x-ray beam collimation or width. Most multi–detector row CT scanners offer two or more detector configurations. Some scanners (mostly those with 64 or fewer detector rows) contain detector elements of variable thickness, such that the detector configuration is tied to the desired minimum section thickness. For example, acquisition at 0.625 mm can be accomplished only with a detector configuration of 16 × 0.625 mm and not with 16 × 1.25 mm. Thus if submillimeter sections are desired, a thinner x-ray beam is necessary, which can increase the radiation dose because of increased scanning time and decreased radiation dose efficiency. For other scanners (mostly those with 64 or more detector rows), a uniform array of detector configurations does not affect the
minimum section thickness. With such scanners, a wider detector configuration is preferred for scanning longer body regions (such as the chest, abdomen, and extremities), and a shorter configuration is used for scanning in a short scanning range (such as those used to image the head and joints).

**Dose-saving Technology**

**AEC Techniques**

Most modern scanners employ AEC techniques that modulate the tube current (and therefore the radiation dose) to the patient’s body habitus or size on the basis of regional x-ray attenuation measured from planning projection (scout) radiographs. For most CT protocols in the body, AEC techniques are preferred over fixed or manual selection of tube current (5). AEC techniques allow automatic modulation of tube current according to patient size and shape. Spatial tube current–modulation techniques include angular (transverse or x-y), longitudinal (z), and combined (x-y-z) modulation (Table 1), with combined modulation techniques preferred for most indications when available (23,45). In addition, temporal tube current modulation is available to vary the tube current during different portions of the cardiac cycle at electrocardiographically gated cardiac CT examinations. To configure AEC techniques, users prescribe an image quality parameter on the basis of the body region to be scanned and the clinical indication (Fig 3). For example, a higher image quality requirement is appropriate for CT pulmonary angiography compared with that appropriate for follow-up CT for lung nodules (4). Substantial dose reduction has been described with these techniques in both adult and pediatric patients compared with fixed–tube current techniques (23,45,46).

With the use of AEC techniques, close attention should be paid to patient position in the gantry isocenter, because off-centered patient positioning can lead to miscalculation of patient attenuation and, therefore, also miscalculation of the applied tube current (45). Off centering of the patient in the gantry by the technologist before the helical scan can increase the radiation dose without a substantial gain in diagnostic image quality. This occurs because off centering the patient too close to the x-ray tube for the planning radiograph (scout image) results in an inflated estimate of

<table>
<thead>
<tr>
<th>AEC Type</th>
<th>GE Healthcare</th>
<th>Philips Healthcare</th>
<th>Siemens Healthcare</th>
<th>Toshiba Medical Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse</td>
<td>SmartScan</td>
<td>D-DOM</td>
<td>Care Dose</td>
<td>NA</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>AutomA</td>
<td>Z-DOM</td>
<td>NA</td>
<td>Sure Exposure</td>
</tr>
<tr>
<td>Angular and longitudinal</td>
<td>Smart mA</td>
<td>Work in progress</td>
<td>Care Dose 4D</td>
<td>Sure Exposure 3D</td>
</tr>
<tr>
<td>Image quality reference parameter for AEC</td>
<td>Noise index</td>
<td>Reference image</td>
<td>Quality reference mAs</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>Minimum and maximum tube current control</td>
<td>Present</td>
<td>NA</td>
<td>Controlled with modification of strength of modulation</td>
<td>Present</td>
</tr>
</tbody>
</table>

Note.—NA = not available as separate item.
patient width. CT scanners use the patient width from the scout image to determine the appropriate tube output for AEC. If the patient width from the projection image is artificially high, the scanner will be “fooled” to use a higher-than-necessary tube current to generate an image.

**Automatic Voltage Selection**
Recent automatic tube potential selection techniques enable some modern CT scanners to automatically select the voltage that achieves the desired image quality at the lowest CTDIvol appropriate for the patient’s size and the diagnostic task (eg, nonenhanced CT vs CT angiography). Unlike tube current, voltage is still manually selected by the users of most CT scanners. To simplify and automate the selection of voltage, some vendors have introduced automatic voltage selection techniques (Care kV; Siemens Healthcare; kV Assist, GE Healthcare). These techniques select the most appropriate voltage for the scan, whereas the AEC techniques modulate the tube current throughout the patient anatomy. To configure the automatic voltage selection techniques, users identify the examination type (for example, nonenhanced CT, contrast-enhanced CT, or CT angiography) and select a reference voltage and tube current (Fig 4) (38,39). On the basis of the examination type and the patient size, the algorithm determines the voltage that will achieve the desired image quality at the lowest CTDIvol. Users can constrain the range of allowed voltage for each protocol (for example, by eliminating 140 kV as an option in CT angiographic examinations because of the loss of iodine enhancement at high voltage). Because lower voltage increases contrast enhancement, automatic voltage-selection techniques select lower voltage more frequently for CT angiography and contrast-enhanced scanning than for nonenhanced scanning. Substantial dose reductions have been reported for both chest and abdominal CT examinations with the use of automatic voltage selection techniques (38,39,47).

**IR Techniques**
CT image reconstruction techniques have a profound effect on image quality and artifacts. Traditional filtered backprojection techniques make a number of simplifying assumptions about photon noise statistics and scanner hardware details (presuming that the x-ray focal spot and detector

![Figure 4. Radiation dose reduction with reduction in voltage for CT pulmonary angiography. With use of automatic voltage selection technique (Care kV; Siemens Healthcare), scanners can adapt the voltage on the basis of patient size and protocol type. (a) Axial image in a 66-year-old man with morbid obesity (body mass index, 32 kg/m²) scanned at 120 kV (CTDIvol, 19 mGy) shows segmental pulmonary embolism in right lower lobe (arrow). (b) Axial image in a 44-year-old man (body mass index, 34 kg/m²) scanned at 100 kV (CTDIvol, 7 mGy) shows lobar pulmonary emboli bilaterally in lower lobes (arrows). (c) Axial CT image in a 64-year-old woman (body mass index, 24 kg/m²) scanned at 80 kV (CTDIvol, 3.7 mGy) shows segmental pulmonary embolism in right lower lobe (arrow).]
Table 2: IR Techniques Available from Different CT Vendors

<table>
<thead>
<tr>
<th>Technique and Details</th>
<th>GE Healthcare</th>
<th>Philips Healthcare</th>
<th>Siemens Healthcare</th>
<th>Toshiba Medical Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main IR technique</td>
<td>ASiR</td>
<td>iDose</td>
<td>IRIS</td>
<td>Adaptive iterative dose reduction</td>
</tr>
<tr>
<td>Details of main technique</td>
<td>ASiR level is selected at 10% increments (10%–100%), with increasing percentage associated with lower noise</td>
<td>iDose level can be set on a scale of 1–7, with increasing number suggesting lower noise</td>
<td>These techniques work on a scale of 1–5, with increasing number associated with lower noise</td>
<td>Three settings (mild, standard, strong) represent increasing strength of noise reduction</td>
</tr>
<tr>
<td>Other available IR techniques</td>
<td>Veo, ASiR-V</td>
<td>IMR</td>
<td>Safire, Admire</td>
<td>Adaptive iterative dose reduction 3D</td>
</tr>
</tbody>
</table>

elements are infinitely small) that allow rapid image reconstruction but can produce high image noise and artifacts, particularly at lower radiation dose levels. The CT industry has introduced more computationally intense IR techniques to improve CT image quality and enable use of lower radiation dose compared with filtered backprojection techniques (48,49). There are several types of IR approaches (Table 2) that incorporate different x-ray photon noise statistics and system optics modeling to generate better image quality compared with that of filtered backprojection images. Many IR techniques allow the user to specify the strength of the IR techniques, which allows control of the degree of noise reduction (Figs 5, 6). When “high-strength” IR techniques are used, a distinct or altered image appearance (blotchy appearance on images) can be seen. IR techniques do not reduce radiation dose, but by decreasing image noise, they allow users to adjust scanning parameters (most commonly lowering tube voltage and/or kilovolts) to reduce tube output and, hence, dose compared with that achieved with traditional filtered backprojection techniques (48,49).

IR techniques also have been used in children to enable radiation dose reduction. Wallihan et al (50) recently reported substantial reduction in SSDE for children undergoing CT enterography with an adaptive iterative dose reduction IR technique (6 mGy ± 2.1) compared with that with filtered backprojection (17 mGy ± 5). IR techniques also have been found to help reduce radiation dose in children undergoing CT hematuria protocols and head CT (51–53).

Authors of a recent study (54) reported degradation of low-contrast spatial resolution with at least two commercial IR techniques at a 25%–50% reduction in dose relative to full-dose CT and filtered backprojection techniques. Therefore, radiation dose should be reduced in small steps when IR techniques are implemented.

Hardware-driven Technology for CT Dose Reduction

Vendors have introduced several types of hardware-driven technologies to enable efficient use of radiation with CT (55–57). This type of technology tends to improve the radiation dose efficiency of CT scanners by reducing unused portions of the x-ray beam, which are outside the detector assembly relative to the useful portion of the x-ray beam. For example, beam-shaping or bow-tie filters help reduce radiation dose to the thinner peripheral portions of the body while allowing most x-ray photons to pass through the thicker central parts of the body. Most modern CT scanners are equipped with these filters, which also help to maintain a constant image quality on the central and peripheral parts of the images. These filters function correctly only when the patient is centered appropriately in the CT gantry. Off centering of the patient can result in asymmetric image noise and excessive radiation dose to the thinner peripheral portions of the body and to radiosensitive tissue such as that of the breasts and thyroid (55).

Some multi–detector row CT scanners with wide area detectors (typically ≥4 cm) use adaptive shielding to improve radiation dose efficiency, reducing overranging by blocking the portions of the wide x-ray beam that would otherwise fall outside the desired anatomic regions of the scan at the start and the end of a helical acquisition (56). Overtrending can contribute to a substantial portion of the associated radiation dose, particularly for shorter scanning lengths.

The detector array is one of the most expensive and important parts of a CT scanner. Recent development of more efficient detector elements has helped to improve radiation dose efficiency, as it has introduction of more sophisticated and integrated data assembly systems that produce less electronic noise and thus allow scanning with lower tube outputs (46).
Alternatives to CT

The most important step toward use of the appropriate radiation dose is ensuring its appropriateness on the basis of required clinical information. Several radiologic organizations have developed algorithms to help guide appropriate use of imaging tests for specific clinical indications (1). The ACR appropriateness criteria suggest appropriate modalities for imaging on the basis of the patient’s clinical presentation. Radiology order-entry decision support software has been developed by using these guidelines and other relevant evidence to improve appropriate justification for use of imaging examinations (58).

Ten Steps to Wise and Gentle CT Protocols

1. Establish the appropriateness or justification guidelines for CT scanning. Decision support software can help set this most elementary rule for managing radiation dose.

2. Create clinical indication–specific CT protocols for different anatomic areas of the body. Such protocols help tailor CT dose and image quality on the basis of specific clinical indications.

3. Ensure that the patient is positioned appropriately in the gantry isocenter. Off-centering leads to incorrect estimation of patient attenuation, which results in incorrect tube current modulation with AEC techniques and disproportionate distribution of image noise.

4. Use AEC techniques to adapt tube current. AEC techniques help modulate tube current on the basis of required image quality and patient size. Some techniques allow users to set minimum and maximum tube current limits to prevent radiation levels that are too low or too high. Most body CT examinations must be performed with AEC to reduce radiation dose.

5. Use voltage adjustment on the basis of clinical indication and patient size. Automatic voltage selection techniques help to modify
Figure 6. (a) Axial image in a 71-year-old man (body mass index, 34 kg/m²) who underwent standard-of-care CT (CTDIvol, 13 mGy) shows a right upper lobe lung nodule (arrow). (b–d) With informed consent, the patient was rescanned at CTDIvol of 0.8 (b), 0.4 (c), and 0.2 mGy (d). Reconstructed sections with adaptive statistical IR (ASiR; GE Healthcare) technique at different strengths (50%, 70%, and 90%, respectively) showed that despite the deterioration in image quality with decreasing doses, the right upper lobe lung nodule (arrow) could be seen almost as well as on images from the standard-of-care CT at much higher radiation dose. The strength of IR technique may require fine tuning, depending on associated radiation dose.

voltage on the basis of the examination type and patient size. CT without such techniques should use low voltage for specific clinical indications (CT angiography) and patient size (children and smaller adults).

6. Select appropriate detector and section collimation on the basis of the clinical indication. Section collimation has an effect on image noise, with thinner collimation needing a higher dose to decrease image noise. At advanced CT, an “acquire thin and reconstruct thick” strategy helps decrease image noise and thus dose requirement.

7. Avoid overscanning beyond the anatomic area of interest: Extending the scanning range to regions beyond the required area increases radiation dose. For example, limit the scanning range to lung bases for lung nodule follow-up CT. Kidney stone protocol CT can be initiated from the top of the kidneys to the pubic symphysis instead of the dome of the diaphragm.

8. Limit the use of multiphasic CT protocols, and employ clever strategies for dose reduction.

Repetitive scanning increases radiation dose; multiphasic CT should be performed only when it is expected to help in lesion detection or characterization. For example, routine acquisition of nonenhanced images before routine chest or abdominal CT does not add substantial information in most patients and, therefore, should be discouraged. Split-bolus contrast material injection techniques can help reduce radiation dose by decreasing the number of required phases for some protocols such as those for CT urography.

9. Use IR techniques to improve image quality and allow dose reduction. These techniques help to reduce image noise and artifacts seen at low–radiation-dose CT.

10. Assign a specific personnel team to be responsible for protocol review and dose monitoring. This team should perform periodic and frequent review of CT protocols and also should review the outliers from the dose-monitoring techniques (including the ACR Dose Index Registry initiative).
CT Protocols for Proper Dose Use

Creation of optimally tailored CT protocols is a collaborative team effort among radiologists, CT technologists, medical physicists, and CT vendor specialists. Once the appropriateness of CT has been determined, protocols should be tailored on the basis of patient age, body region, and clinical indication. Timely review of scanning protocols and associated radiation doses is essential to ensure that protocols are correctly configured and updated on a regular basis. Separate protocols often are needed for children and adults.

Head

Although magnetic resonance (MR) imaging is ideal for many neurologic indications, head CT remains a commonly performed examination in patients suspected of having head trauma and acute stroke. Many routine nonenhanced head CT examinations are performed at 120 kV by using a “step-and-shoot” or nonhelical mode of acquisition with a 1-second gantry rotation time and an angulated gantry to avoid radiation to the eyes. However, many institutions are increasingly using helical acquisitions for head CT to increase scanning speed and to enable high-quality multiplanar reformations. To decrease beam-hardening artifacts, an overlapping pitch (<1) is typically used in helical head CT. Head CT can be performed at a fixed tube current or with AEC techniques. IR techniques reduce image noise and thus permit radiation dose reductions. Users should ensure that most examinations are performed at less than the DRL value of a CTDIvol of 75 mGy in adults and 35 mGy in children (37).

CT protocols for evaluation of paranasal sinuses can be performed at a substantially lower dose than that used at routine head CT, because the primary structures of interest are of inherently high tissue contrast between the bones and air in the sinuses (59). CT angiography of the head and neck is another common examination that preferably should be performed at low voltage (80–100 kV) to reduce radiation dose while improving contrast enhancement. As a rule, CT perfusion of the head should be performed at 80 kV to reduce radiation dose associated with repetitive scanning while improving detection of contrast enhancement (60).

Chest

The presence of high inherent tissue contrast and low x-ray attenuation in the predominantly air-filled lungs allow most chest abnormalities to be assessed at a much lower radiation dose (at least 30%–50% lower) than the dose used in abdominal scanning. Routine chest CT examinations with intravenous contrast material in small- to average-sized patients can be performed at 80–100 kV to reduce radiation dose. To minimize motion artifacts, a fast gantry rotation time and a nonoverlapping pitch with wide beam collimation are preferred. AEC techniques should be used to tailor radiation dose according to patient size and large regional variations in tissue attenuation (ie, dose is typically much higher for imaging the shoulders and upper abdomen than for imaging the mid thorax). Special attention should be paid to limit the inferior extent of the scanning range, particularly in young patients without a history of cancer. As in other body regions, IR is useful to reduce noise and to permit further dose reductions by lowering tube current, voltage, or both (49).

Separate CT protocols are recommended for follow-up of lung nodules, because nodules can be observed easily in images obtained at a fraction of the radiation dose used in routine chest CT examinations such as those for chronic cough. AEC techniques or weight-based adjustment of fixed tube current can be used for reducing radiation dose. Thus, compared with routine chest CT (eg, for cancer staging), lung nodule follow-up CT should have much lower radiation dose or CTDIvol. The scanning range for this protocol should be restricted to the lungs only. Authors of several studies have reported that radiation doses for CT follow-up of lung nodules or lung cancer screening at CT can be performed at submillisievert dose levels, especially with use of IR techniques (Figs 5, 6) (61–63).

Abdomen and Pelvis

Abdominal and pelvic abnormalities (eg, lesions in liver, spleen, and pancreas) often show low contrast on images, compared with high-contrast chest CT images. Excessive radiation dose reduction in the abdomen and pelvis can result in high image noise and artifacts that can affect conspicuity of some low-contrast lesions. Therefore, abdominal and pelvic protocols should be stratified carefully on the basis of clinical indications. IR techniques should be used to reduce image noise and enable lower tube current and/or voltage to reduce dose. Abdominal CT should be performed with AEC techniques to adapt radiation dose to patient size. Careful attention should be paid to the scanning range to minimize inclusion of the chest and thighs.

Because the contrast of kidney stones is high relative to that of background soft tissue, abdominal CT performed exclusively for evaluation of urinary calculi can be performed at a lower radiation dose by using a dedicated protocol (if there is not a differential diagnosis encompassing other lower-contrast abdominal structures) (Fig 3). Although most kidney stones can be seen on
Figure 7. (a) Coronal CT image in a 9-year-old girl (weight, 43 kg) with soft-tissue sarcoma of the lower extremities was acquired at 100 kV and 25 mAs (AEC) for evaluation of intrathoracic metastatic disease. (b) Coronal multiplanar reformatted CT image shows acceptable image quality at low radiation dose (CTDIvol, 0.4 mGy; DLP, 39 mGy·cm) without evidence of intrathoracic metastatic disease.

Reduced-dose CT images, subtle changes of pancreatitis or ovarian abnormalities can be missed in some patients; therefore, if there is any suspicion of other confounding abnormalities in the abdomen, reduced-dose CT protocols should be used in moderation. Such dose reduction is generally achieved with a reduction in tube current through suitable modification of AEC techniques (lower image quality requirement compared with that at routine abdominal CT) (64,65).

Multiphasic examinations of the abdomen should be restricted to appropriate clinical situations (1). For example, acquisition of nonenhanced images before contrast-enhanced routine abdominal and/or chest CT should be avoided. Delayed images should be acquired only when they may help in evaluation of an abnormality. Reduction of scanning range for one or more phases to the specific region of interest can help reduce radiation dose substantially. For example, at multiphasic liver CT, the arterial and delayed phases can be limited to the liver, with the entire abdomen imaged only during the portal venous phase, if necessary. In addition, for the arterial phase, the voltage can be reduced to improve contrast enhancement while reducing radiation dose.

Key Features of Pediatric CT Protocols

Special consideration should be given to CT protocols for children because radiation-induced cancer risks are believed to be greater in the pediatric population. Adult CT protocols should not be used in small children, and size-based adjustment of radiation dose must be followed rigidly, with appropriate adjustment of both voltage and tube current (Fig 7). Care must be taken to minimize motion artifacts in small or anxious children with appropriate calming methods and fast scanning speeds accomplished by fast gantry rotation times and nonoverlapping pitch. As they are with adult patients, CT radiation doses for children must be adjusted to the clinical indication (Fig 8). Good scan timing is crucial to avoid “missed” contrast boluses. Routine use of multiphasic CT protocols must be minimized in children. When possible and appropriate to the clinical indication, ultrasonography or MR imaging is preferred to eliminate ionizing radiation.

Agencies and Organizations Involved with Medical Radiation

Many organizations including the ACR, the American Association of Physicists in Medicine, the International Commission on Radiological Protection, the International Atomic Energy Agency, the National Council on Radiation Protection and Measurements, and the U.S. Food and Drug Administration have issued recommendations for management of CT radiation dose (6,35–37,66,67). The Image Gently campaign was created to raise awareness of radiation in the pediatric population (68). The campaign Web site provides teaching materials and optimized scanning protocols to promote safe use of ionizing radiation–based modalities in children. The Image Wisely campaign (www.imagewisely.org) is a joint effort of the ACR, the Radiological Society of North America, the American Association of Physicists in Medicine, and the American Society of Radiologic Technologists that advocates for appropriate use of radiation in adult patients (69). RadiologyInfo.org (www.radiologyinfo.org) is a resource on radiation dose at CT and radiation safety for patients (70).
According to the prepublication requirements of the Joint Commission issued on January 9, 2015, applicable to ambulatory care centers effective July 1, 2015, organizations must archive CTDI$_{vol}$, DLP, or SSDE for every CT examination, summarized by series or anatomic area imaged (71). The prepublication document mandates annual CT review of CTDI$_{vol}$, and also recommends that organizations review and analyze incidents where the CT x-ray tube output metric exceeded expected dose index ranges identified for that particular protocol.

**Dose Monitoring and Registries**

Several commercial dose-tracking software packages are available for monitoring CT dose (72). These software programs automatically extract CT dose metrics from the CT examinations and compile them in a searchable and analyzable database (24). In some, alerts can be configured for doses falling outside the expected range for the particular CT protocol. Dose tracking or monitoring can help in CT radiation dose management by allowing audit and comparison of dose indexes for different CT examinations. Practices are encouraged to participate in the ACR Dose Index Registry, which has captured CT data from more than 5 million CT examinations submitted by more than 1250 imaging facilities in North America (73,74). The ACR Dose Index Registry issues biannual reports to each contributing imaging facility in which values for CTDI$_{vol}$, DLP, and SSDE (when available from centers that transfer planning radiographs along with the dose data) are compared among regional, national, and practice types on a per-protocol basis. Although the ACR did not have published protocol-specific dose reference levels at the time of preparation of this article, the dose report from the ACR Dose Index Registry allows practices to compare their doses by protocol to 1250 other sites in North America. These dose-tracking options have encouraged the radiologic community to become increasingly aware of CT radiation doses and image quality. The use of these dose-tracking options is expected to increase after the Joint Commission recommendations highlighting

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**Figure 8.** (a, b) Images in a 13-year-old boy (weight, 45 kg) who underwent reduced-dose chest CT for evaluation of pectus excavatum deformity. Radiation dose was reduced to as low as achievable on the CT scanner with 80 kV, 4 mAs, nonoverlapping pitch of 1.375:1, and detector configuration of $64 \times 0.625$ mm (CTDI$_{vol}$, 0.08 mGy; DLP, 2.5 mGy·cm). Sagittal (a) and axial (b) images in bone windows reconstructed with ASiR (GE Healthcare) showed pectus excavatum deformity (Haller index, 3.2). (c) Axial CT image obtained with lung window setting demonstrates sufficient image quality for evaluation of lung abnormalities.
the importance of tracking doses for every CT examination are published (71).

Conclusion

CT provides vital diagnostic information that affects patient care. Once the appropriateness of CT is established, scanning protocols should be optimized for the specific clinical indication, body habitus, anatomic area, and patient age. There are several technologic and scanning strategies available to optimize radiation dose associated with CT while maintaining diagnostic image quality. Periodic monitoring of scanning protocols and associated radiation doses with dose-tracking programs should be a part of any radiation dose management initiative. Wise and gentle use of CT with the strategies outlined in this review can help preserve expected diagnostic information while ensuring that radiation doses are as low as reasonably achievable.

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References


CT radiation: key concepts for gentle and wise use

**Question 1:** Would it be correct to state that whilst CT examinations represent only about 17% of radiation-based medical procedures, they contribute nearly 50% of the medical radiation dose of the population as a whole?

A: YES  B: NO

**Question 2:** The BEIR VII study found that for the same x-ray exposure:

A: Risks are expected to be higher for young patients and female patients  
B: There is a threshold dose below which there is no lasting effect  
C: Low levels of radiation are protective  
D: Doubling the radiation exposure is assumed to double the associated cancer risk  
E: A and C

**Question 3:** Which CT radiation output is expressed in milligray centimeters?

A: Absorbed or organ dose  
B: CTDI  
C: DLP

**Question 4:** Patient size may be estimated from ..........?

A: The anteroposterior or lateral diameters  
B: The sum of the anteroposterior and lateral diameters  
C: The effective diameter of the patient

**Question 5:** Which of the following are TRUE regarding effective dose?

A: Effective dose is measured in sieverts  
B: Effective dose is a single dose value that is commonly used to compare the relative biological risks of different exposures  
C: Effective dose reflects the actual risk to a specific patient  
D: Effective dose is intended to represent the uniform whole-body equivalent dose that would be expected to cause the same overall cancer risk as the non-uniform or partial-body exposure delivered to the patient

**Question 6:** In 2013, the CT scanner accreditation process from the ACR set the DRLs for adult and pediatric (5-year-old) abdominal CT examinations, at ...... and ......, respectively:

A: 75 mGy (16-cm CTDI phantom size) and 35 mGy (16-cm CTDI phantom size)  
B: 25 mGy (32-cm CTDI phantom size) and 15 mGy (16-cm CTDI phantom)

**Question 7:** Is it TRUE that for the same clinical indication and body region, smaller patients generally require higher x-ray tube output, while larger patients can be scanned at a lower radiation dose to achieve the same image quality?

A: YES  B: NO

**Question 8:** CT examinations performed to detect ...... require ...... image noise and thus ...... doses for accurate detection and characterization:

A: High-tissue-contrast tasks / less / higher  
B: Low-contrast lesions / more / lower  
C: Low-contrast lesions / less / higher

**Question 9:** Adjustment of which of the following products remains the most practical and most commonly used method of adapting radiation output from CT scanners?

A: Fixed tube current  
B: Tube current  
C: Tube current-time  
D: B or C

**Question 10:** Which of the following require, as a rule of thumb, higher tube current or tube current-time product settings?

A: Smaller patients  
B: Larger patients  
C: Body regions with higher x-ray attenuation  
D: Body regions with lower x-ray attenuation

**Question 11:** Tube voltage represents the peak photon energy of an x-ray energy spectrum. A change in voltage does not have as great an effect on radiation dose as a change in fixed tube current or tube current-time product. Is this statement TRUE or FALSE?

A: TRUE  B: FALSE
Question 12: A decrease in which scanning factor reduces radiation dose and substantially improves image contrast, particularly for contrast-enhanced CT examinations?

A: Tube current  
B: Gantry rotation time  
C: Tube current-time product  
D: Tube voltage

Question 13: Which type of gantry pitch and time should be used to minimize scanning times, as for patients with shortness of breath who are undergoing CT pulmonary angiography?

A: Overlapping pitch with fast gantry rotation time  
B: Non-overlapping pitch with fast gantry rotation time  
C: Overlapping pitch with slow gantry rotation time  
D: Non-overlapping pitch with slow gantry rotation time

Question 14: Which of the following statements are TRUE regarding detector configuration?

A: It determines x-ray beam collimation or width  
B: Most multi-detector row CT scanners offer two or more detector configurations  
C: All scanners contain detector elements of variable thickness, such that detector configuration is tied to the desired minimum section thickness  
D: All the above

Question 15: Which of the following is the result of off-centering a patient too close to the x-ray tube for the planning radiograph?

A: Miscalculation of patient attenuation  
B: Increase in radiation dose without substantial gain in diagnostic image quality  
C: Inflated estimate of patient width

Question 16: For which procedure, would you, for instance, constrain the range of allowed voltage by eliminating 140Kv as an option because of the loss of iodine enhancement at high voltage?

A: Non-enhanced CT  
B: Contrast-enhanced CT  
C: CT angiography

Question 17: By using an adaptive iterative dose reduction IR technique, Wallihan et al recently reported a substantial reduction in SSDE for children undergoing CT enterography. Is this statement TRUE?

A: YES  
B: NO

Question 18: Some hardware-driven technology for CT dose reduction, such as some multi-detector row CT scanners with wide area detectors, use ....... to improve radiation dose efficiency:

A: Beam-shaping  
B: Bow-tie filters  
C: Adaptive shielding

Question 19: Which one of the following, in the opinion of the authors, is the most important step toward use of the appropriate radiation dose during CT scanning?

A: Performing CT scans in accordance with set protocols  
B: Ensuring the appropriateness of the treatment based on required clinical information  
C: Regularly updating, sharpening and checking the skills of the operator

Question 20: Which technique can help to reduce radiation dose by decreasing the number of required phases for some CT protocols?

A: “Acquire thin and reconstruct thick”  
B: Voltage adjustment  
C: Split-bolus contrast material injection  
D: Section collimation

Question 21: Once the appropriateness of CT has been confirmed, protocols should be tailored based on ..........?

A: Body region  
B: Age  
C: Clinical indication  
D: Gender  
E: Weight

Question 22: Regarding head CT, users should ensure that most examinations are performed at less than the DRL value of a CTDI of ....... mGy in adults and ......... mGy in children?

A: 75 and 35  
B: 60 and 40  
C: 85 and 45  
D: 90 and 55

Question 23: As a rule, CT perfusion of the head should be performed at ...... to reduce radiation dose associated with repetitive scanning:

A: 90 kV  
B: 120 kV  
C: 100 kV  
D: 80 kV

Question 24: Authors of several studies have reported that radiation doses for CT follow-up of lung nodules or lung cancer screening at CT can be performed at supra millisieverts dose levels, especially with use of IR techniques. Is this statement TRUE or FALSE?

A: TRUE  
B: FALSE
**Question 25:** Regarding scans of the abdomen and pelvis, which of the following statements are TRUE?

A: Excessive dose reduction can result in high image noise and artifacts that can affect conspicuity of some low-contrast lesions

B: Protocols should be stratified carefully based on clinical indications

C: Abdominal scans should be performed with AEC techniques to adapt radiation dose to patient size

D: Abdominal CT performed exclusively for evaluation of urinary calculi, must be performed at a higher radiation dose by using a dedicated protocol

E: All of the above

**Question 26:** Which of the following are TRUE regarding multiphasic examinations of the abdomen?

A: It should be restricted to appropriate clinical situations

B: Delayed images should always be acquired

C: Acquisition of nonenhanced images before contrast-enhanced routine abdominal and/or chest CT is advised

D: Reduction of scanning range for one or more phases to the specific region of interest can help reduce radiation dose substantially

E: For the arterial phase, the voltage can be reduced to improve contrast enhancement while reducing radiation dose

**Question 27:** Radiation-induced cancer risks are believed to be greater in the pediatric population. Which techniques are preferred to eliminate ionising radiation?

A: Multiphasic CT

B: Ultrasonography

C: MR imaging

D: All the above

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**Ten steps to wise and gentle CT protocols**

**Question 28:** Is it TRUE that most body CT examinations must be performed with AEC to reduce radiation dose?

A: YES

B: NO

**Question 29:** Routine acquisition of nonenhanced images before routine chest or abdominal CT adds substantial information in most patients. Is this statement TRUE or FALSE?

A: TRUE

B: FALSE

**Question 30:** Appropriate detector and section collimation should be selected based on:

A: Clinical indication

B: Age

C: Weight

D: Gender

E: All of the above

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End
CT radiation: key concepts for gentle and wise use

Some questions may have more than one answer; in this case please select every correct answer.

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