Computed Tomography Iterative Reconstruction Techniques

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After completing this article, the reader should be able to:
- Describe patient risks related to computed tomography (CT) radiation dose.
- Discuss the development of CT image reconstruction algorithms.
- List typical steps for CT image reconstruction.
- Describe common terms and vendor-specific applications related to iterative reconstruction techniques.
- Explain the use of CT phantoms in developing imaging protocols.
- Discuss the advantages and disadvantages of iterative reconstruction techniques when applied to various clinical imaging protocols.
- Discuss the significance of dose reporting and CT protocol database creation in the ongoing development of institutional examination protocols as well as national policy.

Recent advances in the ability to detect and quantify damage to DNA have linked the dose-related effects of ionizing radiation from CT examinations to chromosome double-strand breaks.

Computed tomography (CT) is under global scrutiny for the risks associated with radiation exposure and iatrogenic radiation effects linked to CT data acquisition.

In 2009, the National Council on Radiation Protection and Measurements named CT the leading source of artificial radiation exposure in the United States. According to the Norwegian Radiation Protection Authority, in 2002, CT examinations comprised 14% of diagnostic radiography examinations performed but accounted for 59% of the national radiation dose from radiologic examinations. Studies from Australia, the United Kingdom, and the United States have reported a 0.6% to 3.2% increase in the cumulative risk of cancer (before 75 years of age) attributed to diagnostic radiation exposure in the developed world from 1950 to 2007.

Escalating concerns regarding the risks related to ionizing radiation have made CT dose reduction a top priority. One study revealed that patients exposed to radiation dose greater than 7.5 mSv from cardiac computed tomography angiography (CTA) show evidence of double-strand breaks in T lymphocytes. Such damage is associated with direct cell death; activation of transcription factors, biological pathways, and cellular repair genes; or apoptosis (programmed cell death).

CT iterative reconstruction techniques present a powerful way to improve patient care and image quality.

For all their diagnostic value, computed tomography (CT) examinations have relatively high radiation exposure. Past efforts to decrease patient dose emphasized advances in data acquisition technology because attempts to decrease dose resulted in increased image noise from filtered back projection reconstruction techniques. Iterative reconstruction techniques lead to reduced dose and maintain image quality. Improvements in CT technology and protocols can enhance patient care, but the increased amount of data requires new methods for handling information. CT iterative reconstruction techniques present a powerful way to improve patient care and image quality.

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Government policy often follows broad principles for maintenance of a radiation dose, such as keeping dose as low as reasonably achievable. Beginning January 2016, Medicare began reimbursing 5% less for CT scans acquired on equipment that does not comply with Standard XR-29-2013, including the latest specifications for radiation dose optimization and reporting published by the National Electrical Manufacturers Association’s Medical Imaging & Technology Alliance. The requirements to meet these specifications directly affect facilities using CT scanners that do not generate a dose report in the form of a DICOM image for the patient record.

Recognizing the need for automated dose monitoring in radiation reduction and standardization measures at the national and institutional levels, the American College of Radiology (ACR) created the CT Dose Index Registry as a part of the National Radiology Data Registry. The index is a pilot project designed as a database with which participating institutions can compare their average patient radiation doses with other facilities. According to a November 2015 ACR report, more than 465 institutions from across the United States are participating in the project, making the Dose Index Registry the largest database of radiation doses associated with various CT protocols. The CT examination dose information is stripped of unique patient identifiers and communicated to the Dose Index Registry using a secure data feed. Values are recorded in the form of CT dose index (CTDIvol), which are average, weighted calculated doses expressed in milligrays, and dose-length product (DLP) expressed in milligray-centimeters. In turn, the ACR provides data stratified according to several variables, such as CT examination protocol, anatomy of interest, and type of facility, to facilitate comparisons and potential standardization of CT radiation dose for various examinations.

In addition, the ACR is working to standardize quality control phantom parameters to further ensure CT dose optimization through ACR CT accreditation. Quality control phantoms typically are constructed from plastic and designed to measure image quality, including alignment, spatial resolution, contrast resolution, and image noise.

Simultaneously, diagnostic imaging has entered the era of “big data,” a revolution in data creation and management that has placed unanticipated stress on CT technologists and radiologists. Medical informatics is leading worldwide in data generation, and this has a direct effect on the workflow of CT departments. In the field of biomedicine, it often is now less expensive to generate data than it is to analyze and store the data. In the United States, the number of CT examinations performed increased from 13 million scans in 1990 to 62 million scans in 2006. A study on the effect of the increasing amounts of imaging data on radiologist workload found that the total number of annual cross-sectional examinations increased from 84 409 in 1999 to 147 336 in 2010 at a single institution. This increase in data represented a 2-fold increase in radiologist workload. The number of images requiring interpretation per minute per radiologist increased from 2.9 in 1999 to 16.1 in 2010. Therefore, on average, a radiologist interpreting CT or magnetic resonance examinations must now interpret one cross-sectional image every 3 to 4 seconds in an 8-hour workday to meet the workload demands presented by the increasing amount of image data. In short, research into data generation and analysis has revealed that management of CT data is a critical step in reducing patient dose and increasing diagnostic efficacy.

Nevertheless, dose optimization efforts focus on various schemes for reducing patient dose and improving image quality during data acquisition without weighing the potential effects image reconstruction has on dose reduction and improved image quality (see Figure 1). For example, the general methods of dose reduction during data acquisition include:

- Combining applications and using prepatient filtering – reducing the dose by approximately 15%.
- Using faster ceramic detectors – reducing the dose by another 25% compared with conventional CT.
- Using automatic tube current modulation techniques – time-of-flight scanning parameters that alter milliamperesecond settings according to image noise thresholds (see Figure 2).
Manufacturers have developed unique classifications and methods for automatic tube current modulation (see Table 1).\textsuperscript{15,16} Around 2009, CT manufacturers released a new generation of image reconstruction applications that reduce image noise after CT data acquisition.\textsuperscript{17} Although names and parameters differ depending on the manufacturer, the literature refers to this new technology as \textit{iterative reconstruction} (IR).\textsuperscript{6,15} These IR techniques were developed initially to decrease image noise, but researchers soon realized the potential for simultaneously decreasing patient dose.\textsuperscript{6} CT technologists must provide optimal imaging at the lowest dose achievable without sacrificing diagnostic image quality.\textsuperscript{19} Understanding the benefits and risks of IR techniques is vital to developing and implementing the data acquisition and image display methods that best reduce radiation risks and improve patient care in the CT image production process.\textsuperscript{18,19}

**History**

CT image reconstruction is the application of computer algorithms to the linear attenuation data acquired from a series of tomographic x-ray projections through a volume of interest.\textsuperscript{15} A computer algorithm is programmable step-by-step operations executed in a specific order.\textsuperscript{16} In the case of CT image reconstruction algorithms, the computer follows the steps to render the raw scan data into image data revealing the anatomy within the volume of interest.\textsuperscript{15,16} Reconstruction algorithms are completely different from the parameters that control image window width and level.\textsuperscript{16} A change in window setting changes the way the display images can be viewed.\textsuperscript{16} A change in the reconstruction algorithm changes how the raw data is rendered into image data for display.\textsuperscript{16} CT reconstruction algorithms are classified as analytic (ie, conventional filtered back projection) and IR techniques.\textsuperscript{6}

Johann Radon introduced the theoretical framework for image reconstruction in a 1917 publication on determining the shape of functions from their integral values projected into topological space.\textsuperscript{20,21} Mathematical integrals are numbers that measure an area. Radon proposed to project these area measurements into abstract topological space.\textsuperscript{21} Topological space is a mathematical set of points defined by a set of neighborhoods in which each point satisfies a number of axioms relating to points and neighborhoods. In CT image reconstruction, the projected data is referred to as a \textit{sinogram} because it comprises sine waves that indicate the topological neighborhoods of the area measurements.\textsuperscript{20} The sinogram also can be represented as the inverse transform.\textsuperscript{20,21} In other words, the inverse of the Radon transform can be used to deform the sinogram into an image displaying the areas measured within the volume of interest.\textsuperscript{20,21}

Radon’s formula for inverse transformation is the foundation of image reconstruction for areas beyond...
CT, including astronomy and microscopy. In 1963 Alan MacLeod Cormack built upon Radon’s work to apply reconstruction techniques to nuclear medicine; in 1967 Sir Geoffrey Hounsfield incorporated Cormack’s work into his research on the scanning software and hardware needed to reconstruct images of 3-D objects from x-ray projections of the objects acquired in a series of different angles. Hounsfield named the technique computerized transverse axial scanning (tomography) in a landmark study published in 1973 in the British Journal of Radiology. Later, Cormack and Hounsfield would share the Nobel Prize for Medicine for their application of Radon’s work to health care. Hounsfield’s first CT scanner used the algebraic reconstruction technique and required 2.5 hours to process the 28 000 measurements collected by the detector. Limitations in processing power historically have presented the biggest obstacle in developing computational algorithms capable of handling the vast data sets and data acquisition variables of CT image reconstruction.

In this regard, IR techniques are not new—they were among the first proposed methods of image reconstruction in the 1970s, but when combined with historical computer processing limitations, the demanding mathematical properties of IR algorithms, and the large amount of data produced during CT data acquisition, IR did not prove practical for clinical purposes. Instead, IR became the default method of data handling for nuclear medicine emission tomography. Less spatial and temporal resolution is required for single photon emission CT (SPECT) and positron emission tomography (PET) than for conventional CT, and the smaller volumes of raw data required for SPECT and PET made for less complicated data handling coupled with a need for noise suppression. These factors proved ideal for the application of IR techniques in nuclear medicine despite the historically low computer processing power.

For the purposes of conventional CT, the filtered back projection (FBP) reconstruction algorithm provided a faster—if less precise—analytic approach to handling raw image data, and FBP soon became the standard image reconstruction technique for CT data sets regardless of equipment manufacturer or imaging protocol. FBP has remained the standard for more than 30 years, setting a number of clinical benchmarks for quantified measurements of CT images (eg, cardiac calcium scores and precontrast and postcontrast liver attenuation values). Knowledge of the elementary principles of FBP is crucial to understanding the principles and advantages of IR.

### Filtered Back Projection

In third-generation CT scanner data acquisition, continuous x-ray energy is generated as the tube travels in a circular path opposite the travel of the detector array. A ray is the path of the x-ray photons from tube to detector. The detector array measures the attenuation of each arriving ray and computes a ray sum. A set of ray sums is compiled to create a view, and attenuation profiles are generated from views by correlating each ray sum with the position of the ray. The attenuation profiles are then projected onto a matrix in a process referred to as back projection (see Figure 3). Analytical reconstruction algorithms, such as FBP, are based on the assumption that the measurements of ray sums and the matrix of projected attenuation profiles can be reduced to continuous functions. This means that whenever the functions encounter information that interrupts their process, the resultant image noise is represented continuously through the attenuation profile—often in the form of star-shaped streak artifacts on the images. To reduce these artifacts, filters are applied to the attenuation profiles before back projection in a process referred to as convolution. These filters are termed kernels, algorithms, or convolution filters, depending on the manufacturer. In clinical practice, the variations of filters in back-projected image reconstruction represent a compromise between image noise and spatial resolution. For example, while using FBP techniques, if the CT technologist increases compensation for low-pass image blur, the software will simultaneously increase the sharpness of the image and the image noise. This is a fundamental characteristic of FBP: image sharpness and image noise are directly related. The sharper the image, the greater the noise and vice versa.

A similar difficulty arises from a decrease in the amount of photons in the ray. FBP fails to accurately represent the noise that results from Poisson statistical variations in the number of photons arriving at
employs. Medical physicists had to perform a variety of tests to ensure that smoothing the images with the ASiR algorithm would not result in inadvertent oversmoothing and thus obscure pathology during image reconstruction. Another point of concern was whether radiologists accustomed to the texture of FBP-reconstructed CT images would adapt to the smoother images provided by this new technology. Researchers began to investigate whether the diagnostic value of data visible in the ASiR images could be maintained while reducing exposure during data acquisition. This dose reduction would increase the image noise, but the noisy data sets would then be smoothed out using the ASiR algorithm during image reconstruction. This led to the development of new CT data acquisition protocols designed for IR post-processing.

The advantages of FBP reconstruction techniques are efficiency and fast computation. A disadvantage is that at reduced doses, FBP images are noisy and streaked with artifacts. To improve diagnostic quality of image data acquired at decreased dose levels, CT manufacturers incorporated a model of the CT data acquisition system into IR algorithms. This distinction marks the main difference between IR and FBP. Specifically, IR algorithms model the CT scanning system, reproducing the geometry and physics of the data acquisition process to inform the interpolation of attenuation values. This means that image noise is not represented continuously across the attenuation profiles, which results in reduced image noise at the detector array. Poisson distributions express the likelihood of a given number of events happening in a given amount of time (ie, any reduction in radiation dose during data acquisition will result in an increase of image noise during FBP reconstruction).

High levels of image noise reduce the diagnostic value of a CT image, so the technologist must find a minimal dose amount that generates an optimal image with clear delineation and low-contrast detectability for the volume of interest. Decreasing image noise by increasing the smoothing filters impairs spatial resolution in FBP image reconstruction. Reduction of radiation dose is associated with increased image artifacts, which can further compromise diagnostic confidence.

Iterative Image Reconstruction

GE Healthcare provided its first IR package with the development of adaptive statistical iterative reconstruction software called ASiR. ASiR was marketed initially as a way to smooth noise from CT images. GE Healthcare did not provide access to the programming code related to the algorithmic processes that ASiR

a significantly lowered CT dose. Furthermore, IR decreases image noise and subsequently increases contrast-to-noise ratios (CNRs). Using IR techniques to improve image noise makes the image reconstruction process a vital step in patient dose reduction. The CT technologist essentially creates noisy image data at a reduced dose during data acquisition and then cleans up the noisy image data with an IR algorithm during image reconstruction. The literature indicates that average dose reductions range from 29% to 72% compared with FBP. The total reduction depends on the CT examination protocol, IR technique, and independent variables, such as patient body habitus and tissue density.

IR techniques are subclassified as FBP-blending and domain space. Blended, or hybrid, techniques combine IR images with FBP. Examples of blended algorithms include iDose (Philips) and ASiR. Domain space algorithms use information from system hardware details to model the relation of the CT scanner to the attenuation values acquired. Examples include iterative model reconstruction and model-based iterative reconstruction (MBIR). Domain space techniques can perform image reconstruction in the raw data domain or in the image space domain. In hybrid techniques, the FBP images are produced first, and the IR technique is applied to the information in the raw data domain.

IR algorithms are based on 6 key steps (see Figure 4): 1. Data acquisition projection (creation of raw data with forward projection). 2. Image estimation (based on simulated projection data). 3. Estimation to projection comparisons. 4. Image correction. 5. Iterative cycle initiation. 6. Final image production.

The complexity of the reconstruction process is related to how the process handles image noise and the modeling of the geometry of the CT data acquisition system. Geometry modeling includes the isocenter, size and shape of the tube focal spot, size and shape of the detector, and distances between the tube and the detector array. Essentially, this computational modeling process consists of 2 parts: a data term and regularization term. The data term models the acquired data, and the regularization term incorporates nonuniformities, such as noise. During the IR process, the image data is estimated, compared, and assigned a weight based on statistical uncertainty. The algorithm assigns a low weight to data with high statistical uncertainty (high noise) and a high weight to data with low statistical uncertainty (low noise).

Hybrid IR algorithms merge analytic and IR techniques in various combinations. For example, one method first produces an FBP image in the raw data domain after which iterative techniques are deployed to decrease image noise and optimize image quality in the image domain. In the available research, hybrid iterative reconstruction often refers to techniques that...
reduce image noise as *iterative image corrections*. MBIR refers to algorithms that iteratively weight data based on statistical models of the data acquisition system geometry and acquisition process. Nevertheless, in the clinical implementation of IR techniques there might not be a need to differentiate between hybrid and model-based techniques.

Although no research has been conducted to compare the time required for various reconstruction techniques, hybrid IR time is comparable to that of FBP. Specifically, hybrid IR techniques complete reconstruction operations in a matter of seconds to minutes. Nevertheless, because of their complexity, model-based techniques might take 30 minutes to more than an hour to complete the image reconstruction computations. Commercially available IR algorithms use a variety of these principles (see Table 2).

**GE Healthcare**

ASiR was the first hybrid IR technique, and it remains the most widely studied. The algorithm begins by forward projecting the raw scan data and then comparing the image measurements to the measured projection at the detector. By modeling the noise in every scanned projection and assuming the noise differences between neighboring projections during the reconstruction process, ASiR effectively reduces image noise while maintaining image resolution. The user interface provides a blending tool to adjust between FBP and IR. Generally, a 30% application of ASiR provides approximately a 30% decrease in patient dose, and a 50% application of ASiR provides a 50% decrease in dose. Unlike FBP, ASiR models the data acquisition system statistics by using images produced with FBP algorithms as the foundations for each image reconstructed. Similar to other reconstruction techniques, a higher percentage of ASiR can degrade image quality, reducing spatial resolution and giving the images a “plastic” texture.

As the second-generation IR technique released by GE Healthcare, Veo was introduced as MBIR. Veo uses a complex 3-D model of the data acquisition process in addition to modeling Poisson noise statistics and image space domain. For example, Veo represents each voxel element in 3-D and then geometrically accounts for how it relates to the detector element and the tube focal spot. Veo statistically plots the distribution of data from the interactions of x-rays with matter. Compared with ASiR, Veo significantly increases low-contrast resolution and decreases image noise at ultralow doses, but the complexity and extent of this modeling process present significant demands on computational power and reconstruction time. One study reported that creation of images using Veo required one hour per CT examination, whereas ASiR images for the same examination could be created in less than a minute. The effects of the delay between data acquisition and image display must be weighed in clinical practice, especially in emergency care settings.

**Siemens Healthcare**

Iterative reconstruction in image space (IRIS) was the first generation of IR technology released by Siemens Healthcare. IRIS approaches the data within the image domain, creating an initial image and then reconstructing through 3 to 5 iterations of the algorithm designed to reduce noise and enhance contrast resolution.

Siemens’ second generation of IR technology, sinogram

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**Table 2: Commercially Available Iterative Reconstruction Techniques**

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<thead>
<tr>
<th>Vendor</th>
<th>Technique</th>
<th>Reconstruction Type</th>
<th>Reconstruction Time</th>
</tr>
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<tbody>
<tr>
<td>GE Healthcare</td>
<td>ASiR</td>
<td>Hybrid</td>
<td>&lt; 1 min</td>
</tr>
<tr>
<td></td>
<td>Veo (MBIR)</td>
<td>Model-based</td>
<td>30-50 min</td>
</tr>
<tr>
<td>Siemens Healthcare</td>
<td>IRIS</td>
<td>Hybrid</td>
<td>&lt; 1 min</td>
</tr>
<tr>
<td></td>
<td>SAFIRE</td>
<td>Hybrid</td>
<td>&lt; 1 min</td>
</tr>
<tr>
<td></td>
<td>ADMIRE</td>
<td>Model-based</td>
<td>&lt; 1 min</td>
</tr>
<tr>
<td>Philips Healthcare</td>
<td>iDose⁶</td>
<td>Hybrid</td>
<td>&lt; 1 min</td>
</tr>
<tr>
<td></td>
<td>IMR</td>
<td>Model-based</td>
<td>&lt; 3 min</td>
</tr>
<tr>
<td>Toshiba</td>
<td>AIDR 3D</td>
<td>Hybrid</td>
<td>&lt; 1 min</td>
</tr>
<tr>
<td>MedicVision</td>
<td>SafeCT</td>
<td>Image-based</td>
<td>&lt; 1 min</td>
</tr>
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affirmed iterative reconstruction (SAFIRE), incorporates an algorithm that uses both raw image data and image data iterations to adapt the image space domain and control for noise reduction and image impression. SAFIRE first reconstructs a weighted FBP set of images and then introduces 2 separate corrective loops. In the first loop, new synthetic raw data is compared with the original raw data to create correction patterns that remove artifacts, resolve imperfections, and improve spatial resolution. These reprojections are then incorporated into the corrected image. In the second loop, the process is moved to image space, where a statistical optimization technique removes noise from the image. Because SAFIRE uses raw data for the initial iterative process, the reconstruction time for SAFIRE is similar to FBP.

Advanced modeled iterative reconstruction (ADMIRE) makes use of 3 additional processes:

- Using weighted FBP to increase artifact removal.
- Removing geometric imperfections.
- Performing a local signal-to-noise ratio (SNR) to decompose image data into information and noise according to the model.

ADMIRE is capable of analyzing image information and noise for a larger area than is SAFIRE.

**Philips Healthcare**

Philips introduced iDose in 2010. This hybrid IR algorithm incorporates FBP images into iterative analysis. First, the reconstruction algorithm analyzes the projection data and corrects the noisiest measurements. Second, an iterative process decreases the weight of noisy data and preserves edges. This maintains spatial resolution while reducing noise by retaining the attenuation gradients of surrounding structures. The Philips user interface allows the CT technologist to choose the level of iDose reconstruction and the percentage of dose reduction. This gives the technologist the power to prioritize between goals of image quality improvement, dose reduction, or a compromise between the 2 goals.

In 2012, Philips Healthcare released iterative model reconstruction. More research is needed to establish the details of this new technology, but according to a study by Mehta et al, iterative model reconstruction accounts for noise behavior, data statistics, image statistics, and system models.

**Toshiba**

Toshiba Medical Systems developed adaptive iterative dose reduction (AIDR) to reduce noise in the image domain. With this technique, high noise images are processed through several iterative loops to reduce the image noise to an appropriate evaluation level. Recently a 3-D algorithm (AIDR 3D) replaced the original technique. The 3-D technique operates in the raw data domain to account for quantum noise caused by the x-ray photon interactions with the detector and the electrical noise of the CT scanning system. AIDR 3D performs operations to model scanner geometry and statistical noise. The technique’s final step applies a weighted blend to the data to render the image more “natural” during image viewing.

**Research**

The initial research into IR techniques reveals improvements in image quality and reduction of radiation dose and artifacts. Where FBP ties dose to noise, IR provides a means to reconstruct data that accounts for the geometry of CT scanning to reduce image noise independent of dose. However, data acquisition can be optimized for FBP protocols, and it appears likely that the effect of IR on patient dose reduction is over stated. In addition, although the volume of literature studying IR in the clinical setting is increasing rapidly, it remains difficult to estimate patient dose reduction rates because few published studies compare various IR algorithms. This is in part because IR techniques are specific to each vendor and cannot necessarily be generalized to other CT systems. Furthermore, image quality expectations are institution specific. Those interested in IR must read the available literature carefully to grasp the specifics of any IR algorithm’s bearing on data acquisition and radiation dose in a given clinical application.

In 2012, the Summit on Management of Radiation Dose in Computed Tomography published a report detailing the steps required to achieve routine radiation doses of less than 1 mSv in clinical CT. The report emphasized the development of clinically relevant image...
quality metrics to guide dose optimization and implementation of data acquisition protocols to be used with IR techniques. The chief advantage of IR algorithms is that they incorporate detailed physics models into image processing to improve image quality. Clinically, these technological advances have created a need to develop and standardize methods for assessing image quality as it relates to the dose reduction potentials of the various IR products.

Typical early studies into these IR products compared image-quality measures, such as SNR, CNR, and spatial resolution, by making use of dedicated spatial-resolution phantoms. Ghetti et al compared FBP with SAFIRE and IRIS, finding that both Siemens products preserved spatial resolution while decreasing noise when dose remained constant. SAFIRE can vary in strength from 1 to 5, with related noise reduction of up to 60% depending on the strength of iterative technique. The term strength is proprietary to Siemens iterative reconstruction software packages and indicates the relative amount of image processing. Nevertheless, similar studies showed related findings for Philips’ iDose (11%-55% noise reduction) and Toshiba’s AIDR (35%-44% noise reduction). Another study comparing FBP, iDose, and ASiR with GE’s Veo, found that Veo outperformed all others in spatial resolution, including detection of pathology on low-contrast images at decreased dose levels.

Much of the published research demonstrates either improved image quality or comparable image quality at a lower dose when making use of IR algorithms, and although many of the specific details of these studies differ, all of the studies used either phantoms, clinical trials, or both as the basis of their assessment. Clinical trials are needed to confirm the clinical safety of new technologies, but ethical, logistical, and economic considerations preclude the feasibility of clinical trials for rigorous and scientific CT technique optimization because of the requirement to repeat scans. For example, a clinical trial for optimizing IR for CT scanning of the abdomen would require recruiting a large patient cohort with known subtle pathology, imaging the patients numerous times at different dose levels, reconstructing the images in both FBP and various IR algorithms, and having the resulting images studied by radiologists to determine comparable differences in diagnostic imaging performance. A study such as this would not be possible because of the logistical challenge of recruiting a large patient population with known subtle pathology and the ethical problem of subjecting patients to multiple ionizing radiation exposures solely for research purposes.

Experiments using CT phantoms provide the most practical alternative because phantoms contain carefully measured known features for factual analysis and can be imaged multiple times at various dose levels without posing a risk to patients or exposing researchers to ionizing radiation. CT phantoms provide an objective measure of image quality metrics across a broad range of scanner data acquisition settings that researchers can use to guide and optimize scanning protocols. Most commercially available phantoms are geometrically simple with uniform background densities, whereas patient anatomy is not uniform in density or simple in detail, and these subtle distinctions influence image quality, affect observer performance, influence spatial resolution, and produce quantum noise. These complexities between patient anatomic variability and image quality cannot be measured in research relying on simple, uniform CT phantoms. Solomon and Samei raised questions about the clinical relevance of such studies in a 2014 study on quantum noise properties of IR. To address these issues, they designed custom phantoms using 3-D printing technology and recursive mathematic algorithms. The authors used a multimaterial printer (Objt Connex, Stratsys Ltd) capable of mixing 2 plastic resins in various proportions to create shapes of different densities in a single printed object and accurately printing objects within tolerances smaller than the typical resolution of CT detection (20-85 µm). The researchers used a recursive tree-growing algorithm to fabricate a lung phantom. The soft-tissue phantom was based on “clustered lumpy backgrounds” first posited for the production of mammography phantoms and produced using a collection of anisotropic 3-D exponential functions.

To demonstrate the use of these textured phantoms, the authors designed experiments to measure noise properties of CT images reconstructed with FBP and SAFIRE. The textured phantoms and a uniform
density phantom were scanned in axial mode on a clinical multidetector CT unit (SOMATOM Definition Flash, Siemens Healthcare). Their findings indicated that the noise reduction of IR is reduced at edges, limiting image quality at reduced dose to levels comparable to FBP (see Figure 5). Such findings underscore a need for ongoing research into phantom construction and quality measurement specific to assessing IR techniques.

**Clinical Applications**

From a practical point of view, the introduction of most IR techniques does not significantly affect workflow. After data acquisition, the technologist selects the appropriate iterative reconstruction algorithm (ie, the kernel) and the desired strength level. With the exception of Veo, all IR techniques can be combined with specific reconstruction algorithms (eg, bone, lung, or soft tissue). Scanning protocols might call for specific IR protocols to follow data acquisition to comply with the institution’s standard of image quality. One important technical consideration is to avoid oversmoothing. Oversmoothing is marked by a blotchy appearance of IR images caused by excessive application of noise reduction techniques. The images look smoother, and radiologists might question their diagnostic accuracy compared with the texture of FBP images. These and other questions often are answered by increased familiarity with IR techniques and the resultant images.

**Head and Neck**

When used in head and neck scanning, IR techniques have demonstrated capabilities to improve image quality, decrease dose, and reduce artifacts. Studies have reported CT patient dose comparable with conventional radiography for imaging of the cervical spine in trauma patients. Intervertebral disks and ligaments are seen more clearly using SAFIRE. Several studies found that MBIR techniques can reduce photon starvation and metal streak artifacts. CT brain doses have
been reduced from 20% to 40% using SAFIRE, IRIS, iDose, and ASiR.\textsuperscript{38-41} In addition, research shows that ASiR improves delineation of gray and white matter, and initial studies of CT perfusion brain studies show a dose reduction of 20% using IR techniques.\textsuperscript{18,42,45}

In 2015, Niesten et al evaluated improving head and neck CTA examinations with hybrid and MBIR techniques compared with FBP in 34 patients.\textsuperscript{43} CTA of the head and neck is preferred for assessing acute and chronic neurovascular disease including acute ischemic stroke, subarachnoid hemorrhage, cerebral aneurysms, vascular malformations, and sinus venous thrombosis.\textsuperscript{44} The study designed by Niesten et al was aimed at comparing objective image quality (eg, CNR, vascular contrast, automatic vessel analysis, and stenosis grade) and subjective image quality (ranking the circle of Willis, carotid bifurcation, and patient shoulder) of reconstructions performed with iDose\textsuperscript{4}, MBIR, and FBP.\textsuperscript{44}

The authors did not investigate dose reduction, and they limited their investigation to IR software packages from a single vendor.\textsuperscript{44} They also noted that decreased radiation dose can lower spatial resolution in MBIR reconstructed images and cause a related increase of errors in the measurement of vessel diameter.\textsuperscript{19} Nevertheless, they concluded that at conventional radiation doses, the use of iDose\textsuperscript{4} and MBIR in CTA of the head and neck arteries can decrease image noise and increase image quality and automatic vessel analyses.\textsuperscript{44} These findings suggest caution is needed to explore dose reduction in CT examination of small vascular structures.\textsuperscript{18} In examinations requiring fine detail and high spatial resolution, it might be best to exhaustively investigate IR techniques without any associated reduction in patient dose before applying dose reduction measures.\textsuperscript{44}

One study of IR application in routine CT brain examination by Buhk et al addressed the intraindividual dose reduction effects of iDose vs FBP in 31 patients.\textsuperscript{45} Subjective evaluations of the images were performed by 5 radiologists with varying experience levels who each rated the images on a precisely defined 4-point scale. The rating considered artifacts, gray-white matter differentiation, and overall image impression.\textsuperscript{45} Objective image evaluation was conducted through application of 5 pairs of small rectangular regions of interest (1.2 mm × 1.2 mm = 3 × 3 pixel) in cortical gray matter and adjacent white matter.\textsuperscript{45} The researchers noted that objective and subjective evaluations of image contrast were reduced as the IR level increased.\textsuperscript{45} The radiologists’ personal preference in perception of noise and contrast in brain CT images presented a limitation to their study, and the researchers concluded that their data did not allow them to recommend using IR as a dose reduction technique in brain CT.\textsuperscript{45} As protocols are altered to IR parameters, CT technologists must review the literature surrounding the subjective and objective evaluation of any given examination protocol and work closely with interpreting radiologists to account for personal viewing preferences.\textsuperscript{45}

**Thorax**

For CT imaging of the thorax, IR techniques can maintain diagnostic quality while reducing radiation dose in amounts ranging from 27% to 80%.\textsuperscript{46-50} Veo can depict pulmonary nodules at radiation doses comparable to chest radiography.\textsuperscript{46} Lung architecture, including interlobular septa, the centrilobular region, and small bronchi and bronchioles, is seen more easily in a number of IR algorithms when compared with FBP.\textsuperscript{18} Pathology, specifically bronchiectasis, tiny nodules, reticulations, and pediatric cystic fibrosis, is seen more easily using IR techniques.\textsuperscript{18}

Noise power spectrum (NPS) is a valuable parameter for the assessment of IR image quality.\textsuperscript{18,28} NPS allows graphing of image noise and noise texture.\textsuperscript{18,28} IR algorithms tend to affect NPS graphs similarly.\textsuperscript{28} Namely, the visual effect is described as “plastic” or “blurry.”\textsuperscript{18,28} On a graph, NPS curves illustrate reduced noise as the peak of the curve shifts toward lower frequencies.\textsuperscript{18} Hybrid techniques and user-specified iterative strength are 2 options vendors have provided to reduce undesirable levels of image smoothing.\textsuperscript{18} This effect is particularly problematic in imaging subtractive lung pathology, such as emphysema.\textsuperscript{18,28,51} Perhaps for the reasons indicated by Solomon and Samei, findings have diverged related to the efficacy of IR techniques in quantification of emphysema at low radiation doses.\textsuperscript{28} Regardless, it should be noted that any algorithm capable of altering image reconstruction might also be capable of influencing quantification methods that were initially established for FBP.\textsuperscript{18,28}
In 2016 Yasaka et al published a comparison of the image quality of high-resolution CT for evaluating lung nodules with the newest version of GE Healthcare’s MBIR and spatial resolution preference algorithm (MBIRn) compared with conventional model-based IR (MBIRc) and ASiR. They found significant improvements in MBIRn compared with ASiR in objective and subjective image noise, streak artifacts, and diagnostic quality for evaluating border and internal characteristics of nodules. Furthermore, the sharpness of bronchi and small vessels was improved significantly by MBIRn compared with MBIRc and ASiR. Nevertheless, some false cases were registered with MBIRn in the detection of calcification and determination of nodule attenuation. The authors suggested that the discrepancies might be related to the IR algorithm reducing image noise, which made CT attenuation inhomogeneity from motion artifacts and beam hardening more prominent. The precise reason remains unknown. The authors further noted difficulties related to the time required for image reconstruction, which requires at least 30 minutes.

A separate clinical study by Pourjabbar et al published in 2015 compared conventional CT chest examinations with low-dose CT chest examinations on 22 patients with subsequent reconstruction using FBP, SAFIRE at various strength settings, and the third-party IR platform SafeCT (MedicVision) at comparable settings. The U.S. Food and Drug Administration has approved SafeCT, a vendor-neutral, hybrid IR technique. It works from FBP DICOM images to iteratively perform patch decomposition, signal and noise separation, and noise estimation. Pourjabbar et al worked with 3 thoracic radiologists to evaluate all resulting images for lesion detection, comparison of lesion margin, visibility of normal structures, and diagnostic confidence. A total of 110 lesions were seen in 19 of the 22 patients. No additional lesions were found in conventional CT examination when compared with the low-dose examinations. Number, size, and attenuation values of the lesions were identical on conventional and low-dose CT images. Small vessels, subsegmental bronchial walls, small lymph nodes, and internal mammary vessels all were well demonstrated on low-dose images. In 5 of the 22 cases, lung fissures were not depicted clearly on the low-dose images. The authors concluded that SAFIRE and SafeCT allowed optimal image evaluation of lung and mediastinum findings on low-dose CT image data acquired at 1.8 mGy (or a patient radiation dose just under 1 mSv) regardless of patient size and weight. These doses represent an 80% dose reduction compared with conventional CT chest examination using FBP.

**Lung**

Several studies have reported considerable radiation dose reduction in pulmonary CTA studies using IR (25%-40%). Yuan et al demonstrated a preservation of reader confidence without changes in the rate of nondiagnostic studies. Using IR techniques solely for image optimization in CTA chest studies independent of radiation dose reduction might prove beneficial when imaging larger patients whose images show elevated noise levels that limit the evaluation of small pulmonary arteries.

**Heart**

All commercially available IR platforms have demonstrated benefits to coronary CTA primarily in the areas of noise reduction compared with FBP. Toshiba’s AIDR produced improved subjective and objective image quality in simulated half-dose acquisitions compared with full-dose FBP reconstructions. In a 2010 study by Leipsi et al, ASiR was reported to improve image quality at a 25% dose reduction compared with FBP, and 2 years later, Pontone et al reported equivalent diagnostic quality at dose reductions of up to 72%. Several clinical observational studies reported dose reductions of 44% to 54% after implementation of ASiR in CT cardiac protocols. IRIS has demonstrated 62% dose reduction with improved image quality compared with FBP in CT cardiac protocols, and research on SAFIRE has reported a range of dose reductions from 50% to 80% compared with FBP. Philip’s iDose has shown dose reductions from 55% to 63% without compromising image quality in cardiac studies.

Patient body habitus, pathology, and prior procedures, such as coronary stents, all can present obstacles to CT coronary imaging, and within the available literature, researchers have attempted to suggest options related to adapting data acquisition techniques to the patient’s body mass index and adjusting scan techniques.
based on image noise at the time of scanning. IR techniques are useful in reducing beam hardening and blooming artifacts caused by coronary stents and calcified vessels. Early in the past, ultrathin examinations (0.23-mm spatial resolution) were limited by high levels of noise related to photon starvation. Early IR research shows improvements for CT images in the form of noise reduction at very small spatial resolution settings.

A number of comparisons of calcium scores between IR images and FBP images found reduction in calcium volume measurements largely due to a reduction in noise. For example, IRIS had an overall diagnostic accuracy of 95.9% compared with 91.8% using FBP in evaluation of cardiac calcium CT images. This suggests the need to reevaluate quantitative measures derived from FBP images when using IR techniques. Studies have reported decreased Agatston and volumetric calcium scores due to reduced blooming artifacts when ASiR was used compared with FBP. The clinical indication is that when IR is used in calcium scoring, it might result in incorrect risk stratification because the majority of population-based studies that provide calcium scoring data are based on FBP reconstructions. Conversely, IR does not appear to alter analysis of plaque burden and composition quantification.

**Abdomen and Pelvis**

Research into routine CT examinations of the abdomen and pelvis using IR techniques consistently have shown improvements of subjective and objective image quality with dose reductions of 25% to 50% compared with dose optimized FBP. Researchers continue to push for lower patient dose settings with hybrid and MBIR techniques and report diagnostic quality images with dose-reduced protocols performed using only reduced milliamperage for a 75% dose reduction compared with standard data acquisition. CTA of the abdomen using IR techniques is not as widely researched, but some suggest dose reduction and improved accuracy in evaluating vascular diameter and vessel wall attenuation.

**Liver**

Without sacrificing image quality, IR applied to liver CT has shown 41% to 50% dose reductions in clinical and phantom studies. This might be of particular importance in hepatic perfusion imaging, which historically has involved high patient radiation doses. By applying reduced milliamperage, one study using AIDR produced a 45% dose reduction without deteriorating image quality or quantifying of hepatic perfusion value. Similar to reducing peak kilovolts (kVp) to increase contrast in radiographic film technique, researchers are exploring a CT technique for increasing CNR by reducing kVp and then using IR to smooth the noise from the images. Scanning at a decreased kVp increases attenuation and consequentially increases contrast. This technique could increase detection of small lesions and is an effective way to increase CNR in all phases of liver enhancement. Several studies demonstrated no improvement in the detection of low-contrast liver lesions; however, this reduced kVp technique has helped detect hypervascular liver lesions such as hepatocellular carcinoma.

One study by Martinsen et al used an anthropomorphic liver phantom to acquire data at 250, 185, 155, 140, 120, and 100 mAs on a 64-slice GE Lightspeed VCT scanner. The data was reconstructed with ASiR and FBP, and the resulting images were evaluated independently by 4 readers using a 5-point scale. The results indicated that it might be possible to reduce radiation doses up to 50% and maintain diagnostic performance in liver examination. Nevertheless, they recommend further clinical testing on in vivo liver examinations to assess the real benefits of IR using ASiR. Further clinical testing, however, should simulate low-dose IR protocols on anthropomorphic phantoms and evaluate reader confidence in the resulting changes in diagnostic image quality before clinical application of low-dose IR protocols on any patient population.

**Colon**

In screening for colorectal cancer, CT colonography is valuable but limited in application because of concerns about radiation dose in screening healthy populations. Researchers have found that application of IR techniques can produce diagnostic images at roughly the same dose as conventional abdomen radiography. In 2016, Shin et al reported a mean effective radiation dose for supine and prone data acquisitions of only 1.002 mSv—similar
to that of conventional abdominal radiography. This decrease is important because 1 mSv CT colonography might decrease the risk of screening radiation exposure. By extension, this would imply a 7-fold to 8-fold increase in the benefit-to-risk ratio (ie, cancers prevented vs induced) for screening colonography every 5 years for patients aged between 50 and 80 years at 7 mSv to 8 mSv per screening. Shin et al compared subsequent images reconstructed using Veo, ASiR, and FBP. Findings included unacceptable per-polyp findings for FBP (50%-57%). ASiR improved per-polyp findings to 64.3% to 78.6%, and Veo further improved findings to 78.6% to 83.3%.

**Urinary Tract**

The first description of noncontrast CT of the kidneys, ureters, and bladder for the evaluation of kidney stones was by Smith et al in 1995. Since then, noncontrast CT examination of the urinary tract evolved into the imaging examination of choice for investigating patients with acute renal colic. This is largely because of the examination’s high specificity of recorded detail (96%-100%) and high sensitivity (95%-97%). At the initial presentation of renal colic, patients might be young, and recurrence throughout the patient’s lifetime is reported in 25% to 50% of cases. Given the related potential need for early and repeated CT examinations in these patients, there is an impetus for radiation dose reduction.

One study by McLaughlin et al examined effective dose measures in 33 patients using conventional CT data acquisition and FBP image reconstruction compared with low-dose CT data acquisition and IR techniques. For each patient examination, an effective dose was determined using imaging performance and assessment in a CT patient dosimetry calculator (ImPACT version 0.99x). The researchers excluded radiation exposure resultant from scout imaging to compare only conventional and low-dose data acquisition. The mean DLP for low-dose acquisition (34.18 + 5.3 mGy/cm) was significantly lower than the mean DLP for conventional CT data acquisition (272.17 + 190.99 mGy/cm). They reported a statistically significant reduction in diagnostic acceptability and spatial resolution for low-dose data acquisitions reconstructed with 90% ASiR techniques due to oversmoothing of the image and resultant loss of diagnostic information. The 70% ASiR technique was reported as optimal for clinical interpretation of low-dose CT images although scores for diagnostic acceptability, subjective noise, spatial resolution, and contrast resolution remained low. Other factors that had a deleterious effect on low-dose CT images were streak artifacts caused by low photon fluence at the level of the pelvis and increases in patient BMI. At 70% ASiR, sensitivity and specificity for detection of renal calculi greater than 3 mm in diameter were 87% and 100%, respectively. When all renal calculi were accounted for—including those less than 3 mm in diameter—the sensitivity and specificity were reduced to 72% and 94%, respectively. Clinically significant findings outside the urinary tract were missed on the 70% ASiR images, including 2 cases of acute appendicitis and one 3-cm ovarian dermoid. Because of these missed extraurinary tract findings and decreased sensitivity, the researchers concluded that low-dose CT examination could not be recommended as a replacement for conventional CT imaging in the assessment of patients with acute renal colic. These findings underscore the limitations presented by the oversmoothing of low-dose images and suggest the need for a coordinated and measured method for developing any low-dose IR examination protocol.

Research into applications of IR in CT urography with contrast show significant dose reduction (45%-84%) without degrading image quality or diagnostic confidence. Kulkarni et al reduced dose 82%, from 9.9 mGy to 1.8 mGy, and produced diagnostic images capable of demonstrating urinary stones and evaluating the abdomen and pelvis to exclude differential findings.

**Spine**

One potential advantage of IR techniques independent of reducing radiation dose and image noise is the possibility of improving display of relevant anatomy and pathology in the presence of metal-related artifacts from orthopedic spinal hardware. A study by Kotsenas et al archived CT projection data from 68 patients with instrumented spinal fusion. The images were reconstructed using FBP and a prototype iterative metal artifact reduction (iMAR) algorithm (Siemens...
Pediatric Imaging

Use of CT for pediatric patients presents the potential for cancer risk from stochastic effects of ionizing radiation and has been a legitimate concern since the development of CT technology.6,17,18 Because a pediatric patient’s tissue is immature and a child has a longer life expectancy, pediatric patients are thought to have more time to develop stochastic effects from singular or repeated CT examinations.6,17,18 Therefore, dose reduction efforts through education and communication, such as the Image Gently campaign, have been implemented.6,17,18

A retrospective study by Pearce et al followed up with 178,604 patients without previous cancer diagnoses who were examined with CT between 1985 and 2002, when they were younger than 22.76 The authors found that 74 patients had been diagnosed with leukemia, and 135 were found to have brain cancers. These findings indicate a positive association between pediatric patient radiation dose from conventional CT examination and leukemia and brain tumors. Use of CT examination that delivers cumulative doses of approximately 50 mGy to children might triple the risk of leukemia, and cumulative doses of 60 mGy could triple the risk of brain cancer.76

Research into IR techniques in pediatric CT suggests improvements in CNR, SNR, noise, and image quality.18 In addition, researchers have reported dose reductions between 22% and 48% without degrading diagnostic confidence.17,18,39 Khawaja et al reviewed the reconstruction principles, radiation dose reduction potential, and effects on image quality of AIDR 3D, ASiR, iDose, SAFIRE, and MBIR in pediatric abdominal CT.6 They noted considerable differences among IR techniques from different CT vendors with regard to data acquisition technique, protocol parameters, and reconstruction time.6 The authors’ institution uses a set of color-coded routine pediatric abdominal CT protocols to calculate patient radiation dose according to patient size and clinical indication.6

The authors achieved 62% to 75% reduced dose compared with FBP technique in routine pediatric abdominal CT.6 They recommended that institutions adopt IR techniques using a gradual reduction in radiation dose by proceeding in a stepwise manner (15%-20% for each decrease).6 After interpreting radiologists become accustomed to IR image appearance, the radiation dose can be decreased further by increasing the strength of the IR technique.6 CT technologists, radiologists, and health physicists must work together and communicate as IR techniques are developed at any institution.6,14 One study recommended a Deming cycle, also known as a plan, do, study, act cycle, to guide incremental changes steered by an interprofessional team, including the senior radiologist, senior CT technologist, and a physicist.14 Khawaja et al further noted that children who undergo repeated CT examination for cancer staging and follow-up can benefit from lower-kVp and lower-milliamper second protocols with a higher strength of IR technique for noise reduction.6 Nevertheless, kVp should be reduced to optimize CT scan dose regardless of IR use.6,14

Bariatric Imaging

Obese populations present a number of technical challenges to CT technologists. Noise is increased because of scatter, affecting image quality and diagnostic confidence.19 Scan protocols that can adapt to BMI generally increase kVp and result in significantly increased patient dose.18 The noise-smoothing capabilities of iDose have shown associated reduction in dose when compared with data acquisition for FBP in bariatric imaging.19 Wang et al demonstrated a dose reduction of 50% while using SAFIRE in reconstruction of coronary CTA examinations.77
Emergency Radiology

One concern related to IR techniques centers on the time required to process CT data, but researchers are finding that these techniques consistently can reduce patient dose while providing effective imaging in emergency medical situations. Another study reported dose decreases of 20% in DLP without loss of image quality in the evaluation of acute aortic syndrome. Another found that trauma surveys of the brain, cervical spine, chest, abdomen, and pelvis could be acquired rapidly with ASiR at a 20% dose reduction compared with FBP. Willimink et al reported similar findings with iDose without a significant delay in reconstruction time or speed of workload.

Future Considerations

In 1965, Gordon E Moore, the cofounder of Intel and Fairchild Semiconductor, published a paper that predicted a doubling every year in computer processing power, and in 1975, he amended his prediction to a doubling of processing power every 2 years. The observation came to be called Moore’s Law, and advances in digital electronics are strongly linked to this pattern of exponential growth. The exponential growth in electronics has fostered the availability and affordability of the computing power necessary for the development of IR applications. In general, historical growth does not guarantee indefinite future growth, but much of the recent literature surrounding IR suggests that improvements to CT image quality and reductions to patient dose will be served by more robust data handling for some time to come.

Although specific IR products differ, the clinical benefits of implementing IR techniques now outweigh the advantages of FBP. The visual and computational differences between FBP and IR techniques suggest a need to reevaluate quantitative measures of image quality and pathology based on data derived from FBP images. Numerous studies suggest an improvement in diagnostic accuracy of CT images through the reduction of artifacts and enhancement of CNR through IR techniques. Further scientific evidence confirming IR’s capability to reduce dose while improving image quality in larger populations is needed. Professional societies could create guidelines for the design of CT acquisition protocols that reduce patient dose but maintain image quality. Government policy already has played a significant role in the ongoing development of CT technology, and it likely will continue to incentivize the innovations needed to decrease patient dose.

For now, however, it is the CT technologist’s responsibility to understand the evidence-based research into IR techniques to aid construction and implementation of examination protocols and policies. As IR applications become more widespread and refined, their use likely will become more effective and universally adopted. Some researchers predict that IR techniques will replace traditional analytic methods, such as FBP, as the standard for CT image reconstruction.

CT technologists have an obligation to maintain the professional development and enhancement of their workforce. The ACR stresses the importance of a team approach to CT dose optimization. As part of its comprehensive dose reduction program, the ACR Commission on Quality & Safety consults with a multidisciplinary team to implement changes in protocols, technologist education, and technologist and radiologist feedback. The commission consists of multiple stakeholders, including radiologists from each clinical division, CT technologists, supervisors, medical physicists, radiology residents, and others. A successful CT radiation dose reduction program must function as a multifaceted, long-term project necessitating baseline dose evaluation, illustration of technique variations with specific protocols and across CT scanner vendors and models, implementation of a comprehensive dose reduction strategy, and dose tracking. The program should be reevaluated after implementation.

Conclusion

Diagnostic imaging has entered the era of big data—a revolution in data creation and management—that has placed unanticipated stress on CT technologists and radiologists. Medical informatics is leading worldwide in data generation, and this has direct bearing on the workflow of CT departments. Research into data generation and analysis has revealed that managing CT data is a critical step in reducing patient dose. Technologists must continue to educate themselves on vendor-specific and institution-specific CT examination protocols. Imaging
dose reduction techniques form the core of ongoing quality improvement in CT imaging. In addition to comparing radiation doses among institutions, the index can track radiation doses across various scanners within a single institution. Large-set data analysis and information sharing as well as application of established dose reduction techniques form the core of ongoing quality improvement in CT imaging.

CT technologists must work comprehensively with all aspects of CT data—data acquisition protocols, image reconstruction, dose reports, transmission, reporting, and data registry—to improve patient care and decrease radiation dose within a diagnostic modality that produces ever-increasing amounts of data to improve the global practice of radiology and individual patient outcomes.

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RADIOLOGIC TECHNOLOGY, July/August 2016, Volume 87, Number 6


Computing Tomography Iterative Reconstruction Techniques

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

1. One study revealed that patients exposed to radia-
tion dose greater than 7.5 mSv from cardiac com-
puted tomography angiography show evidence of:
   1. double-strand breaks in T lymphocytes.
   2. damage associated with direct cell death.
   3. activation of transcription factors.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

2. The American College of Radiology’s (ACR) CT
   Dose Index Registry provides data for comparison
   of which of the following variables?
   1. anatomy of interest
   2. cost of supplies
   3. examination protocol
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

3. Reconstruction algorithms are similar to the
   parameters that control image window width and
   level.
   a. true
   b. false

4. Using filtered back projection techniques, if the
   technologist increases compensation for low-pass
   image blur, the software simultaneously will increase:
   a. attenuation.
   b. matrix size.
   c. convolution.
   d. image noise.

5. During the iterative reconstruction (IR) process, the
   image data is estimated, compared, and assigned a
   weight based on statistical uncertainty. A low weight
   is assigned to data with:
   a. low frequency.
   b. high frequency.
   c. low statistical uncertainty.
   d. high statistical uncertainty.

continued on next page
6. How much time is required to complete hybrid IR operations?
   a. milliseconds to seconds
   b. seconds to minutes
   c. minutes to an hour
   d. 1 to 2 hours

7. Which hybrid IR technique remains the most widely studied?
   a. Veo
   b. ASiR
   c. IRIS
   d. SAFIRE

8. When performing clinical trials to confirm the safety of new computed tomography (CT) technologies, what considerations might preclude the feasibility of rigorous technique optimization?
   1. ethics
   2. economics
   3. logistics
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

9. To research the relationship between IR techniques and the complexities of patient anatomic variability and image quality, Solomon and Samei studied quantum noise using CT phantoms constructed with what tools?
   a. ACR parameters and recursive mathematic algorithms
   b. 3-D printing and recursive mathematic algorithms
   c. ACR parameters and iterative reconstruction algorithms
   d. 3-D printing and iterative reconstruction algorithms

10. One important technical consideration of IR is to avoid excessive application of noise reduction techniques that might result in blotchy images. In the literature, this commonly is called:
    a. overexposure.
    b. underexposure.
    c. oversmoothing.
    d. undersmoothing.

11. Noise power spectrum parameters allow graphing of image noise and:
    a. photon quality.
    b. noise correction.
    c. photon quantity.
    d. noise texture.

12. Coronary stents can present obstacles to CT coronary imaging; however, IR techniques are useful in reducing which artifacts related to this obstacle?
    a. beam hardening and ring artifacts
    b. cone beam and ring artifacts
    c. beam hardening and blooming artifacts
    d. cone beam and blooming artifacts

13. A retrospective study by Pearce et al indicated that radiation doses from pediatric CT examinations have a positive association with _______ and _______.
    a. fibrosis; epilation
    b. leukemia; brain tumors
    c. fibrosis; cataracts
    d. leukemia; colon tumors

14. The observation that computer processing power doubles every 2 years is called:
    a. Radon transform.
    b. Nyquist’s Theorem.
    c. Fourier transform.
    d. Moore’s Law.