NAEOTOM Alpha with Quantum Technology

Whitepaper: The technology behind photon-counting CT

How photon-counting works and the benefits it provides

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Introduction

Throughout the history of computed tomography (CT), radical innovations have redefined how images are produced and how CT can support radiologists and clinicians in their clinical decision making: Spiral CT in 1990, Multislice CT in 1998 and Dual Source CT in 2005, for example. NAEOTOM Alpha® is the latest radical innovation in computed tomography, bringing the world's first photon-counting detector CT to the clinical space with the introduction of the QuantaMax™ detector.

NAEOTOM Alpha is the culmination of decades of research, and represents a paradigm shift in imaging that will redefine CT for years to come.

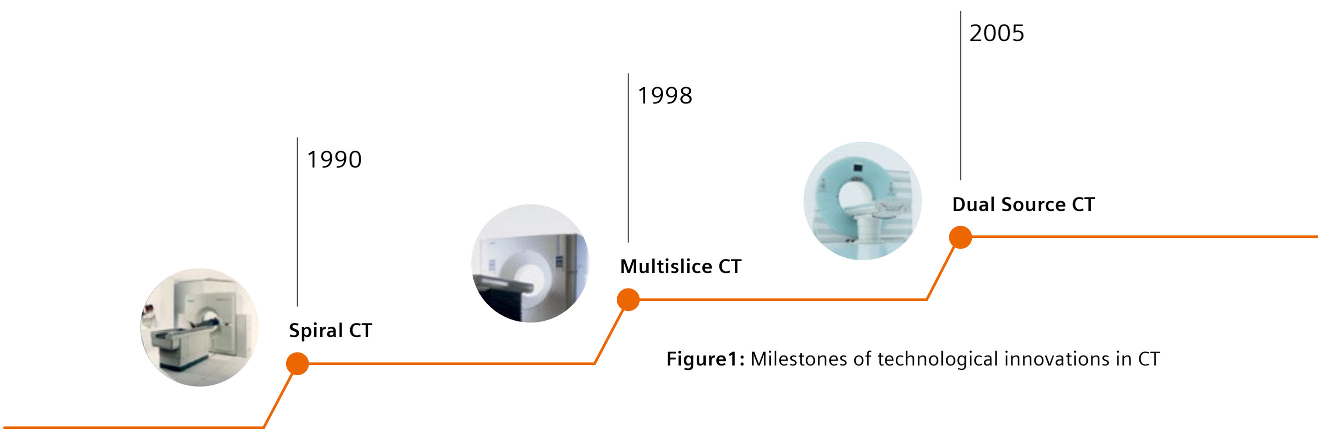

Figure1: Milestones of technological innovations in CT

The new QuantaMax™ detector and Quantum Technology enable higher spatial resolution and improved contrast-to-noise ratio (CNR) when compared to conventional energy-integrating detectors, plus elimination of electronic noise and intrinsic spectral sensitivity. Whether your clinical need is using virtual monoenergetic images to standardize scans, increase iodine enhancement, suppress metal artifacts, examining virtual noncontrast images or iodine maps, viewing vessel lumen unobstructed by calcium or tapping into a suite of post-processing applications to quantify and classify disease, spectral imaging opens the door to precision medicine so you can get the right diagnosis.

Combination of Quantum Technology with Dual Source architecture

NAEOTOM Alpha is a high-end Dual Source CT system that provides additional capabilities in performance, data management and workflow. For cardiac imaging, the use of the new QuantaMax™ detectors with Dual Source geometry allows for high spatial resolution with spectral information without compromises in temporal resolution, which is maintained at 66 ms.

This combination allows you to characterize coronary plaque, assess the myocardium, or plan a structural heart procedure, even in patients with calcifications.

With the Turbo Flash mode, it is now possible to use higher pitch values, as high as 3.2, while still obtaining spectral information. This means there is no need to compromise between acquisition speed and the functional information provided by spectral imaging, for example, when imaging pediatric patients without sedation.

NAEOTOM Alpha has a large, 82 cm bore and uses two powerful Vectron™ X-ray tubes, with power reserves of 240 kW (2 × 120 kW/tube) that aid in achieving high diagnostic image quality for patients regardless of their size. This also enables enough photon flux to successfully image at high temporal resolution and low tube potential. The small focal spot of 0.4 mm × 0.5 mm according to IEC (International Electrotechnical Commission), combined with both the smaller detector pixel size and a new reconstruction engine optimized for Quantum Technology, enables image reconstruction at levels of details not seen before with Siemens Healthineers CT systems: 0.2 mm in-plane and 0.4 mm slice thickness in standard mode, and 0.11 mm in-plane and 0.2 mm slice thickness using ultra-high resolution mode [2]. During acquisition, the QuantaMax™ detectors produce 6 to 8 times as much raw data as conventional Dual Source predecessor systems.[1]

An improved gantry data chain and powerful image reconstruction computing hardware supports the increased data transmission demands.

Contents

[1]*Data on file*

The QuantaMax™ Detector: Why Quantum Technology is different

Conventional energy integrating X-ray detection technology

Conventional energy integrating detectors (EID) employ a scintillation (light producing) layer made from a solid state ceramic in which incident X-rays are converted into light in a process known as luminescence [1]. This detector technology has been available since the early 1990s and is used in almost all clinical CT systems available from the major vendors. The intensity of light produced is proportional to the X-ray energy (Figure 2). This light is collected by photodiodes and subsequently converted into electrical signals for further processing. The amplitude of the induced current pulse is proportional to the total energy of the absorbed X-ray photons. An analog-to-digital converter (ADC) then digitizes the signal. The photodiodes and ADC can be combined into a single ASIC (application specific integrated circuit) layer, reducing the signal pathlength. The electric current is integrated over the measurement time of each frame (projection) and results in a cumulated signal of all pulses during this time, while the energy information of the incident X-rays is not retained.

Quantum photon-counting detection technology

Photon-counting detectors (PCD) on the other hand, do not require a ceramic scintillation layer. Instead they employ a semiconducting material (cadmium telluride – CdTe) in which incident X-rays directly produce an electrical signal (Figure 3). The semiconductor crystal itself is home-grown in Siemens Healthineers dedicated facilities in Japan and Germany. A constant external voltage applied across the semiconductor (typically on the order of several hundred V) causes electrons to be accelerated towards an array of pixelated anodes and produces a short pulse of current (typically lasting around 10 ns). Electrical circuitry transforms these current pulses to voltage pulses, with the resulting height of the voltage pulse (and thus the number of electrons) being proportional to the energy of the absorbed x-ray photon. This results in the ability to "count" every pulse produced and discriminate every X-ray photon energy level, and thus provide multispectral imaging. The hardware on NAEOTOM Alpha supports multispectral imaging with up to four energy bins.

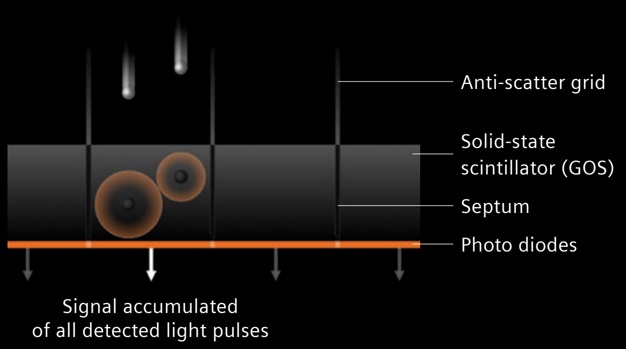

Figure 2: X-ray detection principle of an energy integrating detector (EID)

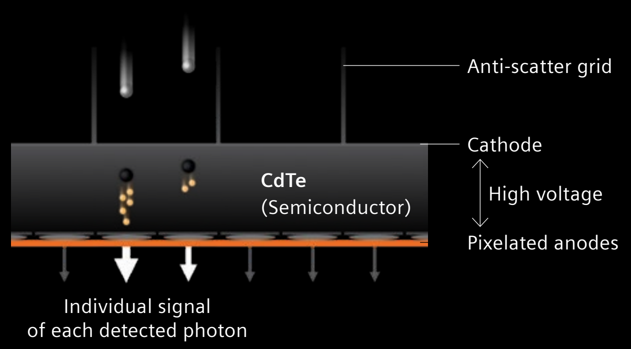

Figure 3: QuantaMax™ photon-counting detection principle whereby photons are detected directly in the semiconductor material rather than a detection process requiring an intermediate scintillation step

Direct conversion of X-ray photons to electrical signal

Usage of a semiconductor material, rather than a traditional scintillator, eliminates the need for the intermediate light-producing step traditionally required by X-ray detector materials used in CT imaging. In scintillating materials, light spreads out into a sphere once X-ray energy is deposited into the scintillator. To ensure that the light produced by scintillators is retained only in the incident detector element, each detector pixel is physically shielded from others by optically reflecting septa. With semiconductors, these septa are no longer required in between each pixel in the QuantaMax™ detectors. This ensures the detector grid has no "dead space" in between individual pixels [3], in turn improving the detector efficiency due to increased active area of photon detection, allowing for dose reduction while maintaining comparable quality.

Imaging benefits of QuantaMax™ detectors and Quantum Technology

Smaller detector pixels and higher spatial resolution

Traditional EIDs require physical septa between the photodiodes in order to avoid optical cross-talk between neighboring detector pixels causing misdetection of X-ray photons. This limits the amount of space within the scintillating layer for active detection of X-rays. For the QuantaMax detector, each "large" pixel defined by the collimator blades (0.4 mm × 0.4 mm) can be further sub-divided into smaller sub pixels (read out separately by the ASIC) to increase spatial resolution. These sub-pixels reach a minimum pixel size of 0.2 mm × 0.2 mm, resulting in an in-plane (x-y) resolution of 44.3 lp/cm (at 2% MTF).

Elimination of electronic noise

Electric charge is collected for a fixed time in a detecting pixel on the ASIC called the integration time, with a resulting current pulse typically lasting around 10 ns. As a threshold can be applied digitally to the pulse height on analysis, electronic noise can subsequently be removed from the detection process. The threshold is typically set at around 20 keV and is optimized to be just above the low-amplitude baseline noise. This enables improved image quality in patients who are obese and for scans with an overall lower radiation dose while still maintaining stable, reproducible CT numbers for quantitative CT imaging.

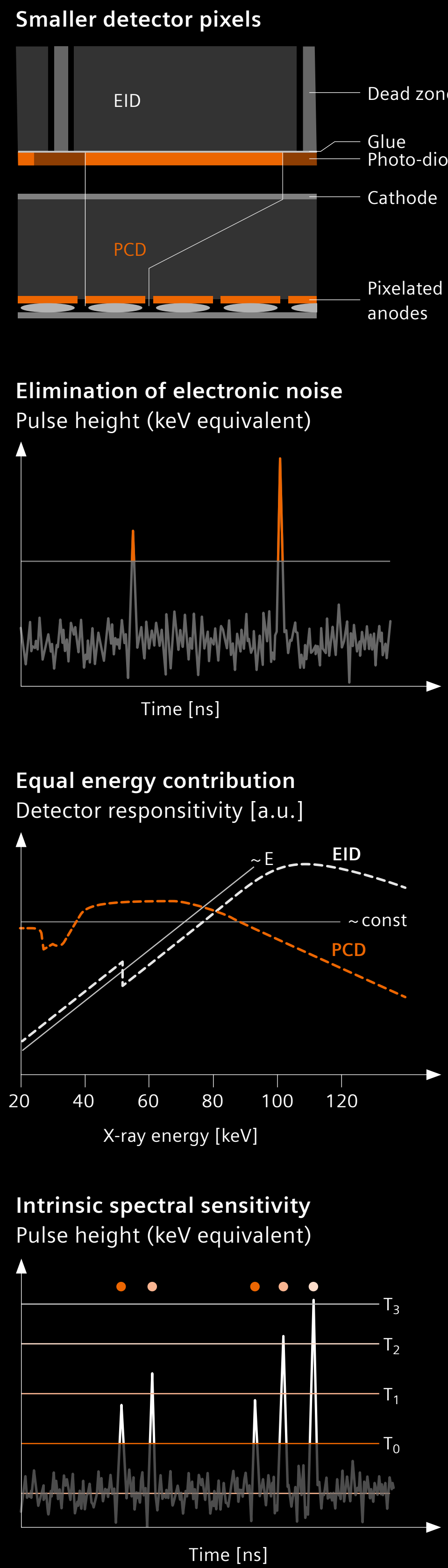

Figure 4: Benefits of using QuantaMax™ detectors demonstrating smaller pixels, the elimination of electronic noise, energy weighting and energy thresholding

Equal energy contribution

In a traditional EID, the response of the detector over the range of photon energies used in clinical CT imaging is not constant but rather proportional to photon energy [3]. However, X-ray photons with lower energy carry most of the low-contrast-information required by many imaging tasks. This results in low-energy X-rays (i.e., those below the K-edge of iodine) contributing less to the detector signal. Compared to an EID, the QuantaMax™ detector weights photons equally, leading to an enhanced iodine signal. This allows for lower iodine contrast dose, without sacrificing enhancement or image quality [6].

Intrinsic spectral sensitivity

When the QuantaMax detector registers a current pulse that exceeds the threshold for electronic noise, it is sorted into one of four energy bins—according to the measured pulse height in keV. The detector thereby always acquires a spectrally resolved signal—regardless of scan speed or temporal resolution.

Tube and Detector specifications

Tube

Tube type	2× Vectron™				
High voltage power (kW)	2 × 120				
Tube voltage (kV)	70	90	100	120	140
Max. current @ tube voltage	1300	1300	1200	1000	857
Tube current range (mA)	10–1300				
Nominal focal spot values according to IEC 60336:2005/ anode angle to reference axis	0.4 × 0.5 / 8°		0.6 × 0.7 / 8°		0.8 × 1.1 / 8°

Detector

Number of Detector arrays	2× QuantaMax (A & B)
Detector coverage	2 × 6 cm
Detector field of view	500 mm (A), 360 mm (B)
Collimation	Standard modes: 144 / 96 / 48 × 0.4 mm slices Ultra-high resolution mode: 120 × 0.2 mm slices
Minimum rotation time	0.25 s

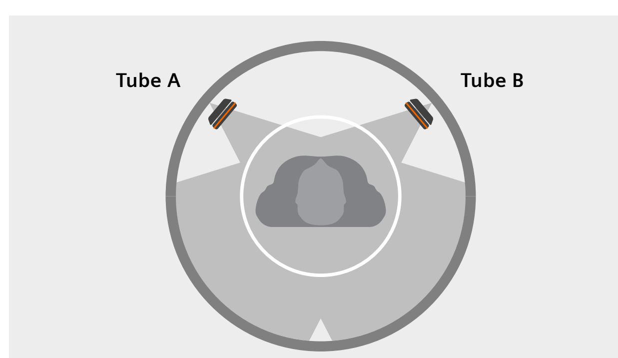

Figure 5: Schematic showing dual-source configuration

Scanning workflow and image reconstruction

To match the groundbreaking new QuantaMax™ detector technology, Siemens Healthineers has built a powerful new spectral reconstruction and post-processing engine to make the most out of every image.

One of the most exciting promises of Quantum Technology is the intrinsic spectral sensitivity, allowing spectral information with every scan, with full spatial and temporal registration. NAEOTOM Alpha performs low- and high-energy thresholding at the detector, allowing spectral reconstruction right from the start. Furthermore, all photons below the lowest threshold—the noise floor—can be discarded, leading to less noise in the image [4].

Quantum Technology allows the use of material decomposition techniques, enabling the quantification of clinically-relevant materials such as iodine, calcium, and soft tissue.

All the established spectral techniques integral to your clinical workflow

Spectral capabilities include the classic spectral post-processed series from Siemens Healthineers Dual Source Dual Energy products. With 120 kV or 140 kV tube potential, virtual monoenergetic images are available between 40–190 keV in the so-called "QuantumPlus" scan modes (see next page), and Virtual Non-contrast (VNC) and iodine maps allow for quantitative iodine assessment.

New possibilities with Spectral imaging

In addition to virtual monoenergetic, iodine, and VNC images, Quantum Technology opens the door for expanded material-classification postprocessing techniques such as calcium removal and calcium maps, kidney stone classification[1], gout detection[1], bone marrow edema analysis[1] and more. New exciting opportunities will also be enabled such as selectively removing iodine or calcium in gated coronary CTA examinations; which will open the door to better assess the vessel lumen [5], or selectively remove iodine and robustly estimate the calcium score in the same examination [7]. As photon-counting CT technology continues to evolve, Siemens Healthineers will continue to develop new algorithms to address a wide variety of clinical needs.

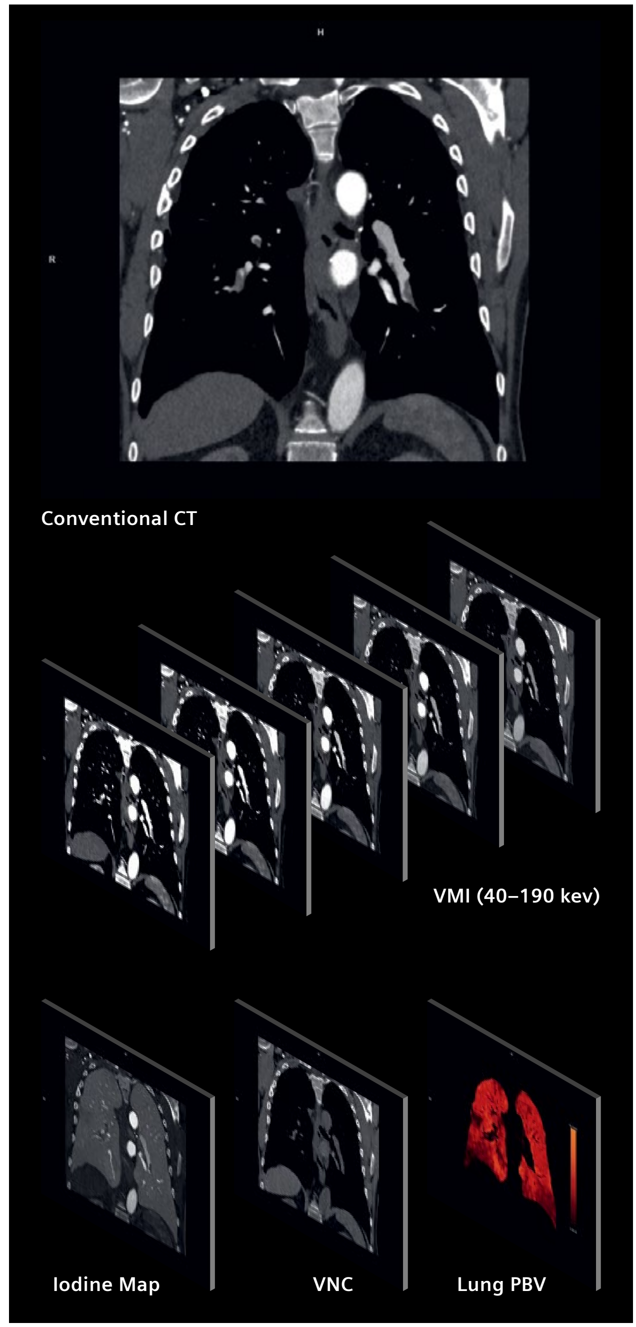

Figure 6: Due to its specral sensitivity, NAEOTOM Alpha is able to produce—in addition to a conventional CT image—a range of spectral results for every exam. In this example: Virtual Monoenergetic Images (VMI), Iodine Map, Virtual Non-Contrast (VNC), and Lung Perfused Blood Volume (Lung PBV)[1].

[1]*Kidney stone classification, gout detection, bone marrow edema analysis are under development. Not available for sale.*

Scan modes for non-gated exams

Like all Siemens Healthineers scanners running the SOMARIS X platform (SOM/X), NAEOTOM Alpha uses special keywords in the scan mode description to convey what features are available.

- **Ultra-high resolution (UHR):** Capable of 0.2 mm slice thickness and 110 µm in-plane resolution. For visualizing the smallest details such as bone trabecula, microvasculature, and the stapes and modiolus in the inner ear.
- **Quantum:** Virtual monoenergetic images available based on selected kV, used with low-kV (< 120 kV) and/or tin filter. Access quantitative images and lower-dose low kV imaging simultaneously.
- **Quantum Plus:** Full suite of spectral capabilities; virtual monoenergetic images, VNC, and iodine maps. Available with 120 and 140 kV scans. Ideal for vascular imaging in CT angiography (CTA) and soft tissue imaging with contrast with strong iodine signal in virtual monoenergetic images reconstructed at low energies (e.g., 55 keV or 60 keV), or in patients with metal implants for metal artifact reduction in virtual monoenergetic images reconstructed at higher energies up to 190 keV.
- **Quantum Plus UHR** (available with system version VA50): Full suite of spectral capabilities as in Quantum Plus, even in ultra-high resolution acquisitions.
- **QuantumSn:** Quantum imaging with tin filtration, ideal for low-dose screening exams.

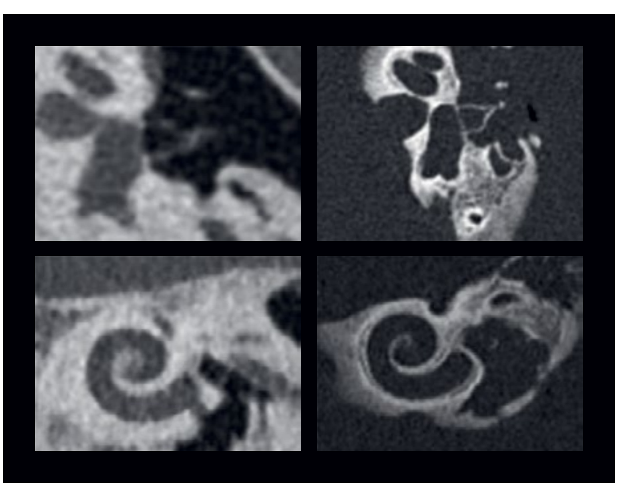

Figure 7: Ultra-high resolution image of inner ear specimen displaying stapes bone (top row) and cochlea (bottom row) acquired with EID-CT using 0.4 mm collimation (left column) and PCD-CT using 0.2 mm collimation (right column)
Image Courtesy of A. Persson, University Linkoeping, Linkoeping, Sweden

Cardiac ECG-gated modes

- **Dual Source:** Sequential and spiral cardiac modes available, especially for high or irregular heart rates.
- **Turbo Flash:** Single beat high pitch Dual Source cardiac CT acquisition at up to 737 mm/sec with 66 ms temporal resolution for low-dose cardiac scanning.

Quantum technology is enabled by Quantum Beam Hardening Correction, allowing reduced beam hardening artifacts, and automatically enabled for Quantum and Quantum Plus scans.

Noise and dose reduction techniques

These scan modes are enabled by the latest iterative reconstruction engine made specifically for photon counting, Quantum Iterative Reconstruction (QIR). QIR offers 4 levels of iterative reconstruction strength, leaving room for radiologist preference and task-dependent noise reduction.

Quantum Iterative Reconstruction is our approach to apply model based iterative reconstruction to spectral data produced by a photon-counting detector. Building on the excellent performance of our proven ADMIRE reconstruction algorithm, QIR splits the raw data coming out of the detector into two data streams, separated by energy level. Both raw data streams enter into the iterative loops separately. However, to ensure perfect geometric alignment between the different energy levels, synchronization points are implemented in both the projection data loop as well as the image data loop.

The fully synchronous data streams then undergo spectral processing out of which the spectral maps and monoenergetic images are created.

Get the right dose and image quality, every time

CARE keV is a task-based dose reduction algorithm that helps you get the right dose, for every patient and every exam. Similar to CARE kV, CARE keV allows the user to choose the task to optimize for: Non-Contrast, Bone/Calcium, Soft Tissue with Contrast, or Vascular. With knowledge of the imaging task, the algorithm can select the monoenergetic image level and required dose appropriate for the exam.

CARE keV includes an adjustable image quality (IQ) level, which can be increased for better image quality, or decreased for higher dose savings. For a selected IQ level and task, the algorithm picks the right acquisition kV, reconstruction keV, and dose for your scan. CARE keV accounts for the increased dose efficiency and CNR of lower keV images, letting you maximize dose savings without compromising on quality.

All SOM/X scanners have an adjustable IQ level, allowing image quality standardization across your entire SOM/X fleet of CT scanners, for confidence in the prescribed dose and resulting image. CARE keV IQ level integrates seamlessly with CARE Dose4D, so all dose reduction strategies are in one place. CARE keV can be operated in full mode with CARE Dose4D, in manual kV mode, or turned off.

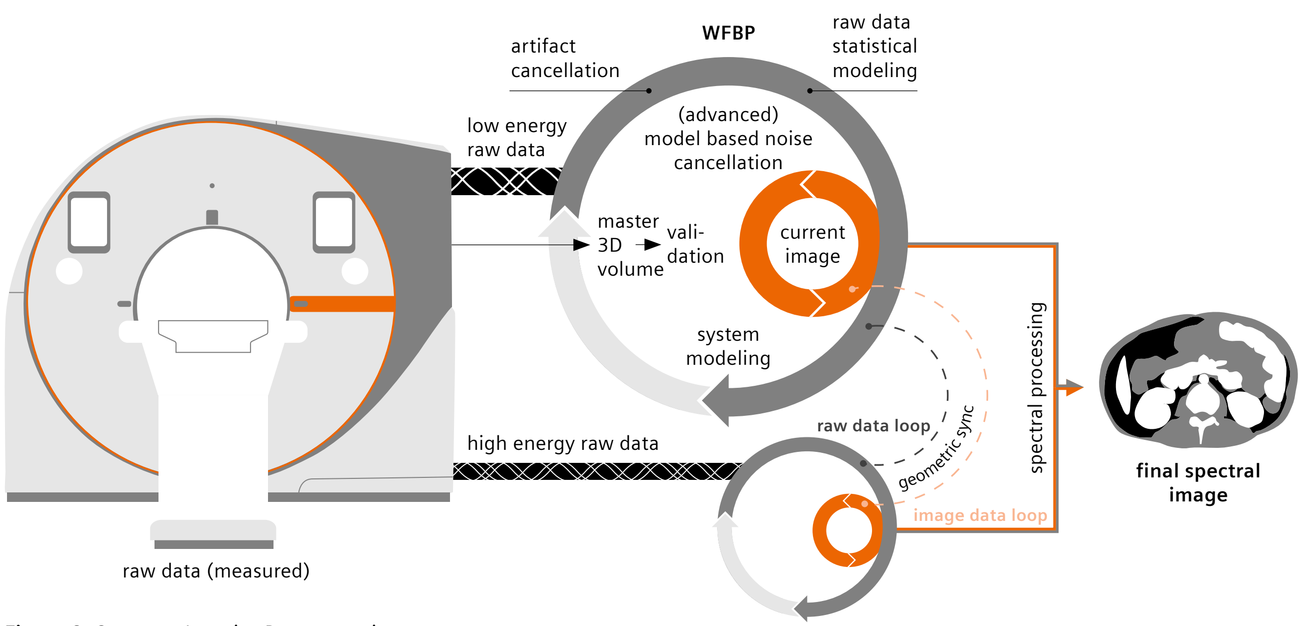

Figure 8: Quantum Iterative Reconstruction

Workflow and standardization

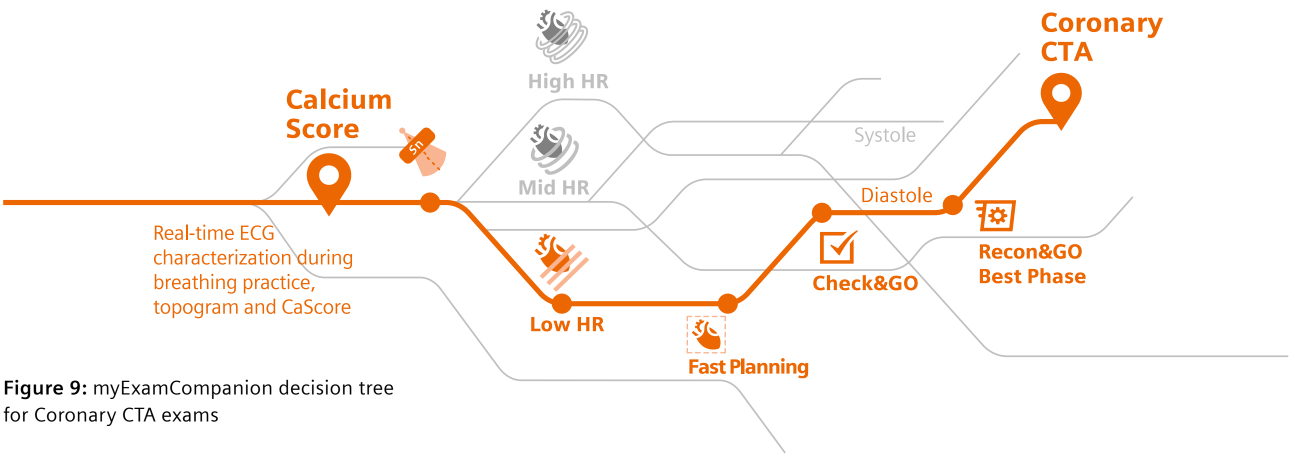

Figure 9: myExamCompanion decision tree for Coronary CTA exams

To harness the full potential of NAEOTOM Alpha, a seamless workflow is needed. Patient-friendly features include visual patient instructions, an AI-powered automated patient positioning with the FAST 3D camera, and mobile workflow with a tablet so the CT technologist can spend more time near the patient.

At the scanner, **myExam Companion** aids in selecting examination protocols based on individual patient characteristics. Depending on the selected examination type, **myExam Companion** will automatically aid in selecting acquisition parameters that will determine radiation exposure and acquisition speed. With every acquisition, high spatial resolution and spectral information is available. The image workflow has the flexibility to provide radiologists with the image series that will be most relevant for the diagnosis.

With NAEOTOM Alpha, monoenergetic images can always be reconstructed regardless of the tube voltage during acquisition. This means that the acquisition technique can be optimized to reduce radiation dose while still being able to obtain a consistent output image to enable quantitative imaging. In the example of Figure 10, a phantom image with various inserts was scanned with 3 different tube voltages. With standard CT using EIDs, a different image contrast would be achieved for each scan. However, with Quantum technology, the output can be standardized regardless of the acquisition tube voltage. This provides great opportunities for oncology and applications where serial imaging is required so that one can concentrate on tracking physiological changes rather than changes induced by the acquisition and reconstruction technique.

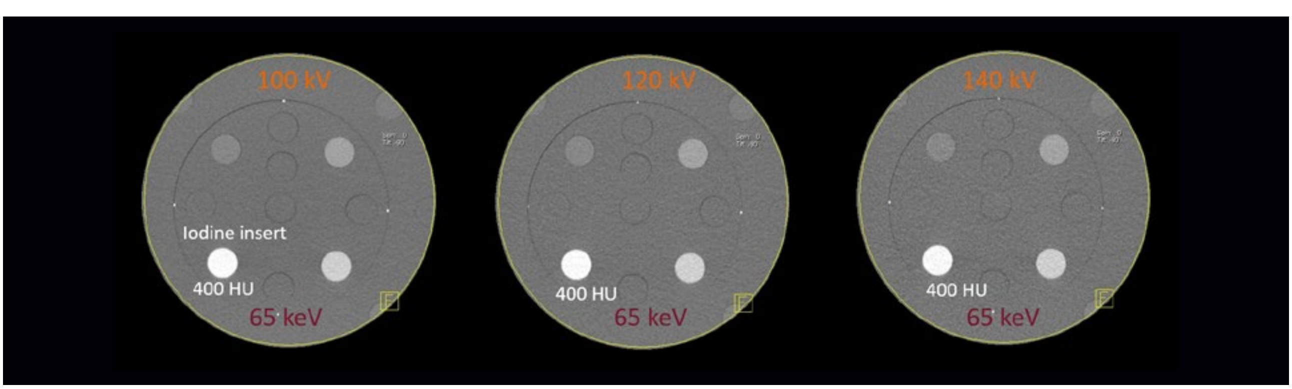

Figure 10: Output standardization. Regardless of the tube potential used during acquisition, we can standardize the output images using monoenergetic imaging.

Conclusion

NAEOTOM Alpha represents a new era in CT imaging. 50 years after the first ever CT scan was performed on a human, a clinical photon-counting system is finally here. Behind the powerful QuantaMax™ detectors are a seamless workflow, an easy-to-use interface, and clinical integration. NAEOTOM Alpha is ushering in a new area of CT standardization, more flexible imaging, and diagnostic excellence.

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How photon-counting works and the benefits it provides

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