PURE ViSION Optics: The optimal balance between image quality and dose

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Introduction

In CT imaging, the optimal balance between radiation dose to patients and image quality depends on many factors, including the particular clinical indication for a scan and the size of the patient. Over the years, Canon Medical has introduced a range of technologies to personalize patient dose, including automatic exposure control (AEC) systems, and later, AEC systems that could adjust to each new dose savings technology.

The evolving clinical and technological landscape has posed new challenges to optimizing the balance between image quality and dose.

For example, increasing adoption of dose-saving features, including iterative reconstruction technologies like AIDR (Adaptive Iterative Dose Reduction) 3D and FIRST (Forward projected model-based Iterative Reconstruction SoluTion), has enabled acquisition of diagnostic-quality images at very low radiation doses. In fact, iterative reconstruction has been able to generate diagnostic-quality images at doses so low that the limiting factor in going even lower became low photon counts. Maximizing the benefits of iterative reconstruction algorithms therefore required that we push this limit by developing new hardware: detector technology with the capability of converting more photons into diagnostic quality image data.

As radiation doses acceptable in clinical practice have decreased, patient populations have changed as well. Since 1975, obesity has nearly tripled worldwide, to the point where over a third of the world's population is now overweight or obese[1]. Obtaining diagnostic-quality CT images on large patients poses challenges; adipose tissue preferentially absorbs low-energy X-rays, leading to imaging artifacts. A solution to optimizing imaging for patients of all sizes, by keeping doses low while maintaining diagnostic excellence, is the use of new filtration technology that optimizes the distribution of energies in the X-ray beam.

To make optimal use of new reconstruction methods and to adapt to the evolution of the global patient population, Canon Medical has developed PURE ViSION Optics, new detector and filtration technology launched on the Aquilion Prime SP, Aquilion ONE / GENESIS Edition and Aquilion Precision. The new filtration technology optimizes the X-ray beam, recalibrating the entire imaging chain. The new detector technology then takes the signal and more efficiently converts it into light. The result is an optimal balance between image quality and radiation dose. PURE ViSION Optics improves low-contrast detectability while reducing streak artifacts and noise for low-dose acquisitions. An improvement in low-contrast detectability means that physicians can more easily identify low-contrast anatomical or pathological features. A reduction in streak artifacts means better imaging of anatomical sites with high attenuation, like the shoulder, and also better imaging in the presence of metal artifacts. A reduction in noise at low doses is particularly helpful in imaging large patients and enabling the use of low-dose protocols. By optimizing the balance between image quality and dose, PURE ViSION Optics helps physicians diagnose with confidence.

With the introduction of PURE ViSION technology, we have effectively readjusted the operational range of CT to lower doses. PURE ViSION technology is only one of a variety of dose-savings features that Canon Medical has introduced, including our iterative reconstruction algorithms, AIDR 3D and FIRST; SURE Exposure automatic exposure control; and vHP (variable Helical Pitch), Canon Medical has continuously worked to provide the optimal balance between radiation dose and image quality; PURE ViSION Optics continues this tradition, enabling physicians to provide high-quality patient care.

PUREViSION Optics optimizes imaging performance

The integration of PUREViSION Optics filtration technology with the detector's 40% increase in light output[2-4] yields measurable improvements in image quality, including:

- 12-22% improvement in low-contrast detectability for body and brain imaging at equivalent radiation dose[3,4]
- 13% reduction in noise at equivalent radiation dose[3]
- equivalent low-contrast detectability at 20-31% lower radiation dose for the body[2-4]
- reduced streak artifacts[4]

PUREViSION's optimized imaging performance translates into improved patient care. Low-contrast detectability measures how well a reader can identify low-contrast anatomical or pathological features on images; in clinical practice, such features might include low-contrast liver lesions. Streak artifacts tend to occur when imaging anatomy with high attenuation such as the shoulder, or when imaging near a metal object; PUREViSION reduces these artifacts. When imaging patients (especially large patients) or using low-dose protocols, noise can limit the diagnostic quality of an image. PUREViSION reduces noise without requiring additional radiation dose.

At the same radiation dose, PUREViSION Optics yields a 12-22% improvement in low-contrast detectability[3,4] for body and brain imaging[2]. Figure 1 illustrates PUREViSION Optics performance on phantom images: at the same CTDI value, more of the simulated lesions on the phantom are visible on the images obtained with PUREViSION.

At equivalent radiation dose, PUREViSION can generate images with 13% less noise[2]. Figure 2 illustrates PUREViSION's capability to generate images with high diagnostic content and low noise. A nodule is clearly visible in the axial view on the left panel.

Figure 3 illustrates images of a lung phantom acquired with and without the use of PUREViSION. Note that PUREViSION reduces streak artifacts; the severity of streak artifacts is much less on the PUREViSION image (right panel).

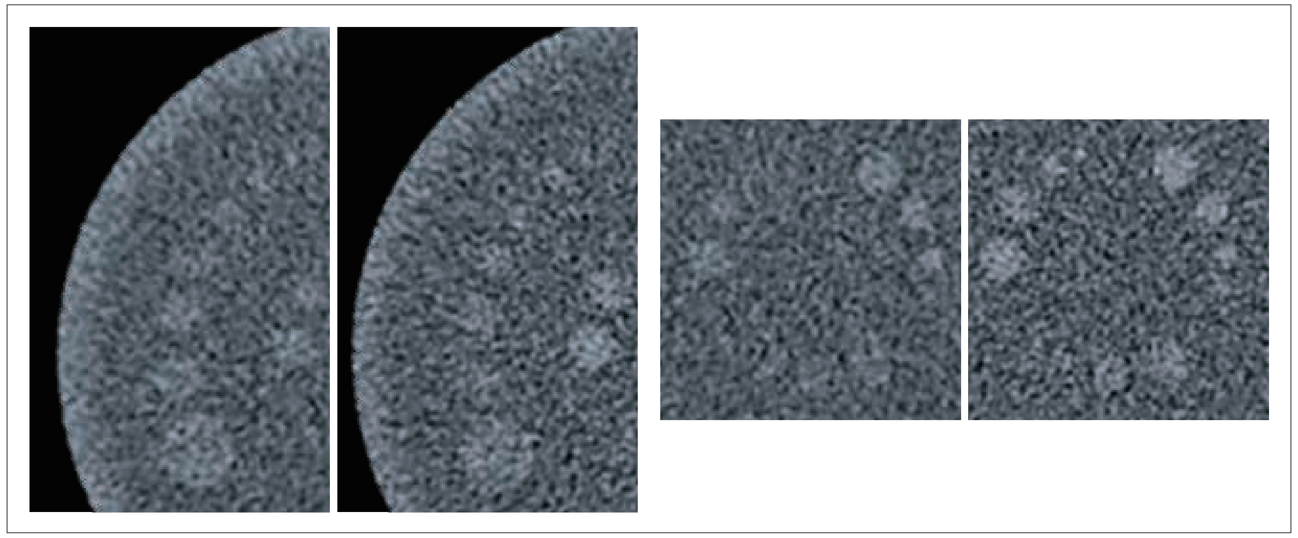

Figure 1 Regions of interest extracted from images of the Catphan® 600 phantom low-contrast module, without (left) and with (right) PUREViSION technology (Aquilion ONE on the left; Aquilion ONE / GENESIS Edition on the right). Both images were obtained at similar CTDI values (left: 58 mGy, right: 59 mGy) and reconstructed with AIDR 3D. At similar CTDI, the PUREViSION image shows improved low-contrast detectability, with more of the simulated lesions visible on the PUREViSION images.

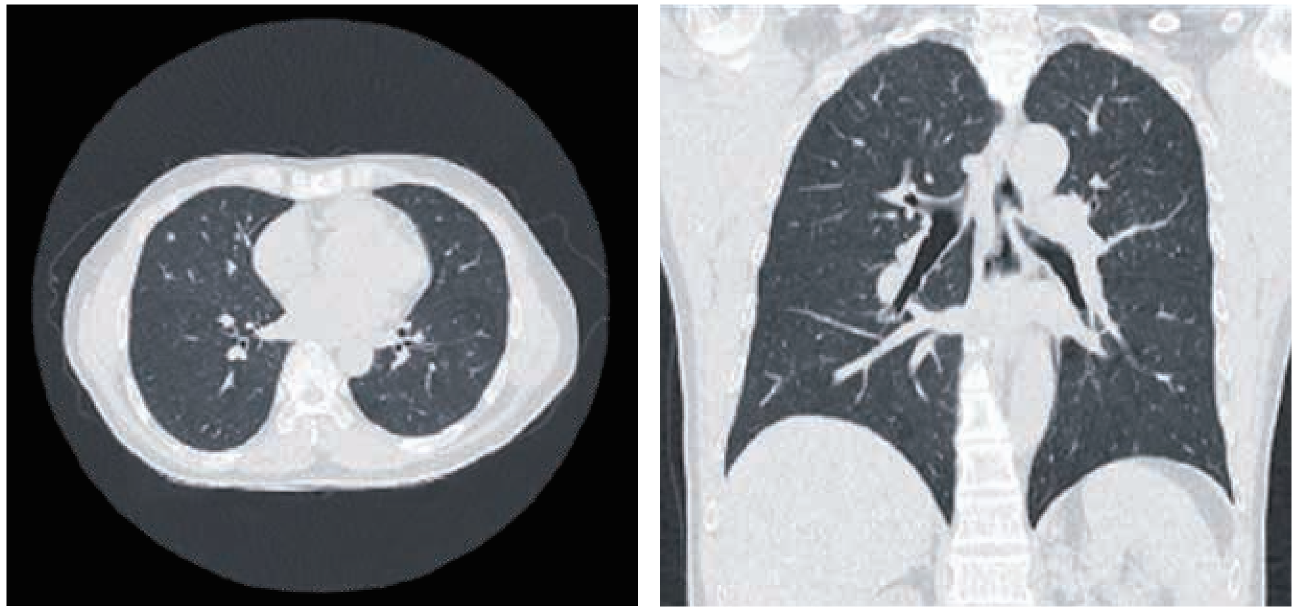

Figure 2 The introduction of AIDR 3D and FIRST iterative reconstruction has pushed imaging systems to ultra-low photon counts. This acquisition, with a nodule clearly visible in the axial view, was obtained at 2.5 CTDI, 98.9 DLP, or 1.38 mSv. PUREViSION technology reduces noise while maintaining high image quality.

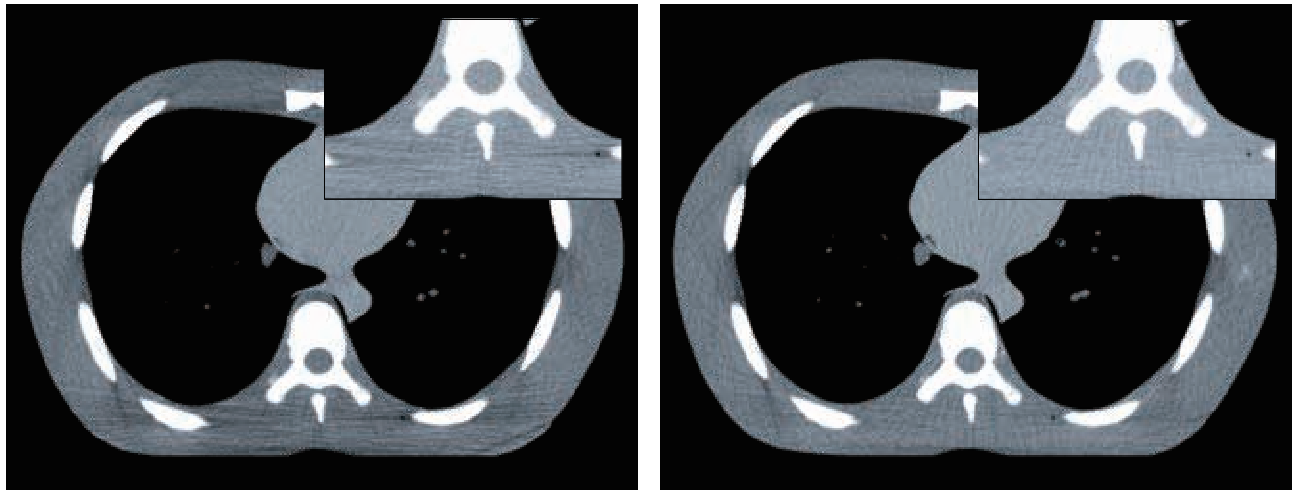

Figure 3 This image shows a lung phantom imaged with conventional (left, Aquilion ONE / ViSION Edition) and PUREViSION (right, Aquilion ONE / GENESIS Edition) technology. Streak artifact reduction is visible in the inset. These are helical scans, obtained at the following parameters: Helical, 120 kV, AEC (SD7@5 mm, FC13, AIDR 3D Standard) , 0.5 s/r , 0.5 mm × 80, HP111, 350 mmΦ, FC03, AIDR 3D OFF, CTDIvol 6.7 mGy. Display parameters: WW=300, WL=30.

PUREViSION Optics prioritizes patient safety

Canon Medical strives to provide imaging tools to generate diagnostic-quality images using the lowest achievable radiation doses. For body CT, model observer studies demonstrate that PUREViSION yields equivalent low- contrast detectability at 20-31% less radiation dose[2]. Figure 4 illustrates the dose reduction on lung images, with the image on the right obtained at approximately half the CTDI as the one on the left.

The dose reduction that PUREViSION achieves has a demonstrable impact on patient care. Figure 5 shows the results of tracking dose on 1800 patients at Fujita Health University Hospital, the largest single medical facility in Japan. Of the patient cohort, eight hundred patients were imaged with the filtration technology that would ultimately become an element of PUREViSION Optics. The remaining one thousand patients were imaged with conventional optics. The results show that the average dose delivered to the patients was lower with PUREViSION filtration in place.

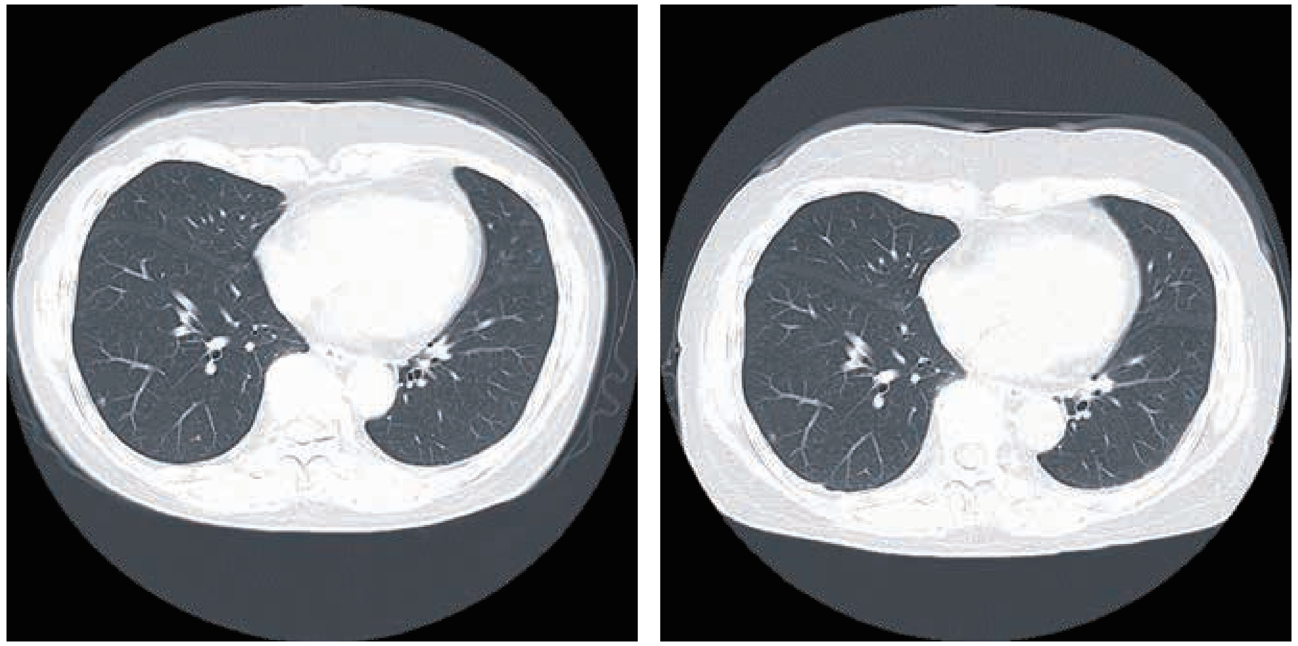

Figure 4 These images obtained without (left) and with (right) PUREViSION show similar image quality, at approximately half the CTDI; the left image was obtained at CTDI of 13.9 mGy; the right image at 7.2 mGy. The images were reconstructed at 5 mm slice thickness, with AIDR 3D Mild (FC 52) SD 10. Images courtesy of Fukuoka Wajiro Hospital, Japan.

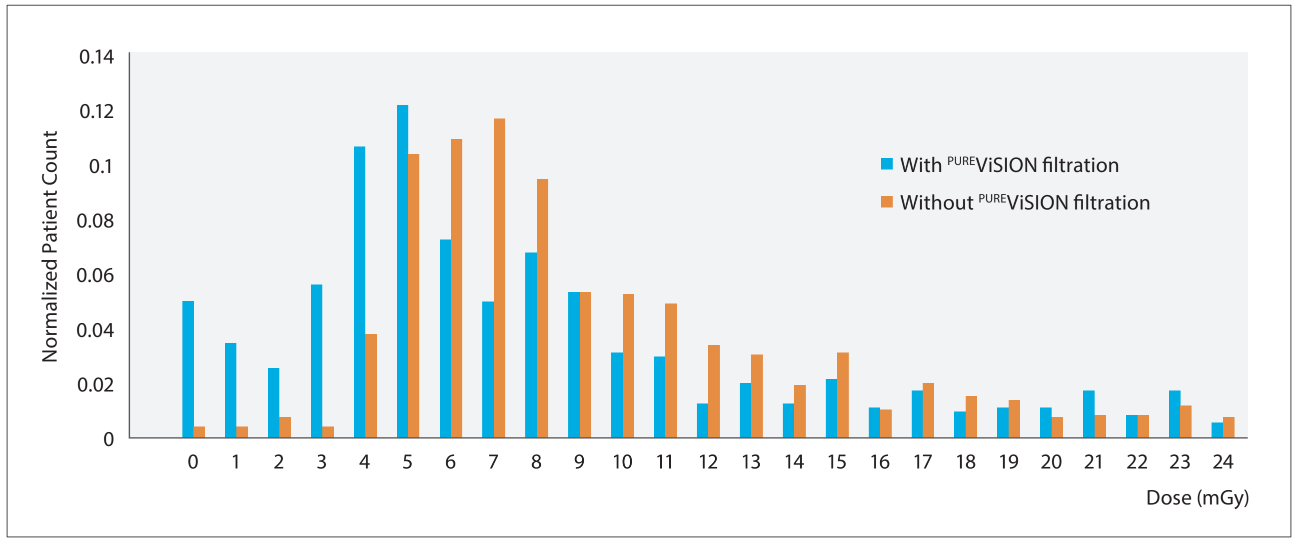

Figure 5 Frequency distribution of radiation doses delivered to 1800 patients at Fujita Health University Hospital, Japan. All patients were scanned on the Aquilion ONE / GENESIS Edition; 800 with and 1000 without the upgraded filtration technology that is now a component of our PUREViSION Optics. The new filtration technology resulted in a lower mean dose. Dose values were obtained using Vitrea™ Vitality Dose Tracking software.

PUREViSION Optics transforms routine CT imaging: A clinical case

"With PUREViSION Optics we experience a dramatic reduction in radiation dose in combination with much better image quality."

Dr. Russell Bull, MRCP, FRCR
Consultant Radiologist, Royal Bournemouth Hospital
Bournemouth, United Kingdom

A 77-year-old man presented at the Royal Bournemouth Hospital radiology department for a follow up scan after an aorta stent placement for a type B dissection. A CTA examination of the aorta was requested to rule out complications after surgery.

The type B dissection is visible in the follow-up scan (Figure 6) two years after treatment. Contrast is visualized within the false lumen of the thoracic aorta without expansion of the lumen, indicating that the dissection is stable.

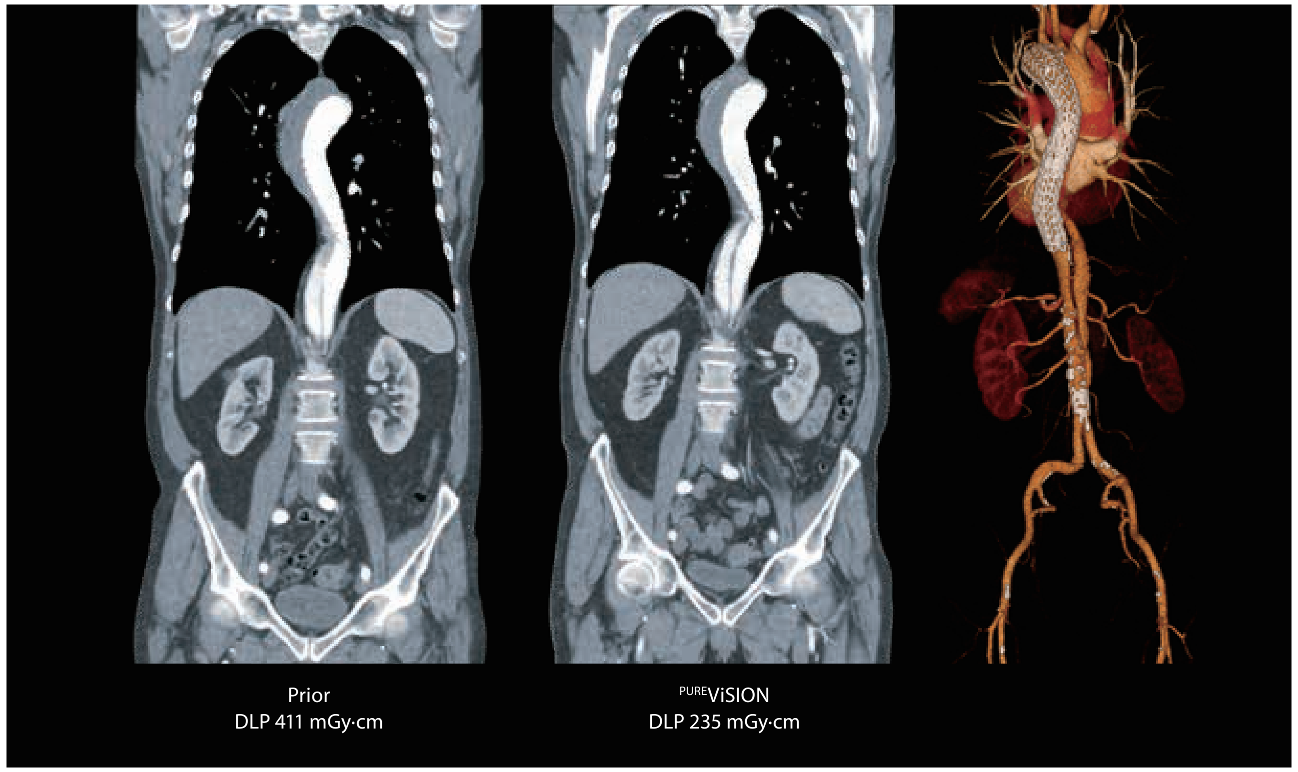

Figure 6 CTA of aorta, without (Left) and with (Right) PUREViSION Optics.

This case demonstrates the capabilities of PUREViSION technology: The scan performed with PUREViSION Optics technology is clearer, has fewer artifacts, and was acquired at a reduced radiation dose.

PUREViSION Optics optimizes the imaging chain

To meet the challenges of today's clinical environment, PUREViSION Optics optimizes each step of the imaging chain, from X-ray generation and transmission to X-ray detection.

X-ray generation:
Beam shaping by PUREViSION Optics

CT imaging begins with emission of radiation from the X-ray tube's anode. The emitted X-rays are polychromatic, consisting of photons with a range of energies. Figure 7 shows a schematic of an X-ray spectrum.

Figure 8 illustrates PUREViSION Optics' improved filtration, which optimizes the X-ray spectrum by removing more low-energy photons. The result is a beam with a higher effective energy, known as a "harder" beam.

Harder beams are better able to penetrate dense anatomy (such as the bony skull). Harder beams also minimize the relative radiation dose absorption of low energy, or "soft," X-rays. Since the human body, and also iodinated contrast, preferentially absorb lower-energy, soft X-rays, these soft X-rays contribute to the radiation dose that a patient receives without contributing information to the resulting CT image. The use of a harder beam therefore enables more photons to contribute to the image. The harder beam helps optimize the balance between image quality and dose.

Because the X-ray beam becomes harder as it passes through tissue that preferentially absorbs the softer X-rays, pre-emptively removing the lower energy photons also reduces artifacts that would otherwise result from this beam hardening, potentially improving imaging of larger patients.

Although harder beams can reduce low-contrast detectability, by optimizing both filtration and detection, PUREViSION actually enhances low-contrast detectability, as illustrated in Figure 1.

X-ray detection: PUREViSION detector technology increases light output and decreases noise for low-dose imaging

The PUREViSION detector (Figure 9) offers 40% more light output and reduces noise. Figure 10 shows the ratio of the raw photon counts at the detector, using our upgraded filtration technology. With the upgraded filter, more photons reach the detector, which contributes to the improved light output.

Traditional detector manufacturing methods require the reassembly of detector rows into a matrix array which can result in imperfections, reducing X-ray conversion efficiency. To manufacture the PUREViSION detector, the entire scintillator array is produced from a solid ceramic ingot. This process reduces imperfections, ensuring superior luminescent properties.

Each individual PUREViSION detector element is delineated using precision micro-blade technology. The resulting septa (spaces between detector elements) are narrow, maximizing the surface area available for X-ray absorption. The use of microblade technology to cut the scintillator yields straight, smooth edges. The clean edges and near-microscopic septa permit more X-rays to interact with the scintillator, increasing the number of photons detected and the detection efficiency of the detectors. More scintillation means more light output and more output means more signal. In other words, rather than increasing radiation dose to increase signal, the detectors themselves avoid signal loss, capture more X-rays, and, in turn, allow for lower-noise image acquisitions.

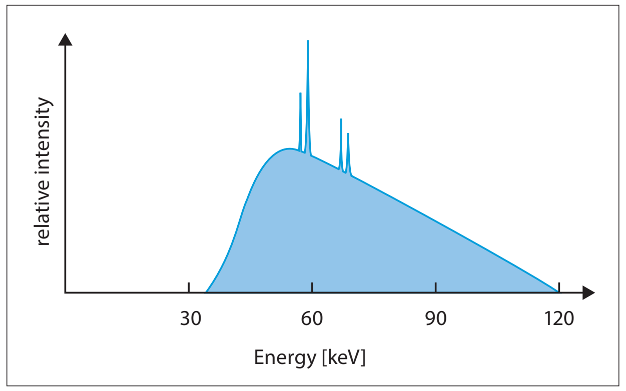

Figure 7 A typical X-ray spectrum, showing the distribution of energies within a beam.

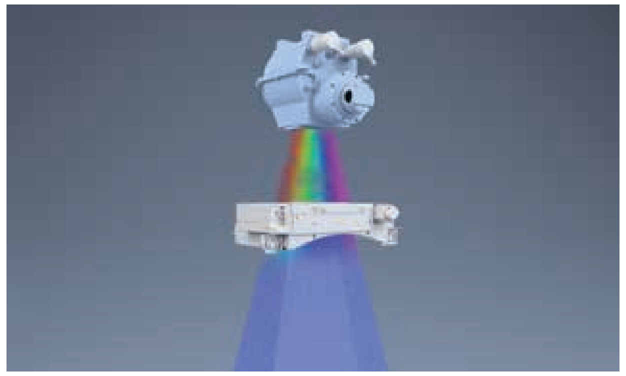

Figure 8 An X-ray tube generates photons at a range of energies (illustrated by the rainbow spectrum). Filtration removes the lower-energy components, leaving a more homogeneous beam.

Figure 9 PUREViSION detector technology, from the Aquilion ONE / GENESIS Edition

Figure 11 demonstrates noise reduction by the PUREViSION detector. The data are from images of a 40 cm diameter water phantom.

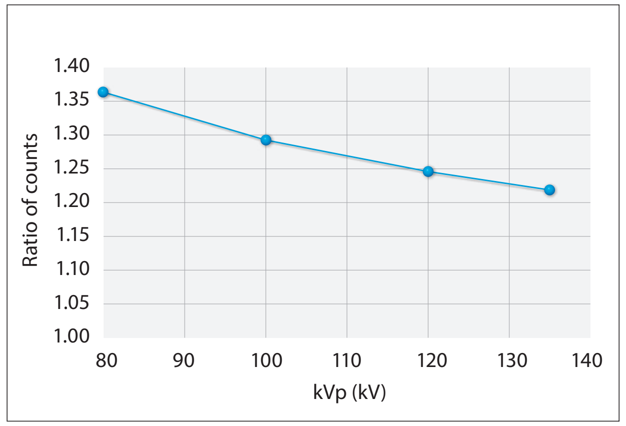

Figure 10 Raw photon counts at detector vs. kVp, for PUREViSION vs. conventional filtration. The improved filtration not only results in a harder beam but in more photons reaching the detector, meaning more information that can contribute to the final image. At 80 kVp, the photon counts are approximately 40% greater.

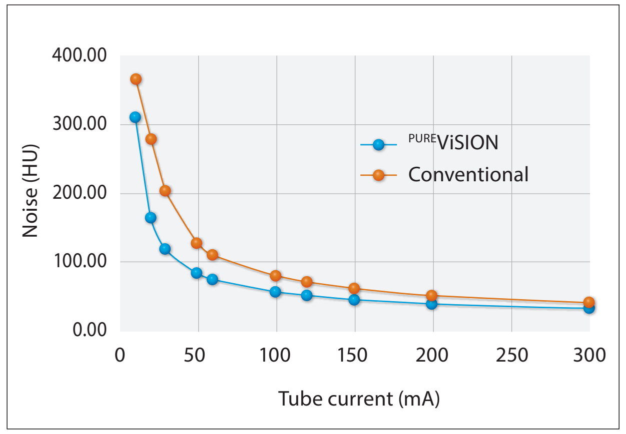

Figure 11 Image noise for a conventional detector versus the PUREViSION detector, 40 cm diameter water phantom. Note that the PUREViSION detector demonstrates lower noise at all dose levels due to improved detector output. The noise reduction is more significant at lower doses due to a reduction in electronic noise. Lower noise translates to less need for signal and lower dose.

Canon Medical's scientists and engineers have a history of innovation in CT detector design. Since 1999, the Aquilion CT has had the smallest detector apertures in the industry. Nearly 20 years later, Canon Medical has further improved on that record, with the introduction of the world's first 0.25 mm aperture clinical CT detector, available in the Aquilion Precision. The PUREViSION detector is the result of many years of refining and perfecting detector design, with the goal of high quality, low-dose imaging.

Conclusions

The challenges of today's clinical environment, which require imaging larger patients and imaging at lower doses, were the key drivers of the development of PUREViSION Optics.

The integration of PUREViSION Optics' filtration technology with the detector's 40% increase in light output[3,4] yields measurable improvements in image quality, including:

- 12-22% improvement in low-contrast detectability for body and brain imaging at equivalent radiation dose[3]
- 13% reduction in noise at the same radiation dose[3]
- equivalent low-contrast detectability at 20-31% lower radiation dose[2-4]
- reduced streak artifacts[4]

PUREViSION Optics optimizes the X-ray spectrum to achieve a better balance between image quality and dose, and includes new detector technology that can accommodate a range of imaging needs from ultra-low dose chest CT to advanced dynamic 4D imaging.

PUREViSION's performance is apparent in clinical images, in performance testing, and most importantly, in daily use: The data in Figure 5 demonstrate a reduction in dose over a sample of 1800 patients in a hospital, showing how PUREViSION impacted patient care and safety. PUREViSION makes quantifiable improvements in low-contrast detectability, noise and patient dose, empowering healthcare providers to meet the challenges of today's clinical environment and deliver the best possible patient care.

References

1. World Health Organization. Obesity and overweight. World Health Organization. [Online] February 16, 2018. [Cited: September 7, 2018.] http://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight.
2. All results are based on measurements of detectability from a model observer study (non-prewhitening observer) on the FDA-MITA head and body phantoms. Please see "Computed Tomography Image Quality (CTIQ): Low-Contrast Detectability (LCD) Assessment When Using Dose Reduction Technology (NEMA/MITA WP 1-2017). NEMA Medical Imaging & Technology Alliance Document, July 7, 2017 for methodology.
3. Aquilion Prime SP compared to Aquilion PRIME.
4. Aquilion ONE / GENESIS Edition compared to Aquilion ONE.

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