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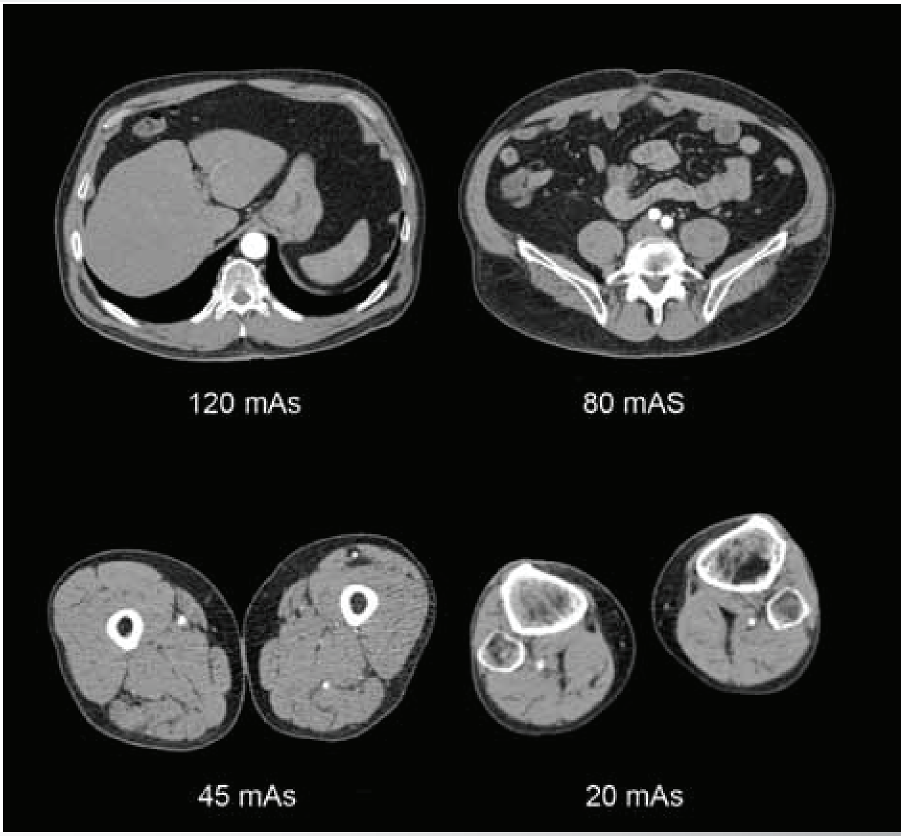

SURE Exposure™

Low Dose
Diagnostic Image Quality

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Since its inception, Computed Tomography (CT) has advanced medicine and become an invaluable diagnostic tool. Technological advances in CT have expanded its clinical capabilities leading to a substantial increase in CT utilization. The large number of patients and diagnostic tasks in CT imaging warrants methods for ensuring that every individual patient receives the best diagnostic image quality at the lowest possible dose. A busy clinical practice will interact with a wide range of patients varying in age and body habitus, each requiring a CT exam from an array of diagnostic tasks. The optimized image quality for a clinical exam will depend on the diagnostic task at hand and the size and shape of the patient being imaged. Toshiba Medical Systems has designed its Aquilion™ line of CT scanners to yield high image quality with minimal radiation dose for all patients. One of the key technologies that Toshiba has developed to achieve this goal is the SUREExposure dose-reduction tool.

The utilization of CT has increased substantially over the past few decades. Since 1993, the number of CT exams in the US has more than tripled[1]. The increased utilization of CT is a reflection of the many technological advances of the imaging modality, which have led to CT being one of the most useful tools available to clinicians in modern medicine.

In order to minimize radiation dose in medical imaging, Toshiba is dedicated to finding new ways of adhering to the ALARA principle. ALARA, meaning As Low As Reasonably Achievable, is a guideline used to ensure that only the minimum radiation exposure is used to accomplish the task at hand. In medical imaging, the minimum radiation dose is fundamentally linked with the image quality requirements of the exam. Increasing the tube current increases the number of X-rays contributing to an image and thus, improves image quality. However, an increase in tube current also increases the patient's exposure to ionizing radiation. Therefore, rather than simply increasing tube current, minimizing radiation exposure by tailoring the tube current to the size and shape of specific patients is vital.

The ultimate goal of CT technology is to create the best diagnostic image quality while minimizing radiation dose to the patient. Individual patients undergoing CT imaging have different needs depending on their size and shape and depending on the diagnostic task. Thus, it is essential that tools be used to tailor each scan for the individual patient to ensure excellent image quality while maintaining the lowest possible radiation dose. Analogous to Automatic Exposure Control (AEC) in X-ray imaging, the increased utilization in CT has led to the invention of new technologies such as SUREExposure for managing dose on a patient-specific basis. SUREExposure is a sophisticated suite of dose-reduction technologies integrating acquisition and reconstruction parameters with advanced dose-reduction algorithms. An important component contributing to dose reduction is SUREExposure tube current modulation, which tailors tube current to account for differences in patient size between patients and for the natural variations in size and shape within different regions of the body. In addition, SUREExposure adjusts the tube current appropriately for the selected acquisition and reconstruction parameters, and dose-reduction algorithms. SUREExposure tube current modulation has the ability to reduce patient dose while maintaining optimized image quality.

Different Size Patients Have Different Needs

Larger patients require a higher tube current than smaller patients to ensure diagnostic image quality in CT (**Figure 1**). Before the introduction of tube current modulation, acquisition parameters had to be adjusted manually to account for the size of the patient[2].

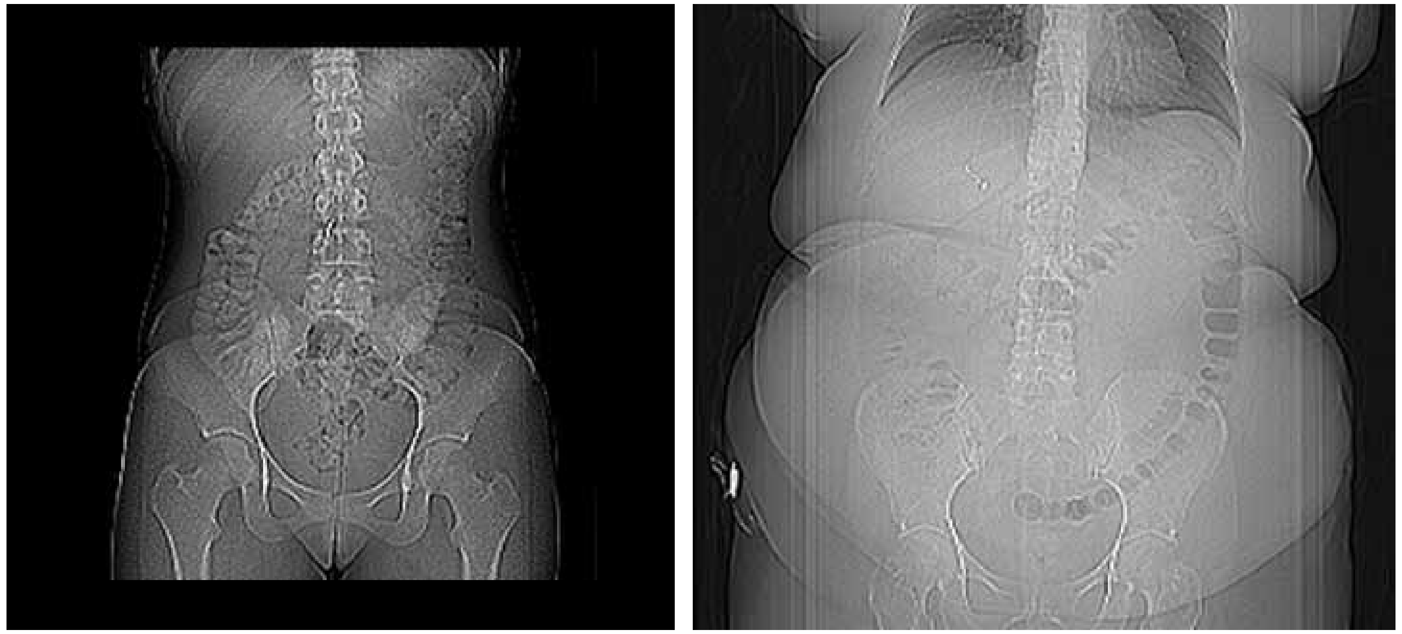

Figure 1: SUREExposure will automatically adjust the mA values needed for different patient sizes in order to maintain image quality.

These manual protocol settings required an experienced CT operator with the ability to properly assess patient size and determine the appropriate tube current settings for the exam. When improperly selected, manual adjustments led to inconsistent image quality between patients. In the same way that AEC offers automated patient size adjustments in planar X-ray imaging, SUREExposure automatically adjusts the tube current in CT imaging to account for the size of the patient and thus, provides greater consistency of image quality between patients.

Patient Shape and Density

SUREExposure differs from AEC in that it takes dose reduction to the next level, not only scaling by patient size, but also scaling tube current throughout the CT acquisition, based on the patient's shape and density. Different regions within a patient vary in size and density causing region-specific tube current requirements. For example, the low-density lungs do not require as much tube current as the pelvis to obtain the same image quality.

SUREExposure tailors the tube current along the longitudinal direction (or z-direction) of the patient to account for variations in size and density (**Figure 2**). SUREExposure also modulates the tube current to account for variations in patient shape and density in the axial (or x/y) plane (**Figure 3**). For example, a patient's lateral dimension is typically wider and more attenuating than the anteroposterior (AP) dimension.

SUREExposure decreases the tube current for less attenuating regions as the tube rotates and traverses the patient. To accomplish this, SUREExposure determines the relative attenuation of a patient from either a single or dual scanogram, and converts this information into a "water equivalent thickness." The user-chosen image quality level is then used to calculate the amount of tube current needed to achieve the desired image quality. If a single scanogram is used, SUREExposure will modulate longitudinally along the length of the patient in the z-direction. If a dual scanogram is used, SUREExposure will modulate in all three dimensions as the tube rotates and traverses the patient (**Figure 4**).

Image Quality

The appropriate image quality for each diagnostic task is determined by the physician. SUREExposure then modulates tube current to achieve the lowest possible dose for that desired image quality. The image quality level can be automatically set by the protocol selected for the clinical exam. Three or more global image quality settings are automatically available for each scan region. For example, an adult abdomen protocol has three global settings: High Quality, Standard, and Low Dose (**Figure 5**). The global settings are specific to the image quality requirements of the body region being imaged (adult head, adult body, pediatric head, or pediatric body). Each image quality setting is defined by a target standard deviation of noise. The range of tube current values used for each image quality setting is limited by an adjustable minimum and maximum mA value.

The automated image quality settings operate on a global level, are tailored for the body region, and are available from any protocol. SUREExposure is fully customizable and adjustments can be made to the default image quality levels. Some users may also prefer to generate additional global settings. A good example of this is the addition of an Ultra Low Dose image quality setting (**Figure 6**) which may be used for protocols that are more robust to noise such as

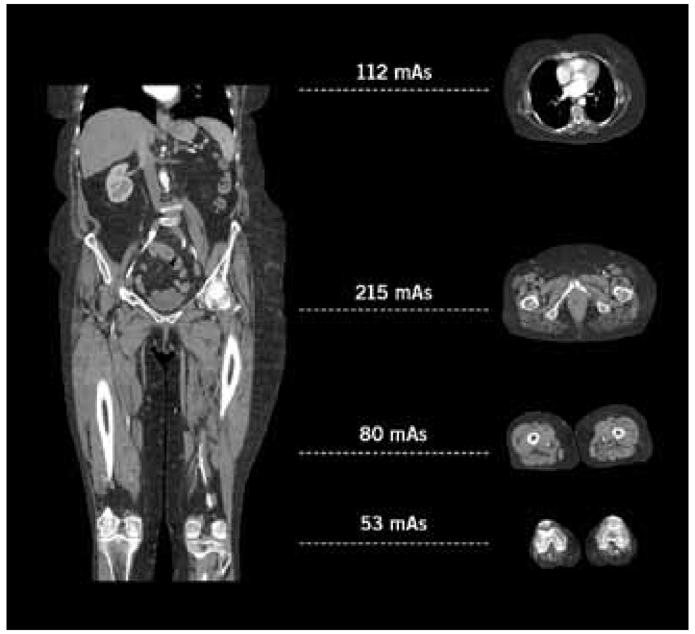

Figure 2: SUREExposure modulates tube current in the longitudinal z-direction. The mA is decreased for smaller regions (such as the extremities) or less dense regions (such as the lungs) to minimize dose.

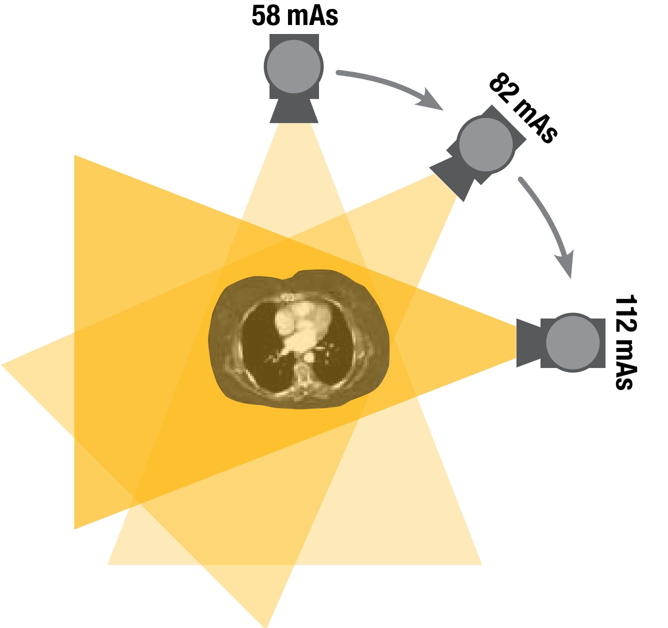

Figure 3: SUREExposure can also modulate tube current in the axial (x/y) plane. The mA is decreased for X-rays traversing smaller amounts of tissue. For example, X-rays traversing the anteroposterior direction often require less tube current than X-rays traversing the lateral direction.

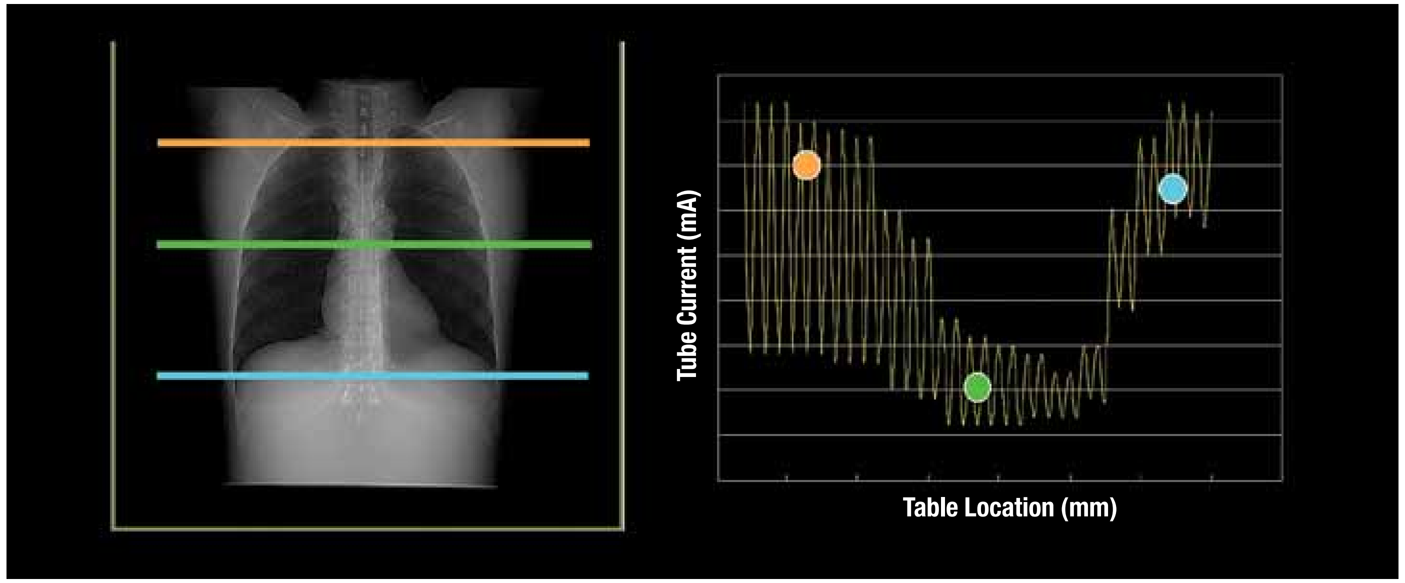

Figure 4: SUREExposure modulates tube current in the x/y-plane as well as along the z-direction. The lower frequency variations in the plot on the right are due to the longitudinal or z-direction modulation. The higher frequency oscillations are due to the tube current modulation in the x/y-plane.

Figure 5: Global SUREExposure image quality settings come standard on the Aquilion scanners. These default settings are designed to meet the needs of the majority of users.

Figure 6: New global image quality settings can be generated. This option is useful for users who want the flexibility to design their own image quality settings.

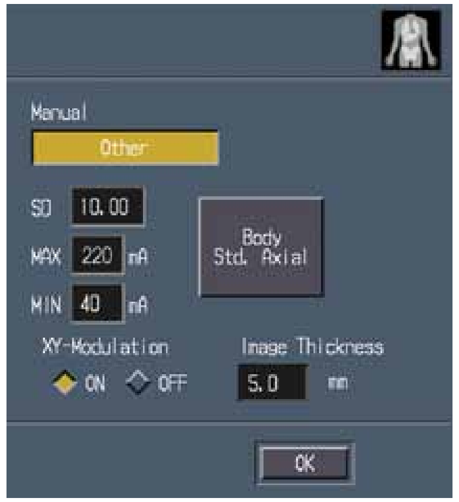

Figure 7: The SUREExposure settings can be adjusted to fine tune image quality for specific protocols or for individual patients. This option is useful when clinicians image a patient, or use a protocol with specific image quality or dose-reduction requirements.

follow-up exams.

Most often, simply selecting one of the global levels of image quality is appropriate for routine clinical scanning. However, there may be instances when the best level of target image quality for an imaging task is between two global settings or outside the range of the global settings. When more flexibility is required, SUREExposure can be customized and built into specific protocols or customized for individual patients.

Protocol-specific image quality settings can be used for exams that have specific image quality or dose requirements. For a given protocol, image quality settings can be specified using the SUREExposure noise level and maximum and minimum mA values (**Figure 7**). For example, a group of patients may require chest CT studies for the purpose of lung volume measurements. Since the images will not require as high of image quality as required for conventional chest CT, the protocol for these volume scans can achieve maximum dose savings by utilizing a higher noise level than a standard chest protocol. This customized protocol can then be saved and used for all lung volume measurement exams. Protocol-specific image quality settings can also be useful for sites involved in clinical trials with protocols that require specific tube current limits and noise levels. Creating automatic image quality settings for such specific protocols helps avoid operator error and accelerates workflow.

Steinberg Diagnostic Medical Imaging (SDMI) in Henderson, Nevada, a key protocol development partner for Toshiba CT technology, is leading the way in optimizing their clinical protocols to achieve ALARA for the wide range of patient sizes encountered in their patient populations. SDMI's innovative approach takes advantage of the flexibility of SUREExposure by incorporating protocols based on patient size – small, typical, large, and extra large – each using imaging parameters that are fine-tuned to the imaging needs of patients in that size range. For example, the SUREExposure image quality settings for patients scanned with the "extra large" protocol are allowed a larger target noise level and maximum mA than the patients scanned with the "small" protocol. SUREExposure can also be adjusted for individual patient exams. To adjust the image quality settings for an individual patient, the CT operator selects a desired standard deviation noise level and/or a minimum and maximum mA (**Figure 7**). This type of individualized image quality adjustment may be necessary in patient-specific situations, which may be warranted for a patient with a known pregnancy, or an inherently radiosensitive patient (i.e., ataxia-telangiectasia or AT patients).

SUREExposure Incorporates Acquisition and Reconstruction Parameters

SUREExposure is not just a stand-alone tube current modulation algorithm. One of the unique benefits of SUREExposure is its ability to achieve excellent image quality by incorporating the acquisition and reconstruction parameters. Since acquisition and reconstruction parameters can have substantial effects on image noise, the tube current must be appropriately adjusted. SUREExposure helps ensure optimized image quality by tailoring not only to patient size and shape, but

also to the imaging parameters selected for each imaging task.

The primary acquisition parameters affecting image noise are pitch, rotation time, and kVp. In helical scanning, higher pitch values (or faster table travel) can reduce scan time but can also affect image noise. SUREExposure counteracts this effect by adjusting the tube current to achieve optimized image quality regardless of the selected pitch value. Likewise, SUREExposure adjusts tube current to account for faster rotation times or lower kVp settings. By automatically adjusting to these acquisition parameters, SUREExposure helps ensure that the target image quality is obtained at the lowest possible dose.

The parameters used to reconstruct an image can also have an effect on image noise. SUREExposure accounts for reconstruction parameters selected for the initial reconstruction to adjust for these effects. For example, smoother reconstruction kernels will decrease image noise. SUREExposure recognizes the selection of a smooth kernel and decreases the tube current to achieve the lowest possible dose for that scan while achieving the target image quality. SUREExposure also recognizes the selection of reconstructed slice width and automatically adjusts to ensure high quality images.

An "Easy Mode" is also available, which offers users the option to automatically set SUREExposure settings according to the reconstruction parameters most used for viewing each task-specific protocol.

SUREExposure is Integrated with Dose-Reduction Technologies and Iterative Reconstruction

Toshiba's CT scanners are equipped with many tools to reduce radiation dose, reduce noise, and improve image quality. When dose-reduction and noise-reduction methods are used in a scan, SUREExposure automatically incorporates their effects. For example, two dose-reduction technologies available on Aquilion scanners are Quantum Denoising Software (QDS) and Adaptive Iterative Dose Reduction 3D (AIDR 3D). QDS is an adaptive noise-reduction algorithm that allows for lower mA imaging than would otherwise be possible by smoothing areas of uniform density while preserving spatial resolution and edge content within a reconstructed image. AIDR 3D is a sophisticated iterative reconstruction

Figure 8: Ultra Low Dose scan acquired using protocols from Steinberg Diagnostic Medical imaging. Images for 33 cm of anatomy were acquired in a total scan time of 7.42 seconds with 397 mAs (total). $CTDI_{vol}$ was 5.8 mGy and DLP was 153.7 mGy×cm.

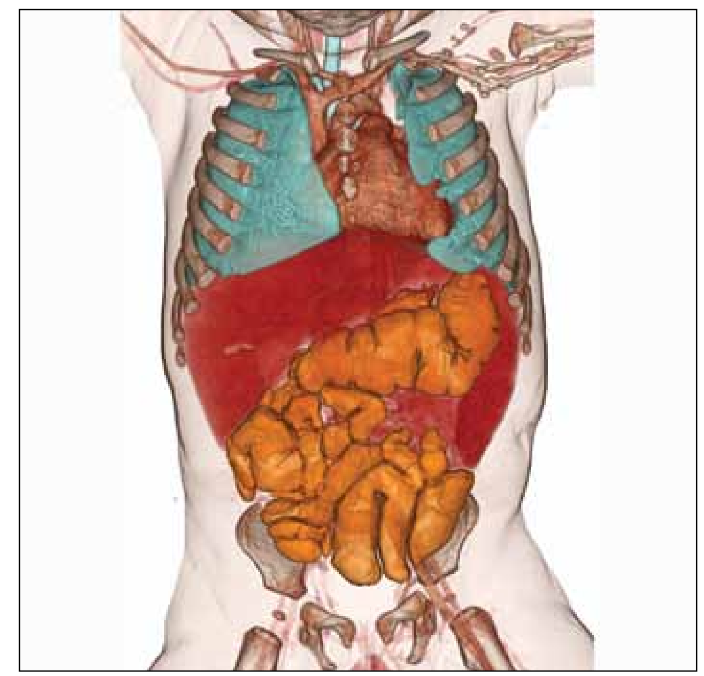

Figure 9: Pediatric abdomen CT using SUREExposure Pediatric. Average tube current was 12 mAs.

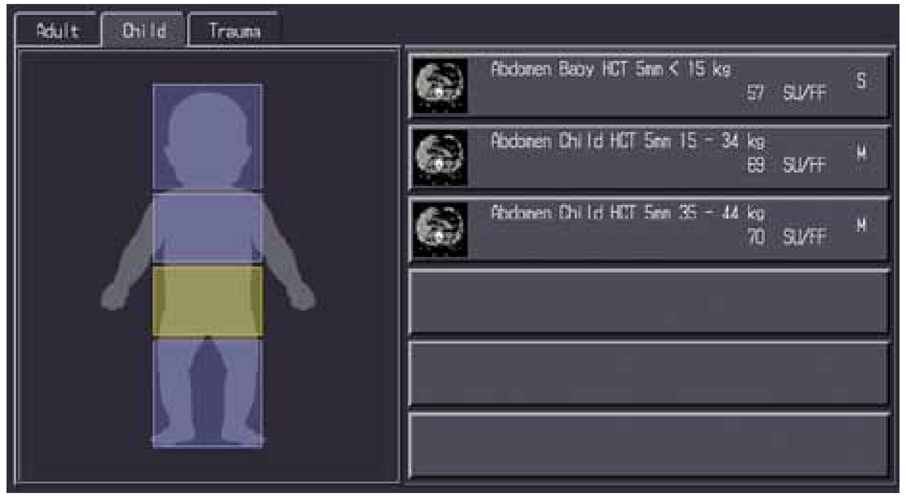

Figure 10: SUREExposure Pediatric automatically selects pediatric exam plans as a default on all Aquilion CT scanners based on the child's weight or age.

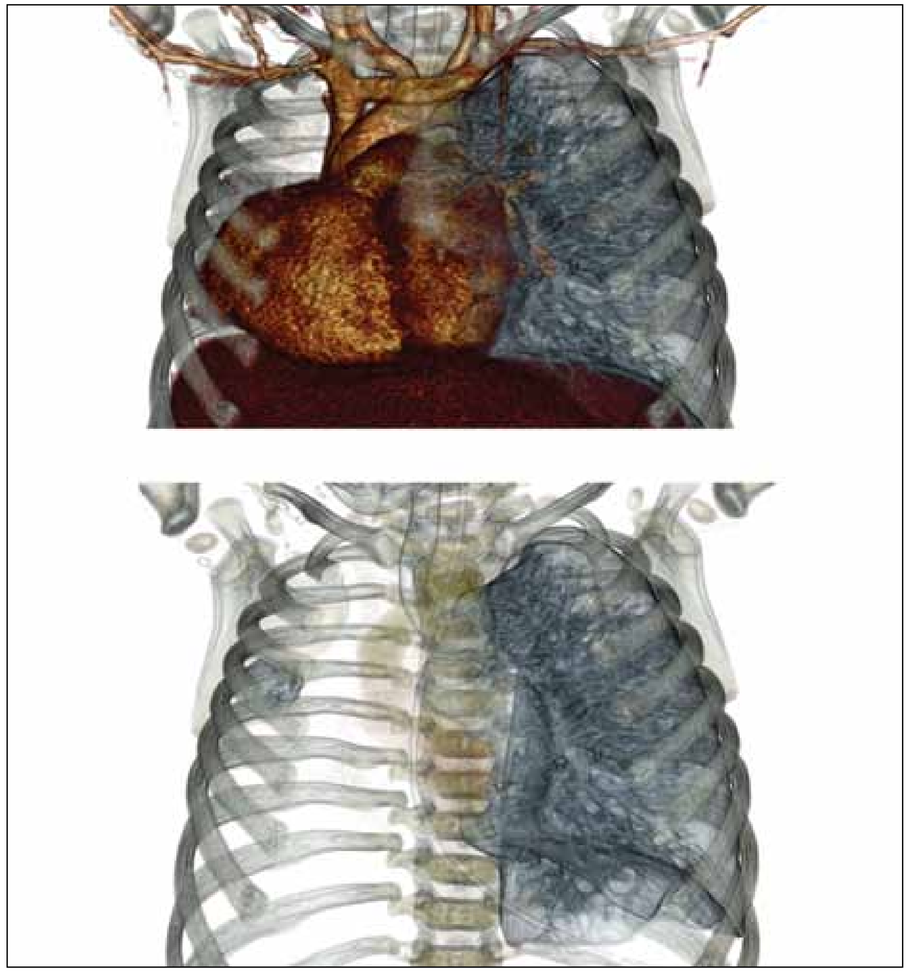

Figure 11: Using SUREExposure Pediatric this pediatric patient was scanned resulting in an Ultra Low Dose Technique, 100 kVp and an average tube current of 20 mAs.

algorithm designed to reduce dose by reducing the magnitude of image noise while preserving spatial resolution. This iterative reconstruction algorithm is superior in removing background noise while preserving image texture similar to the image texture from non-iterative approaches. When QDS or AIDR 3D are used in an imaging protocol, SUREExposure ensures that the patient receives the lowest possible dose by automatically decreasing the tube current to account for the signal-to-noise benefits gained from these technologies. This automatic adjustment ensures that patients automatically get the benefit of dose-saving methods.

SUREExposure Pediatric

Children have a higher sensitivity to ionizing radiation than adults[3]. In order to minimize the risks to children, it is critical that the appropriate dose is used on each individual child[4]. Furthermore, it is essential that all images are acquired with optimized image quality, regardless of patient size, to prevent the need for unwarranted repeat scanning. Aquilion scanners come equipped with SUREExposure Pediatric, which incorporates the unique imaging requirements of pediatric imaging and ensures the lowest possible dose while maintaining diagnostic image quality. Pediatric patients have unique imaging requirements compared to adults. For example, the natural contrast provided by intra-abdominal fat in adults is reduced in pediatric patients and the images generally require more signal to noise compared to adult images. SUREExposure adjusts the default image quality settings to account for these additional image quality requirements and limits the maximum mA settings to minimize the dose to pediatric patients. Another example of Toshiba's dedication to maintaining the ALARA principle in pediatric patients is their involvement in The Image Gently℠ campaign. The Image Gently campaign was developed to increase awareness about radiation dose in pediatric imaging and to promote best practices for dose reduction[5]. Toshiba's commitment to patient-centered imaging and support of the Image Gently campaign mandate continuous development of technologies that enhance pediatric patient safety. In Toshiba's CT scanners, dose minimization begins working from the moment a patient is registered on the CT console. Monitoring the patient's age during the registration process, the software automatically takes the operator to Aquilion's optimized suite of pediatric protocols for patients under 12-years-old. For each clinical task, the pediatric protocol is tailored to the task's diagnostic needs and incorporates the small size of pediatric patients.

Arkansas Children's Hospital in Little Rock, Arkansas, uses the flexibility of the SUREExposure application to ensure protocol optimization for their specific patient population. Arkansas Children's, which serves patients under 21 years of age, separates their clinical protocols into age categories and then further subdivides protocols in each age group by weight. This approach allows for better matching of body habitus with technical parameters than categorizing by age or weight alone. This layered approach to protocol design enables Arkansas Children's to take full advantage of the 80 kVp and 100 kVp settings, and to customize their SUREExposure image quality and max/min settings with a high degree of precision.

Weight-based imaging protocols for SUREExposure Pediatric were developed in conjunction with Arkansas Children's Hospital and are now available with Aquilion software (**Figure 10**). The SUREExposure Pediatric imaging protocols are specific to the weight of the patient and ensure that every scan is customized for the patient's age, weight, and imaging task.

Conclusion

Toshiba's commitment to patient-centered imaging mandates continuous development of technologies that enhance patient safety. SUREExposure is just one example of the dose-reduction capabilities of the Aquilion CT product line. SUREExposure is a powerful dose-reduction tool that incorporates the imaging task, patient size and shape, noise-reduction technologies, and the imaging parameters, to dramatically reduce radiation dose while ensuring excellent image quality.

Figure 12: Top left image: Chest CT acquired on Aquilion 16 using SUREExposure with an mAs range of 24 to 80 mAs.

Figure 13: CT Urogram acquired on Aquilion 32 using SUREExposure. A tube current range of 32 mAs to 100 mAs was automatically prescribed by the scanner.

Image Gallery

Figure 14: CTA Aorta and runoff acquired on Aquilion 64. SUREExposure automatically selected a high of 120 mAs and a low of 20 mAs to acquire this exam.

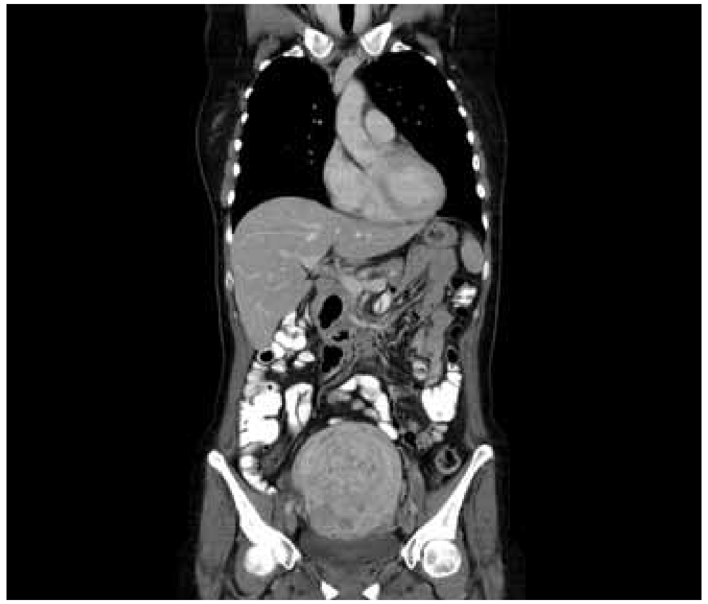

Figure 15: Chest, abdomen, and pelvis CT acquired using SUREExposure on Aquilion 64. A low tube current of 25 mAs was used through this patient's lungs and a high of 110 mAs was used through the abdomen and pelvis.

Figure 16: 3D VR lung scan acquired on Aquilion ONE CT. Total average mAs for the study was calculated at 55 mAs.

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