TOSHIBA
Leading Innovation >>>

AIDR 3D - Reduces Dose and Simultaneously Improves Image Quality

R. Irwan
Toshiba Medical Systems Europe (TMSE),
CT Business Unit, Zoetermeer, The Netherlands

S. Nakanishi
Toshiba Medical Systems Corporation (TMSC),
CT Systems Division, Otawara, Japan

A. Blum
University Hospital (CHU) Nancy,
Radiology Department, Nancy, France

Abstract

In Computed Tomography (CT), image quality is often quantified by the measuring the amount of noise (SD) in the image in relation to the spatial resolution (lp/cm). The simplest way to influence the amount of image noise is with the selection of a specific convolution filter in the reconstruction process. Selecting a "smooth" convolution filter will reduce image noise; however, it will also smooth out the details and therefore deteriorate spatial resolution.

This paper briefly describes Toshiba's dose reduction technologies and focuses on the latest iterative dose reduction technique, i.e. Adaptive Iterative Dose Reduction 3D (AIDR 3D) which not only reduces image noise but also improves spatial resolution.

Both phantom and clinical studies are presented and discussed. Quantitative analysis of Noise Power Spectra (NPS), Low Contrast Detectability (LCD), and spatial resolution improvements are presented to evaluate the performance of the AIDR 3D algorithm.

1. Introduction

There has been remarkable attention to dose saving technologies in CT both commercially available and under development. Toshiba's commitment to reducing patient dose is always at the forefront of development. Some of the most significant developments over the past decade are outlined in Figure 1.

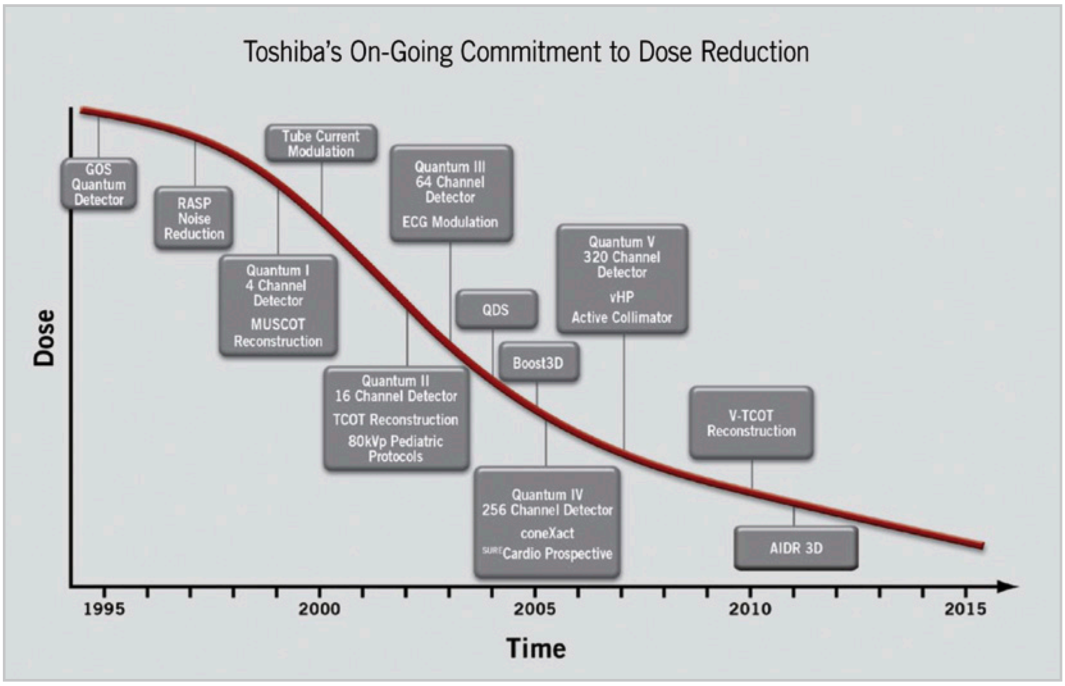


Figure 1 Toshiba's on-going commitment to dose reduction.

Toshiba's dose saving technologies include Active Collimator, SUREExposure 3D, Boost 3D, QDS, and AIDR 3D, among others, which have been extensively utilized in many clinical applications such as cardiac CT Angiography (CTA), dual energy, and perfusion. Below we present a brief overview of Toshiba's dose saving tools up to date.

Active Collimator

In Helical scanning, exposure is necessary before the start and after the end of the planned scan range in order to reconstruct images at these positions. This over-ranging requires at least one extra rotation in total, although only a small portion of this data is utilized.

Active collimation synchronizes the width of the X-ray beam at the ends of the scan range to the clinically useful area needed for image reconstruction. By eliminating exposure that is not used for diagnosis, patient dose can be reduced by up to 20%.

The collimator automatically opens at the start of the scan and closes at the end of the scan to keep the exposed area as short as possible, as illustrated in Figure 2.

The use of active collimator in ultra helical scanning has been described in [1] which confirmed that active collimator eliminates unnecessary radiation exposure.

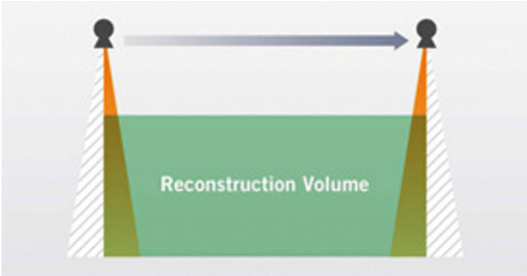


Figure 2 Active collimator diagram demonstrating elimination of the unnecessary radiation exposure at the beginning and end of the scan length (dashed areas).

SUREExposure 3D

SUREExposure 3D is Toshiba's Automatic Exposure Control which modulate the tube current according to the anatomical region and maintains the image SD at a certain level. 3D permits the tube current to be controlled in the xy-plane and the z-axis rather than only in the z-axis. This results in a more uniform image quality at a lower dose.

The image quality (SD) for each diagnostic task is determined by the physician. Dose savings of up to 40% with respect to a fixed tube current (mA) can be achieved.

Boost 3D

In non-homogeneous axial images, streak artifacts can appear between two dense objects in an image. They occur because highly attenuating structures reduce the number of photons reaching the detector at certain tube positions.

Boost 3D is a raw data based 3D data processing technique that eliminates streak artifacts in high attenuation areas such as the shoulders and pelvis.

A schematic diagram of Boost 3D and more detailed information can be found in [2] and will not be repeated here.

Quantum Denoising Software (QDS)

The QDS algorithm works in image space and applies three parallel mathematical processes to the original image data. Edge structure detection, analysis and extraction are firstly performed, followed by image smoothing and edge structure enhancement [2,3]. This allows image noise to be reduced while spatial resolution and image texture are preserved.

QDS was introduced in 2004 and has been routinely employed into routine clinical examinations resulting in a dose reduction of up 50%. Until the emergence of iterative reconstruction algorithms, Toshiba was the only manufacturer offering robust noise reduction technology that contributed to reducing patient dose [3].

AIDR 3D Integrated

Since patients come in all shapes and sizes, automatic exposure control systems have proven to be very useful in maintaining diagnostic image quality at a radiation dose suitable for each patient. It is therefore imperative that exposure control systems automatically react to dose reduction technology where made available to the customer.

SUREExposure 3D is fully integrated into the imaging chain and can therefore calculate the minimum radiation exposure required for each examination in every patient. With the inclusion of AIDR 3D in the scan protocol, the calculated exposure is automatically reduced by up to 75% when compared to a scan performed with traditional filtered back projection (FBP) reconstruction. Later in the clinical application section, we will demonstrate that dose reduction in a clinical setting can be even more than 75%.

The AIDR 3D algorithm is designed to work in both the raw data and reconstruction domains (Fig 3). In a low dose scan, the number of X-ray photon becomes relatively small and electronic noise in the Data Acquisition Systems (DAS) becomes dominant which will degrade image quality. AIDR 3D processing uses a scanner model and a statistical noise model considering both photon and electronic noise to eliminate noise due to a photon starvation in the projection data [4].

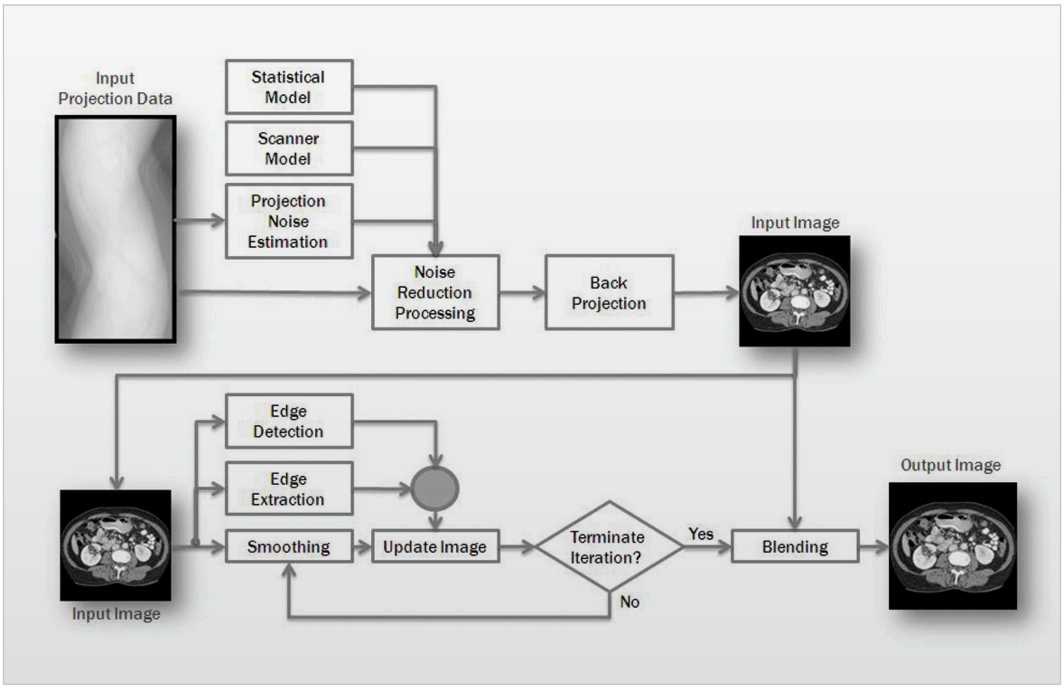


Figure 3 AIDR 3D is an advanced iterative reconstruction algorithm that reduces noise both in the raw data domain and also in the reconstruction process in 3-dimensions.

The statistical and scanner models are used together with projection noise estimation for electronic noise reduction processing which takes place in the raw data domain. The first model analyzes the physical properties of the CT system at the time of the acquisition, while the second model characterizes both electronic and quantum noise patterns in the raw data domain. The projection noise estimation takes care of noise and artifacts reduction.

The initial image (FBP) is used as an input image in every iteration to be compared with the output image.

A sophisticated iterative technique is then performed to optimize reconstructions for the particular body region being scanned by detecting and preserving sharp details and smoothing the image at the same time. Finally, a weighted blending is applied to the original reconstruction and the output of this iterative process to maintain the noise granularity. The complete AIDR 3D reconstruction therefore increases the SNR while improving the spatial resolution and produces images which look natural [5].

In summary, with the use of Toshiba's unique AIDR 3D, image noise can be reduced while spatial resolution and structural edges are preserved and even improved. This iterative algorithm permits scanning to be performed at lower doses. The dose reduction is approximately 75% and may even be more depending on the anatomical regions and body weight and height (body mass index, BMI). Patients with a low BMI may benefit from reducing the tube voltage from 120 kV to 100 kV or even 80 kV.

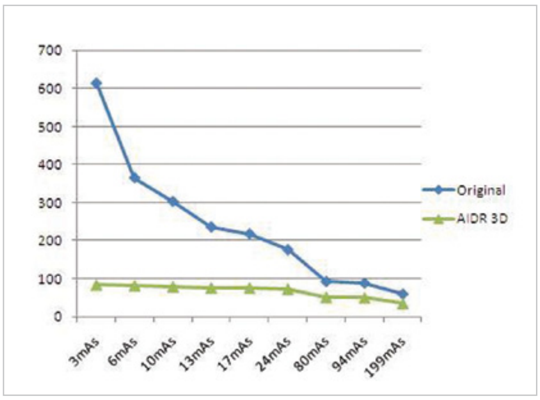


Figure 4a Image quality comparison between original (FBP) and AIDR 3D reconstructions as a function of tube current time product (mAs).

2. Physics and phantom study

Noise Power Spectrum (NPS)

Noise is one of the most important components in the evaluation of image quality. The standard deviation (SD) is often used to measure the CT noise.

Figure 4a illustrates the amplification of noise in FBP when the tube current time product (mAs) is reduced (blue curve). As one can appreciate from the figure, the AIDR 3D image quality shows an almost constant behavior and even slightly reduced at higher dose.

However, it provides no information about the image texture, i.e. appearance, resulting from different reconstruction techniques. Although two images may have the same SD, the appearance of the images can be very different.

One method to study the noise properties is using Noise Power Spectrum (NPS) where the shift in the noise spectrum due to filtering can easily be analyzed. There are several methods to generate a NPS curve, but we adopted the method described in [6].

Figure 4b shows the normalized NPS curves, of the original FBP and AIDR 3D reconstructions in one graph. The original FBP curve is considered to be the reference NPS to which the similarity in terms of shape of other NPS curves is highly desired to achieve similar image texture and therefore "natural look".

It can be seen from the figure that the NPS of AIDR 3D is similar to that of the reference, which guarantees the "natural look" of the overall image.

This constant behavior of AIDR 3D image quality in various dose levels (Figure 4a) in combination with the ability to preserve NPS curve (Figure 4b) have made AIDR 3D a powerful dose reduction technology in clinical practice today.

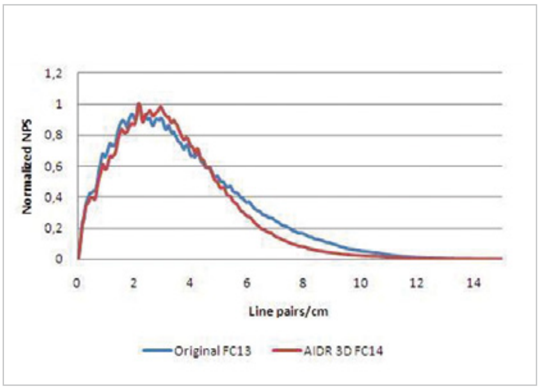


Figure 4b *Similar shape of normalized Noise Power Spectrum (NPS) curves of original FBP (blue), and AIDR 3D (red) reconstructions which ensures "natural looking" images.*

Low Contrast Detectability (LCD) and spatial resolution

LCD tests were performed using Catphan 600 [7] on Aquilion PRIME with the following acquisition parameters: collimation 80 × 0.5 mm, tube voltage 120 kVp, tube current 20 - 80 mA, rotation time 1 second, helical pitch 65 corresponding to beam pitch 0.8125, FOV 240 mm. The matrix size was 512 × 512 and the images were reconstructed using convolution filter FC 50 with slice thickness of 10 mm.

The results of LCD inserts are shown in Figure 5: using standard FBP (left) and AIDR 3D (right). The images on the right had lower noise levels when compared to that of the left. The noise measurement was carried out using five regions of interest (ROI) demonstrating approximately 50% noise reduction for the AIDR 3D images. The CT number of each ROI in all images are almost identical.

Spatial resolution was investigated by high resolution acquisitions using the same Catphan phantom and on the same scanner (Aquilion PRIME) with the same scan parameters as those of LCD tests. We used a convolution filter FC 50 for the standard FBP reconstruction, and AIDR 3D reconstructions for the following reasons. AIDR 3D images show reconstructions obtained using "sharp" protocol, which combines noise reduction with sharp FC filter. This way, a slight spatial resolution improvement has been achieved as shown by red arrows in Figure 6. Such low noise and high resolution combination may prove valuable in the diagnosis.

It is, therefore, expected that the proposed "sharp" protocol will have significant impact on clinical practice by making iterative dose reduction more valuable.

Antrophomorphic phantom

In Figure 7, the FBP (Left) and AIDR 3D (Right) reconstructions of an ultra low dose thorax scan of a Rando phantom are presented. The improvement in the image quality is clearly noticeable. Especially the small details in the pulmonary branches can be clearly seen. The dose length product (DLP) is 6.43 mGy*cm which is equivalent to 0.09 mSv. The scan and reconstruction protocol of the images in Figure 7 are summarized in Table 1.

Tube voltage (kV)	120
Tube current (mA)	10
Rotation time (s)	0.35
Reconstruction	FBP/AIDR 3D
FOV [mm]	320
Matrix	512×512
Pitch	1.391
Reconstruction filter	FC 51

Table 1 *Scan and reconstruction parameters for the images displayed in Figure 7.*

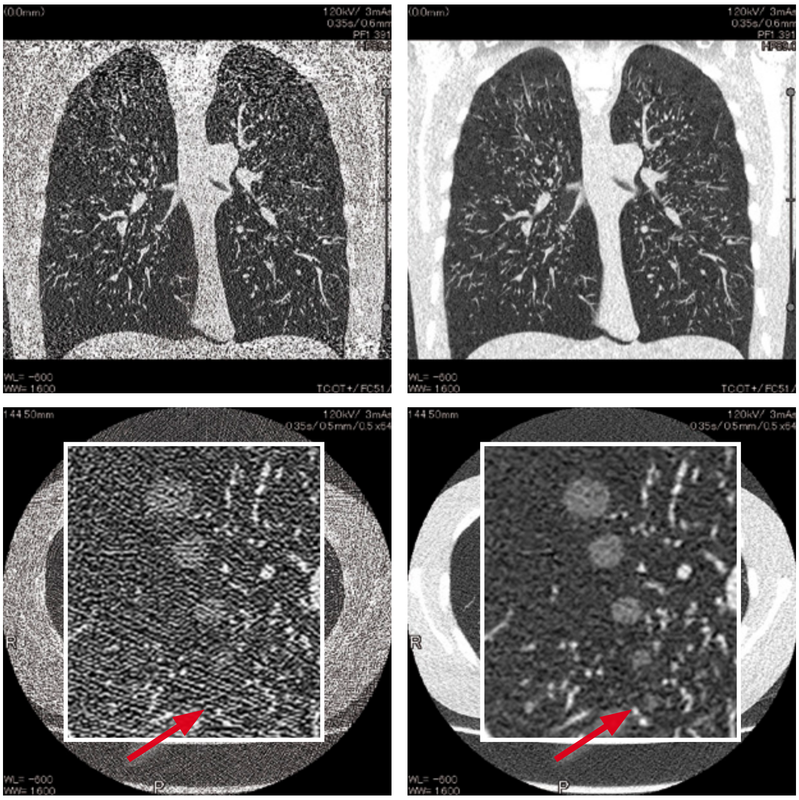


Figure 7 *Images obtained with FBP reconstruction (Left), and AIDR 3D reconstruction (Right) of a Thorax scan of a Rando phantom. The effective dose is 0.09 mSv (k-factor = 0.014 mGy*cm*mSv-1). Images courtesy of Keio University, Japan.*

120 kV
80 mAs
FC13

120 kV
60 mAs
FC13

120 kV
40 mAs
FC13

120 kV
20 mAs
FC13

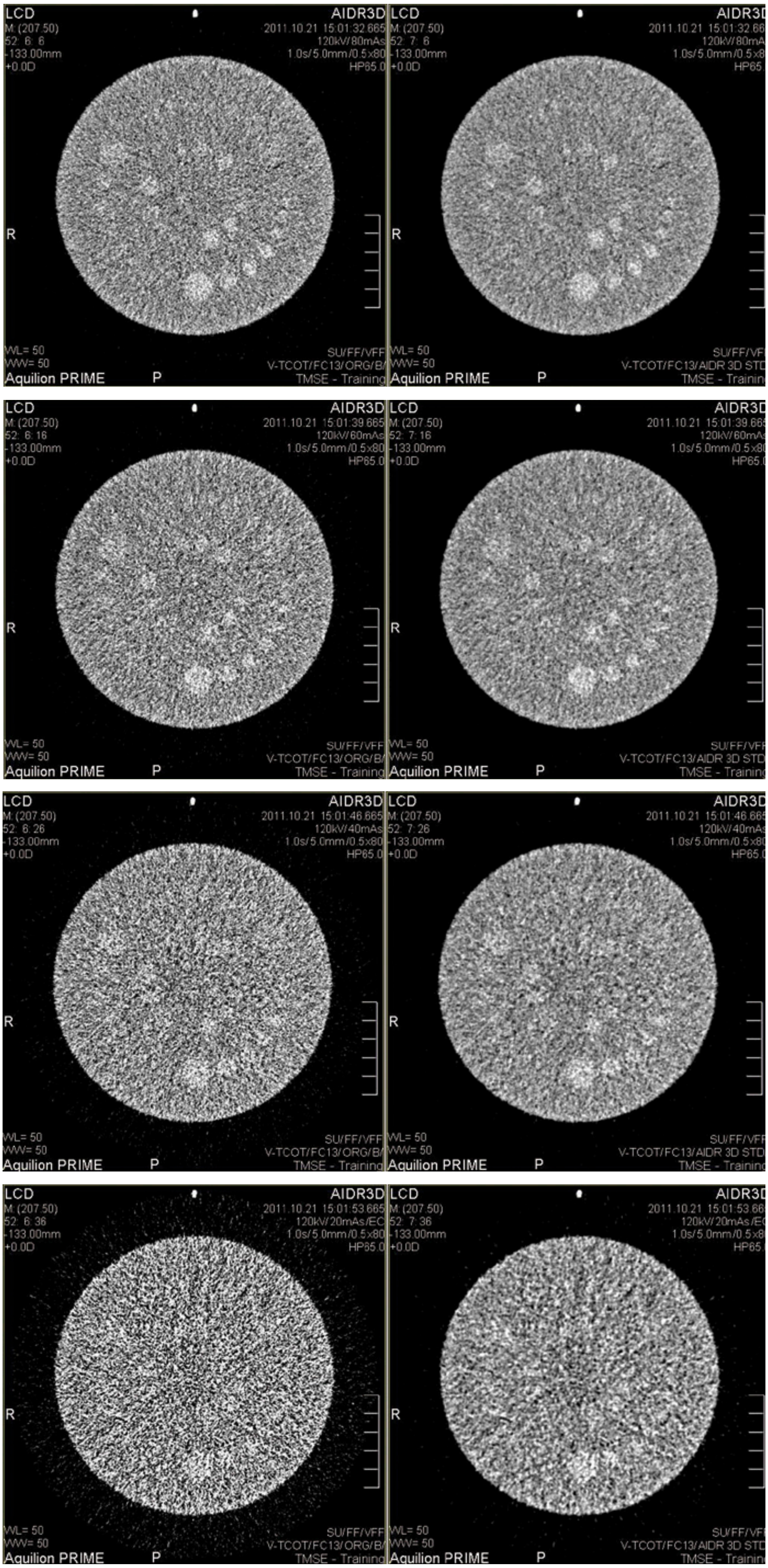
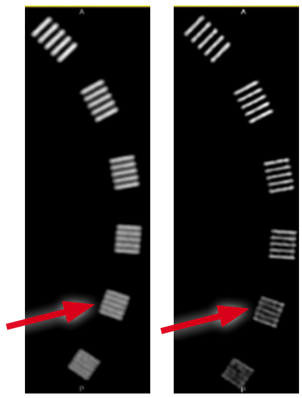


Figure 5 *Low Contrast Detectability: axial images reconstructed using standard FBP (left), and AIDR 3D (right) from a clinical CT scanner. The mAs was reduced from top to bottom: 80, 60, 40, and 20 mAs, respectively, while keeping the kVp and FC filter constant.*



FBP
FC 50
0.5 mm slice

AIDR 3D
FC 52
0.5 mm slice

Figure 6 *Line pair images demonstrating spatial resolution improvement achieved with AIDR 3D (right) compared to the reference FBP image (left). Red arrows show the line pairs visibility improvement from left to right.*

3. Clinical applications

Cardiac

A 75-year old female with BMI of 20 was scanned using the prospectively gated volume mode with Aquilion ONE. SUREExposure 3D and AIDR 3D were used resulting in a DLP of 29 mGy*cm which is equivalent to an effective dose of 0.4 mSv (k-factor = 0.014). Furthermore, in only a 0.35 second scan, coronary CTA using 80 kVp tube voltage produces images presented in Figure 8.

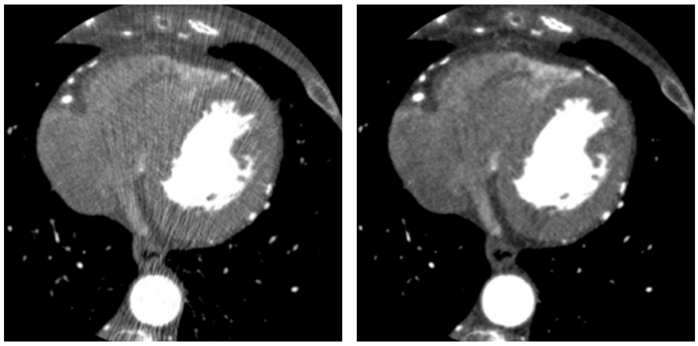


*Figure 8 Cardiac CTA: FBP reconstruction (left) and AIDR 3D reconstruction (right), with a DLP of 29 mGy*cm and an effective dose of 0.4 mSv. Images courtesy of Monash Medical Center, Melbourne, Australia.*

Pediatric

Dose in pediatric imaging is a big concern because the tissues of children are particularly sensitive to radiation. The younger the patient, the higher is the potential risk of radiation. With Aquilion ONE, the dose saving of 18 - 40% has already been reported by Kroft et al. [8]. Furthermore, with 16 cm z-coverage in a single non-helical rotation, use of sedation can be dramatically minimized and even eliminated.

In this example we show that AIDR 3D can reduce the dose even further for a one day old baby with a congenital heart defect. The scan protocol was: 80 kVp, 100 mA, 0.35 seconds, and 80 mm scan range, resulting in a DLP of 6.8 mGy*cm (equivalent to 0.27 mSv). Figure 9 shows the clinical images demonstrating narrowing of pulmonary trunk while there is no compression of the airways.

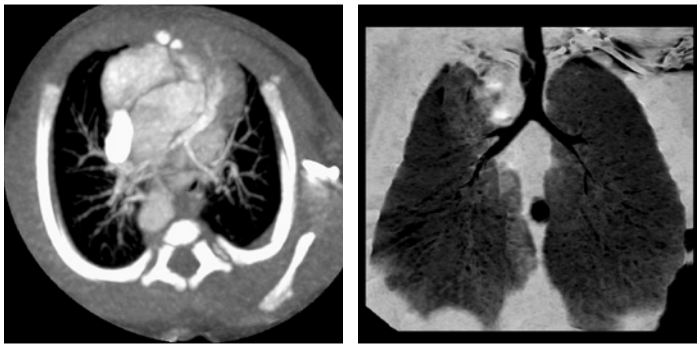


*Figure 9 One day old baby with Tetralogy of Fallot. In 0.35 seconds the infant was scanned with Aquilion ONE and reconstructed with AIDR 3D producing a DLP of 6.8 mGy*cm (equivalent of 0.27 mSv). Images courtesy of Monash Medical Center, Melbourne, Australia.*

Dual Energy

Dual Energy is one of the clinical applications where AIDR 3D can be appropriately applied to. For example, standard abdominal pelvic CT scanning protocols can be converted to Dual Energy protocols by maintaining the same DLP. Tube currents for each energy are chosen so that the image noise of both images is matched.

Figure 10A shows coronal and axial images of a patient with Renal Colic with a total effective dose of just 2.2 mSv. The top row presents images without AIDR 3D while the bottom row with AIDR 3D.

Images reconstructed using AIDR 3D (Figure 10a, left row) demonstrate clear noise reduction from FBP images (Figure 10a, right row). Based on the improved image quality using AIDR 3D, it was decided by the radiologist to increase the SD level in the SUREExposure 3D to save further dose.

The percentage of noise reduction using AIDR 3D is generally about 50%. In CT, image noise is inversely proportional to the square root of dose, hence a factor of two reduction in noise accomplished by AIDR 3D corresponds to a dose reduction of a factor of 4 (i.e. 75%) to achieve the same image noise (SD) as the conventional FBP image. Because the SD has now been increased from 9 to 10 in this example, the corresponding dose reduction was more than 75%.

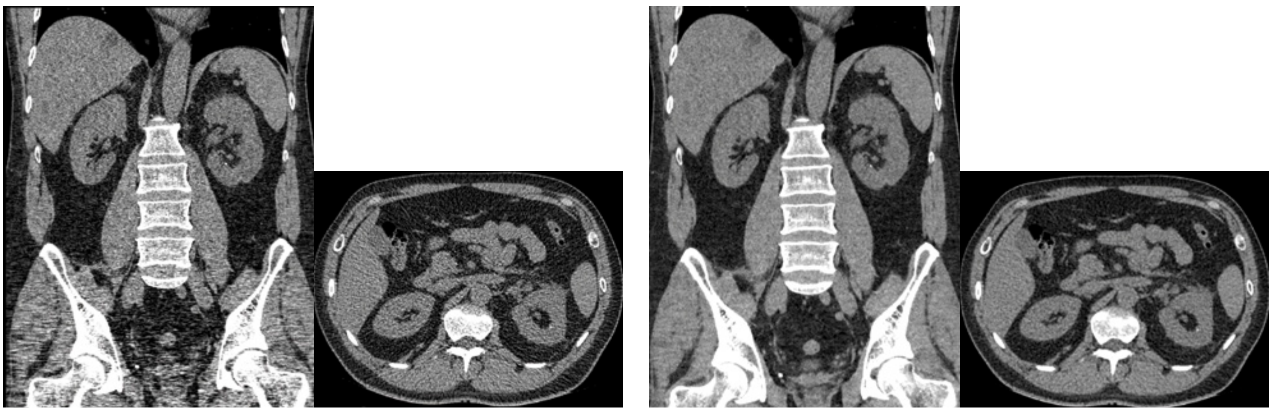


Figure 10a Dual Energy Composition coronal and axial images of patient with Renal Colic: without AIDR 3D (left row), with AIDR 3D (right row). The total effective dose is 2.2 mSv. Images courtesy of Nancy University Hospital (CHU), France.

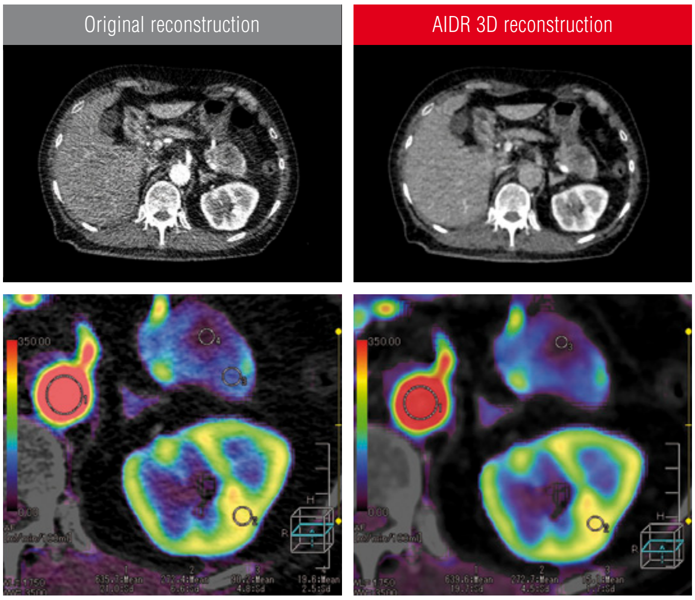


Figure 11 *AIDR 3D (right) was applied to a low dose kidney perfusion protocol: 100 kV, 25 mAs, 16 cm z-coverage, producing an effective dose of 9 mSv (k-factor = 0.015 mGy*cm*mSv-1). Images courtesy of Keio University, Japan.*

Body perfusion

Renal Cell Carcinoma (RCC) is the most common renal neoplasm accounting for cancer. While Ultrasound and MR have been used to detect this disease, body perfusion with CT is becoming a more and more important tool as it produces fast and accurate diagnostic results and allows better evaluation of malignant or benign renal masses.

In Figure 11 we demonstrate a clinical application of AIDR 3D for low dose kidney perfusion performed at Keio University, Japan. With a z-coverage of 16 cm, Toshiba's body perfusion technology guarantees the temporal uniformity across the images. A powerful image registration algorithm was applied to make sure that the mismatch due to the motion during respiration is eliminated.

Using a low dose protocol of 100 kV, 25 mAs for each volume, and a full z-coverage of 16 cm, renal masses can be detected with a total effective dose of below 10 mSv.

Trauma

A fast reconstruction speed is very important mainly in the emergency department. We measured the reconstruction speed with and without AIDR 3D which is below 10% depending on anatomical regions being scanned. Figure 12 illustrates an example of whole body (thorax, abdomen, pelvis) of a trauma patient. A fast helical mode of 80×0.5 mm has been used with helical pitch of 111 and rotation time of 0.35 seconds.

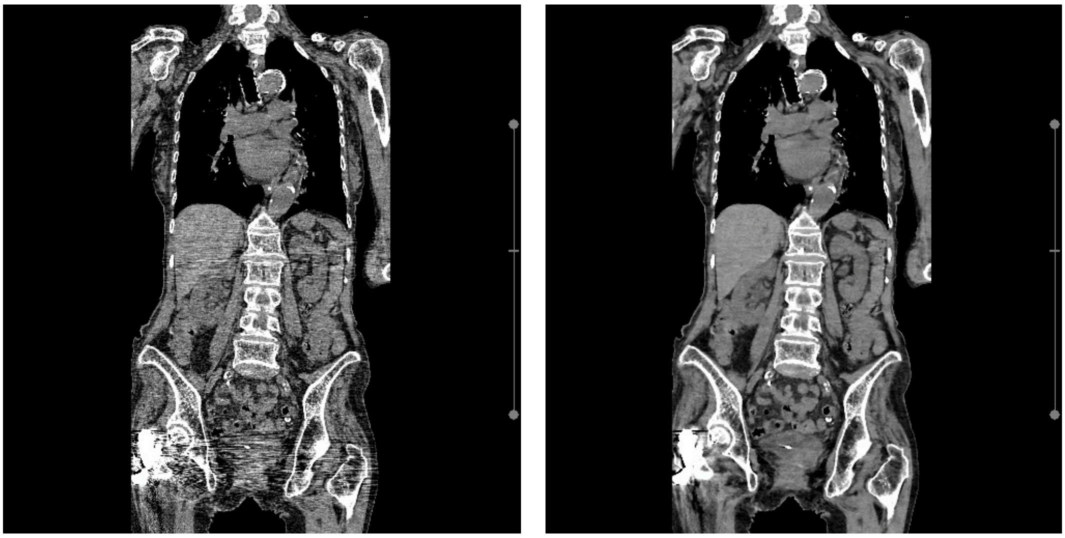


Figure 12 *FBP reconstruction (left) and AIDR 3D reconstruction of a trauma patient. A total scan range was 649 mm. Images courtesy of Fujita Health University, Japan. The reconstruction speed difference between FBP and AIDR 3D was below 10%.*

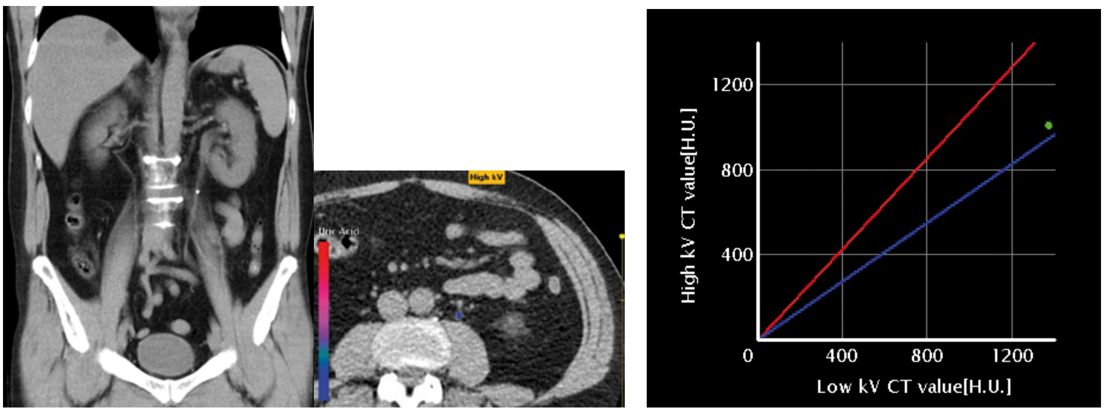


Figure 10b *Example of calcium classification using Toshiba's Dual Energy protocol (referring to Figure 10A). Images courtesy of Nancy University Hospital (CHU), France.*

4. Conclusion

An overview of Toshiba's dose saving technology and AIDR 3D have been described in this paper. AIDR 3D is Toshiba's newest iterative technology which has been designed to be fully integrated into Automatic Exposure Control (SUREExposure 3D). The reported results demonstrate that a dose reduction of 75% or more can be achieved while improving the spatial resolution. Results confirm that the images look natural and clinical details are preserved despite an effective dose of 0.09 mSv for a thorax scan. In terms of reconstruction speed, there is no significant difference between FBP and AIDR 3D processing. This is particularly important for trauma and emergency departments.

In conclusion, it has been demonstrated that the ability to substantially reduce noise in CT images using AIDR 3D produces "natural looking" image quality with almost no penalty in reconstruction speed.

Acknowledgements

We thank Jeff Hall, Chloe Steveson, Henk de Vries, Joanne Schuijf, Niels Smit, René Ceuleers, and TMSC engineering team for their contribution.

References

[1] Joemai RMS, "Ultra Helical scanning - fast acquisition of CT images", VISIONS Vol. 17, pp. 17 - 19 (2011).

[2] Paul N.S. et al., "The reduction of image noise and streak artifact in the thoracic inlet during low dose and ultra-low dose thoracic CT", Phys. Med. Biol. 55 (2010) 1363-1380.

[3] Okumura M. et al., "New method of evaluating edge-preserving adaptive filters for computed tomography (CT): digital phantom method" Japan. J. Radiol. Technol. 62 (2006) 971-8.

[4] Yang Z. et al., "Effective Data-domain Noise and Streak Reduction for X-Ray CT", 11th International Meeting on Fully Three-Dimensional Image Reconstruction in Radiology and Nuclear Medicine, Potsdam, Germany, July 11-15, 2011.

[5] Yang Z. et al., "Adaptive Weighted Anisotropic Diffusion For Computed Tomography Denoising", 11th International Meeting on Fully Three-Dimensional Image Reconstruction in Radiology and Nuclear Medicine, Potsdam, Germany, July 11-15, 2011.

[6] Boedeker K.L., et al., "Application of the noise power spectrum in modern diagnostic MDCT: part I. Measurement of noise power spectra and noise equivalent quanta", Phys. Med. Biol. 52, 4027-4046, 2007.

[7] The phantom laboratory, http://www.phantomlab.com/library/pdf/catphan500-600manual.pdf

[8] Kroft L.J.M. et al., "Scan time and patient dose for thoracic imaging in neonates and small children using axial volumetric 320-detector row CT compared to helical 64-, 32-, and 16- detector row CT acquisitions", Pediatric Radiology 40 (2010).

Made for Life

TOSHIBA MEDICAL SYSTEMS

© Toshiba Medical Systems Europe BV 2011 all rights reserved.
Design and specifications subject to change without notice.
Model: TWPCT0002EA.EU

www.toshiba-medical.eu

MIX
Papier van verantwoorde herkomst
FSC® C016391
FSC www.fsc.org