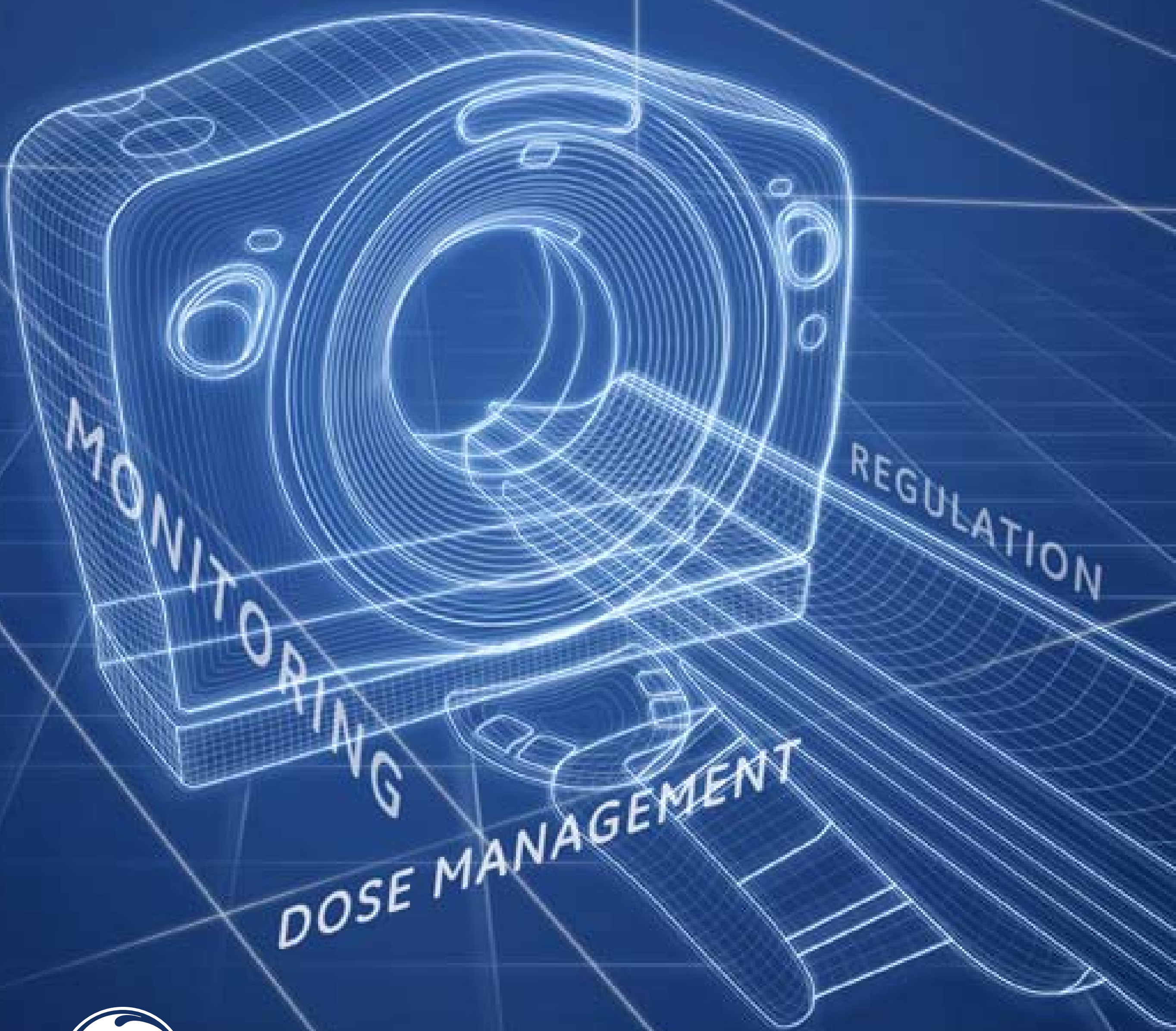
GE Healthcare

GE Blueprint

A Guide to CT Radiation Dose Management

Developed in conjunction with
Weill Cornell Imaging at NewYork–Presbyterian

Lower Dose by Design



GE Healthcare sincerely thanks the following staff at Weill Cornell Imaging, who contributed of their time freely and with a true sense of dedication for improving patient care, for their contributions and dedication to making this guide a reality:

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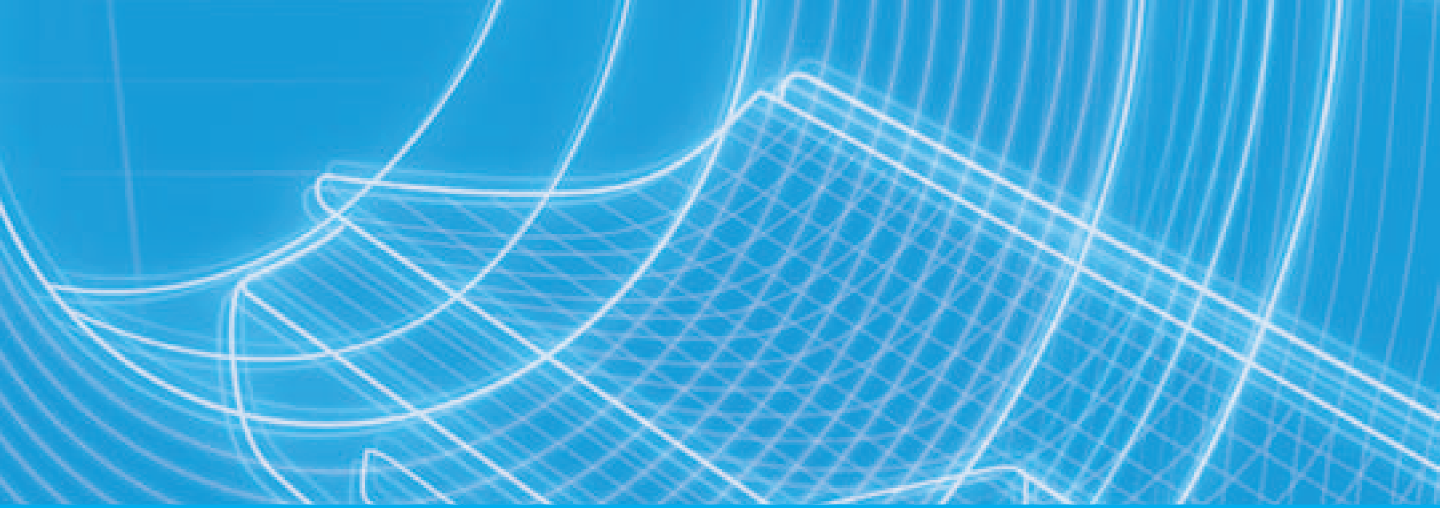


1

Introduction

Introduced in the early 1970s, computed tomography (CT) has become an invaluable diagnostic tool. Today, approximately 81 million CT scans are performed annually in the United States alone.[1]

The clinical benefit of the technology is tempered by the fact that the typical organ doses from CT can be higher than those from other radiology procedures that utilize ionizing radiation.

Although CT accounts for only about 15% of all radiological procedures, it contributes more than 50% of the collective radiation dose to the population from diagnostic radiology.[2]

For these reasons, we believe it is incumbent on imaging professionals to develop, implement, and adhere to a low-dose CT imaging program to ensure that patients can receive the significant medical benefits of CT technology while minimizing potential risks associated with radiation dose. Such a program aligns with American College of Radiology recommendations, which call for "education for all stakeholders in the principles of radiation safety [and] the appropriate utilization of imaging to minimize any associated radiation risk," among other measures,[3] such as a robust quality assurance program. An established program also can provide a much-needed operational framework to support the ALARA principle that most imaging practices have adopted to keep radiation doses of patients and personnel As Low As Reasonably Achievable.

Do you need a low-dose imaging program?

Despite having the best intentions, appropriate equipment, and a highly professional, patient-oriented staff, your practice still may not be achieving the dose levels or diagnostic image quality you want on a consistent basis. Contributing factors may include: a high number of niche protocols; dose creep over time due to technology changes; insufficient training (and accountability) around dose management; an ineffective QA program; and lack of methods to assess the patient's dose and avoid inappropriate or duplicative imaging.

In our experience, there needs to be a program with rigorous processes in place to avoid these pitfalls and assure effective, consistent low-dose CT imaging.

This Guidebook is intended to assist your organization in developing such a program. The recommendations are based on the CT imaging philosophies, protocols, and procedures followed by the managers, radiologists, technologists, physicists, and administrative personnel at Weill Cornell Imaging. While there is no "one right way" to practice low-dose, ALARA CT, we believe that Weill Cornell's Imaging program follows effective guidelines that any imaging practice can adapt to its own culture, patient mix, and goals.

1. IMV CT Market Study, May 2011.

2. Deak PD. Effects of Adaptive Section Collimation on Patient Radiation Dose in Multisection Spiral CT. Radiology, 252, 140-147 (July 2009).

3. Amis Jr ES et al. American College of Radiology White Paper on Radiation Dose in Medicine. J Am Coll Radiol 4: 272-284 (2007).

For all healthcare professionals

The Guidebook is meant for all healthcare professionals involved in providing CT imaging services, including administrators, radiologists, technologists, physicists, referring physicians, and office staff. The scope is comprehensive, covering everything from basic radiation safety principles to application-specific low-dose CT protocols. It includes recommendations on how to talk to patients about radiation concerns, how to train staff members, and how to develop and communicate a low-dose imaging culture to differentiate your practice.

Step one: select a champion

There's no sugar-coating it: Implementing and maintaining a low-dose CT program entails hard work. Momentum may be difficult to sustain. Some people will lose interest; others may be slow to accept change. Not everyone will agree on everything but the internal debates will make your practice that much better. That's why the critical first step is to select a project champion with the passion and commitment to drive implementation. A high level of leadership is required to overcome barriers, to engage others in the effort and sustain their interest, and to make sure that low-dose CT imaging becomes an integral part of the practice culture.

The results will be well worth the effort. A practice that visibly demonstrates its commitment to ALARA and effective CT imaging, is in a better position to provide responsible, high quality patient care, differentiate its services to attract more business, meet regulatory and payer requirements, and enhance revenue growth.

2

Fundamentals of Scanning Parameters and Radiation Dose

First introduced in 1972, CT technology has evolved rapidly. As a result, the number of CT examinations ordered in the US has climbed steadily from 26 million in 1998 to about 85.3 million in 2011.[1]

Recent data suggests that while accounting for only 17% of all radiological procedures performed, CT procedures are nevertheless responsible for 49% of the total medical radiation dose to the population of the United States and 24% of the total from all sources of radiation.[2] Due to CT's continuing rise in use, increased attention continues to be placed on CT radiation dose by the medical community and the popular press.

While physicians are aware that there is potentially a small risk related to CT radiation, or any other X-ray sources, they are also aware that CT is a powerful diagnostic tool that in the vast majority of cases is used in an appropriate manner to provide necessary information for the care of the patient. Thanks to CT scans, exploratory surgery, once common, is now a rare procedure. However, with all of the attention that CT dose has received patients may have questions about having a needed test.[3] As an example, there was a young child who suffered a fall of several stories who presented to the NYPH/Weill Cornell Emergency Department. Despite the fact that there was a high likelihood that this child had internal injuries, the family initially did not want their child to have a CT scan because it involved radiation. Fortunately the CT technologist and radiologist were able to discuss the potential risks and benefits of performing a CT scan with the family and explain the urgency of diagnosing any internal bleeding. The family understood and the patient received the scan without significant delay.

The story to the left emphasizes the need for those who perform CT scans to understand and be able to communicate the potential risks of X-ray radiation from CT. However, there remains some confusion on how to quantify this risk even within the medical literature.

Not everyone in an imaging practice, nor every member of the dose-reduction team, needs to have a physicist's knowledge of radiation physics. However, it is important that all have a basic understanding in order to be able to speak with patients and referring physicians. This chapter presents an explanation of the terminology used by medical physicists to estimate a patient's radiation dose, and methods to reduce it.

It is important to remember that the dose measures that are discussed are estimates, either based on measurements taken in a phantom, which is usually a uniform acrylic cylinder of a standard diameter, or calculations based on a computer model of a "standard" man/woman. Doses are not measured, or calculated, for individual patients. Factors such as patient size are important in estimating the actual dose but are not generally factored into the estimates currently provided by physicists.

1. IMV (2012). IMV Medical Information Division. 2012 CT Market Outlook Report. (IMV Medical Information Division, Des Plaines, Illinois).

2. National Council on Radiation Protection and Measurements. Ionizing radiation exposure of the population of the United States: 2006. NCRP report no. 160, Page 236, Table 8.1. Bethesda, Md: National Council on Radiation Protection and Measurements, 2009.

3. Bogdanich, W. (2011). "Radiation Overdoses Point Up Dangers of CT Scans". The New York Times. Retrieved from: http://www.nytimes.com.

The guiding principle of dose reduction is based on the concept of ALARA: As Low As Reasonably Achievable. Consideration must always be given to minimizing dose to the patient while ensuring the necessary diagnostic quality. While several techniques to reduce dose will be discussed, consideration must always be given to maintaining the diagnostic quality of the images.

Image Quality versus Dose

Perhaps the greatest challenge in implementing a dose reduction program is ensuring that image quality remains adequate, particularly since radiation dose and image noise (which degrades quality) are inversely related. One can always reduce the noise in an image by increasing the radiation dose. The challenge is in finding a balance between dose and noise that allows the images to be of diagnostic quality while utilizing the lowest dose possible.

Image Noise is one of the primary factors in CT Image Quality

Noise (specifically, quantum noise) is generally characterized by graininess, or a salt and pepper pattern on the image. Noise is inversely related to the number of X-rays (which are proportional to mAs) used to create the image by the following relationships (assuming all other parameters are kept constant):

$$\text{Noise} \propto \frac{1}{\sqrt{\textit{Number of X-rays}}} \propto \frac{1}{\sqrt{\textit{mAs}}} \propto \frac{1}{\sqrt{\textit{Dose}}}$$

$$\text{Noise}^2 \propto \frac{1}{\textit{Number of X-rays}} \propto \frac{1}{\textit{mAs}} \propto \frac{1}{\textit{Dose}}$$

These relationships are illustrated in Figure 1. Note that the mA in Figure 1C is four times that in Figure 1A but that the standard deviation in Figure 1C is approximately that in Figure 1A divided by the square root of 4, which is 2.

Figure 1. Illustrating the inverse-square root relationship between mA and standard deviation.

Figure 1A. Higher noise.
100mA
std: 28

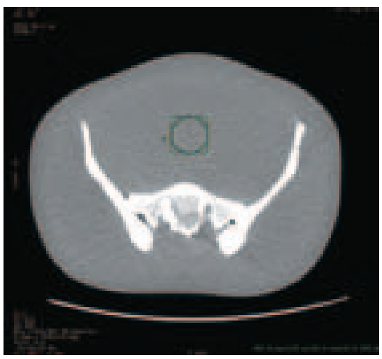


Figure 1B. Medium noise.
200mA
std: 20

Figure 1C. Lower noise.
400mA
std: 13

Figure 2. Comparing levels of noise in body phantom images.

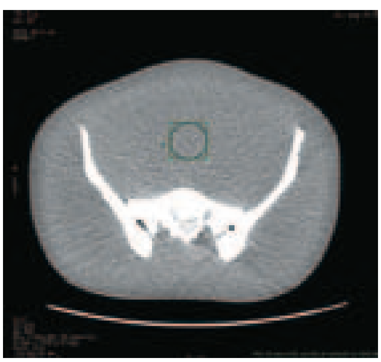


Figure 2A. Narrow window.
200WW
std: 20

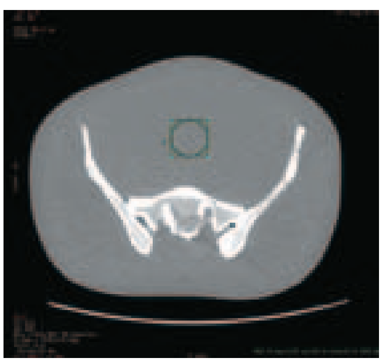


Figure 2B. 600WW
std: 20

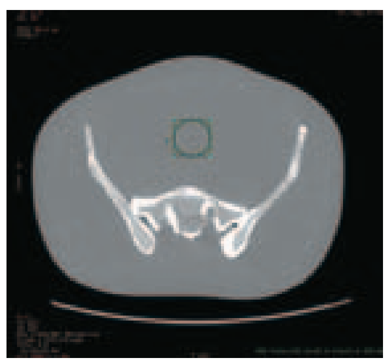


Figure 2C. Wide window.
1000WW
std: 20

If there is too much noise in an image it can obscure borders, affect edge discrimination, and obscure underlying differences in shading. Contrast enhanced studies are less impacted by noise due to the higher contrast-to-noise ratio that the administered contrast material provides. Keep in mind that how we perceive noise in an image is dependent on the window width and level settings. A wide window decreases the image contrast and thereby makes the inherent image noise less visible. However, the inherent noise does not change with windowing, and this can be confirmed by noting that the standard deviation of CT numbers within a region-of-interest (ROI) does not change. This is illustrated in Figure 2.

Units Used to Measure the Quantity of Radiation

Exposure: The traditional unit used is the roentgen (R). While used extensively in the radiological field, it is not generally used when referring to the radiation from CT scanners.

Air Kerma: Air Kerma is replacing the quantity exposure in radiology and, like it, is not typically used in discussing CT scanner radiation.

Absorbed Dose: Absorbed dose is a measure of the amount of energy deposited by radiation in a given mass of an object. Its original unit was the rad but that has been replaced by the gray (Gy), where 1 Gy = 100 rad. Typically the absorbed dose will be expressed in milligray (mGy). This is the preferred quantity for expressing the amount of radiation to a patient, as well as the potential risk, though it is not easily measured or calculated.

Equivalent Dose: This quantity goes beyond absorbed dose to include the varying biological effects of different types of radiation. It is equal to the absorbed dose multiplied by a weighting factor that expresses this variation. Since the weighting factor for X-rays is 1, the equivalent dose, expressed in sieverts (Sv), is numerically equal to the absorbed dose expressed in Gy. This quantity is occasionally, but not commonly, used in discussing radiation from CT scans. It is preferable not to use it because of possible confusion with the quantity "effective dose."

Effective Dose: A calculated quantity that goes beyond equivalent dose by taking into account the variation in radiosensitivity of different tissues and organs. While the unit of effective dose, like equivalent dose, is the sievert (Sv), it is a very different radiation quantity and should not be confused with it. Effective dose is calculated by multiplying the equivalent dose to a particular tissue/organ by a weighting factor that expresses the radiation sensitivity of that tissue/organ and then adding these products for all organs in the body. Specifically, the weighting factor is designed as an estimate of the "detriment" due to potential carcinogenic and genetic risks and does not include the risks from deterministic effects (e.g., skin burns). The resultant effective dose is a single number expressing the radiation risk to a "standard" person, ignoring the effects of gender and age on risk. In practice, for CT, this quantity is calculated using the output from the CT scanner with a computer model of a person that likewise ignores variations in patient size, age and gender. **Therefore it does not represent the personalized risk to any individual patient.**

Effective dose should only be used to represent the nominal radiation risk from a procedure. For example, we can compare the relative carcinogenic risk from a chest CT (7 mSv) to that of a chest radiograph (0.1 mSv) or to a nuclear medicine lung perfusion scan (1.6 mSv).

One must be careful not to confuse the three "dose" quantities with each other. For example, whereas the calculated value of effective dose for a particular chest CT scan may be 7 mSv, the absorbed dose to the lung from that same procedure might be 17 mGy and the equivalent dose would be 17 mSv.

Estimating Dose to the Patient

As one can see from the above, measuring and calculating actual doses to patients is highly complex and not feasible for everyday practice. Instead, modern CT units display the Computed Tomography Dose Index (CTDI), which is a measure of the quantity of radiation output by the CT scanner for a particular study. The dose length product (DLP), a related quantity, is also displayed. These are both shown in Figure 3, below.

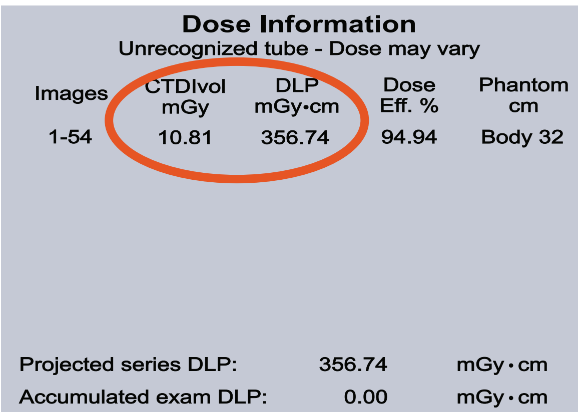


Figure 3.

Computed Tomography Dose Index (CTDI)

The CTDI is defined to represent an approximation to the average absorbed dose to a particular location in a standard acrylic phantom from multiple CT slices. CTDIw is a weighted average of the CTDI's at the center and periphery of the phantom. $CTDI_{vol}$ is similar to CTDIw but also includes the effect of pitch on the radiation dose. It is the $CTDI_{vol}$ that is displayed on the CT console and dose report.

In practice, $CTDI_{vol}$ is computed using the radiation output of the CT for a given set of scan parameters. The calculation is then performed by applying this output to either a 16 cm diameter "head" phantom or a 32 cm diameter "body" phantom. Both phantoms are solid cylinders of acrylic material. For this, as well as other reasons, $CTDI_{vol}$ does not represent the dose to a particular patient. At best, it represents an approximation of the absorbed dose to the acrylic phantom.

Dose Length Product (DLP)

The dose length product (DLP) is an indicator of the integrated radiation dose of an entire CT examination.

$DLP = CTDI_{vol} \times$ Length of the Irradiated Region

Since scan length is ignored in the definition of CTDI, we define the dose length product (DLP) as the product of $CTDI_{vol}$ and the length of the irradiated region. This quantity, along with the $CTDI_{vol}$, is displayed by the CT scanner. Note that, for any given set of scan parameters, both the $CTDI_{vol}$ and DLP will always be the same, regardless of the size of the patient. This allows us to view their values before the scan is performed and the effect of altering specific scan parameters may then be observed.

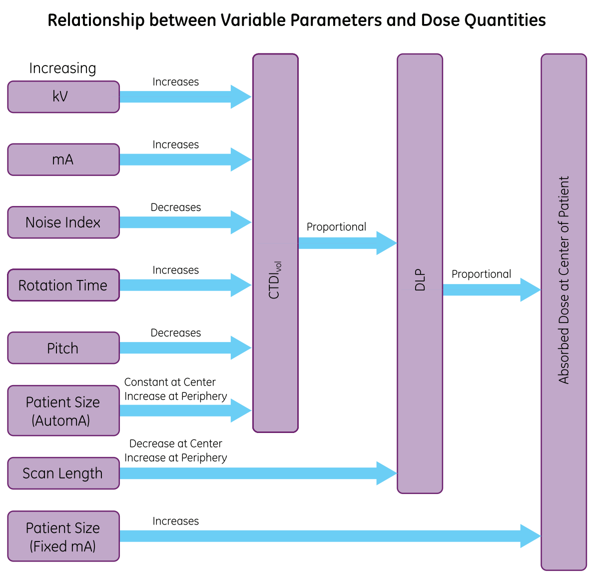


Figure 4. The relationship between variable parameters and measures of dose.

Figure 4 shows how various CT parameters affect each of the three measures of dose used in reference to CT scanning. While most affect all three, note that increasing patient size does not affect the $CTDI_{vol}$ or the DLP, since the latter only refer to a reference phantom, while the actual absorbed dose to the patient is affected.

For more information on measures of radiation, the interested reader may refer to *The Measurement, Reporting, and Management of Radiation Dose in CT.* Report of AAPM Task Group 23 of the Diagnostic Imaging Council CT committee.

Setting the Tube Current (mA) and Rotation Time

Patient dose is directly proportional to the tube current. That is, if we increase the mA by 50%, the patient dose (and $CTDI_{vol}$) will also increase by 50%. The same can be said for the time for a single rotation. Their product is the mAs.

AutomA: A reproducible method to control noise in your images

When performing CT scans, AutomA is a more efficient way to lower dose than using a manually selected mA. This is because AutomA varies the mA for each slice of the patient using attenuation calculations based on the scout images, which take into account the patient's density, size and shape. As illustrated in Figure 5, each anatomical location is modeled as an equivalent ellipse. An oval ratio is computed as the ratio of the long and short axes of that ellipse.

For example, for a patient having a CT scan of the chest, abdomen, and pelvis, if AutomA is selected, the scanner will use a significantly lower mA for the images of the chest (which is relatively low density) than for the slices through the abdomen (which is mostly soft tissue and relatively higher density). See Figure 6.

Noise Index (NI): The parameter that controls AutomA

The noise index, a user selectable variable that is part of the GE CT platform, allows the user to select the amount of (quantum) noise that will be present in the reconstructed images. It is the heart of the AutomA algorithm.

The NI represents the desired noise level at the center of patient images for a given protocol. Specifically, images of a uniform polyethylene phantom, if taken using the same scan parameters, and reconstructed with the standard reconstruction algorithm, will have a standard deviation in the central region approximately equal to the NI. When scanning a patient, the system will adjust

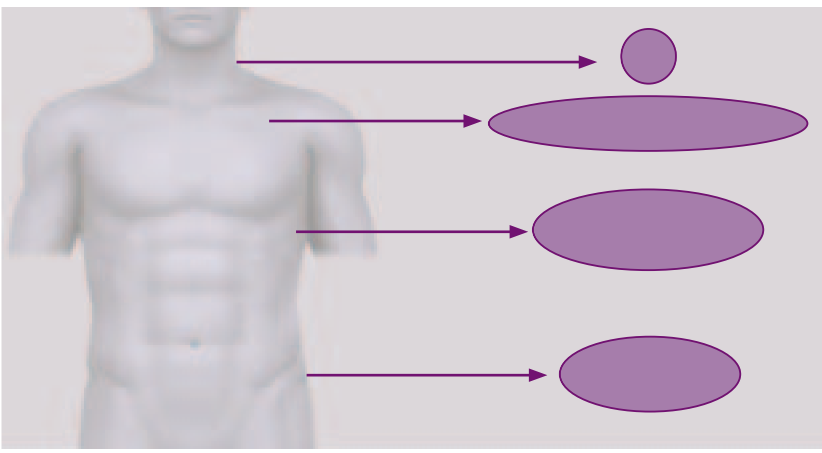


Figure 5.

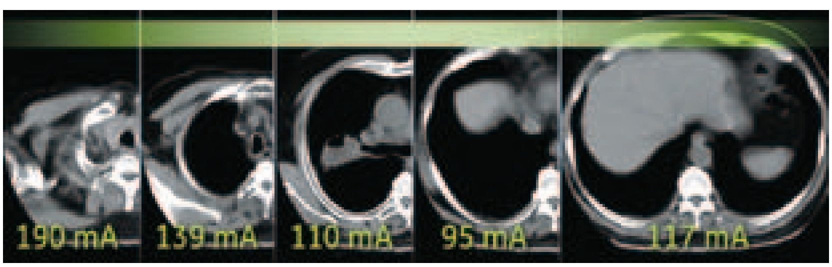


Figure 6. Demonstration of how AutomA modulates the mA in the Z-axis.

Figure 7A. 477mA.
NI 11.

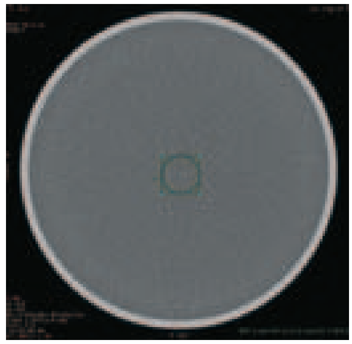


Figure 7B. 116mA.
NI 12.

the mA taking into account the NI, scan technique factors, the desired scan thickness for Recon 1 and the attenuation computed from the scout images to produce axial slices all having approximately the same central standard deviation. In practice, when scanning patients, the variation in standard deviation between slices will be increased somewhat because of pixel fluctuations due to variations in patient anatomy.

Figure 7 shows the effect of AutomA on the mA. Two objects of different size, shape and density are scanned using a Noise Index of 11. The system selected the appropriate mA (477 and 116) in each case, resulting in images with standard deviations of approximately 11 for both. The advantage of using the NI to determine the noise within the image, as opposed to directly modifying other scanning parameters, is that the NI allows for a consistent level of noise, from one scan slice to another, as well as between patients.

Illustrating the effect of the Noise Index on $CTDI_{vol}$

Figure 8A.

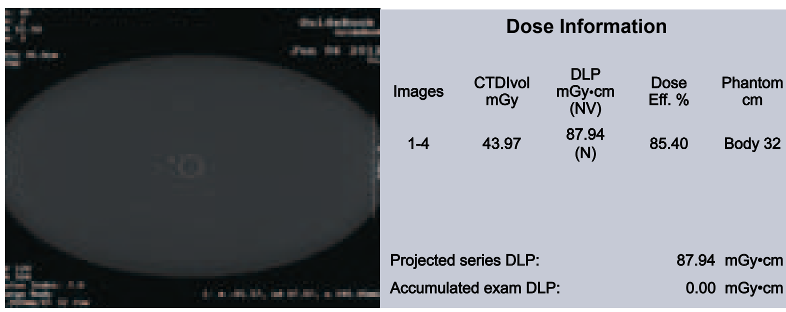


Figure 8B.

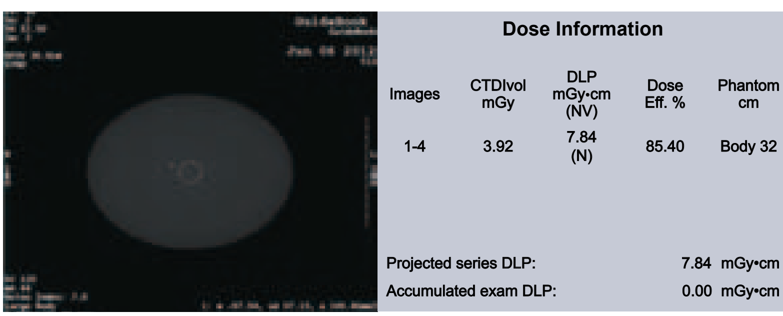


Figure 8C.

Figure 8: Illustrating the effect of the Noise Index on $CTDI_{vol}$: **(8A)** We see that a Noise Index value of 7 has been selected on the control panel; **(8B)** The larger volume required 504 mA, with a resultant $CTDI_{vol}$ of 43.97 mGy to maintain the required noise level; **(8C)** the much smaller volume needed only 44 mA with a $CTDI_{vol}$ of 3.92 mGy to keep the same noise level.

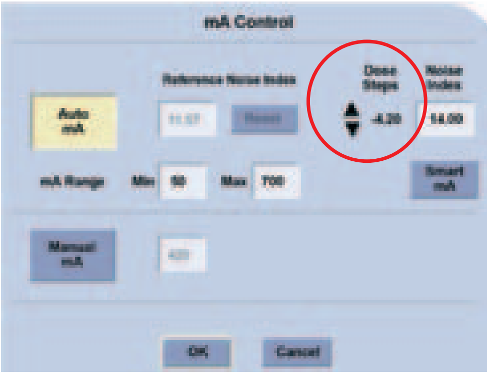


Figure 9. Dose Steps – Decreasing dose values increases image noise, thus decreasing the required mA. Each decrease in dose step will increase the NI by 5% and reduce the mA (and patient dose) by about 10%.

To avoid excessive radiation dose to large patients, the maximum mA setting in the control box should be set to a value corresponding to the maximum $CTDI_{vol}$ that the user is willing to accept. (The medical physicist member of the Dose Reduction Team will be able to relate the $CTDI_{vol}$ to patient dose.)

For consistency in changing protocols you may want to adjust the noise index using the Dose Step feature, as shown in Figure 9 (circled).

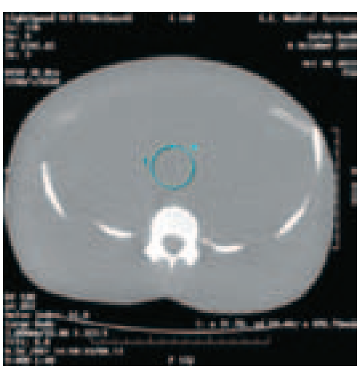
How does setting the Noise Index impact dose information?

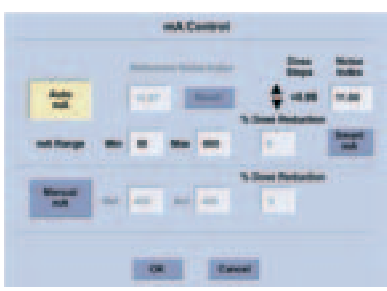
In general, experience shows that NI typically needs to be adjusted by at least 15% in order to see a significant change in patient image noise. Therefore, as you evaluate how to adjust your existing protocols to lower patient dose, an easy and effective way may be to begin by raising the noise index. As stated earlier in this section, the absorbed dose to a patient will vary as the inverse square of the noise level. Therefore, by raising the noise level by a minimal 20% we will cut the dose by approximately 30%. On the other hand, lowering the noise level by 20% will raise the dose by over 55%.

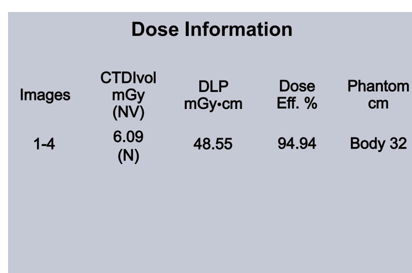
Note that since the image noise (more exactly referred to as the quantum noise) is dependent on the radiation level within the patient, it is the patient's absorbed dose that is directly correlated with noise, rather than the $CTDI_{vol}$. $CTDI_{vol}$, you will recall, refers to the dose level within a standardized phantom and is therefore independent of patient size. As a result, while the $CTDI_{vol}$ will vary with the Noise Index, its variation will not reflect the effects of patient size and therefore it will not vary to the same degree as the actual patient's absorbed dose.

As an example, refer to Figure 8 above, where two different "patients" were scanned using the same Noise Index. To maintain the same noise level at the center of the patients, the mA has been increased from 19 to 560 and the $CTDI_{vol}$ has changed by the same ratio. The absorbed dose at the center of the patient, however, not displayed, will stay virtually the same, reflecting the equal noise levels.

Now, let us look at Figures 10A and 10B. Here we have a patient being scanned with two different NIs. Since the patient size has not changed, both the absorbed dose and the $CTDI_{vol}$ will change in proportion to the resulting mA's. We see that an increase in the Noise Index of 16% (from 11 to 12.74) results in a $CTDI_{vol}$ (and dose) reduction of 26% (from $CTDI_{vol}$ of 6.09 to 4.53).







Dose Information

Images	CTDIvol mGy (NV)	DLP mGy•cm	Dose Eff. %	Phantom cm
1-4	6.09 (N)	48.55	94.94	Body 32

Figure 10A.

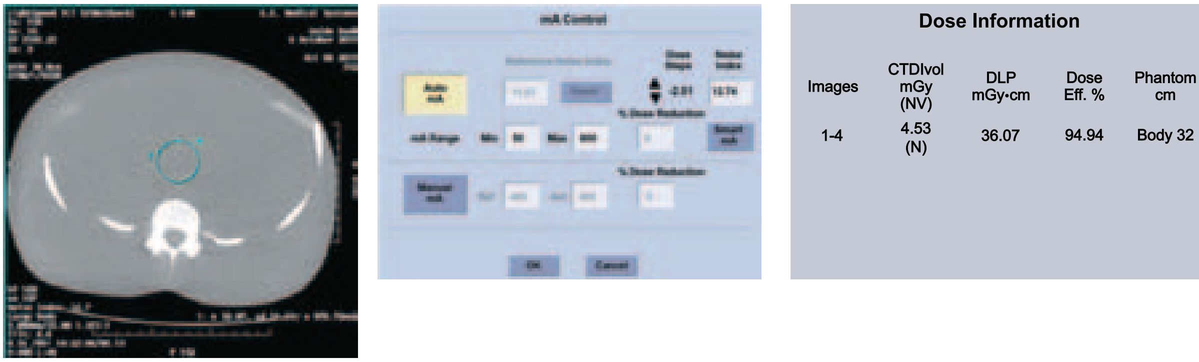


Figure 10B.

SmartmA

The use of AutomA allows the mA to be varied automatically from slice to slice and patient to patient. The additional selection of SmartmA (see Figure 11) adds a variation in mA during a single 360 degree tube rotation, i.e., a single slice. This will further reduce dose by decreasing the mA in the antero-posterior (AP) (smaller) dimension relative to that in the lateral (larger) dimension. As illustrated in Figure 11 below, there is less attenuation of the X-ray beam in the AP direction as compared to that in the lateral direction so reducing the mA in the AP direction will have a larger impact in reducing the dose.

Adaptive Statistical Iterative Reconstruction (ASiR)
(option on some GE CT systems)

ASiR is an image reconstruction technique designed to reduce the statistical noise in diagnostic images while preserving structure details. ASiR works on the original projection data during the image reconstruction, where the system noise statistics can be accurately modeled. The ASiR noise reduction technique should allow us to reduce the X-ray dose in some studies while maintaining image noise levels (see Figure 13) or, alternatively, to improve images with an otherwise unacceptable level of noise.

Generating images using ASiR involves first defining the desired level of dose reduction. The image reconstruction then involves a blending of the original image with a percentage of that same image that has undergone 100% of the noise reduction process. The percentage of blending defines the amount of potential dose reduction. For example, using a level of 40% ASiR may allow a mA (and dose) reduction of approximately 40% for normal scan modes.

Reduced dose values can be calculated and entered manually, or entered using the Dose Reduction Guidance (DRG) feature, which is available on some scanner models. It must be remembered that when setting the value of ASiR to be used, the mA is not automatically reduced. The mA and dose will be reduced only when explicitly done so by the operator using one of the methods that follows.

Figure 11.

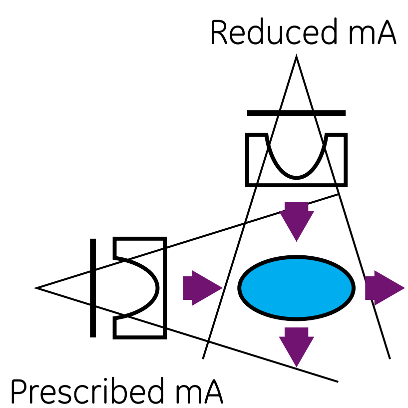


Figure 12.

Original mA Without ASiR | **mA Reduced by appx. 50% with 50% ASiR**

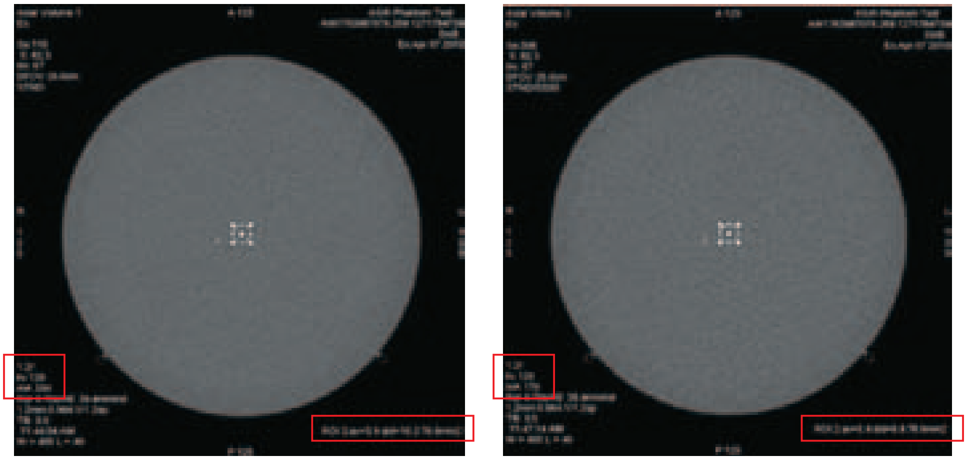


Figure 13. Note that the image on the right has a noise level similar to the image on the left, but was taken with approximately one half the mA.

ASiR using Manual Entry of Parameters

When applying ASiR[4] while using a fixed mA technique (Figure 14A), you may refer to Columns A and B in the sample "mA Reduction Table" (Table 1) to adjust the normally used mA value to achieve the desired mA (and dose) reduction.

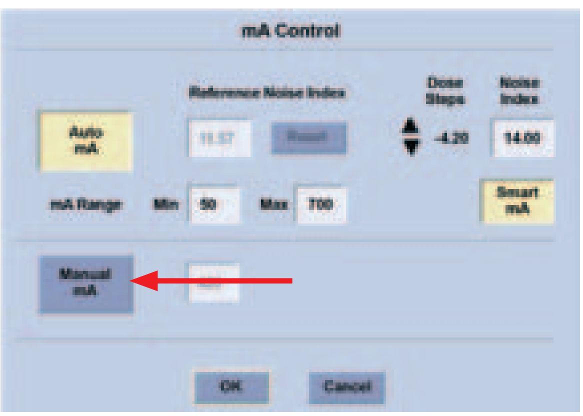


Figure 14A.

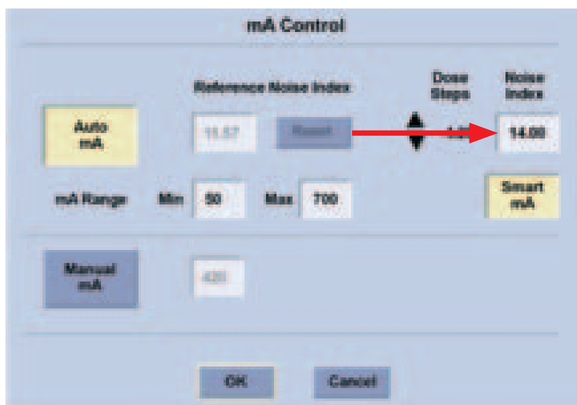


Figure 14B.

4. ASiR scan set-up varies with the model of the GE CT system; refer to your operator's manual. Before using ASiR, the site physicist, in collaboration with the radiologist, should conduct image quality evaluations with varying percentages of ASiR and different scan techniques, both at routine dose and with decreased dose.

As seen in Table 1, protocols using ASiR can be prescribed in steps of 10%, from 10% ASiR (with a potential dose reduction of 12%) to 100% ASiR (with a potential dose reduction of 80%).**

mA Reduction Table		
Column A	Column B	Column C
ASiR Level Used	Multiply Manual mA by	Noise Index will be Multiplied by
10%	0.88	1.07
20%	0.76	1.14
30%	0.66	1.23
40%	0.57	1.33
50%	0.48	1.44
60%	0.41	1.57
70%	0.34	1.71
80%	0.28	1.88
90%	0.24	2.06
100%	0.20	2.25

Table 1.

For example, if using 40% ASiR, Column B shows that the normally used mA should by multiplied by 0.57. Thus, a regularly used mA of 400 would be changed to 228.

ASiR with Dose Reduction Guidance
(optionally available on some CT scanner models)

Dose Reduction Guidance (DRG) is an alternative tool to assist in building protocols that utilize ASiR reconstruction to reduce the mA needed for the scan acquisition. Unlike the procedure discussed above, where the level of ASiR, as well as the mA or NI, is manually entered, the use of DRG allows the user to directly enter the percentage of dose (and mA) reduction with the system automatically entering the corresponding level of ASiR to be used.

For manual mA settings (Figure 15A), set a reference (Ref) mA value (i.e., the original fixed mA value used) and enter the percentage by which you would like to reduce this value. The result will be displayed as the actual (Act) mA. Note that the percentage change in dose is exactly the same as the percentage change in mA. As noted above, the system will automatically enter the necessary level of ASiR, as can be confirmed by viewing the value of ASiR on the Recon tab.

For AutomA (Figure 15B), we again set the percentage dose reduction desired. During the scan, the system will automatically reduce the mA by this percentage and apply the associated ASiR. The displayed Noise Index will not change since it reflects the value that will result after applying ASiR. Nevertheless, the displayed $CTDI_{vol}$ will reflect this same reduction.

Procedural Note: In practice, when setting up a protocol, ASiR levels and the corresponding mA reductions should start at low values and gradually be increased in small steps. After each step an image should be reviewed and the process continued until the desired image quality and dose reduction are achieved. The mA reduction values shown in the table should be thought of as reduction goals for the selected ASiR level – not required values.

When applying ASiR with the AutomA option selected (Figure 13B), refer to Columns A and C in Table 1. For a selected level of ASiR, multiply the Noise Index usually used for this exam by the corresponding value in Column C. For example, if using 40% ASiR, Column C shows that the normally used NI should by multiplied by 1.33. Thus, a regularly used NI of 14 would be changed to 18.6 (resulting in a mA reduction of 43%).

**The data shown in Table 1 represents the design functioning of ASiR in relation to the setting for the Noise Index and the image pixel standard deviation, and does not represent a claim of actual clinical performance or utility. In clinical practice, the use of ASiR may reduce CT patient dose depending on the clinical task, patient size, anatomical location and clinical practice. A consultation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task.

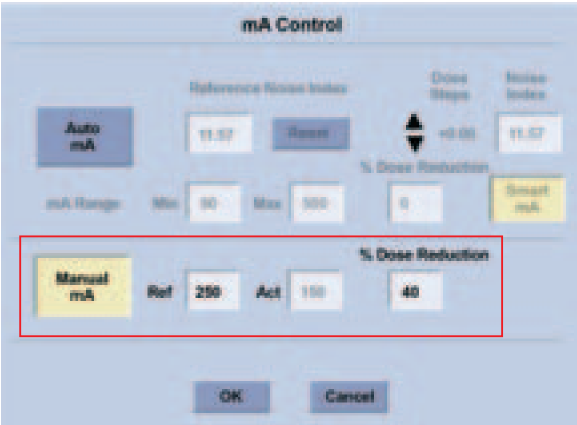


Figure 15A.

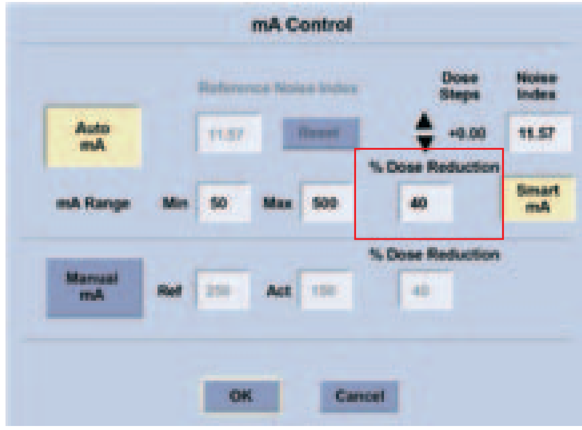


Figure 15B.

Adjusting the kilovoltage (kV)

Another approach that can be taken in order to reduce dose is the kV selection. Adjusting the kV impacts both the quantity and energy of the X-rays emitted, which will result in changes to the dose, image noise and image contrast. Therefore, patient size and the type of study should be taken into account in choosing the kV. When the kV is changed, attention must be paid to the mA setting in order to achieve the desired results.

When using a fixed, manual mA setting, lowering the kV will lower patient dose, along with a concomitant increase in image noise. For example, lowering the kV from 140 to 120 might produce a 30% dose reduction if all other factors remain the same. However the statistical noise level will increase by about 20%. If AutomA mode is engaged, on the other hand, lowering the kV will have minimal effect on image noise because of a compensating increase in mA. Consequently, the dose to the center of the patient will change only slightly.

The impact of kV on image contrast is most evident for CT examinations utilizing iodinated contrast agents. Because the attenuation properties of iodine change significantly within the diagnostic energy range, lowering the kV results in increased image contrast for the iodine.

This increase in image contrast can be leveraged in a number of ways, depending on how the protocol is defined:

- Reduced dose – the increase in image contrast may allow the user to tolerate a higher image noise level, which means the NI can be increased.
- Improved image quality – better image quality with the same image noise level.
- It will allow the radiologist to re-assess the amount of contrast needed to achieve the desired level of image quality and perhaps reduce it.

Adjusting Slice Thickness

With thinner slices there is an increase in noise if all the other scanning parameters remain the same. Noise increases because the number of X-rays used to form each image is reduced in proportion to the slice thickness. To put it another way, the voxel size will be thinner and therefore fewer X-rays will interact in it. To compensate for this loss of interacting X-rays, one may increase the dose by increasing the mAs or kV. However, note that a decrease in slice thickness by 50% will necessitate a dose increase by a factor of 2 to fully compensate! To avoid unintended large increases in mA (and patient dose)

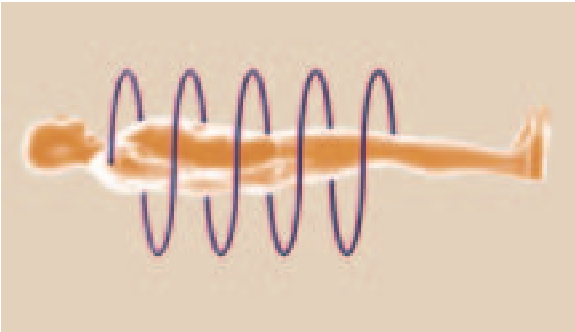


Figure 16A. Higher Pitch.

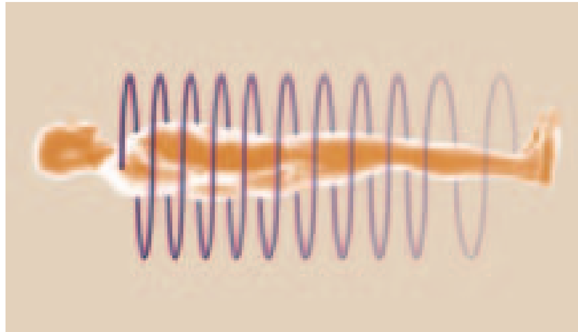


Figure 16B. Lower Pitch.

when AutomA is used, the system will automatically adjust the Noise Index when the slice thickness is changed (in Recon 1 only) to keep the average mA practically unchanged. If the slice thickness is decreased, this will result in a noisier image. The radiologist must decide whether the trade-off between longitudinal resolution and noise, or that between noise and patient dose, is clinically acceptable. Reminder: If you normally reconstruct images with thin sections for 3D reformatting and thicker slices for axial viewing, it is important to understand that the first prospective reconstructed slice thickness (Recon 1) is used in calculations for AutomA. Therefore, in order to set the noise index properly, Recon 1 should use the thickest slice images desired.

Adjusting the Pitch

Pitch (Figure 16) is the table feed during one complete tube rotation divided by the collimated width of the X-ray beam. Pitch can affect patient dose in two ways:

- By increasing the pitch with a fixed scan length and mA, radiation dose is reduced due to the lower total exposure time. The detectability of small lesions, however, like pulmonary nodules, may be reduced due to lower dose and the resulting higher level of noise.
- If AutomA is used, it will adjust the mA to maintain the noise level (and patient dose).

Patient Centering: Do not waste X-rays— Always check your scouts for centering accuracy

Correct patient centering within the gantry will allow the bow tie filters to deliver dose where it is needed and filter more where it's not. Patients not properly centered may be partially under – or over-exposed because the bowtie filter projects the maximum X-ray intensity at isocenter. This is normally the region of maximum attenuation when the patient is properly centered. If the patient is off-centered, there are fewer X-rays projected to the thickest part of the patient, and hence image noise will increase in that region. Likewise, more X-rays will intercept a thinner section of the patient, unnecessarily.

An additional effect of off-centering when using AutomA is that the projected size of the patient will be affected, and therefore AutomA will set the mA based on this less accurate size. This is illustrated in Figures 17A and 17B.

Shielding of superficial organs

It has recently been shown that direct shielding of sensitive organs may result in significant dose reduction to those organs. However, it is critical that such shielding be performed very carefully in order to avoid significant artifacts, noise and patient overdosing. This is especially important when using AutomA. A review of this debated technique has recently been published. In addition, the AAPM has recently (2/7/12) published

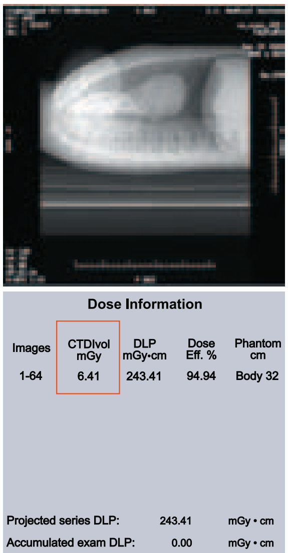


Figure 17A.

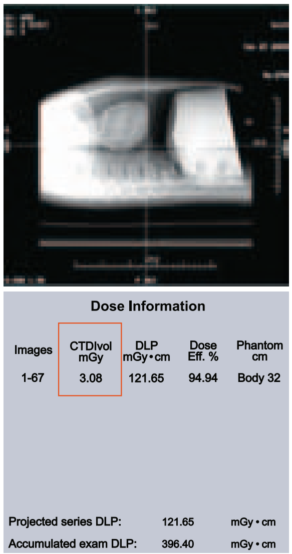


Figure 17B.

Off-centering by as little as 4 cm, as shown in **(A)** could increase dose by a factor of two, as compared to the proper positioning shown in **(B).**

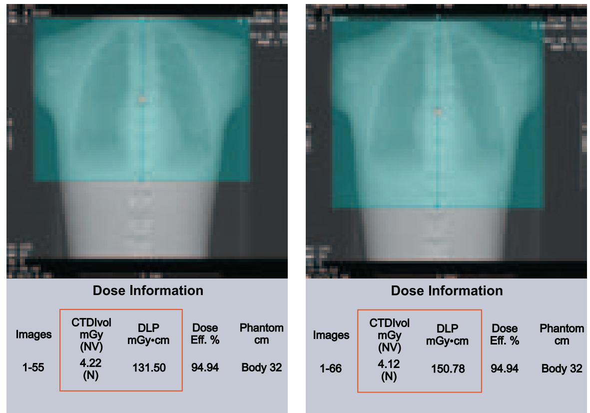


Figure 18.

a position statement discouraging the use of bismuth shields, especially when alternatives such as tube current modulation are available. See AAPM statement on shielding of superficial organs at AAPM.org.

Minimize the scanned region

The scanned region should always be limited to the minimum area necessary. Although the patient dose (and $CTDI_{vol}$) within the scanned region will not change, the irradiation of a smaller area reduces the radiation risk to patients, as reflected in a reduced DLP. Also, the scatter radiation to organs adjacent to the scanned region will be reduced. As illustrated in Figure 18, reducing the scan length, while not significantly affecting the $CTDI_{vol}$, reduces the DLP by an amount proportional to the scanned length.

Conclusion

The guiding principle of dose reduction is based on the concept of ALARA: As Low As Reasonably Achievable. Consideration must always be given to minimizing the radiation dose to the patient while ensuring the necessary quality of diagnostic images.

4. "Bismuth Shields for CT Dose Reduction: Do they Help or Hurt?", C. McCollough, et al., J. of the American College of Radiology, 8(12) 2011.

3

GE Healthcare Dose Reduction Technologies

GE Healthcare is as conscious about dose as the clinicians who use our CT scanners and the patients they image.

As a leader in low-dose technology, we continually invest in developing new and better dose reduction technologies that enable providers to optimize dose while achieving clinically diagnostic image quality. GE pioneered the new frontier of iterative reconstruction technology.

This section provides an overview of these solutions in four areas:

- Image Reconstruction Algorithms
  - ASiR
  - Veo
- OptiDose Technologies
  - Adaptive Image Space Filters
  - SmartScan
  - Dynamic Z-axis Tracking
  - SmartTrack
  - ECG Helical Modulation
  - SmartBeam
- Dose Management Tools
  - Dose Report
  - Dose Check
  - DoseWatch
- Clinical Applications
  - SnapShot Pulse
  - VolumeShuttle
  - Color Coding for Kids
  - Adventure Series

Image Reconstruction Technology

GE Healthcare has invested many years of research into building from the ground up a powerful class of new reconstruction algorithms, designed to explicitly include the description of data statistics into the reconstruction. The highest standard of dose reduction can only be achieved through breakthrough innovation in image reconstruction such as ASiR and now Veo, the world's first Model-Based Iterative Reconstruction (MBIR) product.

ASiR: may help clinicians obtain diagnostic images with a lower mA*

Introduced in 2008, ASiR (Adaptive Statistical Iterative Reconstruction) dose-reduction technology provides important imaging benefits that may enable dose reduction by reducing pixel noise standard deviation by allowing the use of lower mA protocols,* refer to Figure 1. ASiR may also enable an improvement in LCD.* The result is a reduction in image noise with high definition image quality across anatomies and applications and for all ages.

In the simplest terms, ASiR uses projection data and applies a sophisticated statistical modeling algorithm to remove noise in the reconstructed images while preserving anatomical detail.

*In clinical practice, the use of ASiR may reduce CT patient dose depending on the clinical task, patient size, anatomical location, and clinical practice. A consultation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task.

The ASiR reconstruction algorithm may allow for reduced mA in the acquisition of diagnostic images, thereby reducing the dose required.

ASiR models how noise propagates through the reconstruction steps to feed this model back into the loop and iteratively reduce noise in the reconstructed image without affecting other properties such as detail. To minimize complexity and facilitate fast convergence, ASiR uses the same idealized system optics representation as filtered back projection (FBP), resulting in similar data utilization per image.

Object Size	% Contrast (typical)	Dose Level (mGy $CTDI_{vol}$) Reconstruction Mode		% Change in Dose
		Standard	ASiR	
5 mm	0.30%	14.3	8.8	40%
3 mm	0.30%	39.4	23.8	40%
2 mm	0.30%	86.3	52.3	40%

Figure 1. Percentage contrast ratio is equal when compared to ASiR with a 40% mA reduction.

For example, Weill Cornell Imaging's initial efforts to comprehensively reduce dose including ASiR resulted in dose reduction for Chest CT, CTA for pulmonary embolus, and abdominal and pelvic CT, as seen in Figure 2.

Protocol	Pre (DLP)	Post (DLP)	
Chest CT	319	214	
Chest CT (PE)	1152	650	
Abdominal Pain	1158	710	

Figure 2.

Getting started with ASiR

Before using ASiR, the site physicist, in collaboration with a radiologist, should conduct image quality evaluations using ASiR and different scan techniques, both at routine and decreased dose. This should be done using your site's preferred method and phantoms. Using this information, an appropriate starting point for the ASiR level and diagnostic scanning techniques can be incorporated into your site's user protocols.

Whether ASiR is used for dose reduction or LCD improvement, parameter settings should be changed incrementally and reviewed at each step for diagnostic image quality until the desired clinically appropriate image quality is achieved.

A general guideline for parameter step adjustments is:

- Dose Reduction increments of about 20%.
- ASiR level increments of 10%.

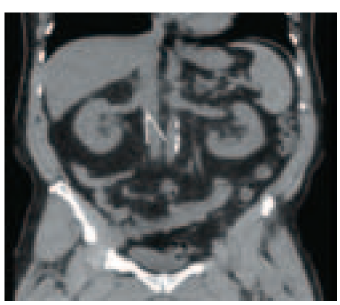


Figure 3A. ASiR provides noise (SD) characteristics of higher dose scan. **Figure 3B.** Compares scans with and without ASiR.

Veo: High-quality images at even-lower dose

Veo† is the world's first true model-based iterative reconstruction product. It may deliver a combination of high-quality images and low dose that was previously unthinkable.[1] By combining sophisticated algorithms and advanced computing power, GE Healthcare has developed a CT reconstruction technique that enables lower pixel noise standard deviation and higher resolution to be achieved within a single image. Its powerful modeling techniques deliver previously unattainable levels of combined noise reduction, resolution gain, improved contrast, and artifact suppression.[2]

Veo establishes new rules in the relationship between image quality and dose reduction, giving clinicians diagnostic information with the ability to reduce kV and mA. In fact, Veo provides the potential for diagnostic-quality images at less than 1 mSv with profound image clarity.

The benefits of dose reduction are significant, especially for the most radiosensitive patients—including children and young women. Veo may also provide the opportunity to dramatically reduce cumulative dose in patients who require regular follow-up exams.[2] Refer to Figure 4 and Figure 5 below.

X-ray image | Veo CT Reconstruction

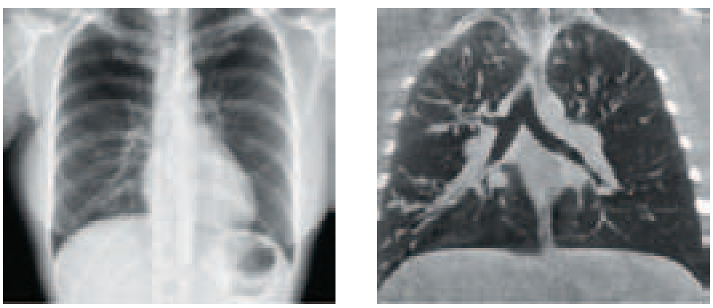


Figure 4. Estimated effective dose for diagnostic chest exam (PA + lateral) = 0.06 mSv (1)
Scan protocol: 4 mAs, 80 kV Slice thickness: 0.625 mm effective dose = 0.05 mSv (2).

FBP Reconstruction | Veo CT Reconstruction

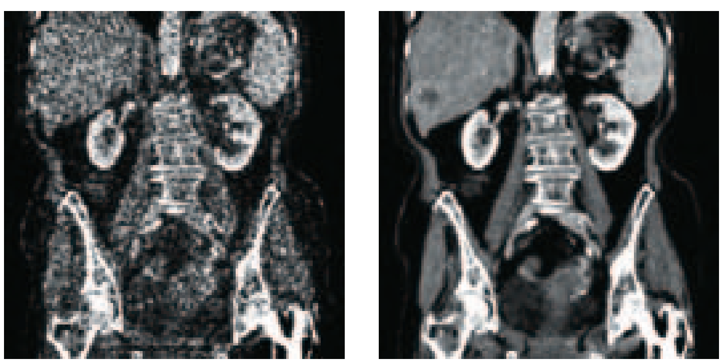


Figure 5. Abdomen Pelvis—Veo reconstruction demonstrates improved visualization of renal liver metastasis. Abdomen pelvis exam, effective dose = 0.61 mSv[2].

†Veo is only available on the Discovery CT750HD.

1. In clinical practice, the actual level of resolution, LCD, spatial resolution, and low signal artifact improvement may vary. Consult with a radiologist and a physicist.
2. In clinical practice, the use of Veo may reduce CT patient dose depending on the clinical task, patient size, anatomical location and clinical practice. A consultation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task.

How Veo works

Model-Based Iterative Reconstruction (MBIR) incorporates a physical model of the CT system into the reconstruction process. This process characterizes the data acquisition, including noise statistics, system optics, radiation, and detection physics. These characteristics can be developed independently with as few approximations as possible to provide a faithful representation of the actual scanning process. MBIR also includes an image model which favors solutions appropriate for a medical tomographic image with the characteristic behavior of human tissue rather than inanimate objects when reconstructing from noisy data.

The collection of all these models is fed into a mathematical formulation to describe the reconstructed image in a manner representative of the way the corresponding projection data were acquired. The resulting function is optimized to find the best possible match between the reconstructed image and the acquired projection data given the knowledge of the CT system operation.

MBIR weights each individual data point to give noisy projections lower influence on the final result than less noisy projections, which eliminates correlated noise and streaks arising from non-circular objects. The metric applied to the discrepancy between each measured projection point and the estimated image is weighted by this factor to minimize the noise content in the reconstructed image.

To apply Veo it is recommended to start with ASiR protocols and then reduce them by steps of 20% until your optimal dose versus image quality is obtained.

The evolution of CT image reconstruction

All CT scans begin with raw data. The method of reconstruction determines the quality of a final image.

1. The diagram compares three reconstruction methods currently applied by GE Healthcare.
2. Image quality/noise is measured as pixel noise standard deviation.
3. In clinical practice the use of ASiR or Veo may reduce patient CT dose depending on the clinical task, patient size, anatomical location and clinical practice. A consultation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task.
4. Defined as pixel standard deviation, low contrast detectability and spatial resolution.

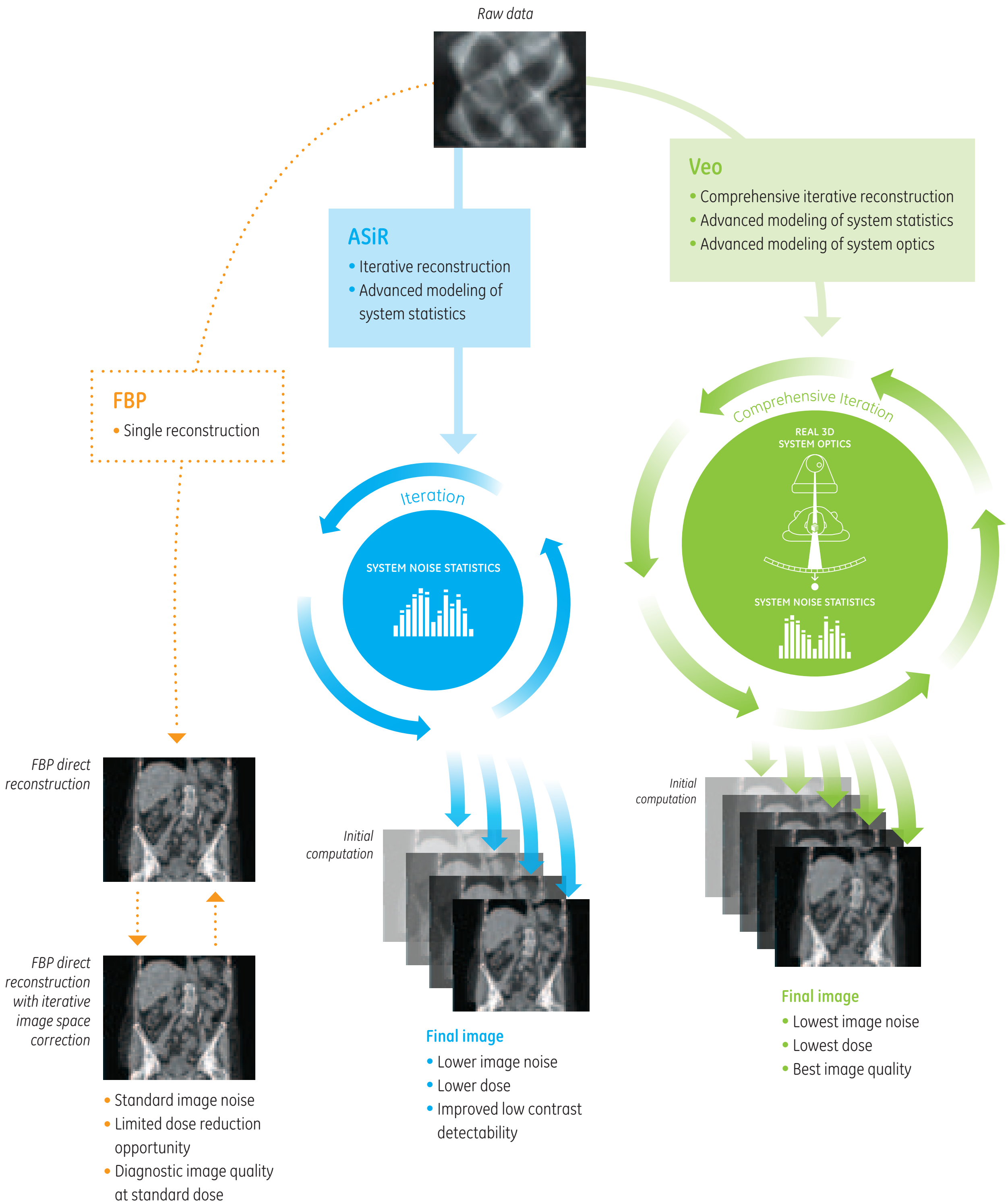

Raw data
ASiR
• Iterative reconstruction
• Advanced modeling of system statistics
Veo
• Comprehensive iterative reconstruction
• Advanced modeling of system statistics
• Advanced modeling of system optics
FBP
• Single reconstruction
Iteration
SYSTEM NOISE STATISTICS
Comprehensive Iteration
REAL 3D SYSTEM OPTICS
SYSTEM NOISE STATISTICS
FBP direct reconstruction
FBP direct reconstruction with iterative image space correction
• Standard image noise
• Limited dose reduction opportunity
• Diagnostic image quality at standard dose
Initial computation
Final image
• Lower image noise
• Lower dose
• Improved low contrast detectability
Initial computation
Final image
• Lowest image noise
• Lowest dose
• Best image quality

Figure 6.

Optidose Technologies

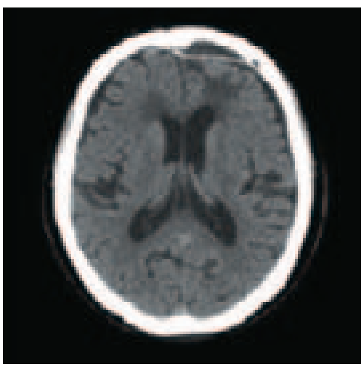
A proven leader in delivering dose efficiency in CT, GE has achieved this position by incorporating dose reduction technologies in all our scanner lines through a "total system" approach, known as OptiDose. OptiDose technologies include the following.

Adaptive Image Space Filtration: Reduce noise, maintain image features

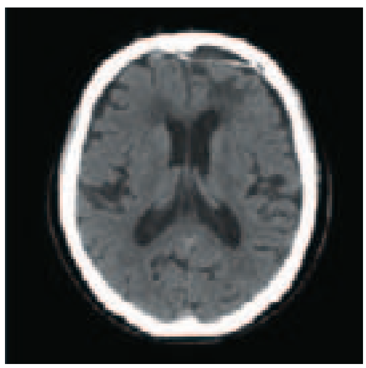
There are several techniques for reducing noise in CT based on the choice of reconstruction kernel and image space smoothing. However, using these techniques may impact the relationship between image resolution and noise reduction. Recognizing this tradeoff, GE Healthcare has developed a group of advanced adaptive image filters, which can identify image features and make processing adjustments in order to reduce noise and yet maintain resolution quality. GE Healthcare's technology enables small regions of voxels to be examined in order to determine the presence and orientation of image features. Then, the image smoothing is modified to retain or enhance image features and still achieve the desired reduction in noise. On the other hand, uniform smoothing can be applied in regions without image features. Some examples of Adaptive Image Space Filtration in current GE Healthcare systems are:

Neuro 3D Filters—GE has developed user selectable 3 dimensional filters designed to meet the challenges and characteristics specific to the inherent issues in brain imaging. The Neuro 3D Filter, Figure 7, is a noise reduction filter optimized for thin slice data that is intended for post processing to create Average and MIP images, Volume Rendering and 3D models for neurological studies such as Circle of Willis, carotids, sinuses, orbits, mandible and helical brain.

Cardiac Noise Reduction Filters—There are three cardiac noise reduction and edge-preserving filters labeled C1 (low), C2 (medium) and C3 (high). They have been shown to help clinicians reduce dose while maintaining coronary anatomy for a broad range of patient sizes. Once the user chooses the filter, the mA can then be reduced manually to maintain the same noise (SD). Use of these filtration techniques allows users to push the scanning techniques to their lower limit, while retaining sufficient diagnostic image quality.



Axial brain.



Axial brain with Neuro 3D Filter.

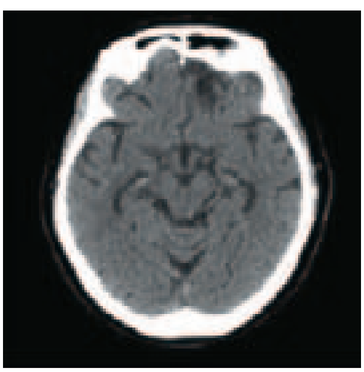
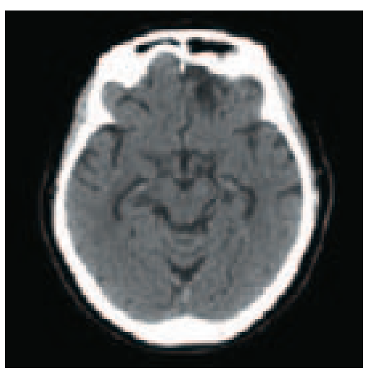


Figure 7. Axial brain.



Axial brain with Neuro 3D Filter.

AutomA plus SmartmA: Personalizes 3D Dose Modulation for every patient

Volumetric knowledge prior to scanning allows users to personalize protocols and optimize dose for every patient—large and small. During the scan, real-time, 3D dose modulation helps deliver consistent image quality (noise) because it automatically accounts for the changing dimensions of the patient.

3D Modulation recognizes the body is not cylindrical so it automatically adjusts the mA to achieve dose optimization without impacting the image quality prescribed by the technologist. Dose is optimized by adjusting the mA for each scan rotation according to the X-ray attenuation, modulating the radiation dose to a patient in the X and Y or X, Y and Z directions.

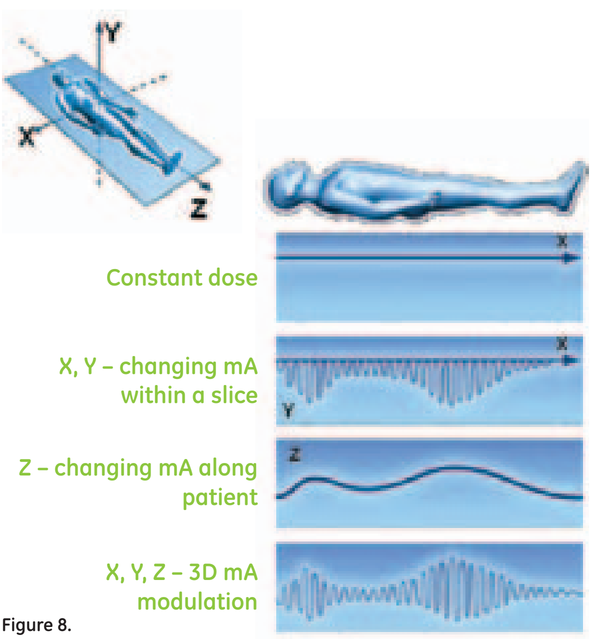


Figure 8.

AutomA (Z-axis modulation) adjusts the tube current to maintain a user selected quantum noise level in the image data. It regulates the noise in the final image to a level desired by the user. AutomA is the CT equivalent of the auto exposure control systems employed for many years in conventional X-ray systems. The goal of AutomA is to make all images contain similar X-ray quantum noise independent of patient size and anatomy. The AutomA tube current modulation is determined from the attenuation and shape of scout scan projections of the patient just prior to CT exam sequence.

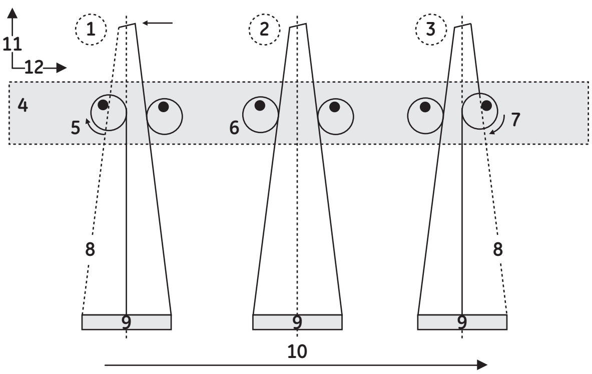
SmartmA (angular or XY modulation) has a different objective than Z-modulation. It adjusts the tube current to minimize X-rays over angles that have less importance in reducing the overall image noise content. In anatomy that is highly asymmetric, such as the shoulders, X-rays are significantly less attenuated in antero-posterior (AP) direction than in the lateral direction. Thus, the overwhelming abundance of AP X-rays can be substantially reduced without a significant effect on overall image noise. Angular modulation was first introduced on GE single slice scanners in 1994.

3D Dose Modulation, refer to Figure 8, accounts for the body in all three dimensions—personalizing each scan.

Dynamic Z-axis Tracking: Reduce unnecessary dose in helical scanning

Dynamic Z-axis tracking is used in addition to Z-axis tracking when in the helical mode. It provides automatic and continuous correction of the X-ray beam position to block unused X-ray at the beginning and end of a helical scan to reduce unnecessary radiation.

Beam tracking at the beginning and end of helical scan acquisitions allows the system to control the X-ray beam to target only the portion of the detector used by image reconstruction, thereby limiting patient dose and maintaining image quality. Even with highly efficient image reconstruction algorithms, some of the outer row data is not required at the ends of the scan range. During helical scanning there is some over ranging during the acquisition; the independent beam edge control provided for beam tracking is perfectly suited to deal with this, by adjusting the beam edges at the start and end of a helical acquisition. The amount of dose reduction achieved by this technique is a function of the aperture, pitch and scan length.



Dynamic Z-axis Tracking Architecture Descriptions	
1	Start of helical scan, lead cam closed and begin to open
2	Middle of scan, cams open and normal Z-axis tracking
3	End of helical scan, tracking cam closes
4	Collimator
5	Leading Cam Opens
6	Tungsten Cams
7	Trailing Cam Closes
8	Blocked X-ray Region
9	Detector
10	Table Travel
11	Y Axis
12	Z Axis

Figure 9.

Dynamic Z-axis tracking closes off the outside of the beam (trailing edge at the start and leading edge at the end) at the start and end of the helical scan. These are portions of the data never used to make an image. At the start of the 40 mm scan, the trailing cam is closed in to make the beam a forward offset 20 mm. This cam opens as the scan progresses and the beam is then 40 mm for most of the scan. At the end of the helical, the leading cam closes in to make the beam a backward offset 20 mm.

SmartTrack: Narrow the X-ray exposure profile

SmartTrack Z-axis tracking is used in all scanning modes. It is an advanced hardware and software that works in real-time adjusting the collimator to follow focal spot movements caused by centrifugal, gravitational and thermal forces during the scan rotation.

The closed loop control repositions the collimator to hold the beam steady keeping the X-ray beam centered on the detector as it rotates around the patient. Z-axis tracking provides automatic and continuous correction of the X-ray beam position, adjusting the beam collimation and position to get a constant narrow beam on the detector, optimizing dose.

Z-axis Tracking Architecture

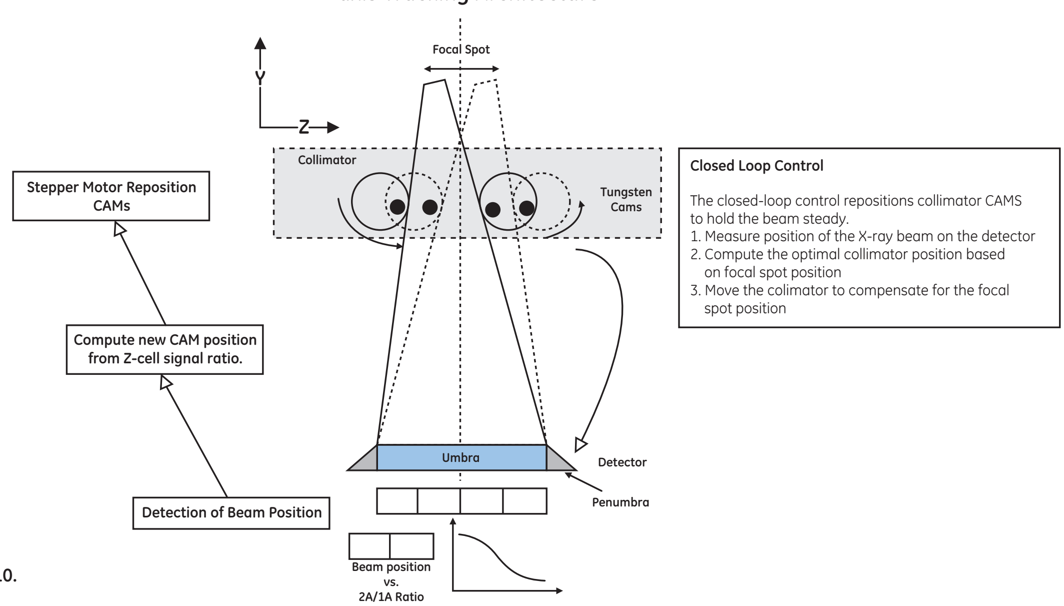


Figure 10.

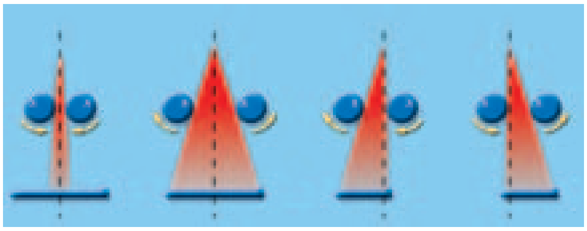


Figure 11.

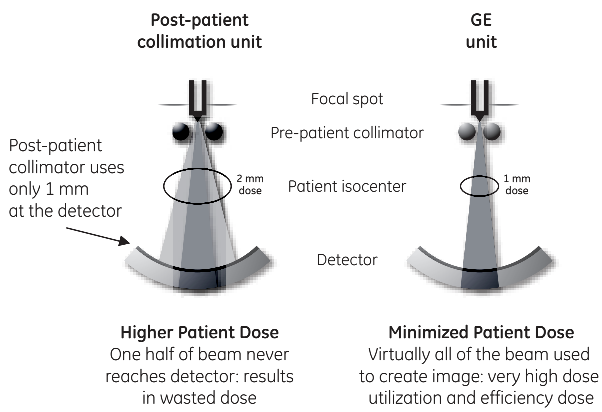


Figure 12.

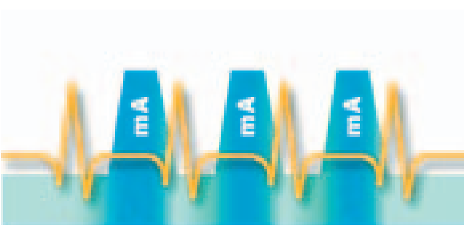


Figure 13. ECG dose modulation achieves up to 50% less dose for most cardiac studies through the use of ECG gating.

No Post-Patient Collimation

GE Healthcare CT systems have always been designed without post-patient collimation, Figure 12. By utilizing a design that narrows the beam before entering the patient, it is very efficient in dose utilization and optimizes the beam for image generation. Virtually the entire beam is used to create the image.

ECG Helical Modulation: Visualize the heart with less dose

ECG helical modulation reduces dose in the systolic phase of the heart cycles by using ECG gating to modulate the mA. Full tube current is applied to the patient only during the diastolic phase when motion is minimal.

ECG modulation allows the user to vary the mA based on R-R interval percent. The area can be scanned with peak mA during the phase range of interest. The mA for phases of interest will be higher than for all other phases so the physician can visualize the coronary vessels and heart during phases of interest peak cycle.

The minimum mA can equal as little as 20% of the maximum mA. When the HR is <65 BPM, only use maximum mA for the 70%–80% phases of the heart. When a HR is >65 BPM or varying you may not always freeze the motion of the heart at end diastole. This can lead to a dose decrease in low stable heart rates. Maximum mA may be used from 40–80% of the heart cycle so systolic phase is included. This will allow you to have peak power from systole to diastole and review images at any of these phases. This can lead to a dose decrease in low stable heart rates.

SmartBeam: Optimizing X-ray beam filtration

SmartBeam bowtie beam-shaping hardware and software optimizes X-ray beam filtration independently for body, head, and cardiac applications. SmartBeam filters reduce radiation dose to the patient without sacrificing image quality. They block or filter off-axis X-rays, minimizing dose and reducing X-ray scattering effects. There are different size filters that are used for different scan fields of view. SmartBeam filters can provide a significant surface dose reduction compared to a uniform X-ray field.

Dose Management Tools

DICOM–RDSR—Radiation Dose Structured Report: Improve record-keeping

Prior to the scan on GE Healthcare CT systems, an onscreen display presents data on $CTDI_{vol}$, DLP, and dose efficiency to be evaluated by the operator. At the end of every scan, dose reports are generated, providing a clear summary of how the procedure was performed. The post scan reports take two forms: a text page breakdown by scan groups and the DICOM Radiation Dose Structured Report (RDSR), which enables tracking of patient dose by the hospital radiation tracking system/RIS/HIS. Saved as part of the patient's exam, a dose report indicates the dose for each group performed.

Patient Name:
Accession Number:
Patient ID: ytyt
Exam Description:

Exam no: 744
Dec 16 2005
LightSpeed YCT

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Helical	587.750-I152.250	656	184.46	Body 32
3	Smartstep	I80.000-I78.125	581	581	Body 32
3	Smartstep	I80.000-I78.125	581	581	Body 32
3	Smartstep	I80.000-I78.125	581	581	Body 32
3	Smartstep	I80.000-I78.125	581	581	Body 32
3	Smartstep	I80.000-I78.125	581	581	Body 32
3	Smartstep	I80.000-I78.125	581	581	Body 32
3	Smartstep	I80.000-I78.125	581	581	Body 32
			Total Exam DLP:	225.13	

Smartstep Accumulated Exposure time 00.00.07.0

Figure 14.

Dose Check: Alerts of potentially high exposures

Dose Check helps to notify and alert CT operators when scan settings would exceed pre-assigned dose thresholds (from either $CTDI_{vol}$, DLP, or both). These dose thresholds are established by the healthcare provider based on their practice through the Dose Check Management Tool, Figure 15A. Dose Check is a tool that enables users to be more aware of the associated dose index of the scan they are prescribing, and provides a "Notification", Figure 15B, if that dose index is above the institution's established values for the protocol. This notification level is intended to be set at a level that would be considered above "routine" or "normally expected" dose, but not at such a high level as to pose a significant risk to the patient. Dose Check compares the estimated exposure from current scan settings to two different thresholds prior to scanning: Notification Values (NV) for individual groups of scans and Alert Values (AV) for accumulated exposure from an entire exam.

When Dose Check determines that the current scan settings would exceed one of the user-defined, Notification Values or Alert Values, a Dose Notification pop-up screen, Figure 15B, alerts the operator that the scan will exceed the NV or AV. For NV alerts the user can then either change the scan settings, or continue with the current settings by entering a diagnostic reason. Performing a scan exceeding an AV value demands

Figure 15A and 15B.

Abbreviations: DC: Dose Check NV: Notification Value AV: Alert Value

*Dose Check is installed at no cost on your new and compatible existing GE CT systems, (FMI 2nd half 2011 through 2012). It will also be part of the standard configuration for all new GE CT systems produced worldwide.

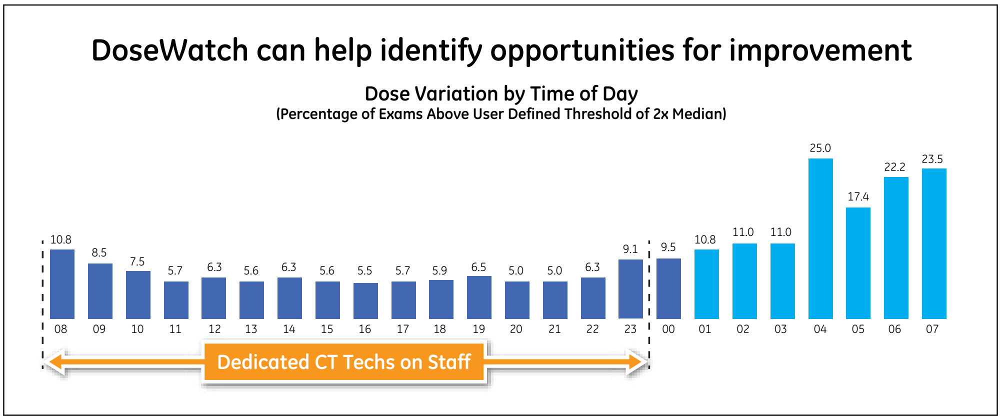


Figure 16.

a high degree of consideration for appropriateness. Therefore, in most cases, operators will adjust parameters. However, if there is a true diagnostic need to perform a scan exceeding an AV value, the system allows continuance of the scan with the entering of a password. Dose Check also maintains a log for QA review whenever an NV or AV is exceeded.

DoseWatch: If you measure it, you can improve it

DoseWatch is a new information technology application that facilitates the tracking and monitoring of dose from multiple manufacturers and multiple types of imaging devices. It can provide information to help you assess your professional practices, improve protocol management, and monitor the effectiveness of change. As an example, Figure 16 demonstrates how data could be collected to review scan parameters by time of day, assisting in identifying variances.

Through your facility's existing network and IT infrastructure, Figure 17, DoseWatch captures patient dose information from imaging devices and organizes the data by modality and type of imaging protocol. The DoseWatch database stores all data, accumulates dose by patient, and retains key acquisition parameters. Reference points can be established by noting average dose by protocol, location, system, operators and radiologist. These details can help you assess how to standardize protocols and understand the levels of dose. DoseWatch also has complete reporting and editing capabilities for your quality assurance program.

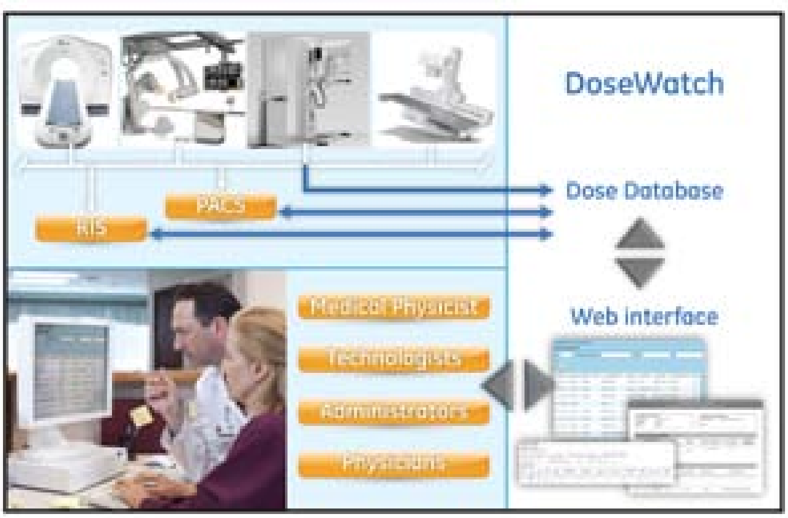


Figure 17.

Clinical Applications

SnapShot Pulse: Improves coronary CTA dose management

SnapShot Pulse is a prospectively gated acquisition and reconstruction method, which can provide a reduction in radiation dose compared to cardiac helical mode. Because the X-ray is on only during the prescribed cardiac phases, data is not collected continuously across the cardiac cycle. This is an alternative to helical acquisition using an axial step-and-shoot mode to acquire images during a specified phase of the heart cycle. A critical note: it is important that the patient's heart rate is 65 BPM or below. If you are using SnapShot Pulse for non-coronary work (for example, the thorax or left atrium) there is not a heart rate limitation.

The ECG monitor is attached to the CT scanner and synchronizes scanning to occur during the requested phase of the heart, typically diastolic. Prospective reconstruction (step-and-shoot method) captures the images during a certain phase of the heart, usually diastolic. The technique uses a statistical model based on the length and variability of previous heart cycles to time the next axial scan.

The following ECG demonstrates a retrospective and prospective acquisition:

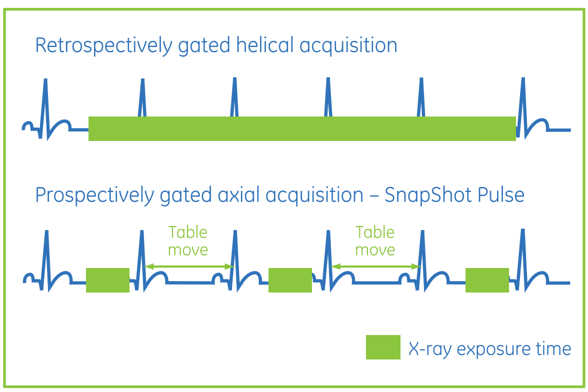


Figure 18. Prospectively gated CCTA reduces radiation exposure by >83% with ASiR for heart rates below 65 BPM.

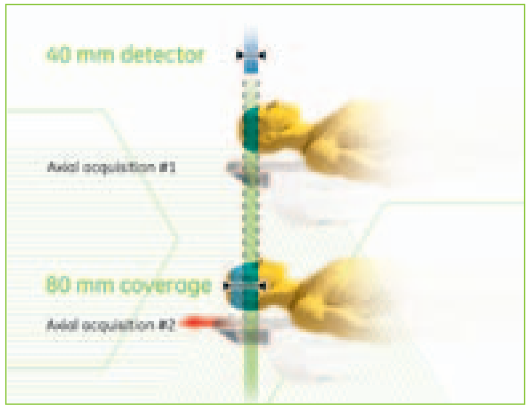


Figure 19.

VolumeShuttle: Double the coverage with less dose

VolumeShuttle helps make the most challenging neuro CT perfusion and angiographic studies possible. It doubles the acquisition coverage to 80 mm, with less dose. As a result, practitioners can perform studies such as 4D-CTA and CT perfusion in a single scan and with a single contrast injection. For Neuro imaging it ensures ample coverage to perform "whole territory perfusion" (from the basal ganglia to the top of the lateral ventricles).

VolumeShuttle uses two acquisitions to capture twice the coverage with less dose due to turning off the X-ray during table moves. This allows practitioners to perform expansive studies, such as 4D-CTA and CT perfusion, in a single scan with one contrast injection. Dynamic CT acquisition performed using VolumeShuttle produces datasets that can capture the kinetic behavior of contrast medium in the anatomy being imaged. These datasets can be viewed in a dynamic sense as a 3D volume over time. VolumeShuttle provides the ability for a bone-free visualization of the vasculature in a dynamic CT angiography exam.

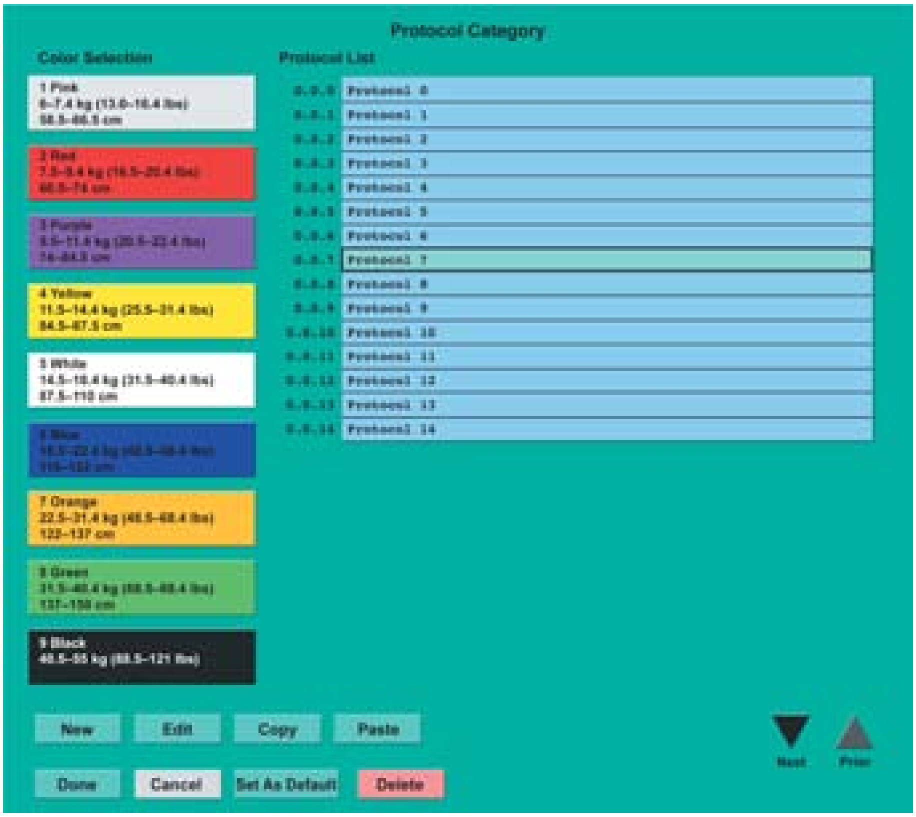


Figure 20.

Color Coding for Kids: Award-winning pediatric protocol selection tool

Winner of a National Heroes Award from the Emergency Medical Services for Children, Color Coding for Kids provides pediatric scan protocols based on the Broselow-Luten® Pediatric System. This Color Coding system is incorporated into the protocol selection on the operator's console and is designed to facilitate pediatric emergency care and reduce medical errors. For over 20 years, the Broselow-Luten system has been used in emergency departments (ED) to facilitate care and reduce medical errors. The system categorizes the pediatric patient into one of eight color zones based on the child's weight and size. With these color-coded categories, clinicians can determine a safe medication dose and utilize appropriately-sized equipment. Donald Frush, MD, Chief of Pediatric Radiology at Duke Children's Hospital and Health Center (CHC), developed the Broselow-Luten color-coding protocols for use with GE's scanners. In 2001, GE became the first CT manufacturer to introduce pre-loaded pediatric protocols based on the child's color code classification.

1. Sarabjeet Singh, MBBS, Mannudeep K. Kalra, MD el al, Dose Reduction and Compliance with Pediatric CT Protocols Adapted to Patient Size, Clinical Indication, and Number of Prior Studies, Radiology 2009.

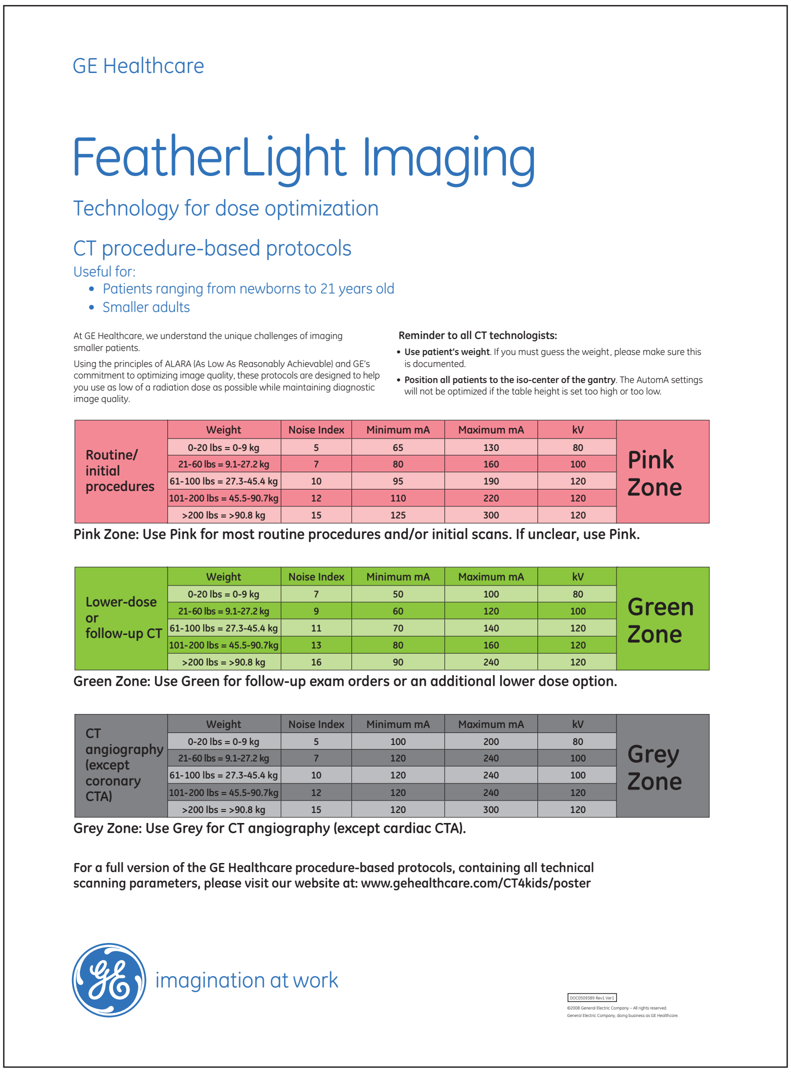
FeatherLight: Pediatric Procedure-Based Protocols for Dose Optimization

The FeatherLight Procedure-Based protocols, otherwise known as procedure-based protocols, were developed in conjunction with Massachusetts General Hospital in Boston, MA. A team of researchers, led by Dr. Mannudeep Kalra, studied 692 pediatric patients undergoing CT for various regions of interest over a 19-month period.

The purpose of the study was to assess compliance and resultant radiation dose reduction with new pediatric chest and abdominal computed tomographic (CT) protocols based on patient weight, clinical indication, number of prior CT studies, and automatic exposure control.

It was concluded that substantial dose reduction and high compliance can be obtained with pediatric CT protocols tailored to clinical indications, patient weight, and number of prior studies.[1]

All studies use Z-axis tracking with AutomA. Three color zones can help radiologists manage levels of radiation dose based on clinical need, index or follow-up CT. Within each zone, AutomA is used according to five weight zones.



GE Healthcare

FeatherLight Imaging

Technology for dose optimization

CT procedure-based protocols

Useful for:

- Patients ranging from newborns to 21 years old
- Smaller adults

At GE Healthcare, we understand the unique challenges of imaging smaller patients.

Using the principles of ALARA (As Low As Reasonably Achievable) and GE's commitment to optimizing image quality, these protocols are designed to help you use as low of a radiation dose as possible while maintaining diagnostic image quality.

Reminder to all CT technologists:

- **Use patient's weight.** If you must guess the weight, please make sure this is documented.
- **Position all patients to the iso-center of the gantry.** The AutomA settings will not be optimized if the table height is set too high or too low.

	Weight	Noise Index	Minimum mA	Maximum mA	kV	
Routine/ initial procedures	0-20 lbs = 0-9 kg	5	65	130	80	Pink Zone
	21-60 lbs = 9.1-27.2 kg	7	80	160	100	
	61-100 lbs = 27.3-45.4 kg	10	95	190	120	
	101-200 lbs = 45.5-90.7kg	12	110	220	120	
	>200 lbs = >90.8 kg	15	125	300	120	

Pink Zone: Use Pink for most routine procedures and/or initial scans. If unclear, use Pink.

	Weight	Noise Index	Minimum mA	Maximum mA	kV	
Lower-dose or follow-up CT	0-20 lbs = 0-9 kg	7	50	100	80	Green Zone
	21-60 lbs = 9.1-27.2 kg	9	60	120	100	
	61-100 lbs = 27.3-45.4 kg	11	70	140	120	
	101-200 lbs = 45.5-90.7kg	13	80	160	120	
	>200 lbs = >90.8 kg	16	90	240	120	

Green Zone: Use Green for follow-up exam orders or an additional lower dose option.

	Weight	Noise Index	Minimum mA	Maximum mA	kV	
CT angiography (except coronary CTA)	0-20 lbs = 0-9 kg	5	100	200	80	Grey Zone
	21-60 lbs = 9.1-27.2 kg	7	120	240	100	
	61-100 lbs = 27.3-45.4 kg	10	120	240	100	
	101-200 lbs = 45.5-90.7kg	12	120	240	120	
	>200 lbs = >90.8 kg	15	120	300	120	

Grey Zone: Use Grey for CT angiography (except cardiac CTA).

For a full version of the GE Healthcare procedure-based protocols, containing all technical scanning parameters, please visit our website at: www.gehealthcare.com/CT4kids/poster

imagination at work

Figure 21.

Figure 22.

Image quality to meet a clinical need is also taken into account, a zone with higher mA levels is used for more subtle lesions, whereas images taken for a calcified stone or bone segment are taken in a lower mA level.

For a full version of the GE Healthcare procedure-based protocols, containing all technical scanning parameters, please visit our website at: www.gehealthcare.com/CT4kids/poster.

Adventure Series: Child-friendly scanning environment to help reduce retakes

Pediatric imaging has long presented unique challenges for healthcare providers. Typically, as children enter the sterile, clinical environment of a traditional imaging room they may become anxious or dissolve into tears. As a result, clinicians may need to perform additional scans resulting in additional dose or use sedation to get young patients to successfully complete a scan procedure. Anchors Aweigh!, Figure 22, is one of the choices available to distract and entertain the child. In the CT Pirate Island Adventure the scanner is designed to look like a pirate ship and the child is engaged by looking around the room to find Adventure Series characters in an island setting.

Figure 23. The Deep Sea option explores the ocean floor in the CT Coral City Adventure.

Available support materials include hands-on coloring books explaining the procedure from a child's perspective, reward stickers for a job well-done, and field guides to assist staff in weaving the adventure into the scan procedures.

References

Iterative reconstruction algorithm for multi detector computed tomography decreases image noise and improves image quality," J. Budovec, et al, proceedings of SCBT-MR conference, April 2, 2008.

Noise and attenuation characteristics of ultra low-dose abdominal CT reconstructed with Model-Based Iterative Reconstruction: a prospective pilot study," S. Singh et al, proceedings of the RSNA meeting, December 3, 2009.

4

Strategies for CT Dose Reduction

In order to maximize potential benefits to your patients, a comprehensive dose reduction program should make use of several strategies.

Think optimal—do the optimal study with the optimal scanning technique with the optimal protection in place for your patients.

Do the optimal study (Eliminate avoidable examinations)

The lowest dose study is one that is not performed at all. In some cases, imaging may not be necessary, while in other cases the same diagnostic information may be obtained from imaging modalities that do not involve ionizing radiation (e.g., MRI and Sonography). Other examinations that are ordered with and without contrast may be performed with one acquisition or the needed diagnostic information obtained from a study with fewer phases; both scenarios reduce patient dose by avoiding a scan. Therefore, the first step in any low dose program should be to ensure that the CT examination study ordered is appropriate for obtaining the diagnostic information requested.

The American College of Radiology (ACR) advises that no imaging exam should be performed unless there is a clear medical benefit that outweighs any associated risk. It should be the responsibility of the radiologist and the imaging practice to assist the referring physician(s) in determining the appropriate and most effective imaging. Computerized automated decision support systems are commercially available and allow advice to be given to the referring physician as part of the ordering process. While most practices do not have access to this technology at present, there are several tools and processes that can be utilized to ensure the appropriateness of the exams performed.

Clinical Condition:	Acute abdominal pain and fever or suspected abdominal abscess		
Variant 1:	Postoperative patient with fever		
Radiologic Procedure	**Rating**	**Comments**	**RRL†**
CT abdomen and pelvis with contrast	8		●●●●
CT abdomen and pelvis without contrast	7		●●●●
US abdomen	6		0
MRI abdomen and pelvis without and with contrast	6	See statement regarding contrast in the text under "Anticipated Exceptions."	0
X-ray abdomen	5		●●●
MRI abdomen and pelvis without contrast	5		0
X-ray contrast enema	4		●●●
Ga-67 scan abdomen	4		●●●●
X-ray upper GI series with small bowel follow-through	3		●●●
Tc-99m or In-111 WBC scan abdomen and pelvis	3		●●●
Rating Scale: 1, 2, 3: Usually not appropriate; 4, 5, 6: May be appropriate; 7, 8, 9: Usually appropriate			

†Relative Radiation Level

These include:

- **ACR Appropriateness Criteria®**—These evidence-based guidelines compiled and maintained by the American College of Radiology can assist providers and radiologists in determining the most appropriate imaging or treatment decision for a specific clinical condition. They are available online at http://www.acr.org/ac.
- **Review of patient's prior imaging studies**—Helpful to determine what diagnostic information already exists. Repeat studies are one of the leading causes of "avoidable" imaging. Consider creating a process to allow outside studies to be officially reviewed and archived at your practice/institution in order to reduce the need for such repeat examinations.
- **Better communication among healthcare providers**—It's critical to have open lines of communication between radiologists and those who order CT exams. In certain cases, they may be uncertain about the need for a study or perhaps order a CT scan by default. Make it easy for your referring physicians and staff to speak to you.

Use optimal scanning techniques

Once the need for the CT exam has been established, the scan should be performed in an optimal way, minimizing the patient's dose while maintaining diagnostic image quality. All members of a practice should understand and abide by the ALARA principle, which states that imaging should be performed with dose levels that are As Low As Reasonably Achievable. The goal of imaging with the ALARA principle is to obtain diagnostic (not the prettiest) images using the minimum level of radiation to support the timely acquisition of diagnostic information and avoid subjecting the patient to additional imaging studies. Scanning techniques that should be optimized include:

Scanning parameters—Choosing the optimal scanning parameters including mAs, kV, pitch, collimation, and reconstruction type may significantly decrease dose to the patient. These parameters are discussed in the detail in the section "Fundamentals of Scanning Parameters and Radiation Dose" (Chapter 2). Make sure that the technologists verify the estimated dose BEFORE scanning.

Scan length—The best way to prevent unnecessary dose to any organ(s) is not to directly radiate. Make sure that the scan includes only the region of interest and does not extend farther than necessary. For example, during examinations of the chest do not scan through the entire abdomen.

Contiguous studies—Often patients have studies of contiguous body parts at the same time (e.g., chest and abdomen). However, optimal technique is often different for the different regions. Make sure to spend the time to prescribe the scan with optimal imaging techniques for each region imaged.

Reconstructions and reformats—In cases where specific reconstructions and reformats may be useful, make sure the scan is performed in a manner so that these can be done. For example, obtaining scans of the abdomen and pelvis in trauma patients in an optimal manner allows dedicated multiplanar reformats of the spine to be created, thereby eliminating the need for dedicated spine imaging.

Dose reduction technology—If your scanners are equipped with dedicated dose reduction technology, such as ASiR technology, make sure that it is being utilized appropriately for the specific diagnostic needs.

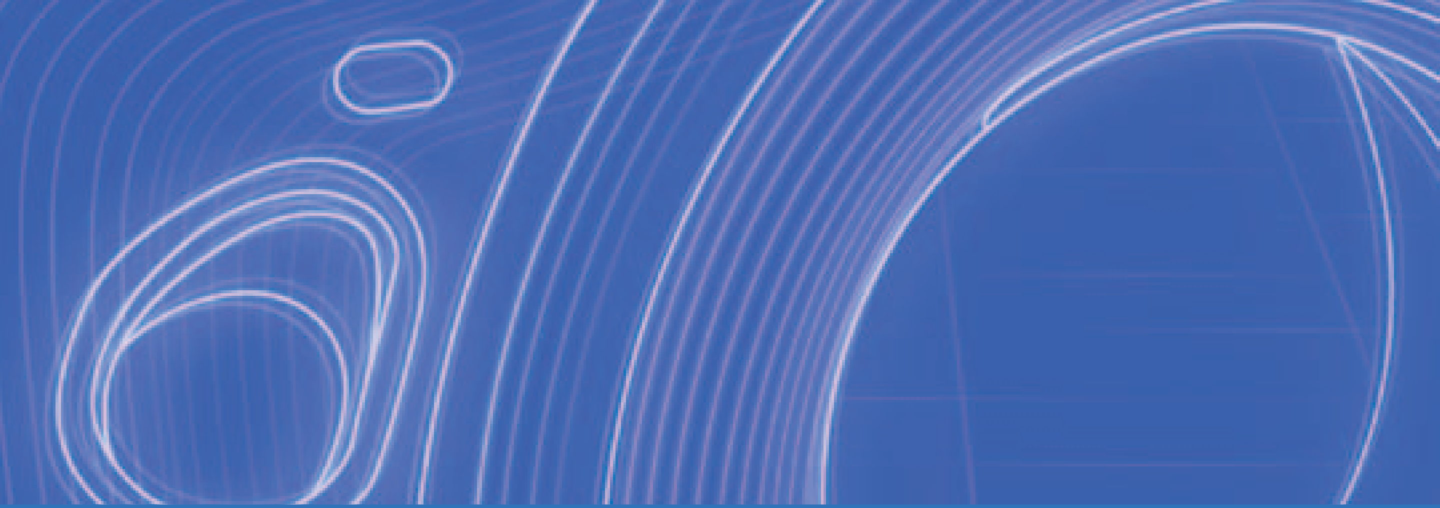
Provide optimal protection

There are several techniques that practices may employ to protect their patients. These include:

Shielding—It has recently been shown that direct shielding of sensitive organs may result in significant dose reduction to those organs. However, it is critical that such shielding be performed very carefully in order to avoid significant artifacts, noise and patient overdosing. This is especially important when using AutomA. A review of this debated technique has recently been published.[1]

Quality control/improvement—The best processes in the world will not be effective if there is not quality control. Make dose a regular topic in your quality reviews. Be sure to address in real time any dose alerts that may be generated by your dose monitoring process. Participating in registries such as the ACR Dose Index Registry may assist in determining accepted limits. Finally, pay attention to the advances that are currently being made in dose reduction. There is always the potential to improve.

1."Bismuth Shields for CT Dose Reduction: Do they Help or Hurt?", C. McCollough, et al., J. of the American College of Radiology, 8(12) 2011.



5

Establishing a Low-Dose CT Imaging Practice

A comprehensive low-dose program should be established in order to achieve measurable dose reduction goals.

A low-dose program is an organization-wide endeavour; key stakeholders and champions should be identified, and measurable dose reduction goals must be defined.

This section outlines the steps involved in creating a low-dose CT imaging program:

- Assessment—evaluating your current state and identifying gaps.
- Planning—determining what type of program you want and setting goals.
- Implementation—making the changes necessary to achieve your goals.
- Maintenance—monitoring performance and adherence to guidelines.

Assessment

The first step in establishing a low-dose, ALARA program is assessing what the current state of your CT practice is. Important questions to consider include:

1. What is the scope of the project? Is it department-wide? Hospital-wide? System-wide? Equipment-specific?

As many practices have a heterogeneous mix of CT scanners, it is important to know the capability of each scanner. Even when a scanner lacks the most recent dose reduction technologies, significant dose savings may still be achievable.

2. Who are the key stakeholders in the CT imaging process?

This will likely include technologists and radiologists, but others may be involved as well. For example, administrators will be interested in potential CT downtime as well as communication opportunities, and referring physicians will want the assurance that their patients will receive the right exam at the right dose for the diagnostic information being sought.

3. Who is responsible for the current process for implementing protocols? What is the current process?

There may be multiple people involved in protocol development, including radiologists (specialists and sub-specialists), physicists, and technologists. In Weill Cornell Imaging's experience, it is helpful to have one person "own" the protocols in each section, with the goal of gaining input and consensus from all stakeholders.

4. What, if any, guidelines are in place to help ordering physicians utilize CT imaging appropriately?

In Weill Cornell Imaging's experience, physicians are interested in ordering the right study for their patients. Since the most effective way to reduce unnecessary radiation dose is to avoid unnecessary studies, imaging appropriateness should be considered part of a low-dose program. Ordering physicians often consult our radiologists about what type of imaging study is most appropriate for their patients. With the increasing use of computerized ordering, automated decision-support systems are becoming more widely utilized.

5. How do you currently monitor CT dose?

At Weill Cornell Imaging we've created our own software program to automate the process of identifying dose metrics that fall outside of our norms. Commercial software is now available on the market. Data may also be manually reviewed by sampling CT studies to see whether dose levels are falling within your protocol guidelines. In any case, it is imperative that some method of collecting and reviewing data is implemented as part of a low-dose program.

6. What training procedures are in place to help staff understand system techniques, protocol set-up, and other operational parameters?

In many imaging practices there can be upwards of 15–30 radiologists and 20–50 technologists, so this process is extremely important. A standardized approach to user training, in combination with refresher training, is recommended.

7. What processes for quality improvement already exist in your practice and can they be leveraged as part of a low-dose program?

At Weill Cornell Imaging, we used our pre-existing Medical Event Reporting System (MERS) from GE Healthcare. This system provides the means for staff to report near-miss and adverse events, including those associated with CT dose. Such a system notifies all relevant parties of an event, leading to root cause analysis and process improvements to avoid future problems.

Table 1.

Data collection establishing a base for measuring changes										
Protocol	Region	Indication	Ax/He	kV	mA	Speed	Collimation	Pitch	$CTDI_{vol}$	DLP

Example of manual data collection to establish a base for measuring changes.

Planning

1. Identify the dose champion(s) for the practice

These should be individuals in the practice with real enthusiasm for CT dose reduction and quality improvement. If possible, identify at least one individual from the physician staff, technologist staff, and practice administration.

2. Identify the remainder of the dose reduction team

Select persons who are the most passionate about dose reduction on your staff. The team should consist of a radiologist, senior technologist, medical physicist and if possible, the CT vendor's application specialist. It is important that the members of this team are empowered by the practice to make any required changes that will be necessary. Having one of the leaders of the practice visibly involved in the project conveys the importance of the dose reduction effort.

3. Educate yourself on dose reduction

You have already begun to do so by reading this material. Even a basic knowledge of dose reduction may assist you in determining what is realistic for your practice. It is likely your CT vendor has an array of classes available on the basics of CT dose as well as specific, dose-related features on their systems, and they will be able to tailor the training to meet your needs. **ImageGently.org**, **ImageWisely.org**, **IAEA.org**, and **Radiologyinfo.org** offer information and courses.

4. Determine a budget for this process

Some dose reduction strategies (e.g., buying new CT scanners) may be expensive and others may come at virtually no cost. Knowing what your practice can afford will help direct your efforts.

5. Engage your vendors

GE and nearly all CT vendors have resources that may assist you in implementing a low-dose program.

6. Determine a timeline

This step will be highly dependent on any new equipment that you may be purchasing as part of your low dose efforts. However, optimizing current protocols and implementing CT dose data collection are activities that may be initiated at any time.

At the same time, consider staging the implementation. Not all of your scanners are the same, and you may need to focus on some before others.

6

Protocol Implementation

Optimized protocols are essential in any dose reduction program.

It does not matter how much sophisticated dose reduction hardware or software is in place if the protocols do not fully utilize them. While the process of optimizing protocols takes thought and effort, it is time well-spent.

At Weill Cornell Imaging, we spent 40–50 hours going through all of our protocols on all of our scanners. We felt it was important to eliminate unnecessary protocols, and we were able to reduce our total number of protocols significantly from over 130 to just over 70. Having fewer protocols has resulted in more consistency in imaging and a decrease in the effort that has been required to maintain our protocols.

Form a team

Select persons who are the most passionate about dose reduction on your staff. The team should consist of a radiologist, senior technologist, medical physicist and if possible, your CT vendor's application specialist. It is important that the members of this team are empowered by the practice to make any necessary changes. Having one of the leaders of the practice visibly involved in the project conveys the importance of the dose reduction effort.

Obtain your practice's baseline data

Baseline dose data is valuable information for a practice going forward, to be able to show positive effect. You don't know what has improved unless you measure it. It is also important to establish a baseline of your current level of image quality that your readers are comfortable and confident with. Having data is crucial in being able to justify the expense of purchasing new dose-lowering technology and is a powerful tool for communicating your accomplishments.

What data should be collected?

Data collection should be done prior to implementation of the dose reduction hardware/protocols.

1. Collect data looking for variances within the same "standard" protocols. Some areas to look for variations of median dose are between study types, within a study type, across institutions, between scanners in the same institution, amongst technologists, radiologists, and the time of day a study is performed. Figure 1 and 2, on the right, are generic examples of what could be found and demonstrate methods of how to display those variances.
2. Next pull data on the protocol parameters under current use, consider comparing protocols between scanners in the same institution and with sister facilities. Choose some of the most commonly performed examinations ordered.

- At Weill Cornell Imaging, we chose:
  - CT Abdomen/Pelvis
  - CTA for evaluation of pulmonary embolism
  - CT Head, non-contrast
  - CT Chest, non-contrast
- Create a form to log the data, use DLP and $CTDI_{vol}$ from the dose report DLP helps you optimize scan area.
- Collect data from 20–30 patients with existing protocols, and calculate the range and the mean DLP and $CTDI_{vol}$ for each protocol.

Dose Variation by Protocol

$CTDI_{vol}$ (mGy)

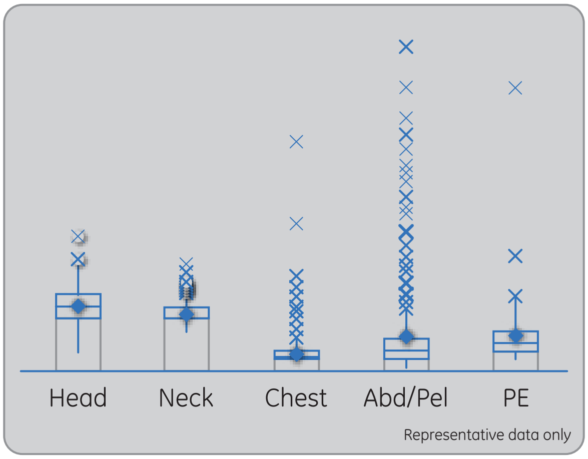


Figure 1.

Dose Variation by Operator

DLP for routine brain exam

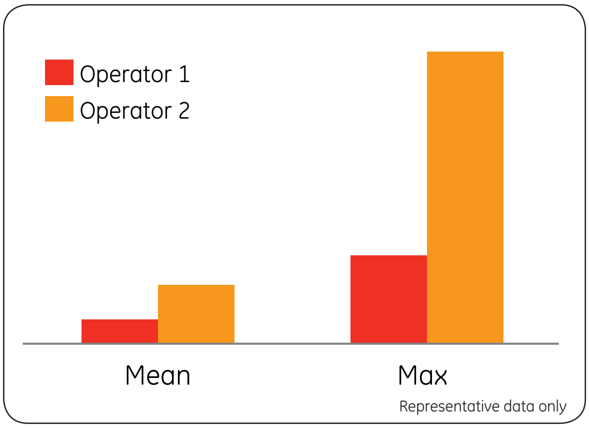


Figure 2.

Protocol	Patient 1–20	DLP	$CTDI_{vol}$	Range	Range	Mean	Mean	Diagnostic Y or N
				DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	
Abd/Pelvis								
Chest CT								
Head CT								
CTA (PE)								

Table 1. Example for collection of DLP and $CTDI_{vol}$ for specific protocols.

Implement the dose reduction changes

- Decide what changes are needed to reduce dose. Take a holistic approach so you don't lose potential gains. Once you have the data and protocols, look at every parameter: kV selection, slice thickness, pitch, scan area, max and min mA, whether AutomA and SmartmA are used. Application specialists from your vendor may be very helpful in working through the implementation of possible dose reducing changes to the protocols.
- Review every protocol on every scanner. Make sure that outdated protocols are removed. If an outdated protocol is left on the scanner, someone will use it. At Weill Cornell Imaging, we document that each protocol on every scanner has been reviewed.
- Implement and monitor dose reducing changes in real time. If possible, an applications specialist, technologist, and radiologist should be present at the scanner while adjustments are being made. If you have radiologists with subspecialty training in specific types of imaging, it is beneficial to include them in the protocol review process as well.
- Monitor the results for both dose and image quality.
- Continue to implement the dose reducing changes until you have lowered the dose to as low as possible while still obtaining adequate diagnostic quality images. (ALARA principle)
- Continue until all protocols have been reviewed and optimized.
- Restrict the ability to change the protocols. At Weill Cornell Imaging we have restricted access to the CT supervisors. All changes to protocols must be reviewed and approved before they are implemented on the scanner.
- It is important to repeat this process on all CT scanners in the practice.

Educate your practice

It is important that everyone in the practice is educated about your dose reduction program. This includes the technologists who will perform the CT examinations, the radiologists who will be protocoling and interpreting the studies, as well as the support staff that will be interacting with patients. Patients are increasingly concerned with dose, and every member of your practice should be aware of your efforts.

At Weill Cornell Imaging we implemented ASiR (the GE iterative reconstruction package) as a dose reduction tool on one of our new scanners. While several of the physicians and technologists received initial applications training we did not follow through with all members of our practice. When we later reviewed the state of our efforts it became clear that we were not making full use of our new capabilities. Now, we formally educate our practice on any new technologies or capabilities. Education for all staff members goes a long way in making full use of your technology.

Match the clinical need

It is important that the protocols are created to provide the necessary diagnostic information and not to produce the greatest number of highest resolution images in each case.

- **Refine protocols to the clinical question.** For example, make sure that scans are only performed in multiple phases of contrast enhancement when absolutely necessary. The typical CT of the abdomen and pelvis does not need to have images in both the arterial and portal venous phase of contrast.
- **Review CT examination orders.** If your radiology practice does not review orders before the patient is scanned, consider adding this step to the workflow. At Weill Cornell Imaging, the exam ordered is modified in close to 10% of cases, commonly resulting in significantly less dose to our patients or at times in the use of a different modality.
- **Scan less area if possible.** Pay attention to the area imaged when reviewing cases. Provide feedback to the technologist when too much of the patient has been scanned.
- **Do appropriate studies.** The most effective way to reduce dose for a CT examination is to not perform it at all. Most CT examinations that are ordered are necessary and indicated. Some are not. At Weill Cornell Imaging, ensuring appropriate imaging is considered an important service that we provide our patients, and we have implemented decision support at the time of order to ensure that it happens.

Exams ordered are modified in close to 10% of cases, which commonly results in significantly less dose to our patients.

Collect your dose optimized data

Collect the DLP and CTDI information for the same types of examinations and same number of patients. If you have completed the above processes then the results should be obvious.

At Weill Cornell Imaging, we have used this improvement data as a communication tool. Patients, referring physicians, and hospital administrators easily understand dose reduction when this information is presented in the form of percentages. For example, our initial efforts to reduce dose resulted in 44% dose reduction for CTA for pulmonary embolus and a 39% reduction for abdominal and pelvic CT.

Protocol	Pre (DLP)	Post (DLP)	% Change
Chest CT	319	214	33.6
Chest CT (PE)	1152	650	43.6
Abdominal Pain	1158	710	38.7

Figure 3.

Body imaging is one of the biggest challenges in implementing a dose reduction program as a result of the varied organs and pathology that are frequently imaged. As the torso is typically the thickest part of a patient, body imaging often requires the highest doses to maintain diagnostic quality. Imaging of specific organs and organ systems may often require multiple phases of imaging, further increasing dose.

Body Imaging Low-Dose CT protocols

Basic principles

Use multiphase imaging only when necessary. If multiple phases are necessary restrict the region of scanning for the organ/lesion(s) that are being evaluated. Consider varying your technique depending on the phase.

One scan does not fit all. Consider prescribing separate acquisitions for different body regions even when imaged at the same time. For example, optimal technique through the chest is different than optimal technique through the abdomen. If you do obtain in one acquisition, consider the use of AutomA to adjust the technique based on the attenuation of the body region being scanned to obtain a desired noise level in the images. Automatic exposure controls such as this can help optimize the dose to different body regions with the goal of keeping image noise consistent across areas of different attenuation.

Evaluate if the use of shielding is appropriate: It has recently been shown that direct shielding of sensitive organs may result in significant dose reduction to those organs. However, it is critical that such shielding be performed very carefully in order to avoid significant artifacts, noise and patient overdosing. This is especially important when using AutomA. A review of this debated technique has recently been published.[1]

Don't be impatient. If you need oral contrast then wait an appropriate amount of time for the contrast to go through the bowel. Patients and referring physicians (especially in the acute setting) may want the scan done as soon as possible. However, if you scan too early and need to repeat once the oral contrast has progressed the dose is increased.

1. "Bismuth Shields for CT Dose Reduction: Do they Help or Hurt?", C. McCollough, et al., J. of the American College of Radiology, 8(12) 2011.

Consider targeted/low dose examinations for follow-up examinations: Many follow-up examinations may be performed at significantly reduced dose as the diagnostic question is only to evaluate for changes. An example of this is follow-up of lung nodules. If you are interested in following up a specific organ or process (e.g. a collection) consider targeting the follow-up examination to the region of interest instead of obtaining a complete follow-up exam.

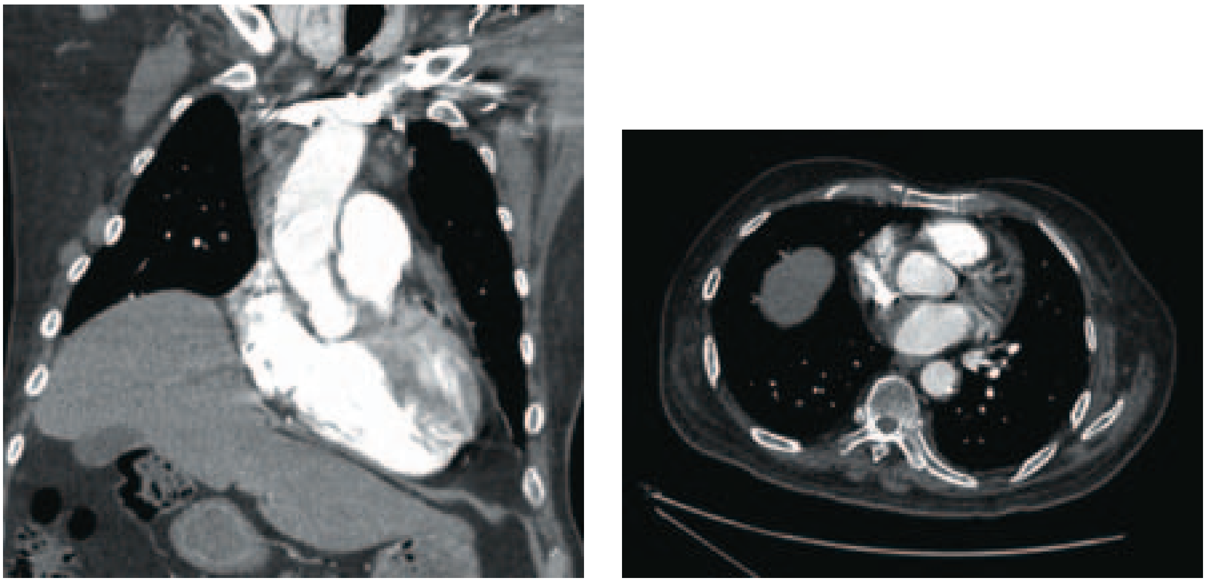


Figure 4. PE1
DLP 391.7 (including legs)
DLP 206.74 (chest only)
AutomA
kV 120
Slice thickness 1.25
ASiR 40%

Cardiac imaging has received much attention related to the issue of dose. There are several techniques that have been demonstrated to reduce the radiation dose associated with cardiac CT imaging. Selection of dose reduction strategies in cardiac CT imaging should consider the patient's body habitus, heart rate and heart rate variability, and the clinical data that is being requested.

Cardiac/Coronary Imaging

Gating techniques

The most potent method of dose reduction is the use of prospective ECG triggering. This method should be considered in patients with a regular and well-controlled heart rate. Rate control medications such as beta-blockers are generally administered to achieve a heart rate <65 beats/minute, although higher thresholds may be considered on some specific platforms.

Prospective ECG triggering results in a large decrease in radiation dose, although this provides fewer phases for reconstruction. As this technique is typically used to acquire images only during mid-diastole, data on end-diastolic sizes and ventricular function is not available when this is used.

When retrospective ECG gating is used, dose modulation should generally be utilized. This technique reduces the tube current outside of mid-diastole, which reduces radiation dose. As images are acquired during the entire cardiac cycle, ventricular function and end-diastolic volumes may be determined.

When prospective ECG triggering is used, some scanner platforms permit manual setting of the time that the tube current is on in addition to a minimum required duration ("padding"). By shortening this time, the radiation dose is lowered, but this may result in only a single phase available for analysis. This method should only be considered in patients with a well-controlled and regular heart rate.

Coverage

Radiation dose is linearly related to Z-axis coverage. In general, Z-axis coverage for cardiac imaging should be limited to a superior margin 1 cm below the carina to just below the inferior margin of the heart. When a coronary artery calcium score is performed, this can be used to better estimate the required Z-axis coverage. Coverage should be expanded if there is a need for imaging of bypass grafts, the aorta, or lung fields.

Tube Voltage

As tube voltage has an exponential relationship to radiation dose, a reduced voltage can result in a significant decrease in radiation dose. The use of 120 kVp should be standard in obese individuals. In non-obese individuals, 100 kVp should be considered as a means to reduce dose. As lower tube voltage is closer to the k-edge of iodine, a lower tube voltage will typically result in improved signal and contrast, although noise will increase as well.

Tube Current

Radiation dose is linearly related to tube current. Tube current should be selected based on patient body habitus, with lower tube current utilized in patients with smaller body habitus. Many sites utilize protocols that assign current based on body-mass index, but as current settings may vary substantially by vendor and platform, manufacturer reference protocols and site-specific procedures should be used as a guide.

Iterative Reconstruction

Iterative reconstruction reduces image noise, which may permit a reduction in tube current with no loss in image noise as compared to reconstructions using filtered back projection. This should be considered as part of a standard protocol depending on site-specific practice. It may be useful to reduce the tube current when iterative reconstruction is used.

Non-coronary cardiac imaging (e.g. to assess pulmonary veins or aortic valve) may permit the use of additional dose reduction strategies. Depending on the imaging requested, Z-axis coverage may be reduced for some indications. Further, the imaging of structures larger than coronary arteries may allow the use of lower tube current and voltage than would be needed for coronary imaging. Slice thickness may be increased if high spatial resolution is not needed. Finally, if multiple cardiac phases are not needed, prospective ECG triggering with no "padding" may be selected to reduce radiation dose.

Figure 5.

Musculoskeletal CT studies present challenges in the performance of low-dose CT due to a number of factors including: the need for high-resolution/low-noise images to allow multiplanar/3D reformats, frequent presence of metallic hardware, and difficulty in positioning patients with musculoskeletal complaints/injuries. However, by adhering to basic principles, high-quality/low-dose imaging can be performed.

Musculoskeletal low-dose CT protocols

Basic Principles

Keep small joints away from the body. If you position a wrist or an elbow on or next to the torso, the body will absorb most of the X-ray dose, resulting in unwanted radiation to the abdominal organs and decreased quality of the images of the joint. The noisy images make the multiplanar and 3D images, which are so important to the referring orthopedists, suboptimal.

Restrict the imaging area to the anatomy of interest. Do not scan an entire limb to evaluate a specific region. If possible, have a radiologist review the images in trauma cases as fractures may often extend farther than they appear on radiographs.

Position patients as comfortably as possible to reduce potential for motion artifact. Having to repeat a scan due to patient movement effectively doubles the dose.

Limit the number of contrast series. In contrast-enhanced exams, limit the number of series as much as possible. At Weill Cornell Imaging, we find that pre-contrast series can be eliminated in most cases, helping to reduce patient dosage.

Scan once, reformat many times. Once bone data is acquired, it can be reformatted many ways, often precluding the need for additional scans. If there has been recent imaging that included the musculoskeletal structures in question, consider reformatting that data instead of re-imaging the patient.

Use other means to reduce metal artifact. To reduce metal artifact in images, many radiologists and technologists default to increasing dose. There are alternative dose-saving strategies that can lessen artifact, including:

- **Iterative reconstruction.**
- **Scan thin, display thick.** Scanning in thin sections and reformatting into thicker slices help to cancel some of the noise, resulting in better looking images.
- **Minimize cross-sectional area of the hardware.** The shorter the length of the hardware in the direction of the X-ray beam, the less artifact.

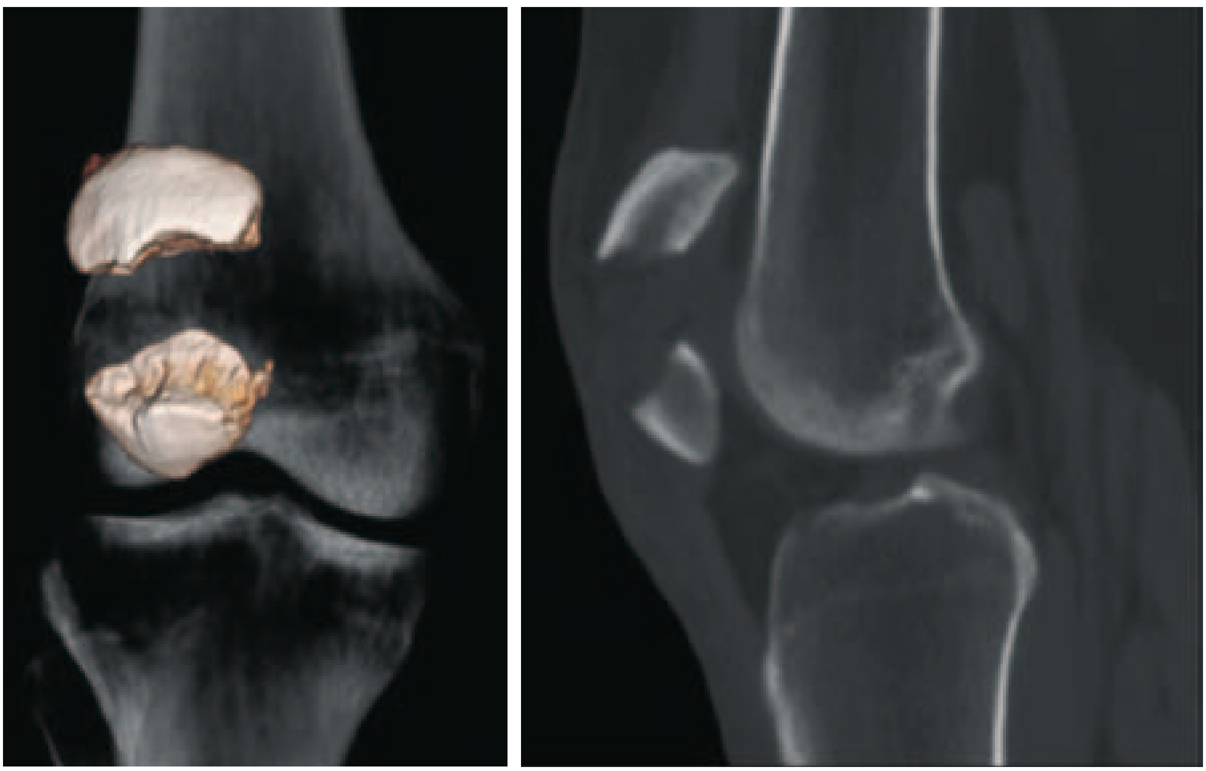


Figure 6. DLP 186.78
AutomA
kV 120
Slice thickness 2.5
ASiR 40%

There are many neuroimaging CT applications that easily tolerate reductions in dose, as supported by published results, and other areas that need ongoing investigation and experimentation to determine the balance between dose reduction and diagnostic efficacy.

Neuro low-dose CT protocols

Basic principles

Be organ-specific. Restrict the imaging area as much as possible to the anatomy of interest. Do not scan the neck as part of a head examination.

Image once. It sounds simple, but making patients as comfortable as possible, particularly in spine studies, can reduce potential for motion artifact.

Scan thin and reconstruct thick. For all of neuroimaging the acquisition slice thickness should be as small as possible. Once acquired, data can be reformatted many ways, often precluding the need for additional scans. Make sure to determine the acceptable noise in an image from the slice thickness that you are going to review, not the thinnest sections you acquire.

Utilize reconstruction techniques

Understand the goals of the exam, matching the reconstruction thickness to what you need to assess. Reconstruct the same data set at different slice thicknesses to address different needs.

This will eliminate the need to rescan the patient, since you have the necessary data in the system to obtain the information you need via reconstructions. Keep the data for a reasonable amount of time, especially for trauma patients.

Examples:

- **Trauma patient**—A trauma patient with a head CT acquired at 0.625 mm. Axial slice data can be reconstructed at 0.625 mm with a bone algorithm to produce beautiful bone images. This avoids having to bring the patient back for a temporal bone CT to rule out facial fracture.
- **Lumbar spine CT**—If the goal of a lumbar spine CT is to assess both bony anatomy and soft tissue disc material, reconstruct with a 0.625 bone algorithm to look at bone detail and reconstruct at a 2.5-mm-thick slice with a soft tissue algorithm to look at disc disease.
- **Routine heads**—Consider reconstructing posterior fossa at 5.0 mm for a smoother image.

Stroke evaluation

Acute strokes get a CT, CTA, and a CT perfusion, which require more dose. But for most patients, an acute stroke is a one-time occurrence. Making the diagnosis quickly and getting the patient into effective therapy overrides most dose concerns of doing multiple studies. But evaluate to be sure each study uses the optimized dose.

- Make sure stroke protocols are established, using as low a technique as possible.
- Lower kV to the 80 kV range for CT perfusion. The iodine will provide the contrast that is necessary.
- ASiR along with acquisition techniques such as VolumeShuttle may aid in the reduction of dose.

Routine heads

Positioning is important. Significantly reduce dose to the eyes[1] by angling the gantry (axial scans) and/or head to the orbital-medial line so the eyes are outside the scan plane. In our practice, we try to angle CT and MR head studies so they look the same.

Trauma heads

Current literature suggests the value of looking at coronal data in trauma settings. Do not rescan the patient but create reformats. According to trauma literature[2, 3] evaluation of subdurals, epidurals, and traumatic subarachnoid hemorrhage may be improved with multi-planar imaging.

Sinus CT

In a focused organ-specific CT study to rule out sinus disease, low-dose techniques are appropriate. Restrict technique to lower mAs. Diagnostic scans may be obtained with the mAs as low as 50 mAs. Post-process the data with thicker images to acquire soft tissue information. Make it clear in the diagnostic report that you are conducting a limited exam to rule out sinus disease and not attempting to define a discrete brain tumor.

Pediatric heads for hydrocephalus and shunt evaluation

Children who come in every 2–4 months for a shunt follow-up or to evaluate a headache can benefit from dose reduction strategies. If MR is not applicable or feasible for hydrocephalus evaluation or shunt follow-up, a limited 3–4 slice head CT exam should be considered. For follow-up ventricular dilatation, at Weill Cornell Imaging we use 2.5 s, with one scan through the middle of the fourth ventricle, one through the inferior third ventricle temporal horns, one mid-third ventricle, and one at the level of the lateral ventricles. This type of directed exam is very low dose.

1. Huda W. Effective Doses in Radiology and Diagnostic Nuclear Medicine: A Catalog. Radiology, 256 (254-263), (July 2008).
2. Zacharia TT, Nguyen DT (2009) Subtle pathology detection with multidetector row coronal and sagittal CT reformations in acute head trauma. Emerg Radiol 17:97–102.
3. Wei SC, Ulmer S, Lev MH, Pomerantz SR, Gonzalez RG, Henson JW (2010) Value of coronal reformations in the CT evaluation of acute head trauma. AJNR Am J Neuroradiol 31:334–339.

Spine CT

The majority of outpatient spine imaging is for degenerative spine disease, to evaluate disc herniation, osteophytes and the like. Although insurance companies are now starting to pay for lumbar spine MRs, most still prefer lower-cost CT, especially for patients who have not had prior surgery.

Radiologist and clinician need to consult on spine studies. You are going to have to use more technique for an orthopedic surgeon who wants to resolve the disc well than for one who simply wants to make sure there isn't any significant bony stenosis.

- Scan thin and reconstruct at a thickness that you feel is appropriate for the anatomy.
- Position carefully when imaging soft tissue necks and spines (cervical, thoracic, and lumbar). Patients with back pain are uncomfortable, and they move, creating the need for rescans. Putting a bolster under the knees, using distraction devices, and other techniques can pay huge dividends in avoiding rescans.
- For cervical scans distract a patient's shoulders by pulling them down with a device or even a sheet they can pull on. This helps immensely and can make a patient more comfortable because it relieves pressure. For soft tissue necks, it can show down to T1-T2 without shoulder artifact, and this keeps your dose lower as well because there is less to penetrate.

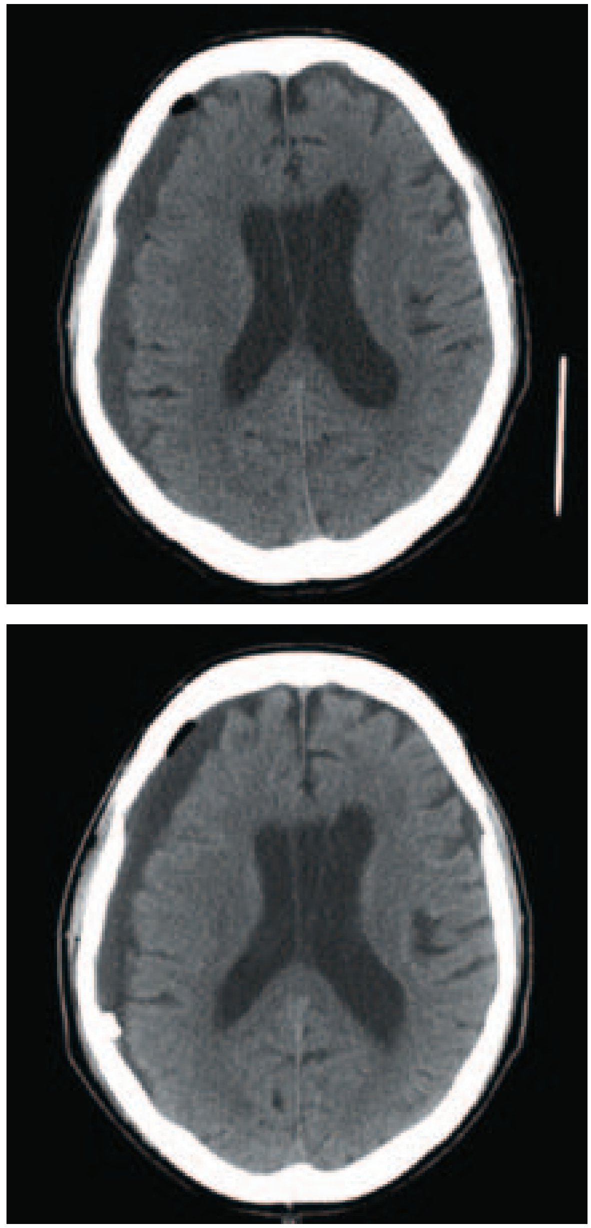


Figure 7. The head CT is of a patient that had the initial scan without ASiR and had a 30% dose savings using the ASiR package on follow-up.

Radiation exposure is a concern for patients of all ages, but especially so in children. Of the approximately 81 million CT examinations performed in the U.S. each year, approximately 9–11%, or 7.5 million, are pediatric scans. This has grown from 2.7 million, an almost three-fold increase in scans since 2003.[1] From 1995 to 2008, the number of emergency department visits that included a pediatric CT increased five-fold.[2] Minimizing radiation dose in pediatric scans is paramount due to children's higher sensitivity to radiation and lifetime potential for cumulative dose.[3] There are a number of principles that can be followed to minimize the amount of radiation used in pediatric studies.

Pediatric Imaging

Basic Principles

As a core recommendation, Weill Cornell Imaging at NewYork-Presbyterian suggests that imaging practices follow the guidelines established by the Image Gently™ campaign of the Alliance for Radiation Safety in Pediatric Imaging to ensure appropriate radiation dose levels for children. Those guidelines—"Ten Steps You Can Take to Optimize Image Quality and Lower CT Dose for Pediatric Patient"—can be found online at **http://www.ajronline.org/cgi/content/full/194/4/868.** Additional Image Gently CT-related resources can be found at **http://pedrad.org/associations/5364/ig/index.cfm?page=369.**

Specific principles that we recommend:

- **Perform only necessary CT exams.** Determine (A) if an ordered CT is justified clinically and (B) if CT is the appropriate procedure or whether an alternative imaging that does not use ionizing radiation would be as good or better. As children are typically smaller than adults ultrasound may be effective in obtaining the diagnosis in cases where it would typically not be used in the adult population. For example, other imaging types may be more appropriate when evaluating for gallstones, hematuria, or appendicitis in some children.
- **Scan only the organ or anatomical region of interest.** Scan coverage should be limited to the region of interest to avoid unnecessary exposure.

1. IMV CT Market Outlook Report, March 2011.
2. Larson DB. Rising Use of CT in Child Visits to the Emergency Department in the United States, 1995–2008. Radiology. http://www.rsna.org/media/pressreleases/pr_target.cfm?ID=540.
3. Huda, An approach for the estimation of effective radiation dose at ct in pediatric patients – radiology 1997.

- **Minimize use of multiphase imaging.** Scan only one series if possible. Multiphase imaging may increase the dose without adding diagnostic information to the study. Eliminate pre-contrast images whenever possible. If multi-phase studies are needed, use lower dose techniques for the non-contrast series compared to the contrast series and limit the scan only to the organ or anatomical region indicated.
- **Properly center patients in the gantry.** It is easier to position a child off center than an adult. Proper positioning enables optimizing the dose reduction benefit of built-in filters and automatic exposure control techniques.
- **Consider increasing pitch**
  Increasing pitch (while holding other parameters constant) will decrease the amount of radiation needed to cover the region indicated, while usually maintaining the diagnostic quality of the scan. Increasing pitch from 1.0 to 1.375:1 can decrease dose by a factor of about 27%.
- **Use small SFOV filters**
  The smallest SFOV should be used whenever possible depending on the exam and size of the patient. Matching the appropriate SFOV bowtie filter to the size of the patient will ensure dose is delivered where it is needed to sufficiently generate the image, and filtered where not needed.
- **Optimize protocol settings based on child's weight.**
  In pediatric imaging, one size does not fit all. We use the GE Healthcare Color Coding for Kids system, which helps users select the correct pediatric CT protocol based on the patient's height and weight. This allows for a more optimal selection of scan parameters such as mA and kV to match the patient's size. The system divides the protocols into nine color zones based on height and weight, and has incrementally increased scan techniques as the patient's size increases. Once the anatomical area is selected, rainbow bars containing the Color Coding for Kids weight-based protocol selections appear on the console screen. The user selects the color category based on the size of the patient, or verifies that the correct color has been selected if a weight was entered.

Whether you use a color-coded system or not, make sure that the following parameters are optimized as part of your protocols.

  - **Lower mA settings** when possible. High-resolution images with their attendant higher dose levels may be unnecessary for many types of studies.
  - **Lower kV if possible.** Consider decreasing the kilovoltage to 80 or 100 kVp for smaller patients.

- **Consider using in-plane bismuth shields.** Recent studies have shown dose reductions to sensitive organs, such as breast tissue in females, the thyroid, and eyes without significantly affecting image quality. If used with AutomA, they should be put in place after the scout scans are acquired to reduce technique overcompensation. Using shielding also has the added benefit of reassuring concerned parents.
- **Use adequate sedation if necessary.** Repeating a series or an examination due to patient motion may double the radiation dose and can be avoided with proper sedation.
- **Use pediatric positioning accessories.** If needed, papoose boards and neonatal immobilizers may be useful with certain patients. These accessories are sometimes helpful in both securing and keeping the patient still, resulting in fewer repeat exams and less dose due to patient motion.
- **Create a child-friendly environment.** Pictures of animals on the wall or ceiling, stuffed animals, and games are all effective ways to help pediatric or small patients feel less scared. Depending on their age, explain the procedure so they know what to expect when they enter the scan room. This will aid in patient cooperation and potentially fewer repeat studies and less dose due to patient motion.

CT chest in a 7-year-old with congenital heart disease. Very low dose and diagnostic quality images. Emphasizes the point that this can be done as well as using low kV for children and when you are interested in what the contrast shows.

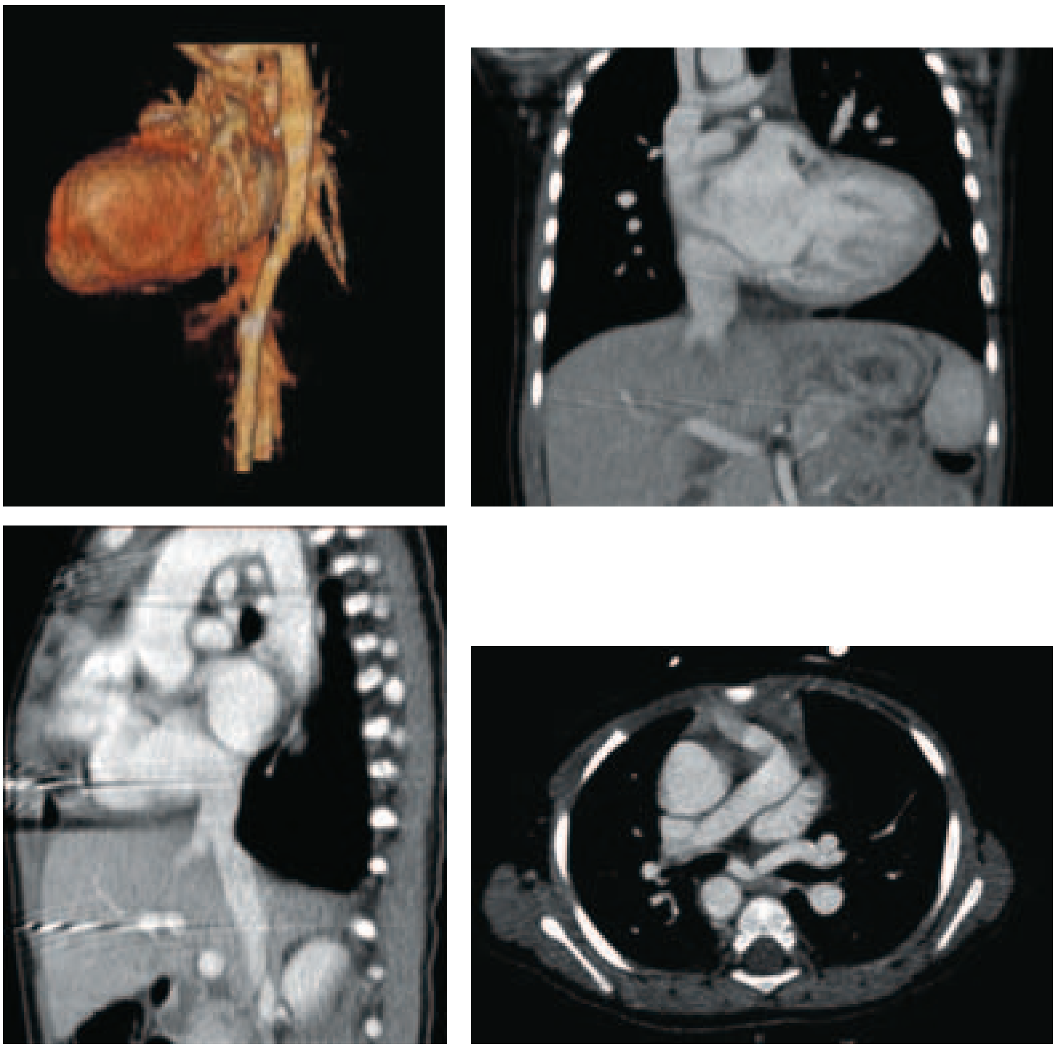


Figure 8. kVp 80
AutomA
2 mm slice thickness
DLP 63.84

Non-invasive vascular CT imaging continues to be increasingly utilized because it allows for the evaluation of vascular disease without an invasive procedure. This is possible due to the high spatial and temporal resolution of modern CT scanners. However, as vascular studies are frequently performed in more than one phase of contrast and in order to produce high-quality multiplanar reformats, careful attention should be given to dose.

Vascular Imaging low-dose CT protocols

Basic Principles

Use multiphase imaging only when necessary. Especially in younger patients, where calcified plaque is not a confounding factor, consider imaging in a single phase of contrast. If pre-contrast images are necessary then use a low dose technique to obtain. One does not need the highest quality images available to assess for calcification.

Consider using dual energy acquisition. If dual energy acquisition is available at your site, consider implementing to obtain a "virtual non-contrast like" series. This may allow you to obtain the necessary diagnostic information without repeat scanning and radiation for a dedicated non-contrast series.

Perfect your timing technique. The timing of your image acquisition relative to your bolus of contrast is critical in vascular imaging. Image too soon, and you will likely not be able to evaluate the vessels in question. Image too late, and there may be venous contamination. Consider using an automated technique (such as GE SmartPrep) to aid in optimizing your bolus/scan timing.

Think thick. While you may acquire very thin sections to allow for high-quality multiplanar and 3D images, remember that the images that should be used to set the acceptable noise level are the thicker ones that you review. Low noise thin slices can significantly increase dose and are often unnecessary.

Consider alternate modalities. This is especially true in vascular imaging where both ultrasound and MRI offer alternatives for vascular imaging without ionizing radiation.

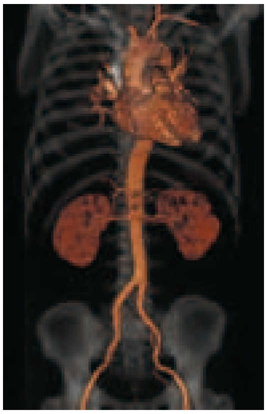


Figure 9.

7

Maintenance

Sustaining your low-dose CT imaging program over time requires monitoring both in real time and at scheduled intervals.

Periodic monitoring of CT protocols ensures that radiation dosage levels and image quality remain within the parameters you have established—or, just as importantly, can be improved based on new information and/or technology advances. Real-time monitoring is an important patient care tool ensuring that dose remains with expected limits.

Maintaining Your Low-Dose Program

Monitoring should be done by members of the team including radiologists, technologists, and physicists. Components of effective maintenance include:

- **Set up an ongoing process to collect and monitor the data.** This can be done in a variety of ways including the following:
  - **Automated Data Capture:** Currently there are several products on the market that allow automatic capture of DLP information for individual studies from both new and older scanners.
  - **Reporting and Mining:** Many practices have decided to record the DLP in the patient's imaging report. When done consistently, this data can be mined and compiled.
  - **Manual Collection:** DLP information can be manually recorded and compiled.

Whatever method is used to collect the data, it must be reviewed. While there are no well-defined metrics or metrics to use at the present time, Weill Cornell Imaging presents the data as rolling averages, and we look for outliers or trends to make sure the DLP is not drifting.

An advantage of automated systems is that they can be configured to send automated notifications when a study results in a greater-than-expected DLP for the protocol performed. At Weill Cornell Imaging, an automated e-mail is generated and sent to designated persons. While in our experience this is almost always caused by a large patient, we feel that this is an important tool.

The following are examples of the quality control charts that are produced by our dose monitoring software. These charts are reviewed as part of the monthly quality assurance program. All outliers (based on review of the chart) are investigated to determine the reason for the higher dose. Typically the DLP is high due to a large sized patient or on occasion due to the fact that a series needed to be repeated. The effect of the size of the patient is greatest when imaging the abdomen and pelvis accounting for the wider variation in the reported DLP values. This type of review confirms that there have been no changes to protocols or other correctable factors that contributed to the higher dose.

- **Periodically review and, if necessary, modify CT protocols** to maintain appropriate image quality and radiation dose. This is particularly important following any changes or upgrades to system software or hardware. As with the implementation of new software or hardware make sure to delete any old or unused protocols as they may lead to errors and create additional work during subsequent reviews.

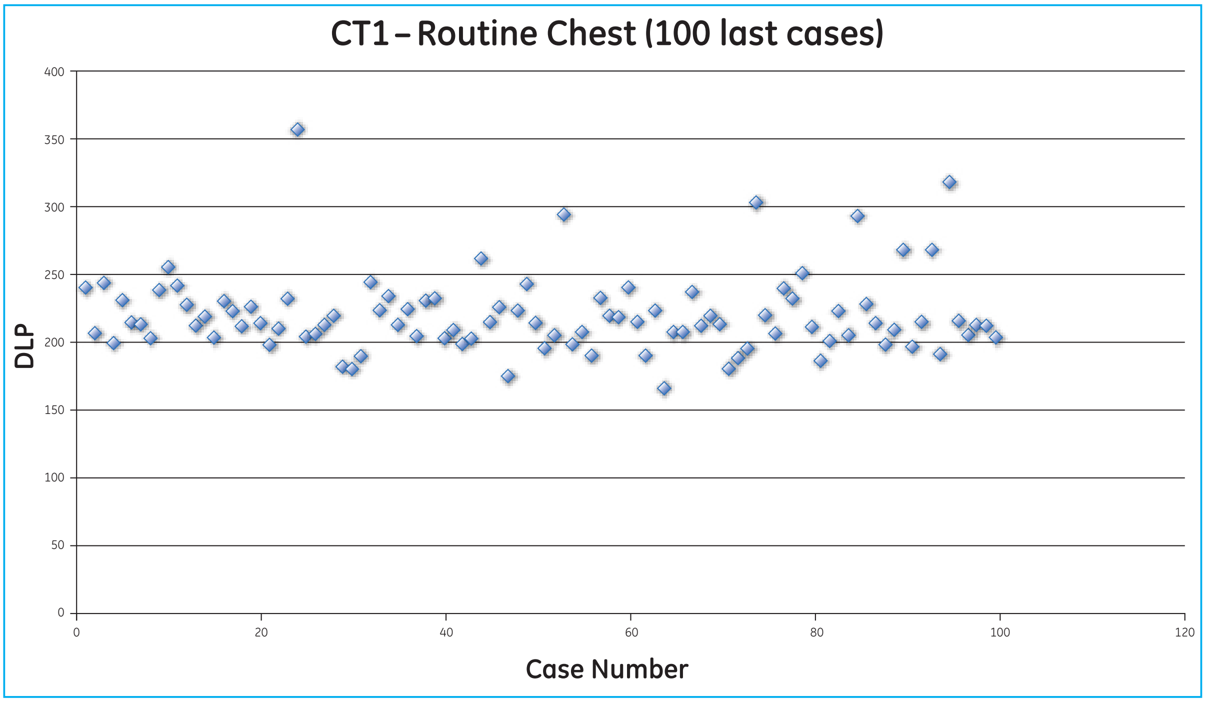


Figure 1.

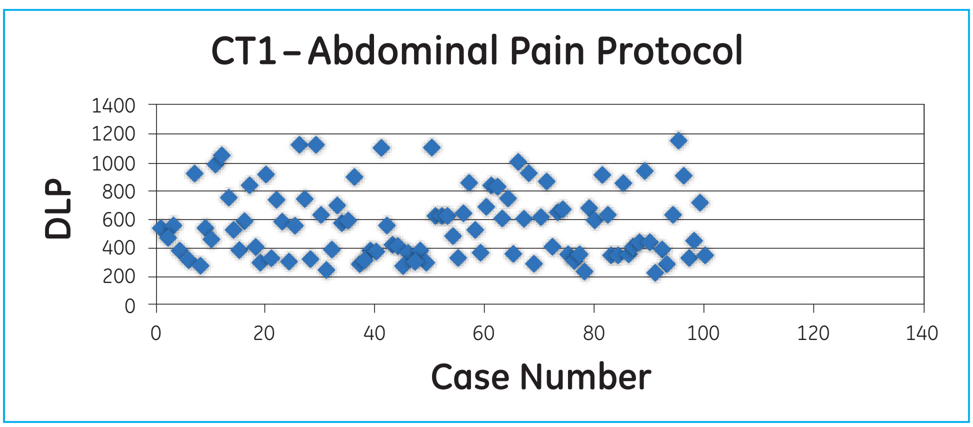


Figure 2.

- **Check protocol performance on all scanners** to see whether the values displayed on the control panel correspond reasonably to the doses you normally associated with the protocol in your practice. If an estimated dose is higher than expected for any routine clinical CT, then implement steps to investigate and adjust as needed.
- **Implement quality control procedures** to ensure that technologists and radiologists follow accepted acquisition protocols with every patient and the planned amount of radiation is administered.
- **Provide annual education** for the staff on CT low-dose imaging.

Reviewing and Modifying CT Protocols

CT protocols are reviewed several times a year at Weill Cornell Imaging. In addition to regular monitoring, triggering events may include the acquisition of a new scanner or a journal article that suggests a new low-dose imaging approach. Our goal when modifying a protocol is to improve image quality at the current dose or lower radiation exposure without sacrificing quality. During a trial period, very small incremental changes—one parameter at a time—are made on a few exams. Then the images are evaluated by the sub-specialty radiologists. The questions to be answered: Are the images of acceptable diagnostic quality? Will they allow us to diagnose certain diseases? Did we achieve the goal of maintaining or lowering dose? If the answer is yes, the new protocol is adopted.

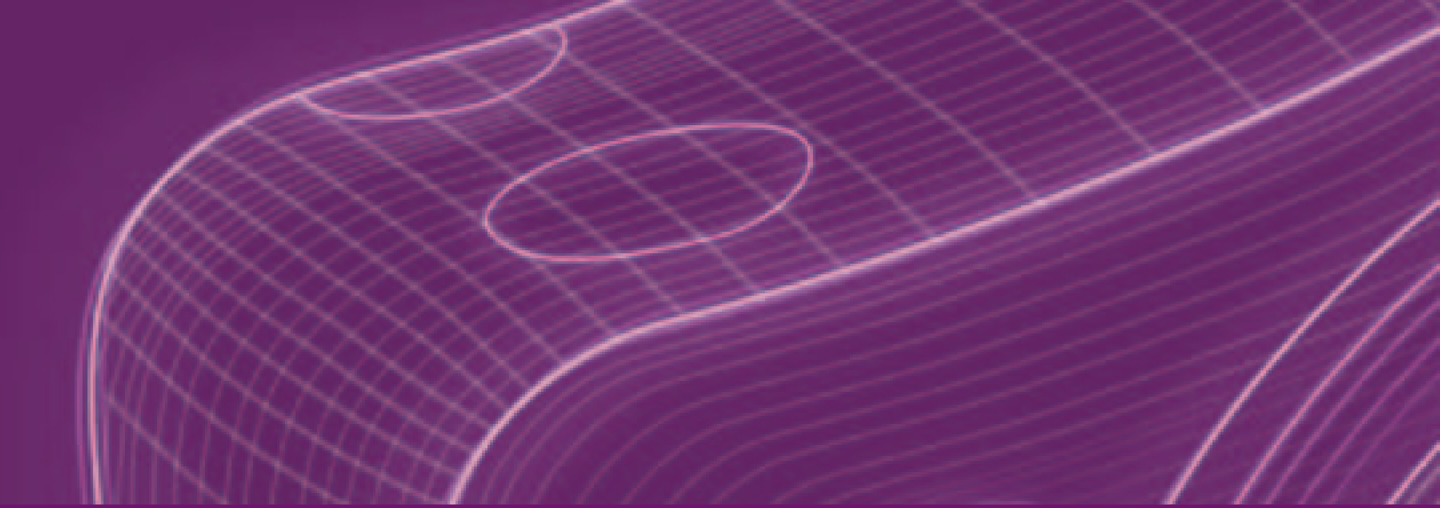
Demonstrating Your Commitment to Improving Patient Care and Imaging Quality

Healthcare professionals have a duty to their patients, to the practice, and to the society at large to continuously work towards optimizing low-dose CT imaging practices and techniques. Your medical community and patients should be aware of your efforts.

Recommendations include:

- **Review radiation dose issues with your practice's Quality Assurance or equivalent committee.** Make the efforts of this committee visible. If part of a larger organization, report the efforts on dose reduction to the larger quality assurance infrastructure. Make sure that responses are sent back to those who raise concerns.
- **Obtain ACR CT accreditation** as an independent verification of the facility's personnel, imaging techniques, image quality, and dosage levels. Display the accreditations where patients may easily see them. Additionally, ensure your technologists have proper certifications and continuing education.
- **Participate in the ACR Dose Index Registry.** Use the data as a benchmark for your practice. The Dose Index Registry (DIR) is a data registry that allows facilities to compare their CT dose indices to regional and national values. Information related to dose indices for all CT exams is collected, anonymized, transmitted to the ACR, and stored in a database. Institutions are then provided with periodic feedback reports comparing their results by body part and exam type to aggregate results. Data collected from the registry will be used to establish national benchmarks for CT dose indices.[1]
- **Transform the process of dose reduction into a culture of dose reduction**. Involve all members of the practice and make them aware of positive results. Designate dose champions and provide them time to educate others in the practice.

1. National Radiology Data Registry https://nrdr.acr.org/.



8

Patient Education

Radiation dose related to CT has made the front page of almost every major newspaper over the past several years. It is not surprising that along with this increase in coverage of the radiation involved in CT, that an increasing number of patients will ask questions and express concern.

It may seem obvious to someone who works in the medical field that the risk of not doing a CT examination (e.g. to rule out appendicitis) far outweighs the potential risk of the radiation dose. However, this is not always clear to the patient faced with making the choice whether to be scanned or not.

Speaking to Patients about Radiation

Background radiation

Naturally-occurring background radiation is the main source of exposure for most people. Levels typically range from about 1.5 to 3.5 millisievert per year (mSv/yr) but can be more than 50 mSv/yr. The highest known level of background radiation affecting a substantial population is in Kerala and Madras States in India where some 140,000 people receive doses which average over 15 mSv/yr from gamma radiation, in addition to a similar dose from radon. Comparable levels occur in Brazil and Sudan, with average exposures up to about 40 mSv/yr to many people.

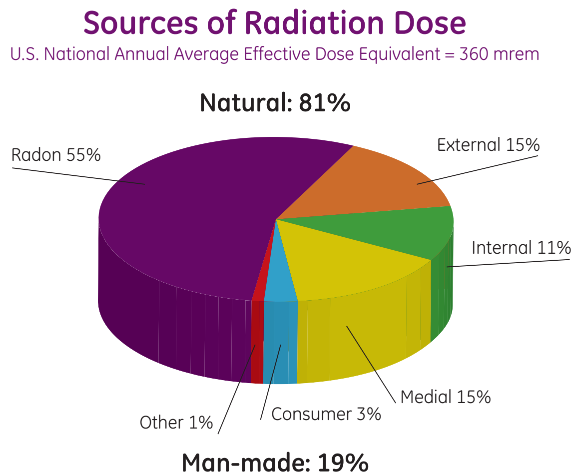


Figure 1. A typical graph of natural radiation contribution. From the NCRP 93 report (1987).

Every patient deserves answers to basic questions on both the potential risks and benefits of a CT exam, including:

Why is the exam being prescribed?

What are the potential benefits of CT procedures?

What are the potential medical risks of not having the exam?

What are the potential risks of the radiation dose?

Table 1.

Sources of Radiation	Average Exposure in mRem/yr (mSv/yr)	Typical Range of Variability in mRem/yr (mSv/yr)
Natural Sources	**300** (3)	
Radon	200 (2)	30–800 (0.3–8)
Internal	40 (0.4)	20–100 (0.02–1.0)
Cosmic	30 (0.3)	30–80 (0.3–0.8)
Terrestrial	30 (0.3)	10–80 (0.1–0.8)
Man-made Sources	**61** (0.61)	
Medical	50 (0.5)	
Consumer products	10 (0.1)	
Other (nuclear fuel cycle and occupational exposure)	1 (0.01)	
Total	**361** (3.6)	**90–1060** (0.9–10.6)

Natural sources of human exposure to radiation, primarily in the form of radon, usually outweigh man-made sources, though medical exposures have become more prominent in recent years. *Sources: NCRP 1987b for average exposure values; U.S. NRC 1994 for ranges for variability; Fisher 2003 for radon.*

Benefits

Research has shown that the increased utilization of advanced medical imaging, such as CT and MRI, between 1991 and 2004 improved life expectancy by 0.62 to 0.71 years.[1] The American College of Radiology (ACR) uses the following language to explain the benefits of CT imaging to a lay audience:

> CT images allow radiologists and other caregivers to identify internal structures and to determine shape, size, density and texture. This detailed information can be used to determine:
>
> - What the medical problem is
> - How extensive it is
> - Exactly where it is located
> - If no abnormality is present

A CT scan that shows no abnormality also provides useful data. The information aids a diagnostician by focusing attention away from unnecessary medical concerns determining when surgeries are necessary.

CT Scans can:

- Reduce the need for "exploratory" surgeries.
- Improve cancer diagnosis and treatment.
- Reduce the length of hospitalizations.
- Guide treatment of common conditions such as injury, cardiac disease and stroke.
- Improve patient placement into appropriate areas of care, such as intensive care units.

For example, in an emergency room, patients can be scanned quickly so doctors can rapidly assess their condition. Emergency surgery might be necessary to stop internal bleeding. CT shows the surgeons exactly where to operate. Without this information, the success of surgery is greatly compromised. The risk of radiation exposure from CT is very small compared to the benefits of a well-planned surgery.[2]

Who should talk to the patient?

While dose issues are typically discussed with the referring physician, these physicians vary widely in their understanding of radiation dose and potential risk. In a 2009 survey, over half of referring physicians felt that the radiology practice should be responsible for providing information about the potential risks of radiation dose to patients.[3] Obviously, such discussions must be tailored to the needs of individual patients and their families. Some patients will be more knowledgeable, ask more questions, and want to have a deeper dialogue; others will opt for a brief discussion.

All members of the patient care team, from the person who schedules the appointment to the radiologist who interprets the examination, should be able to discuss the exam and risk/benefit with the patient. This does not mean that all members of the practice need to be radiation experts, but rather they should be familiar with some commonly asked questions and know whom to contact if more information is necessary or requested. Ultimately it is the radiologist and/or medical physicist who will be able to address more difficult questions.

It is important to let your patients know about your efforts to reduce dose. They will not only feel reassured but also be more likely to request your services in the future.

Know your basic radiation facts

By familiarizing themselves with a few commonly asked questions, the members of your practice will be able to address many of the concerns of your patients and provide reassurance.

"How much radiation will I get from my CT?"

This is one of the most commonly asked questions by patients who are concerned about their CT examination. Surprisingly, many radiologists are not familiar with the estimated doses for specific exams. If possible, compile average doses for the most common examinations that you perform and round to easy-to-remember numbers. This can be done as part of the data collection following the implementation of a low-dose program. Make these numbers available to the members of your practice. If you do not have this data available, search out reputable sources for averages such as ACR or AAPM, but remember that these are only rough average estimates and will not likely represent the specific patient dose, especially if your institution has an effective low dose program or is employing advanced dose reduction features including advanced reconstruction algorithms. It is also important that the members of your practice understand that these values are not specific patient doses, but are rather the best estimates available for the average exam based on scanner dose metrics and conversion factors.

Exam	Approximate effective radiation dose—single exam
CT Sinuses	0.6 mSv
CT Chest Low Dose	1.5 mSv
CT Head	2 mSv
CT Spine	6 mSv
CT Chest Standard	7 mSv
CT Abdomen	10 – 15 mSV

Figure 2. Information available at www.radiologyinfo.org.

1. MITA, Your Health, http://www.medicalimaging.org/benefits-of-medical-imaging/your-health/
Lichtenberg, The Quality of Medical Care, Behavioral Risk Factors, and Longevity Growth, NBER Working Paper No. 15068, Issued in June 2009.

2. Radiologyinfo.org, last visited 11/02/2011; http://www.radiologyinfo.org/en/safety/index.cfm?pg=sfty_hiw_04.

3. Karsli T et al. What physicians think about the need for informed consent for communicating the risk of cancer from low-dose radiation. Pediatric Radiology (2009) 39: 9, 917-925.

4. Radiation Exposure from Medical Exams and Procedures: Fact Sheet. Health Physics Society, January 2010.

Exam	Comparable to natural background radiation
CT Sinuses	2 months
CT Chest Low Dose	6 months
CT Head	8 months
CT Spine	2 years
CT Chest Standard	2 years
CT Abdomen	3 years

Figure 3. Information available at www.radiologyinfo.org.

"What is the risk of my CT exam?"

This is a much more meaningful question than how much radiation will I get, as most patients and physicians have no understanding of the theoretical potential risks of radiation dose. While there are many approaches that may be used to discuss risk with the patient, the following is what we have found to be the better approach at Weill Cornell Imaging.

Weill Cornell Imaging's approach involves comparing the amount of radiation in a CT exam to the amount of radiation a person would experience in everyday life. This has become the preferred method as, in contrast to framing the risk of CT in terms of a negative event (e.g., death), this approach puts the CT dose in context of everyday unavoidable exposure. These natural sources include radioactive radon gas that we breathe, radioactive elements such as potassium-40 that is found in many foods (including salt), flying on airplanes, uranium and thorium (which are found in soils and building materials), and cosmic rays (from space) that continually expose us.

The estimated average effective dose from natural background radiation in the U.S. is about 3.1 mSv/yr (12 months).[4] (Simply living at high altitudes, such as Colorado Springs, can more than double annual radiation exposure to about 7 mSv.[5]) One method of presenting this data that Weill Cornell Imaging has found to be easily understandable to patients, is to present it as the period of time of background radiation equivalent to a CT exam. Take the average values you determined for the previous question (how much radiation will I get), and divide it by 3.1 mSv to obtain the equivalent background radiation exposure time…but remember that these are only rough average estimates and will not likely represent the specific patient dose, especially if your institution has an effective low-dose program.

For patients who want a deeper discussion around risk, especially related to potential long term effects, it's important to emphasize that the potential likelihood of developing cancer from a properly acquired CT study is very low. How low? In the U.S. population, the average risk of developing cancer is 44% for men, 38% for women.[5] The only study to directly evaluate the long-term effect of CT estimated the increased incidence of cancer at one in 10,000. The most commonly-cited statistics are very gross projections based primarily on the levels of radiation experienced by atomic bomb survivors at Hiroshima and Nagasaki.[7] However, even based on those "apples to oranges" comparisons, the increased risk of cancer over a person's lifetime from a single CT scan has been estimated at only 0.03–0.05%.[6] Using this information, you can help assure concerned patients that the low doses of radiation used in typical CT exams have a very small theoretical effect on their likelihood of developing cancer and that the benefits of the exam in helping doctors diagnose medical conditions far exceed the risks.

4. Radiation Exposure from Medical Exams and Procedures: Fact Sheet. Health Physics Society, January 2010.
5. American Cancer Society. http://www.cancer.org/Cancer/CancerBasics/lifetime-probability-of-developing-or-dying-from-cancer.
6. What Parents Should Know About Medical Radiation Safety. http://spr.affiniscape.com/associations/5364/files/Image_Gently_8.5x11_Brochure.pdf.
7. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study, The Lancet, June 2012.

It is important to remember that CT has been one of the greatest advances in healthcare by helping rule out or diagnose disease, trauma or abnormalities. It can also assist in planning, guiding and monitoring therapies. A recent study, conducted by Columbia University professor of business Frank Lichtenberg and based on data from the National Cancer Institute and Thomson Medstat, found that, "cancer imaging innovation accounted for 40 percent of the reduction in U.S. cancer deaths between 1996 and 2006, making it likely the largest single contributor to decreased cancer mortality during this time period."[8]

Be able to provide additional information

There are many very good resources for both healthcare professionals and patients that are available including:

- **www.radiologyinfo.org**
- **www.imagegently.com** (pediatric information)

8. National Bureau of Economic Research, NBER Working Paper No. 15880, Issued in April 2010, Lichtenberg, Frank R.

9

Communications

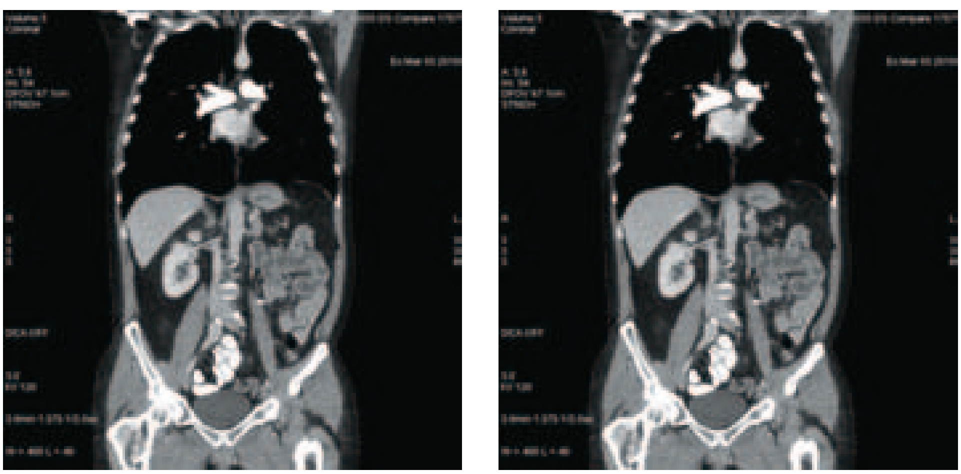
Chances are that your practice, like most practices, needs to work hard to maintain an edge in what has become an increasingly competitive imaging market.

While implementing a low-dose practice is primarily about enhancing patient care and quality, it represents a great opportunity to distinguish your practice and make it an example for others to follow. Make your efforts around low-dose imaging known to both your referring physicians and surrounding community.

Dose Matters

In the past, low-dose imaging was not a topic of great concern to referring physicians or their patients. Recently this has changed dramatically. Patients are asking their referring physicians questions, and these physicians are turning to imaging practices for answers. Provide these physicians with both basic information about CT radiation dose and information on your practice's specific efforts.

Remember that most physicians like data. Including specific results on your low-dose program will get their attention. For example, when Weill Cornell Imaging initially instituted GE's ASiR technology, we would frequently quote the percentage dose savings on our abdominal/pelvic and PET/CT studies.



Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	–	–	–	–
200	Axial	I131.500-I131.500	25.51	12.78	Body 32
2	Helical	I13.000-I248.000	10.31	308.93	Body 32
2	Helical	I253.250-I698.250	15.49	789.37	Body 32
		Total Exam DLP:		1111.08	

1/1

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	–	–	–	–
200	Axial	I88.750-I88.750	22.51	11.26	Body 32
2	Helical	S13.000-I196.000	8.48	230.02	Body 32
2	Helical	I201.250-I621.250	9.47	441.52	Body 32
		Total Exam DLP:		682.80	

1/1

Figure 1.

Becoming #1 on speed dial for referring physicians

At Weill Cornell Imaging, we've increased our internal and external referral volume significantly in recent years by focusing on ease of scheduling, clinical expertise, and the quality of the patient's experience. We cater to referring physicians and are dedicated to providing high value radiology services for their patients. Our efforts to decrease dose while providing high quality diagnoses are important components of this effort.

Our communications approach to referring physicians has been strengthened by:

- Creation of "radiology services liaisons"—staff members dedicated to building and maintaining relationships with referring physicians.
- Developing a database of all referring physicians that contains an up-to-date and detailed contact history on each physician encounter.
- Understanding the ordering profiles of individual physicians by capturing metrics on exam volume and type per physician.
- Segmentation of communication efforts based on high/medium/low referral practices.
- Person-to-person (versus online) scheduling to ensure maximum flexibility in accommodating the needs of referring physicians and their patients.
- Regular visits with referring physicians and their staff to discuss relationship issues and identify reasons for any lost referrals.

When possible, in addition to numerical data, high quality images should be included to emphasize that high quality imaging may be performed with significant dose savings. Never underestimate the "wow factor" of well-produced advanced imaging.

In addition to providing images and metrics that differentiate your practice and demonstrate your commitment to low-dose CT imaging, emphasize policies, procedures, training, and technologies that you have in place to support low dose, high quality imaging, including:

- Make it known that you adhere to accepted low-dose best practices/efforts like ACR Accreditation, ACR Dose Registry, technologist certification, and the Image Gently™ guidelines. Post certificates in visible areas. Have low-dose materials available in your waiting room.
- Communicate your new and enhanced CT technologies for low-dose imaging. You likely paid a large sum of money for the advanced technology, so make it work for you too.
- Most importantly, radiation is invisible and your efforts will be too unless you let your patients know what you are doing. It may seem obvious but even your most savvy patients will not appreciate your efforts to provide low-dose imaging unless they are aware of them. When explaining the procedure to a patient make sure to specifically highlight your dose reduction techniques while providing assurance that you are still getting the images you need for a confident diagnosis.

Use your communication program for your new low-dose capabilities to target patient populations that may benefit most. Examples include:

- **Oncology:** Patients who may require multiple follow-up studies.
- **Pediatrics:** When necessary, CT of children should always be imaged with as low of a dose as possible.
- **OB/GYN:** While these practices may not refer a high volume, they often see women of reproductive age.
- **Internal Medicine/Family Practice:** These practices often have a mix of young and older patients and typically order a wide range of imaging studies. In addition to protecting these patients, many of them will subsequently see specialists and bring with them their high quality/low dose images.
- **High Volume Specialties:** Practices with high volume CT referrals such as ENT and Urology.
- **Transplant Medicine:** Organ donors often require pre-surgical imaging. These are healthy individuals without medical problems.

Physicians have more choices than ever for their imaging referrals. Patients want to take a more proactive role in their healthcare. Communicating your low-dose CT imaging capabilities can be a key differentiator for your practice, giving both physicians and patients another compelling reason to choose your services.

10

Additional Training

GE Healthcare provides multiple education programs in CT dose reduction both online and classroom. For more details, visit http://www3.gehealthcare.com/en/Education

For additional information on lowering CT dose visit the GE Healthcare website to view five new CT Low-Dose Webinars

These webinars are approved by the ASRT for Category A CE credits.

To access the Webinars, please use the link below.

http://www.gehealthcare.com/LowDoseWebinars

CT Radiation Dose—Current Issues and New Techniques

James P. Earls, MD
Director of Cardiovascular CT and MRI
Fairfax Radiological Consultants, P.C. of Fairfax, VA
Co-Director of Cardiac CT Lab
Inova Heart and Vascular Institute of Falls Church, VA

Reducing Radiation Risk in CT Scans For Children

Randy R. Richardson, MD
Chairman of Radiology
St. Joseph's Hospital and Medical Center
Dean of Medical Education
Creighton School of Medicine (Phoenix Campus)

CT in Pregnancy Radiation Dose and Risks

Mannudeep K. Kalra, MD, DNB
Massachusetts General Hospital
Harvard Medical School

Fundamentals of Radiation Dose

Amanda Fox, BS, RT (R)(CT)
Product Development Specialist
GE Healthcare

Roy Nilsen, BS
Principal Engineer
GE Healthcare

Techniques for Reducing CT Radiation Dose

Holly McDaniel, RT (R)
Product Development Specialist
GE Healthcare

Dose Reduction Techniques For Cardiac CT

Patricia Zoltowski, BS, RT (R)(CT)
Clinical Educator
GE Healthcare

Neuro Imaging Considerations

Karen Procknow, R.T. (R)
Product Development Specialist
CT Advanced Applications
GE Healthcare

About Weill Cornell at NewYork-Presbyterian

Founded in 1898, and affiliated with what is now NewYork-Presbyterian Hospital since 1927, Weill Cornell Medical College is among the top-ranked clinical and medical research centers in the country. For the Low Dose Blueprint, GE has collaborated with Weill Cornell Imaging at NewYork-Presbyterian. Weill Cornell Imaging at NewYork-Presbyterian combines the academic excellence of the Weill Cornell Medical College and the world class clinical resources of NewYork-Presbyterian Hospital and are among the leaders in providing low dose imaging to all patients. **http://www.med.cornell.edu/**.

About GE Healthcare

GE Healthcare provides transformational medical technologies and services that are shaping a new age of patient care. Our broad expertise in medical imaging and information technologies, medical diagnostics, patient monitoring systems, drug discovery, biopharmaceutical manufacturing technologies, performance improvement and performance solutions services helps our customers to deliver better care to more people around the world at a lower cost. In addition, we partner with healthcare leaders, striving to leverage the global policy change necessary to implement a successful shift to sustainable healthcare systems.

Our "healthymagination" vision for the future invites the world to join us on our journey as we continuously develop innovations focused on reducing costs, increasing access, and improving quality around the world. Headquartered in the United Kingdom, GE Healthcare is a unit of General Electric Company (NYSE: GE). Worldwide, GE Healthcare employees are committed to serving healthcare professionals and their patients in more than 100 countries. For more information about GE Healthcare, visit our website at www.gehealthcare.com

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