Minimizing radiation exposure while optimizing image quality is critical in diagnostic medical imaging. Radiologic technologists face complex challenges when implementing dose monitoring and reporting systems to assist in radiation safety efforts. Challenges include communicating the risks of radiation exposure, handling variations in dose measurement techniques, and working with a lack of standardized nomenclature for examination types. With increasing attention on radiation safety, many solutions have been presented. A team approach to dose optimization with professionals nationwide can help establish a culture of radiation safety in medical imaging.

Media reports of radiation injuries from medical imaging examinations have raised public awareness about risks associated with ionizing radiation. The health care industry has responded with patient safety campaigns, beginning with efforts to address radiation safety for examinations that deliver the highest doses, namely computed tomography (CT) and fluoroscopy. Efforts also include creation of dose databases to optimize examination techniques, assess individual patient risk, and gather data.

Determining and gathering data on patient dose can be challenging, however. Selecting the most accurate dosimetric value to estimate dose varies among modalities. Effective dose provides the most accurate measure for comparing relative dose for the same body part among examinations, but effective dose is not accurate for estimating an individual patient’s dose.

Developing patient dose monitoring methods and implementing dose index registries are a few strategies to address the rapid increase in the use of medical imaging examinations that rely on ionizing radiation, especially with relatively high-dose procedures such as CT and fluoroscopy-guided interventional examinations and therapy. Both patient safety and quality improvement programs can benefit from monitoring and reporting patient dose data for all procedures using ionizing radiation. Goals of monitoring and reporting patient radiation dose include better tracking of each patient’s lifetime exposure to ionizing radiation for more accurate risk assessment and improved patient safety initiatives within medical imaging facilities.

There is no way to predict the likelihood of radiation-induced effects in a patient without knowing the patient’s history of radiation exposure. Tracking patient dose in an electronic health record would allow physicians to consider radiation risk when selecting imaging exams. For example, interventional studies that deliver relatively high doses to a specific anatomical region might cause deterministic injury

After completing this article, the reader should be able to:
- Describe the purpose of dose monitoring at facility and national levels.
- Review dose metrics and current nomenclature for risk assessment.
- Discuss dose estimation techniques for radiography, computed tomography, interventional radiography, and nuclear medicine studies.
- Discuss challenges of and solutions for dose tracking in each modality.
- Describe dose optimization strategies for each modality.

Current Issues in Radiation Dose Monitoring and Reporting

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if repeated too soon after the initial exposure. For the most accurate lifetime radiation risk assessment, all radiation doses from imaging examinations should be included in patient electronic health records.

Radiologic technologists are expected to follow the ALARA (as low as reasonably achievable) principle even though no evidence links radiation received from medical imaging with malignancies. Imaging professionals have been challenged to establish protocols that use minimal radiation dose but do not degrade the quality of the images, particularly to the point that radiologic technologists must retake the images. Routine auditing of data in a facility’s database of radiation dose reference levels can help imaging professionals set benchmarks for dose optimization, alert staff to examinations that routinely deliver high doses, and capture dose trends of individual technologists.

Radiologic science professionals also must learn to effectively communicate the radiation risk to patients, other health care professionals, and the public. The necessity for informed consent before beginning imaging studies that use ionizing radiation has been debated but has prompted radiology departments and expert panels across the United States to emphasize radiation safety through educating patients and staff about radiation injury risk, monitoring and reporting patient dose for each imaging examination, and adjusting imaging procedure protocols to minimize patient dose.

**Biological Effects of Ionizing Radiation**

Adverse effects occur when ionizing radiation damages DNA. Two types of effects are deterministic and stochastic. Deterministic effects (eg, cataracts and erythema) occur when a threshold dose has been reached, and the severity of the effect increases with dose. Deterministic effects to an unborn child can include malformations, growth retardation, mental retardation, and death but are unlikely to occur at dose levels below 100 mGy. Unfortunately, patients often are discharged from the hospital after interventional procedures without receiving proper information about the amount of radiation they received and their risks for developing deterministic injuries.

Stochastic effects include carcinogenesis and genetic defects. Children are at increased risk of cancer because of higher radiosensitivity and longer life expectancy than adults. However, the risk associated with exposure to medical radiation is minimal when compared with the standard risk for developing cancer in the general population. For example, the risk of developing cancer for children is 1 in 500, and it is 1 in 3 for adults. The increased risk of carcinogenesis is less than 1 in 10 000 from absorbed radiation doses of up to 1 mGy. An effective dose of 10 mSv is associated with a risk of future malignancy in 1 in 1000 40-year-old adults and close to 1 in 100 for female infants aged 1 year. Examinations that deliver a higher dose to an embryo, such as a pelvic CT scan of a pregnant patient, add to the risk of the fetus later developing childhood cancer by less than 1 in 250.

Educating pregnant patients about fetal radiation risks and consulting with a medical physicist before beginning imaging examinations can increase informed decisions regarding risk vs benefit or alternative imaging modalities. Although risks to the fetus must be considered, proper use of CT examinations can benefit pregnant patients with some diseases and conditions. The fetus’s or embryo’s gestational age should be considered when selecting an imaging modality because the stage most vulnerable to radiation is between the 8th and 15th week of gestation. Some patients are unaware of their pregnancy status at this stage, so all imaging facilities should have a written policy in place for screening women of childbearing age.

**Dose Metrics and Definitions**

Dose measurements are not exact for individual patients. Assumptions are made regarding standard patient body habitus, organ size, and radiopharmaceutical activity within organs. In addition, there is a lack of gender-specific dosimetry. No perfect equation exists to determine a patient’s exact dose from a particular imaging examination. A better description for dose measurement is dose risk estimate.

Reporting dose has proved to be challenging because numerous quantities and units exist, and contemporary changes in the literature’s nomenclature for measuring radiation have made comparisons more difficult. Medical imaging staff should be familiar with general terms and specific terminology related to certain types
of radiation or modalities. Some common terms are listed in the Box.

The word exposure often is used to describe a patient being subjected to radiation, but exposure more accurately is described by the technical factors involved in radiographic modalities that control exposure during a given examination. Neither exposure nor air Kerma accurately measures the effect of radiation on humans because each only measures ionization in the air.

Absorbed dose refers to the amount of radiation deposited in the body or a particular anatomical part. It also is used to determine whether changes in specific tissues could result from radiation. Absorbed dose is estimated in joules per kilogram and in gray (Gy), the international (SI) unit. The conventional measurement is rad, where 1 rad equals 0.01 Gy. Anthropomorphic phantoms that contain internal dosimeters or computer programs that simulate patients can help to estimate absorbed dose levels.

The equivalent dose is calculated by multiplying the absorbed dose by the International Commission on Radiological Protection (ICRP) radiation weighting factor of 1.0 for photons. Its unit of measure is the sievert (Sv). Equivalent dose helps to assess potential biological damage that can result from a patient’s absorbed dose. The effective dose estimates the risk of stochastic injury such as cancer and hereditary effects and can be calculated by determining the sum of the product of fractional estimated dose to organs multiplied by their ICRP-designated tissue-weighting coefficients. Effective dose can describe the potential detriment to the entire body when only a section of the body is irradiated, but the measurement is subject to many uncertainties. One problem with comparing current effective dose to previous studies is that the ICRP tissue-weighting factors have changed over time.

The effective dose is useful, however, for comparing relative risk from common imaging procedures.

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**Box Radiation Dose and Effects Terminology**

**Absorbed dose** – The energy released in a volume of matter per unit mass by ionizing radiation. Measured in gray (Gy).

**Air Kerma** – The “kinetic energy released in material” describes the total amount of energy of all the charged particles liberated per unit mass of a substance by ionizing radiation in air. When scatter radiation is excluded, this value equals absorbed dose. Measured in gray.

**Deterministic effects** – Effects from radiation exposure that surpass a threshold dose and increase in severity with the amount of exposure above the threshold level. A common example is radiation-induced erythema.

**Effective dose** – The sum of the products of equivalent dose times the tissue-weighting factors for the tissues irradiated. It describes stochastic risks to entire body when only a designated area is exposed. Measured in joule per kilogram; expressed in sievert (Sv).

**Entrance skin dose** – The greatest dose delivered to the patient from the x-ray tube’s incident radiation.

**Equivalent dose** – The mean absorbed dose in an organ or tissue multiplied by a radiation weighting factor, which is 1.0 for photons. This quantity is used to describe the probability of radiation effects according to the type of radiation delivered. Measured in sievert.

**Exposure** – The total charge of ions, either positive or negative, produced per unit of dry air by a given amount of ionizing radiation. The conventional unit is roentgen (R), but the SI unit is coulombs per kilogram of air (1 R = 2.58 × 10^-4 C/kg).

**Fluoroscopy time** – The amount of time the fluoroscopic tube is used during an imaging or interventional procedure. Time is recorded from the first pulse to the last pulse of x-ray production for each series of images and is measured in seconds.

**Kerma-area product** – Also known as dose-area product, this is the entire amount of radiation from the x-ray beam that reaches a patient. Measured in the absence of scattered radiation with a Kerma-area product meter. Measurement unit expressed as Gy × cm².

**Organ dose** – The amount of radiation delivered to a particular organ. The location of the examination relative to the patient’s anatomy and the proximity of the organ to the x-ray field determine the organ dose level.

**Peak skin dose** – The highest radiation dose at a specified point on the patient’s skin during a procedure.

**Reference air Kerma** – The air Kerma value at a reference point called the interventional reference point during a fluoroscopic procedure. Measured in gray; previously known as cumulative dose or cumulative air Kerma.

**Stochastic effects** – Effects from radiation exposure that increase in probability of occurrence with increased dose. The severity of these effects does not depend on the total dose received, however. A primary example is radiation-induced cancer.

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Several methods are available to evaluate a patient’s radiation dose, depending on modality. An air Kerma-area product, measured in Gy cm², provides the best estimate when using general radiography and fluoroscopy. Imaging staff commonly use “fluoroscopy time” to monitor radiation exposure from these procedures, but it is not an accurate measurement of patient dose. The volume CT dose index (CTDIvol), measured in milligray, and the dose-length product (DLP), measured in milligray-centimeters, are the best dosimetric values to estimate patient dose from CT examinations. Nuclear medicine staff determines delivered dose from the administered activity of radiopharmaceuticals.

**Risk Reduction and Patient Disclosure**

Each imaging examination is accompanied by a different level of risk based upon the intensity of radiation exposure and patient-related risk factors such as sex, age, and comorbidities. All diagnostic tests should be reviewed to assess the risks and benefits of radiation exposure to patients, health care staff, and the public. To maximize the benefit-to-risk ratio, radiologic technologists must achieve diagnostic image quality while following the ALARA principle. An exposure that is too low and requires obtaining a repeat image is not a good dose-minimizing technique.

The importance of and focus on optimizing quality, minimizing dose, and educating health care professionals and the public has led to improved advocacy efforts. Several groups, including the Society for Pediatric Radiology, the American Society of Radiologic Technologists, the American College of Radiology (ACR), and the American Association of Physicists in Medicine, created the Alliance for Radiation Safety in Pediatric Imaging. This alliance initiated the Image Gently campaign to improve awareness among radiology professionals about ways to reduce radiation dose to children during routine examinations and provide information for parents and medical professionals involved in patient care.

A similar campaign, Image Wisely, which is aimed at reducing unnecessary radiation exposure to adults, limits the use of imaging examinations to only those that are clinically necessary with ALARA doses.

Commitment to the campaign involves 3 levels. The first is a formal pledge, which promotes accountability of imaging professionals and radiology groups. By taking the pledge, the professional agrees to:

- Consider the patient’s safety and risk of radiation effects.
- Optimize the use of radiation.
- Share strategies for selecting the most appropriate imaging examinations with referring physicians.
- Continuously review examination protocols to ensure that current exposure techniques and dose limiting tools are used effectively.

The second level adds facility accreditation. The third level requires participation in a national dose registry that providers can query by examination type to compare their facility’s radiation doses to others reported nationwide.

Greater awareness of risk calls for improved communication. Informing patients of the reasons for medical imaging studies and explaining the risks involved are important steps in delivering patient-centered care. When communicating radiation dose to patients, health care professionals should explain the risk of radiation.

Many assumptions and uncertainties enter into calculating effective dose. Two approaches are used to gauge the level of hazard associated with radiation dose for imaging examinations. One approach compares the effective dose for an examination to other examinations that provide similar diagnostic information or to natural background radiation. For comparison purposes, the natural background radiation people receive annually from the Earth’s radioactive sources and cosmic rays is approximately 0.003 Gy, or 3 mGy. The average adult chest radiograph delivers an entrance skin dose of 0.15 mGy and an effective dose of 0.04 mSv. The other method of evaluating and disclosing dose levels for specific examinations is to compare the radiation output of an imaging system for a particular examination against the radiation output levels from other facilities for the same examination. This method can be used when radiology providers want to reassure patients that the dose from a particular examination is consistent with standard clinical practice.

No federal law requires informed consent for diagnostic examinations using ionizing radiation, and most radiology departments only inform a patient of radiation...
risks when he or she asks about them. Individual states set the requirements for documentation of informed consent. Generally, a radiation risk estimate greater than 1 in 10000 should require disclosure to patients. According to one study, better methods of information delivery include sharing written material, verbal informed consent, and written informed consent in which the verbal communication of risk is documented with the patient’s signature.

**Dose Monitoring**

The ACR has created a voluntary dose index registry to help facilities evaluate dose for specific procedures compared with local, regional, national, or international facilities. At this time, the ACR dose index registry is used mostly for CT examinations, but the goal is to incorporate information for all modalities. The registry’s usefulness should improve with standardization of the exposure indexes from all CT and digital radiography equipment manufacturers.

Dose information included in images from each modality is sent to a designated quality control workstation and then to an independent computer loaded with the ACR software required to extract Digital Imaging and Communications in Medicine (DICOM) data. For CT images, DICOM data includes the CTDIvol and dose-length product from the DICOM header. The records can be sent as a single transmission or at a scheduled time to the dose registry.

The ICRP also suggests auditing field-related quantities such as entrance surface air Kerma or air Kerma-area product as part of a quality assurance program. Since 2011, the American Association of Physicists in Medicine has been developing guidelines for the standardization of protocols in an effort to optimize dose reduction during CT studies. The U.S. Food and Drug Administration (FDA) began a campaign called the Initiative to Reduce Unnecessary Radiation Exposure from Medical Imaging that focuses on the ICRP principles of justification for imaging and dose optimization.

Dose reduction and reporting campaigns have focused primarily on CT and fluoroscopy-guided interventional procedures because these examinations and procedures potentially result in the highest radiation dose to patients. Because radiation exposure from general radiography examinations is considered to be well below the risk threshold, some professionals believe that risk disclosure or consent before beginning general radiography examinations is unnecessary. The need to record dose from these examinations has been debated, however, because some experts believe dose information from all medical exposure to radiation should be recorded in consideration of cumulative effect. Dose monitoring, even for low-dose procedures, improves radiation safety awareness, which leads to optimization of equipment use and examination protocols.

The Conference of Radiation Control Program Directors (CRCPD) and the FDA have created a survey to collect data on radiation dose for diagnostic reference level (DRL) analysis. For diagnostic radiography and CT, DRL analysis can be used to evaluate the risk of stochastic effects from radiation exposure. A flaw to using DRLs as performance guides for specific examinations is that they do not ensure competent performance of the practitioner or verify equipment function. One approach for determining the DRL incorporates equipment factors, procedure protocols, and procedure complexity in the data collection process. Highly uniform examinations such as a posteroanterior (PA) chest radiograph work well for such a survey. Standardized anatomical phantoms are used for specified projections to measure air Kerma on the equipment most frequently used for the examination at each facility.

The DRL process is not appropriate for fluoroscopy-guided interventional procedures because the examinations cannot be as highly standardized for patient size or procedure type. Variations in patient dose for the same procedure occur because of patient anatomy, lesion characteristics, and severity of the disease, as well as equipment selection and configuration.

Quality improvement programs must rely on radiology staff compliance in the recording of patient dose. Staff must enter information consistently and accurately for a safety program to be effective. By recording dose data for all radiology examinations, it is less likely that a procedure that inadvertently produced a high dose will be left out of the patient’s record and more likely that the incident will be evaluated for quality improvement. The CRCPD recommends establishing a comprehensive
program for training radiology staff that includes dose monitoring and tracking procedures. Post an information sheet at each workstation that instructs technologists on appropriate data to input into the radiology information system can improve compliance.

The goals of dose reporting are to improve staff training and ensure proper equipment functioning at all facilities. A team approach—including participation by a radiologist, medical physicist, radiologic technologist, manufacturer service engineer, manufacturer applications engineer, and manufacturer imaging scientist—should be used to address dose management in medical imaging. Each modality presents its own challenges and solutions for implementing dose monitoring and reporting, along with unique methods for optimizing dose.

**Digital Radiography**

Radiation exposure from conventional radiography examinations is considered to be well below a dangerous level, yet it is best practice to monitor exposure levels to ensure the ALARA principle is met. Patient dose depends on many factors, including technique (kilo-voltage, milliampere seconds, grid, source-to-image distance, filtration, beam collimation), x-ray beam penetrability and quality, amount of energy deposited in the body, and the size and area of tissue irradiated.

The noise level produced in digital radiography and CT images is inversely proportional to the level of radiation intensity used to produce the image. An image cannot have too much or too little noise and be of diagnostic quality. Although an image’s gray scale can be adjusted in the area of interest on the viewing monitor, doing so can degrade the image to the point that the image is not of diagnostic quality. Radiologic technologists should not compensate for this problem of increased mottle or noise in the low-contrast areas by using higher radiation intensity, which results in reduced image quality and increased radiation exposure to patients. Absorbed dose and exposure to the patient may be estimated with the exposure indicator on digital radiography systems. The exposure indicator is not a measure of patient dose but is a useful measure for quality control and can assist in optimizing radiation exposure and reducing unnecessary repeats.

The exposure indicator value is determined from the remnant radiation, which includes primary beam radiation that has passed through the patient and scatter radiation that reaches the detector and is converted to electronic signals that are formatted into a radiographic image. The exposure indicator measures the signal level produced from the incident exposure through the patient.

Each examination should be assigned an exposure indicator value that technologists can use as a guide to determine whether the proper radiographic technique has been used. Currently, each manufacturer uses unique processing algorithms to establish the exposure indicator. A recently created standard from the International Electrotechnical Commission provides manufacturers a method to convert exposure information into a uniform format. The standardization includes exposure indicator information in the image’s DICOM metadata for each detector-specific procedure, along with standardized deviation index reporting. The deviation index provides feedback to radiographers regarding the level of exposure used to create an image and helps radiographers determine whether corrective action is required. Each radiology department is required to define an anatomy-specific target exposure indicator to assess image quality. The deviation index is calculated to determine underexposure or overexposure as a function of the incident target exposure indicator.

The deviation index reports a plus or minus value to help the radiologic technologist understand the range of overexposure or underexposure. Standardizing of exposure indicators and deviation indexes in relation to imaging examinations and the parameters of automatic exposure control can help improve the ability to determine whether radiographic technique is optimized for presenting anatomy of interest and minimizing patient radiation.

**Computed Tomography**

CT use in the United States has increased markedly, with 67 million examinations performed in 2006, up from 3 million performed in 1980. This jump includes the frequency of CT examinations using contrast media in pregnant patients. Although CT scans make up only 5% to 10% of all imaging
procedures in the United States and Europe, CT imaging produces 40% to 67% of total medical radiation dose.\textsuperscript{14} Approximately 10% of CT scans conducted annually in the United States in 2006 were on pediatric patients.\textsuperscript{14} These factors, along with recent reports of radiation injury during CT scans, have added to the emphasis on safety for this modality.\textsuperscript{21}

In one report, at least 206 patients in a single hospital received more than 8 times the recommended dose index value for head CT scans.\textsuperscript{22} Another example involved a 2-year-old child who was scanned for more than an hour in the same region of the head.\textsuperscript{22} Overexposures can occur because of inadequate policies or human or equipment error.\textsuperscript{22} Monitoring and reporting of patient dose can help technologists and radiologists better assess the appropriate use of examination protocols and exposure techniques and minimize harm to patients.

The CTDI, or CT air-Kerma index, is the most commonly used metric in CT.\textsuperscript{11} It is based on physical measurements from phantoms and reported in units of gray (Gy).\textsuperscript{11} The CTDI provides the average air Kerma or absorbed dose along the z axis during a CT scan.\textsuperscript{11} The dose is higher at the surface of the patient’s body and decreases along the x-ray beam path, so the average CTDI is weighted (CTDI\textsubscript{w}) to provide a more useful indicator of the tube output. Weighting factors are one-third for dose delivered at the center of the beam and two-thirds for dose delivered at the surface of the body.\textsuperscript{11}

The DLP, also known as the air Kerma-length product, represents the radiation dose to the entire volume of tissue exposed during a single CT examination. It is determined by multiplying the CTDI\textsubscript{w} by the length of the field scanned and is expressed as units of mGy cm.\textsuperscript{16} This value can be determined at the completion of a scan or used for prospective planning.\textsuperscript{11} The ICRP has established the CTDI\textsubscript{vol}, which describes the average radiation dose at a specific point in the volume of the patient for a particular scan protocol and increases linearly with increased milliampere seconds. The CTDI\textsubscript{vol} does not take into account patient size, shape, or attenuation factors. Another concern is that when determining the CTDI\textsubscript{vol} for multidetector CT, the beam length extends beyond the length of the pencil ion chamber used to measure it.\textsuperscript{11}

Another method for estimating dose is through Monte Carlo simulations. These simulations are based on mathematical patient phantoms and photon transport through the simulated patient.\textsuperscript{16} Modern software uses parameters of the tube current, tube voltage, pitch, scan area, and scanner type in calculating the dose estimate.\textsuperscript{16} Patient habitus and anatomy are not always reflected in the simulated patient, which must be considered when estimating dose based on Monte Carlo simulations.\textsuperscript{16} The simulated patient is a hermaphrodite representative of the “average sized” patient, which is thin compared with many of today’s typical patients.\textsuperscript{9} A higher tube voltage often is required for imaging obese patients.\textsuperscript{16}

Each CT manufacturer has a unique method of capturing CTDI data within the image file, which makes tracking the data challenging because no simple way exists to share it between information systems.\textsuperscript{22} A challenge for CT providers is to incorporate past image data stored as an image-based DICOM dose report into the current format that records dose data within the DICOM header. This makes it difficult for imaging centers to take part in the ACR’s dose index registry.\textsuperscript{22}

Shih et al developed a dose index reporting application for CT.\textsuperscript{22} The authors reported in 2011 that the application could extract the radiation dose index information from CTDI reports and that the goal of the dose index reporting application is to use CTDI data for automated quality control, improved safety awareness, and to provide a longitudinal record of patient-specific medical radiation exposure.\textsuperscript{22} The authors stated that the tested dose index reporting application could track CT-generated dose index reports while adjusting estimates to account for patient size, which produces a more accurate CTDI estimate.\textsuperscript{22}

Shih et al reported that the dose index reporting application retrieves dose information during image processing in the CT dose report. Patient attributes such as age, sex, and weight are added to adjust the dose.\textsuperscript{22} Calculations for dose adjustments are based on phantom size correction factors that have been verified previously.\textsuperscript{22} Dose estimates and patient information are stored in a database with a Web-based framework.\textsuperscript{22}

The dose index reporting application, designed to be manufacture independent, can be used with most
health care information technology infrastructures and with current and archived CT studies stored in a picture archiving and communication system (PACS). The authors stated that eventually they would like to add a feedback mechanism for physicians to reduce redundant or unnecessary studies and an automated quality control component to alert the departmental safety or quality team to an exposure indicator outside an established range of acceptance.

A similar solution reported in the literature is the Radiation Dose Intelligent Analytics for CT Examinations (RADIANCE) automated extraction software system. RADIANCE is used to extract, archive, and monitor radiation dose data for CT and can be used with major CT vendors. Cook et al reported in 2011 that work was under way to fix system errors, and RADIANCE is currently available.

Dose reduction techniques must be used consistently to reduce unnecessary radiation exposure to patients from CT examinations. Newer multidetector scanners can minimize dose through the iterative reconstruction technique. Iterative reconstruction recreates the image by using measured projections and algorithms based on those measured projections. Iterative reconstruction improves spatial resolution where there is high image contrast and reduces noise on images with low contrast.

Some manufacturers of lower-dose CT scanners have recently incorporated multiple x-ray sources. Using multiple sources reduces overlap between gantry rotations, which facilitates increased pitch. A 320-slice multidetector CT scanner is commercially available that allows further reductions in effective dose by reducing over-ranging, which is the extended scan length beyond the boundaries of interest at the first and last sections of a helical CT scan. Breath-holding and sedation are not required because of the scanner’s image acquisition speed.

During cardiac CT, electrocardiogram (ECG)-controlled tube current modulation can reduce dose. Also called ECG gating or ECG triggering, the technique reduces tube current to a fraction of the current’s highest value during portions of the cardiac cycle when motion obscures the data used for evaluation. This technique can result in dose reductions of 57% to 59.2%. ECG gating is most useful when multiple portions of the cardiac cycle do not need to be reconstructed for image interpretation, such as patients whose heart rate and rhythm are well-controlled with beta (β)-blockers.

Radiologic technologists also can reduce dose by minimizing the scan time. Use of a scout image or calcium scoring scan to verify the ideal tube current and voltage can set the minimum scan time. Because exposure is linearly related to tube current, the tube current should be set at the lowest level that yields diagnostic image quality for a given scanner and patient habitus. A calcium scoring scan can help determine whether the patient has widespread calcification that would make CT angiography challenging to interpret. This type of scan might use retrospective gating, which delivers a mean exposure of 1.0 mSv to 6.2 mSv, or prospective gating, which delivers a mean exposure of 0.5 mSv to 1.8 mSv, when the scanner used is less than a 64-slice unit. Multidetector scanners with 64 or more slices require higher tube currents and usually result in higher exposures.

The dose to superficial organs can be reduced through the use of bismuth shielding. The shielding has been shown to reduce dose by up to 50% to the eye, thyroid, and breast during CT imaging. Bismuth shielding can significantly increase image noise, however. Another downside to bismuth shielding is that streaking artifacts occur with patient motion. This drawback to bismuth shielding should be considered, especially for pediatric imaging.

**Fluoroscopic Image Guidance**

Both diagnostic and therapeutic procedures increasingly are performed under image guidance, especially cardiac procedures. Image guidance is used in radiography, nuclear medicine, radiation therapy, and surgical suites. Radiologists play an important role in planning image guidance and setting standards for use of imaging. However, many nonradiology specialties now depend on image guidance to perform diagnostic and therapeutic examinations and procedures, often in the outpatient practice setting.

European guidelines recommend a certification process for use of image guidance because the knowledge and expertise regarding safe radiation practice varies greatly among medical professionals. In addition,
measurement of relevant equipment and technical factors should be standardized, displayed, and recorded. Intervventional radiology practitioners should only purchase equipment that offers current dose-measurement and dose-management capabilities and should upgrade existing interventional fluoroscopic equipment to improve dose measurement capabilities.

Recording Dose

For quality assurance and patient safety purposes, the Society of Interventional Radiology recommends recording patient radiation doses in the patient’s medical record for all fluoroscopy-guided procedures. The National Council on Radiation Protection and the CRCPD also recommend attaching the dose data to the images from these procedures, especially for those known to produce high radiation doses. High-dose procedures include all embolization procedures, transjugular intrahepatic portosystemic shunt creation, arterial angioplasty or stent placement procedures in the abdomen or pelvis, and biliary drainage procedures. Some procedures that provide midlevel radiation dose (1-3 Gy) are frequently repeated, and patient dose should be recorded.

National averages for radiation doses for U.S. interventional radiology examinations and procedures were reported in the Radiation Doses in Interventional Radiology Procedures study. The CRCPD suggests that any time a patient receives a dose that meets or exceeds the dose threshold level, the radiation safety committee or radiation safety officer at the facility where the examination or procedure was conducted should be involved in a case review to ensure that the patient has been properly notified and any necessary medical intervention has occurred. In addition, serious injuries associated with the use of medical devices, such as radiation burns and other deterministic injuries, must be reported to the FDA according to the Safe Medical Devices Act of 1990. Fluoroscopic equipment operators also should be monitored for trends in patient dose.

Patient Counseling

A facility should provide postprocedure counseling to the patient and his or her family when a dose of 3 Gy or more has been delivered. The counseling helps patients understand the signs of radiation injury. Should symptoms occur, the patient also should be instructed to contact both a primary care physician and the facility at which the imaging examination or procedure was conducted. Further, the imaging facility staff should follow up with the patient 3 weeks after radiation exposure to determine whether a radiation-induced injury has occurred.

Patients should be encouraged to notify the facility of relevant symptoms even after the initial 3-week period. Interventional radiology departments can take the proactive step of establishing a referral network with dermatologists and radiation oncologists to evaluate and treat skin injuries.

Cardiovascular Procedures

Although the overall risk of patient injury from fluoroscopy-guided procedures is low, reports show that ionizing radiation is associated with health risks for exposed individuals, including painful, disfiguring, and long-lasting skin injuries. Cardiac catheterization procedures are associated with a risk for radiation-induced skin injury, including transient erythema and necrosis. Careful monitoring of dose is necessary for complex and repeat procedures.

Some of the most common image-guided procedures are coronary angiography studies. The average exposure for diagnostic conventional coronary angiography reportedly ranges from 2.3 mSv to 22.7 mSv. According to the United Nations Scientific Committee on the Effects of Atomic Radiation, the typical mean exposure is 7 mSv. Factors such as operator experience, workload, use of radiation-reducing techniques, procedure complexity, and equipment used affect dose from catheter-based angiography procedures. The use of a left anterior oblique projection results in a greater dose than a right anterior oblique or PA projection because the left anterior oblique projection requires a greater source-to-object distance and uses a longer course of x-rays through the thorax. Depending on the type of interventional procedure and fluoroscopy time, the exposure can be up to 5 times the typical 7 mSv. Patients should be screened to identify whether they have recently undergone fluoroscopy-guided interventions before undergoing any interventional procedure.
known to place them at an increased risk of developing radiation-induced skin injuries. It also is important to know whether patients who have undergone recent fluoroscopy-guided interventional procedures have signs of radiation-induced skin damage.13

Dose Reporting

Manufacturers of fluoroscopy equipment have different methods for reporting dose data. Many have adopted DICOM radiation dose structured reporting to standardize dose data reporting.14 Equipment used in interventional suites generally records detailed data in the equipment’s service logs about each irradiation event, including each time the radiologist activates the foot pedal for fluoroscopic foot-pedal activation, a cine run, or a DSA run.9 The FDA requires that all fluoroscopy equipment made after June 10, 2006, have an integrated dosimeter in the unit.19 Although the systems are not accurate predictors of skin dose and are allowed ± 35% leeway, their installation is useful to indicate potential deterministic risk. Equipment manufactured before June 2006 can use an aftermarket device to monitor radiation dose, which should be purchased and installed with the help of a qualified medical physicist.19 These indirect dose monitoring methods record cumulative dose, which does account for beam motion and only indicates total radiation to the skin, which likely overestimates the true skin dose.19

Cooperation between medical specialties and societies is necessary for standardization of dose reporting.21 Increasing awareness among patients, healthcare providers, and policymakers could improve the financing and support of standardized image guidance.21 A cost-benefit analysis should be conducted as image-guided procedures replace older techniques.23

Dose Monitoring

Dose can be monitored through direct or indirect methods during fluoroscopy studies, but all reported radiation doses should be considered estimates.16,19 Regardless of the radiation monitoring system used, many factors should be evaluated to improve accuracy of skin dose estimates.19 Patient size, beam position, technical factors, source-to-image distance, source-to-skin distance, backscatter, and equipment capabilities affect dose calculations.19 Each facility should work with a qualified medical physicist to choose the best monitoring method.19 Improving monitoring increases staff awareness, which can lead to actions being taken toward minimizing patient dose.19

Direct monitoring methods include placement of one or more dosimeters on a designated area of the patient.19 Electronic dosimeters, photographic film, and thermoluminescent dosimeters (TLDs) are used currently.19 Several TLDs or electronic dosimeters usually are used during an interventional procedure to collect data for a section of skin because the exact field of exposure is not known when TLDs are placed.19 Use of electronic dosimeters can affect image quality because detectors and leads are visible.19 TLDs are read only at the end of a procedure; therefore, they do not alert radiologists or technologists to exposure issues requiring action during the procedure.19

Alternatively, when examinations do not exceed 2 Gy, dosimetric film can be placed between the x-ray beam and the patient to record dose data.18,19 The dosimetric film darkens proportionally to dose.19 The level of darkness is then measured with a densitometer.19 As facilities phase out use of radiographic film and convert to digital radiography, this method of dose monitoring is becoming less common. Benefits to the dosimetric film method include low cost, simplicity of analysis, and the ability to investigate over a broad exposure area.19

An alternative to radiographic film is radiochromic film, which is sensitive to 0.01 Gy to 30 Gy, available in several versions, and does not require wet processing.19

Indirect methods involve measurements of the beam and technical factors to extract skin dose estimates.19 The 4 patient dose metrics used in the United States for determining patient dose during fluoroscopy procedures are peak skin dose, reference air Kerma, Kerma-area product, and fluoroscopy time. The most accurate method for estimating dose during interventional fluoroscopy procedures is the peak skin dose. The Society of Interventional Radiology recommends computer simulation instead of physical measurement of dose because patient size, age, and sex can be incorporated into the calculation.16,27 Details on the system settings, beam angles, source-to-image distance, kilovolts, milliamperage, and number of frames more precisely calculate the peak skin dose.19
Technology that allows radiology staff to view peak skin dose data as a skin dose map has been developed but is not commercially available. When it becomes available, the skin dose map can be recorded in the patient’s medical record.\textsuperscript{8} Peak skin dose is difficult and costly to measure, but work is underway to standardize the export of dosimetric data from the fluoroscopy equipment as a radiation dose structured report.\textsuperscript{9} With the structured report data, dose and geometric information for each procedure can be available to use with databases and mathematical phantoms to produce modeling algorithms that calculate skin and organ doses.\textsuperscript{8}

The next best methods for determining peak skin dose are using both the reference air Kerma and Kerma-area product, followed by the reference air Kerma alone, the Kerma-area product alone, or fluoroscopy time along with the total number of fluoroscopic frames or images.\textsuperscript{8} Even so, the peak skin dose is estimated to be within only $\pm$ 50% of the actual skin dose to a patient, excluding backscatter radiation.

Reference air Kerma is defined as the air Kerma value at a designated location called the \textit{interventional reference point}, which is located between the focal spot and the gantry along the central ray.\textsuperscript{9} The reference point location can vary between different fluoroscope configurations, including isocentric C-arm and operating room C-arm systems.\textsuperscript{9} The true reference point is described in each fluoroscopic system’s manual.\textsuperscript{9} The reference air Kerma does not account for backscatter but correlates with peak skin dose.\textsuperscript{9}

Kerma-area product measures the entire amount of radiation energy the patient receives. It is better suited for estimating stochastic risk than deterministic risk because a large dose to a small area of skin would receive the same recording as a small radiation dose to a large area of skin.\textsuperscript{8,9,19} Kerma-area product is measured with a dedicated meter that might be included in the fluoroscopy unit or as a separate device that is connected to the unit.\textsuperscript{5,19} The meter is attached to the face of the x-ray tube collimator and can adjust the dose to the selected image field. Kerma-area product meters are widely available and can be used on older equipment.\textsuperscript{19} Factors such as patient size, mode selection, beam geometry, and motion are not included in Kerma-area product measurements.\textsuperscript{19}

Although manually recording fluoroscopy time and number of image frames has been common practice in the past, this method is not sufficient for determining patient dose.\textsuperscript{19} Recording time and frames fails to include factors such as patient size, mode selection, beam geometry, and motion.\textsuperscript{9} Dose thresholds at which operators should be alerted during procedures include:

- Peak skin dose – 2000 mGy, and again at every 500 mGy.
- Reference air Kerma – 3000 mGy, and again at every 1000 mGy.
- Kerma-area product – 300 Gy $\times $ cm$^2$, and again at every 100 Gy $\times $ cm$^2$.
- Fluoroscopy time – 30 minutes, and again at 15-minute intervals.\textsuperscript{19}

All recorded dose data should be reviewed immediately after each fluoroscopic procedure to determine the patient’s risk for deterministic effects.\textsuperscript{19} The data log should be reviewed regularly as part of the quality management program to assess appropriate use of radiation in the department or facility. Staff should incorporate dose reduction practices for procedures that consistently exceed the 5-Gy dose limit. Technologists should be able to communicate with attending interventional radiologists during complex procedures to modify techniques or terminate a procedure when patient safety is at risk.\textsuperscript{13}

**Dose Thresholds and Tracking**

No federal requirements currently exist in the United States for recording or tracking patient radiation dose data for interventional procedures.\textsuperscript{8} Some states have developed regulations based on guidance from the CRCPD, but the regulations vary among states, and threshold values range between 1 Gy and 6 Gy.\textsuperscript{8,19} The FDA supports recording the absorbed dose in a patient’s chart when a procedure reaches 1 Gy.\textsuperscript{19} The ICRP stated in 2000 that the dose threshold was 3 Gy, or 1 Gy if a procedure is likely to be repeated. The ACR states that a skin dose of 2 Gy is the threshold at which dose should be tracked.\textsuperscript{19} The Society of Interventional Radiology recommends the following measures as thresholds for notifying radiologists and technologists promptly:

- Peak skin dose exceeding 3000 mGy.
- Reference air Kerma exceeding 5000 mGy.
- Kerma-area product exceeding 500 Gy × cm².
- Fluoroscopy time of 60 minutes.¹⁹

When these threshold values have been reached, the patient should be monitored for deterministic injury, and the dose should be included in the patient’s chart.¹⁹ In addition, the dose from procedures completed within 60 days of a previous procedure should be added to the dose recorded for the first procedure.¹⁹ Regardless of the threshold used, dose management systems raise awareness and help reduce radiation dose.¹⁹ Although recommendations from several regulatory committees are available for guidance, radiology practitioners should follow the most stringent regulatory guidelines that apply in their imaging center or hospital.⁴

**Data Sharing and Audits**

Several radiation safety programs have been established for interventional radiology procedures that involve patient education, radiation monitoring during procedures, documentation of radiation dose, and radiation injury risk counseling for patients following procedures.⁴,¹³ Data sharing has been encouraged between facilities through the International Atomic Energy Agency’s Safety in Radiological Procedures reporting system. The system allows institutions to voluntarily report patient dose for education and quality improvement.⁴ The agency suggests using an audit process that relies on large dosimetric data sets from participating facilities to set an action level for patient follow-up when the patient’s risk of deterministic skin injury is significantly increased.⁹ The dosimetric data is collected from specific procedures using fluoroscopic systems with common reference point locations.⁹

With this audit process, the distribution of the reference air Kerma values is included every time a given procedure is performed at a facility.⁶ Each facility that participates in the audit creates a facility data set with dosimetric data such as reference air Kerma values each time specific examinations are performed.⁶ Each facility establishes a substantial radiation dose level, or threshold, that is used to alert the staff that a patient needs follow-up for possible deterministic injury.⁶ The information from each facility’s data set is collected to compile an advisory data set consisting of dosimetric data for procedure instances across all participating facilities.⁹

Factors used to determine the substantial radiation dose level include the imaging system geometry, radiobiology, and effects of radiation on the skin.⁹ Several advisory groups suggest that the maximum reference air Kerma for isocentric C-arm units be 5 Gy, which usually yields a peak skin dose of about 3 Gy during interventional radiology procedures.⁹ A more conservative reference air Kerma level of 3 Gy also has been suggested. Each facility must determine the optimal level for its practice.⁹

The challenge with setting a value to alert staff is that there is no guarantee that injury can be prevented if dose is lower than the threshold or that injury will occur if dose exceeds the threshold.⁹ The substantial radiation dose level should be low enough to include all patients who could experience an adverse skin effect but high enough to allow efficient patient follow-up.⁹

Once the facility data set median is determined, it is compared with the 75th percentile of the advisory data set to begin the dose audit process.⁹ A facility might wish to investigate protocol or equipment when the median dose falls above the 50th percentile or below the 25th percentile of the advisory data set.⁹ Below-normal radiation use could indicate incomplete exposures, poor image quality, or optimal dose management. Radiation levels above the norm could be caused by substandard equipment, incorrect settings, reduced procedure performance, operator inexperience, or a challenging clinical situation.⁹

After the median is determined, the facility should review the percentage of local events that exceed the facility-selected substantial radiation dose level.⁹ When the dose level varies greatly from the advisory data set level, radiology staff should observe clinical results and potential skin injuries. The quality-control committee should analyze the equipment, examination protocols, and operator trends and practices. The final step in this audit process is to ensure that adequate follow-up is reached for each patient whose dose level surpasses the local substantial radiation dose level.⁷ The goal of the audit is to ensure adequate follow-up for patients who receive a high dose of radiation, not to set a mandatory maximum dose limit. The risk vs benefit of interventional examinations and procedures is continually monitored by physicians.⁹
Pediatric Dose

Dose reduction strategies are particularly important for pediatric imaging studies. The greater need to use magnification techniques with children automatically increases dose. Some ways to reduce radiation dose during fluoroscopic procedures are minimizing x-ray beam-on time, changing the entrance point location on the patient when possible, using optimal collimation, relying on the least amount of magnification necessary, accurately placing the x-ray source and image receptor, and properly using equipment dose reduction features such as last image hold and pulsed fluoroscopy.

The use of pulsed fluoroscopy can reduce dose up to 10-fold without a significant loss of spatial resolution or contrast. Another technique to reduce entrance skin dose is to position the fluoroscopy table as far from the x-ray source as possible. Conversely, the image intensifier should be positioned as close to the patient as possible. The radiologic technologist can use shielding to protect the patient but must place the shield under the patient when using an undercouch tube. When acquiring images with automatic exposure control, shielding placed directly in the beam’s path increases the entrance skin dose. Optimizing the technique helps to achieve dose reduction in diagnostic conventional coronary angiography, and the risk of skin injuries can be reduced by changing the radiographic projection during a procedure or with real-time skin dose monitoring.

When using digital angiography or digital subtraction angiography during pediatric studies, recording of image acquisition should be limited to diagnosis or assessment of outcome when a procedure is completed. To reduce patient dose, the acquisition setting should use the least number of frames per second necessary and the lowest magnification possible, along with tight collimation to the area of interest. Physicians can work with anesthesiologists to help minimize patient motion and increase cooperation for fine-detail digital subtraction angiography. The PACS can store images from last-image hold, image capture, video recording, and digital fluoroscopy runs for evaluation.

With C-arm equipment, the operator should consider the proximity of the x-ray source to the skin in the lateral and oblique projections for all patients. If possible, the radiologic technologist should position the patient with his or her arms raised with the assistance of arm supports for lateral or oblique positions to maximize the distance between the x-ray source and the patient’s skin. Operators also should limit use of projections that overlap the field of interest.

Nuclear Medicine

Although the radiation risks of most nuclear medicine scans are low because of the low-level (< 100 mSv) exposure to ionizing radiation, a significant percentage of the annual exposure to all ionizing radiation in the United States is from nuclear medicine studies. Scientists stress that the benefits of nuclear medicine procedures far outweigh the risks, helping patients avoid invasive procedures such as cardiovascular and interventional radiology or exploratory surgery. Some nuclear medicine experts report that the risks of nuclear medicine scans are overstressed, even for pregnant women, compared with the benefits of the scans. The equivalent dose to any organ must be less than 50 mGy from radiopharmaceuticals used in diagnostic imaging, according to the CRCPD. No dose registry system is in place as of this writing to track patient dose in nuclear medicine. Increased public awareness of the cancer risk associated with medical radiation exposure has prompted advances in single-photon emission computed tomography (SPECT) and positron emission tomography (PET) scanners that include improved software to reduce patient dose.

In recent years, the most common use of nuclear medicine has been with cardiac nuclear imaging. The highest effective dose to patients is generally from myocardial perfusion imaging. Whereas PA chest radiography produces an average effective dose of 0.02 mSv, myocardial perfusion studies deliver effective doses of between 2.2 mSv and 31.5 mSv. Both the selection of a radiopharmaceutical and of a single or dual isotope protocol can have a significant effect on the dose. Dual isotope studies can deliver up to 3 times the dose of a single-injection protocol, and the rate of use has been increasing in the United States since 1997. Dual isotope studies have been popular in the outpatient setting because patient throughput is faster; however, choosing a modality or technique for its speed over patient radiation risk does not align with the ALARA concept.
Careful pretest screening and communication between the nuclear medicine staff and the referring physician can ensure ordering of the most diagnostically appropriate test that uses the lowest amount of radiation possible.\textsuperscript{16} In addition, the dose from myocardial perfusion studies can be reduced if stress-only protocols are used rather than stress-rest protocols.\textsuperscript{30}

Both SPECT and PET scanners now are available with list-mode capabilities that allow retrospective analysis and reconstruction of data, which allows a lower tube current to be used to create diagnostic quality images. Efforts to improve hardware design of SPECT systems include much better collimation and optimized scanner geometry that allows counts of photon events in the myocardium to be collected from all directions without rotating the camera. The number of counts in the myocardium determines the quality of the perfusion imaging scan.\textsuperscript{30} Advances in reconstruction algorithms have led to reduced imaging time or radiation dose while providing better image quality than traditional software.\textsuperscript{30} Older systems can be retrofitted with this new software.\textsuperscript{30}

Using lower doses of injected radiopharmaceuticals also has resulted in decreased patient dose. An ultra-low-dose technique with rest imaging has been tested that uses injected doses below 3.5 mCi. This technique results in patient doses less than 1 mSv.\textsuperscript{30} PET-CT enables dose reduction for cardiac imaging with increased sensitivity of 3-D data acquisition.\textsuperscript{30} Dose reduction might be achieved by using newer, more sensitive systems with a reduced radiopharmaceutical dose and maintaining scan times.\textsuperscript{30}

Because of the relatively low levels of radiation dose reported from nuclear imaging studies, there does not seem to be an intense effort to incorporate dose data into an index registry at this time. Increased public awareness of radiation risks in general has encouraged the development of dose reduction techniques and improved staff accountability, however, for selection of system upgrades and examination protocols.\textsuperscript{29}

**Conclusion**

With increasing use of medical imaging in recent years, the risks of exposure to ionizing radiation have been addressed in the media. Public concern has prompted action from multiple advisory groups to better measure and track patient radiation dose, especially for CT and fluoroscopy-guided interventional studies that can deliver high amounts of ionizing radiation. Risk must be properly understood by staff and explained to patients so patients can make informed decisions regarding their care.

Medical imaging facilities should provide educational programs for patients and staff to ensure understanding of radiobiological effects from procedures provided in the department.\textsuperscript{19} Individualized training programs relevant to the facility should include biological effects of ionizing radiation, radiation protection of the patient and staff, use of personal protective equipment, dose monitoring, and threshold action levels.\textsuperscript{19} Specific training for those involved with pediatric imaging also should be required.\textsuperscript{11} New employees should be subject to an orientation or certification system to ensure proficiency in safe radiation practices.\textsuperscript{19} Staff also should be supervised until they have completed the orientation or certification system.\textsuperscript{19} Annual refresher courses and training on new equipment to optimize operator performance is recommended.\textsuperscript{19}

Sharing dose data within a radiology practice and with national radiology data registries will improve awareness of protocols and techniques that need to be optimized. Use of data, along with improved communication among providers and patients, equipment manufacturers, and radiation safety officers will emphasize a culture of radiation safety in medical imaging.

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Current Issues in Radiation Dose Monitoring and Reporting

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Read the preceding Directed Reading and choose the answer that is most correct based on the article.

1. For the most accurate lifetime radiation risk assessment, all radiation doses from imaging examinations should be included in:
   a. a statewide health registry.
   b. a national health registry.
   c. patient electronic health records.
   d. personal health risk cards.

2. ______ is an example of stochastic radiation effects.
   a. A cataract
   b. Erythema
   c. Growth retardation
   d. Carcinogenesis

3. An effective dose of 10 mSv is associated with a risk of future malignancy in 1 in _____ 40-year-old adults.
   a. 10
   b. 100
   c. 1000
   d. 10 000

4. The entire amount of radiation from the x-ray beam that reaches a patient and that is measured in the absence of scattered radiation is known as:
   a. Kerma-area product.
   b. peak skin dose.
   c. effective dose.
   d. reference air Kerma.

5. The ______ dose estimates the risk of stochastic effects.
   a. effective
   b. equivalent
   c. absorbed
   d. peak skin

6. ______ provides the best estimate for patient dose for general radiography and fluoroscopy.
   a. Reference air Kerma
   b. Air Kerma-area product
   c. Effective dose
   d. Historical tissue-weighting

continued on next page
7. To gauge the level of radiation hazard associated with an imaging examination, one can compare:
   1. effective dose for the examination to examinations that provide similar diagnostic information.
   2. effective dose for the examination to natural background radiation.
   3. an imaging system's radiation output for a particular examination against levels from other facilities for the same examination.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

8. Campaigns to address unnecessary radiation exposure have focused primarily on high-dose examinations and procedures from:
   1. computed tomography (CT).
   2. fluoroscopy-guided interventional procedures.
   3. digital radiography.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

9. The goals of dose reporting are to:
   1. improve staff training.
   2. provide error data to state licensing boards.
   3. ensure proper equipment function at all facilities.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

10. The noise level produced in digital radiography is ______ proportional to the level of radiation intensity used to produce the image.
   a. linearly
   b. inversely
   c. directly
   d. exponentially

11. The exposure indicator used in digital radiography is an accurate measurement of individual patient dose.
   a. true
   b. false

12. A recently created standard from the International Electrotechnical Commission provides manufacturers with a method to:
   a. lower tube currents on digital imaging equipment.
   b. better train staff on how to optimize dose.
   c. convert exposure information into a uniform format.
   d. improve automatic exposure control so technologists do not have to optimize dose.

13. The CT dose index is based on:
   a. an average of overexposures and underexposures.
   b. surface skin dose only.
   c. physical surface skin dose measurements on patients of all sizes.
   d. physical measurements of phantoms.

14. When using Monte Carlo simulations to estimate CT dose, patient habitus and anatomy always are reflected in the simulated patient.
   a. true
   b. false

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15. Iterative reconstruction improves _____ where there is high image contrast and reduces _____ on images with low contrast.
   a. dose; spatial resolution
   b. spatial resolution; dose
   c. spatial resolution; noise
   d. noise; dose

16. When performing cardiac CT, a calcium scoring scan can help:
   1. verify ideal tube current and voltage.
   2. set the minimum scan time.
   3. determine whether the patient has widespread calcification that would make CT angiography challenging to interpret.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

17. The range for midlevel radiation dose fluoroscopy procedures is _____ Gy.
   a. 1 to 3
   b. 3 to 5
   c. 5 to 7
   d. 7 to 9

18. A facility should provide counseling after a fluoroscopic interventional procedure if the patient received a radiation dose of at least _____ Gy.
   a. 0.3
   b. 0.5
   c. 1
   d. 3

19. During conventional coronary angiography, the greatest dose is delivered to the patient when using a _____ projection.
   a. left anterior oblique
   b. right anterior oblique
   c. posteroanterior
   d. anteroposterior

20. An example of direct dose monitoring is:
   a. placing dosimeters on a designated area of the patient.
   b. measuring x-ray beam.
   c. measuring technical factors.
   d. extracting peak skin dose.

21. When evaluating a patient’s risk for deterministic injury from interventional procedures, the dose from procedures completed within ______ days of a previous procedure should be added to the original dose.
   a. 15
   b. 30
   c. 45
   d. 60

22. Which of the following generally could cause radiation levels above the norm in fluoroscopy-guided procedures?
   1. substandard equipment
   2. incomplete exposures
   3. incorrect settings
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3
23. To reduce pediatric patient dose when using digital angiography or digital subtraction angiography, the operator should use:
   1. the acquisition setting with the least number of frames per second necessary.
   2. the lowest magnification possible.
   3. tight collimation to the area of interest.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

24. The use of a dual isotope protocol in nuclear imaging studies can deliver up to ______ times the dose of a single-injection protocol.
   a. 1.5
   b. 2
   c. 2.5
   d. 3

25. Efforts to lower dose from positron emission tomography and single-photon emission computed tomography include:
   1. advances in reconstruction algorithms.
   2. using lower doses of radiopharmaceuticals.
   3. increasing the use of myocardial perfusion imaging.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3