Evolve to Essence

Essence technology, a new scalable platform for optimizing image quality

Abstract
Recent trends in multidetector computed tomography (MDCT), such as increasing scan speed, coverage, and resolution, have enabled a wide range of clinical advancements in one of the most useful diagnostic devices of modern medicine. However, for some routine and advanced applications, optimization of image quality and other factors — such as radiation dose and workflow — can vary considerably in radiological practice, and could be simplified for application to broader patient populations.

To address this, many years of Philips research and development for the Brilliance CT platform have culminated in a set of scalable innovations for present and future scanners, referred to collectively as Essence technology. These innovations include multiple enhancements of the X-ray tube, detector, and image reconstruction system, that were designed to deliver a new level of MDCT image quality optimization. In addition, Essence technology is seamlessly integrated with dose-management techniques and a rich suite of advanced image analysis and enterprise applications to streamline workflow.

Phantom and other scan-related measurements demonstrate the application-specific and intrinsically-available performance gains of Essence technology that ease the optimization of image quality along with other imaging factors. Clinical results illustrate how this platform synergistically provides significant imaging benefits for challenging applications. The scalable Essence technology platform has extra capacity that holds promise to enable MDCT results not previously possible and to facilitate improved clinical decisions and patient care.

PHILIPS

Introduction

Beginning with the introduction of the Twin detector CT scanner in 1992 (Philips), trends in MDCT have continually increased the number and diversity of emerging examinations while improving imaging performance for routine applications (Table 1).

Table 1: Increasing MDCT Trends
coverage per second
longitudinal resolution
temporal resolution
rotation speed
tube power
number of channels
reconstruction performance

These trends include adopting diagnostic and therapeutic procedures in earlier stages of the care cycle over a wider range of disease conditions and across broader patient populations. In addition, MDCT has been employed for some examinations, such as angiography, that were formerly performed with other invasive imaging modalities.

With this expansion, unique challenges and opportunities for routine image quality optimization remain for many applications, body regions, and patient populations (Table 2). Accordingly, optimization of patient-specific imaging factors without trading off the as low as reasonably achievable (ALARA) principle and other factors can vary in radiological practice.

Table 2

Patient Population or Body Region	Challenge
Cardiac	To image small and rapidly moving coronary arteries with a low X-ray dose.
Abdominal	To image subtle changes in low contrast lesions, such as the monitoring of response to therapy.
Pulmonary	To image dyspneic patients with small lesions and rapidly distributing contrast agents at high resolution with a low X-ray dose.
Pediatric	To image restless patients with a low X-ray dose.
Bariatric	To maintain image quality for thoracic and abdominal scans.

Scalable enhancements to the main components of the MDCT imaging chain, referred to as **"Essence technology,"** were designed to meet these challenges and to further the expansion of MDCT (Figure 1). The synergistic set of scalable Essence technology components provide application-specific and intrinsically available performance enhancements that optimize image quality across broader populations, as well as streamline workflow and simplify X-ray dose management. Ultimately — and most importantly — these performance enhancements have extra capacity to facilitate improved clinical results for both today's challenging routine applications and for future applications.

Components of Essence technology

Essence technology includes scalable enhancements to the **MRC tube**, the **Nano-Panel detector**, and the **RapidView reconstruction engine** for the Philips Brilliance CT 64-channel scanner and future MDCT scanners (Figures 1 and 2). There are nine enhancements (Figures 3-11) coupled with a set of dose-management techniques, such as **DoseRight**[11], and a rich suite of advanced image post-processing and enterprise applications to streamline workflow. Each Essence technology component is explained in the following sections in terms of:

- ***Design rationale***, (Figures 3A-11A),
- ***Performance enhancements***, as measured with phantom images and tests of scan performance and durability (Figures 3B-11B), and
- ***Clinical benefit***, as illustrated with a clinical example (Figures 3C-11C).

These components are seamlessly integrated with the Brilliance CT advanced gantry control system to create a new synergistic level of performance beyond individual component enhancements.

Essence technology imaging chain components deliver image quality optimization.

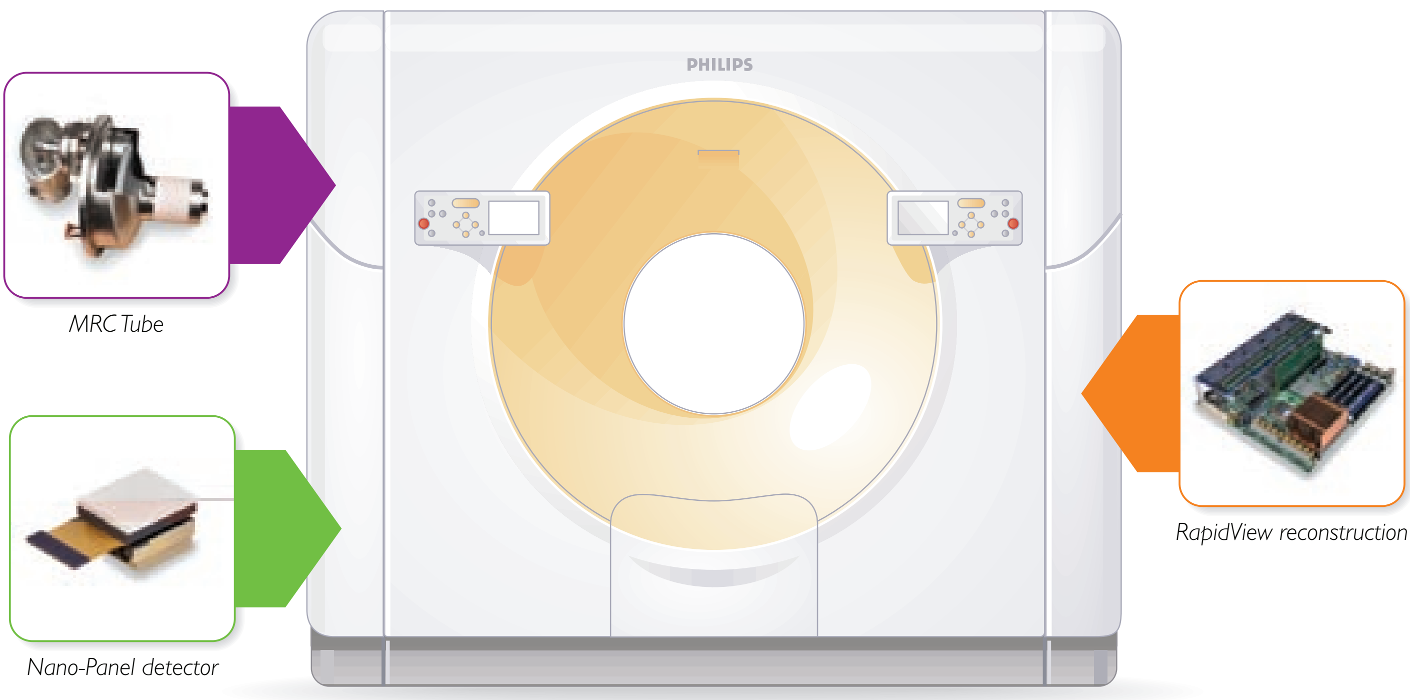


Figure 1: Essence technology components of the MDCT imaging chain shown on the Brilliance CT 64-channel scanner. MRC Tube, Nano-Panel detector, and the RapidView reconstruction engine.

Essence technology components are designed on a scalable MDCT platform.

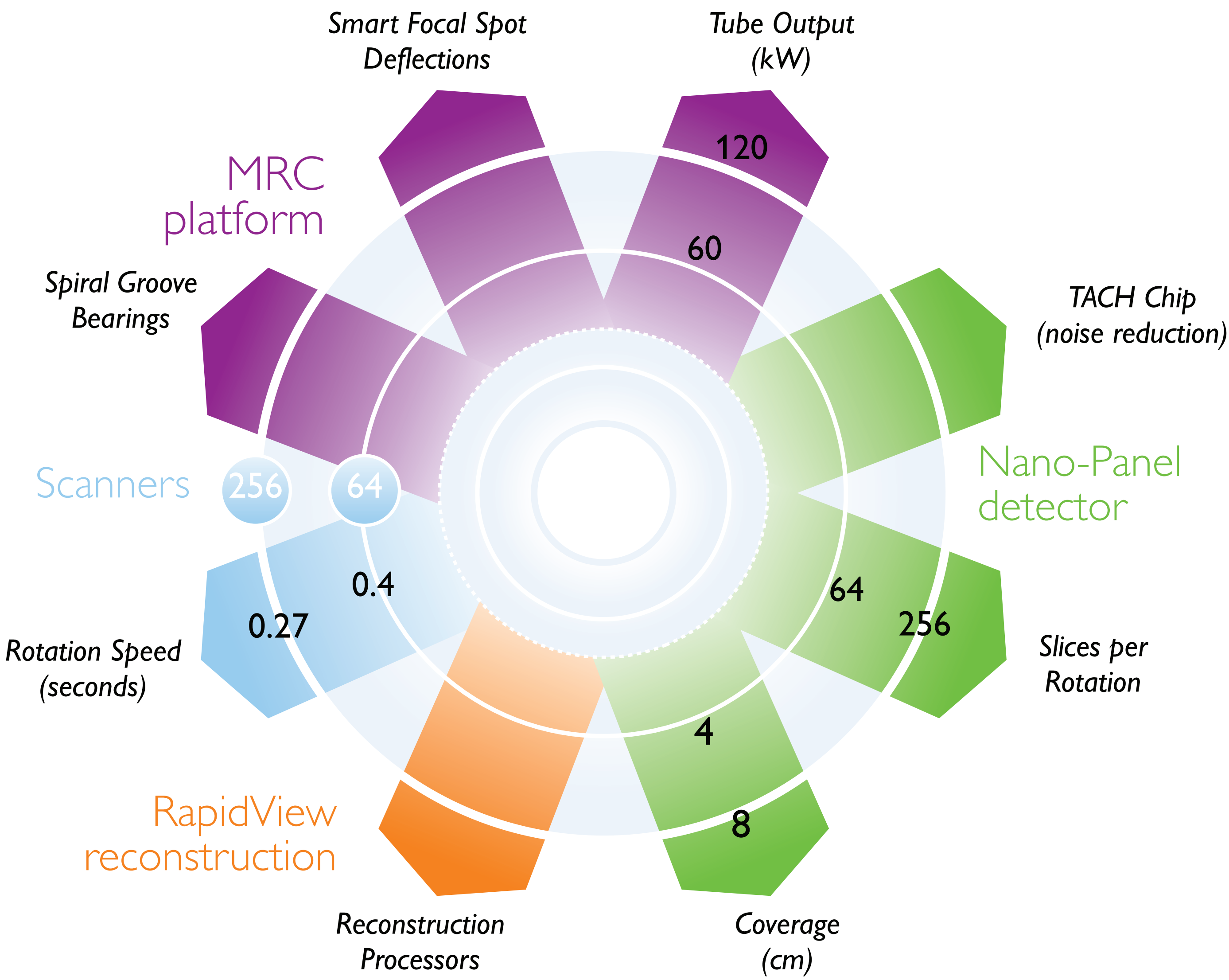


Figure 2: Essence technology component enhancements are designed on a scalable MDCT platform and are represented as radial vectors. Center contours represent present and future Brilliance CT scanners.

MRC X-ray Tube

Challenging routine and emerging MDCT applications can place high thermal demands on X-ray tube performance. These can include the need to reliably deliver high initial power, maintain tube current for full body and dynamic scans at high rotation speeds, and sustain stable targeting of a smaller focal spot.

The Maximus Rotalix Ceramic (**MRC**) tube platform, undergoing continuous improvements since its original introduction nearly two decades ago, provides the solution. Recent quantum-leap refinements of the **MRC** tube (Figures 1A and 2), at the origin of the MDCT imaging chain, include the **Segmented Anode** (Figure 3) and the **Spiral Groove Bearing** (Figure 4). These refinements were designed to meet the increased tube performance demands of MDCT and patient throughput, while maintaining tube dependability and inherent capacity for all examinations. The **MRC tube** has also been designed with a dual focal spot targeting mechanism, the **Smart Focal Spot**, to double the number of in-plane ray-samples and projections (Figure 5).

Segmented Anode

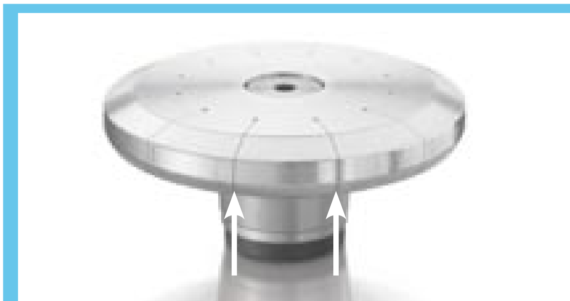


Figure 3A

Description: The MRC anode is segmented with several slots (arrows) that improve tube life by providing stress relief from the rapid heating and cooling cycles that occur in high power, fast MDCT scans.

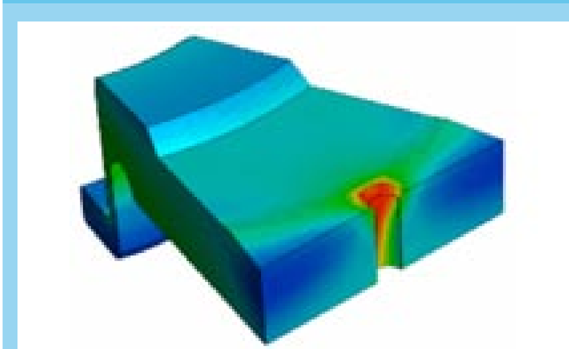


Figure 3B

Performance Result: Computational testing shows that the use of anode segments relieves and controls the distribution of stress areas throughout the anode when simulating an extraordinarily high number of energy loads.

Figure 3C

Clinical Benefit: The MRC tube performance with the **Segmented Anode** is especially highlighted in Cardiac CT examinations. Both Step & Shoot Cardiac and spiral retrospective CT angiography examinations (left) require high tube power for short duration scans.

Spiral Groove Bearing

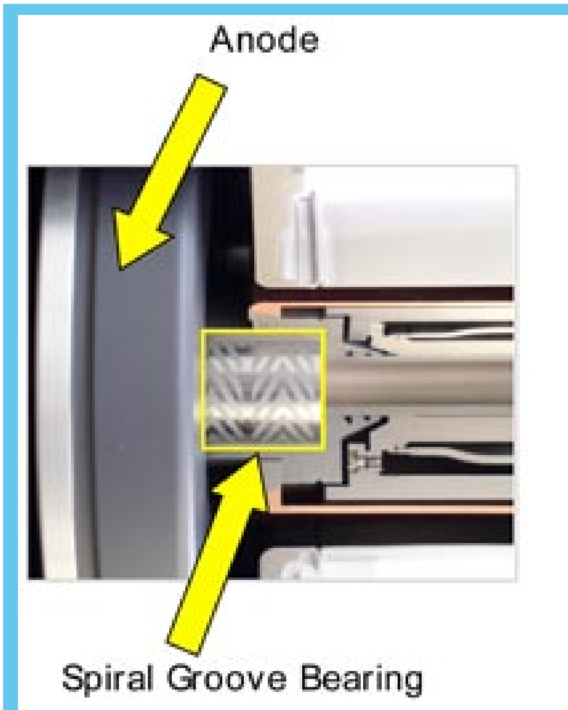


Figure 4A

Description: Spiral grooves in the bearing are designed to increase thermal conductivity and cooling. The grooves also provide rotational stability for the focal spot which helps to optimize spatial resolution and allows for noiseless operation from the liquid-bearing interface.

Figure 4B

Performance Result: The bearing's spiral (herringbone) groove pattern has less surface wear and imperfections relative to conventional bearings. It also maintains better rotational track registration and stability, a technology that is also used in computer hard drives with higher track density.

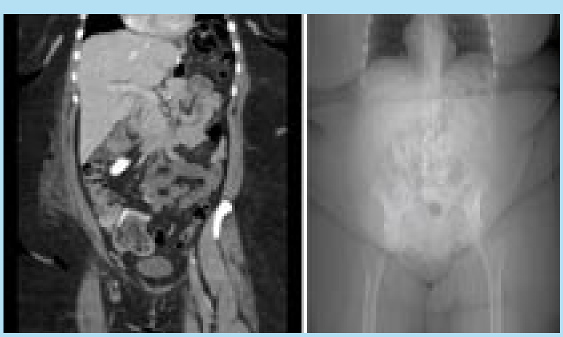


Figure 4C

Clinical Benefit: High, sustained tube power is required for many protocols, including successful imaging of trauma and bariatric (Figure 4C) patients without trade-offs. The needs for increased spatial resolution are also exemplified in **Figures 5, 6 and 10**.

Smart Focal Spot

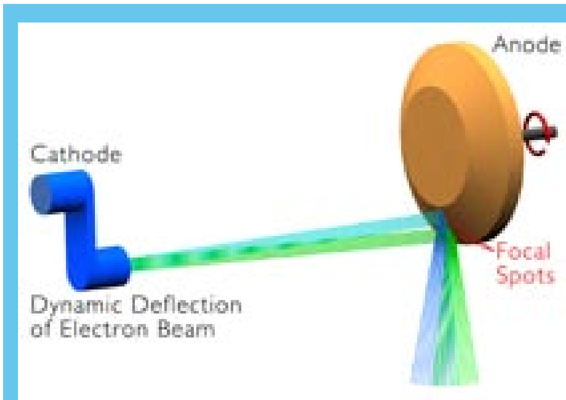


Figure 5A

Description: The Smart Focal Spot system oscillates the electron beam in order to create two focal spots, which doubles the number of in-plane ray samples and projections. This concept is scalable to three focal spots, to also double the number of longitudinal samples and facilitate spatially isotropic scanning.

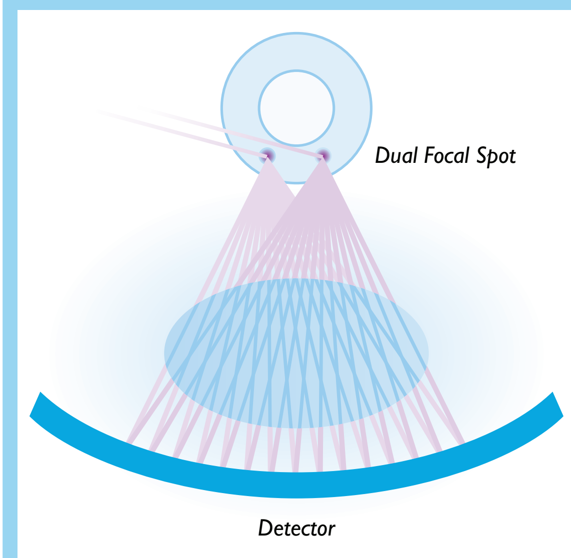


Figure 5B

Performance Result: This figure geometrically illustrates how dual focal spot oscillations double the number of in-plane ray samples and projections.

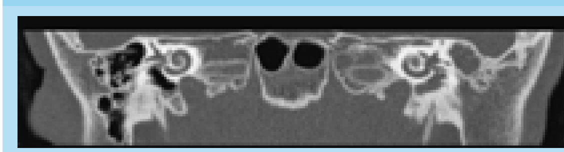


Figure 5C

Clinical Benefit: Spatial resolution enhancements are demonstrated with this internal auditory canal (IAC, inner ear) scan. The same can also be seen when imaging small vasculature and other regions.

Nano-Panel detector system

MDCT scanning with thin slices (e.g., 0.625mm), wide coverage, high resolution, and fast rotation speeds requires a highly advanced detector system to complement the MRC tube. The Nano-Panel detector (Figures 1B and 6) is designed and fabricated to be highly modular and integrated and meet this challenge— thereby ensuring optimization of image quality and scalability to present and future MDCT scanners (Figure 2) for the trends shown in Table 1. It can be thought of, in biological terms, as the wide-eyed retina of the imaging chain.

Recent enhancements in the back-illuminated photodiode and front-end electronics technology enable detector modules with a high dynamic range (1,000,000:1) and frame rate to be tiled in two dimensions. Another key subcomponent of the detector module system is the **TACH 2 chip** (Figure 7), which was designed and tightly-integrated to reduce electronic noise. Since noise level, image quality, and X-ray dose are fundamentally intertwined, the **TACH 2 chip** enables the application-specific optimization of image quality.

This new compact tiled detector with high bandwidth digital data output can be used as a building block to scale the Nano-Panel for future MDCT detection systems. A densely-populated panel can provide scalability to hundreds of thin slices, and since it's seamlessly integrated with Essence technology, the panel can enable larger coverage with the promise of scanning whole organs with a single revolution and increased diagnostic accuracy.

Nano-Panel detector system

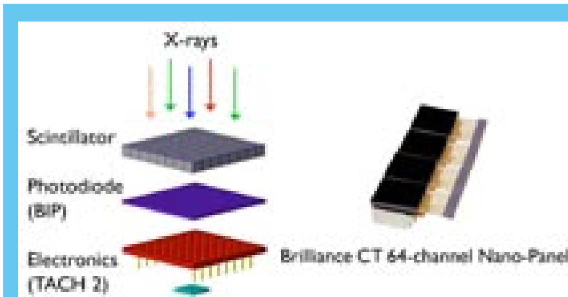


Figure 6A

Description: The Nano-Panel (Figure 6A, right) consists of a 2D tile-patterned arrangement where each module contains three highly integrated components (left):

1. Scintillator which converts X-rays into visible light
2. Back-Illuminated Photodiode (BIP) converts the visible light into an electrical signal
3. **TACH 2 chip** (discussed in **Figure 7**).

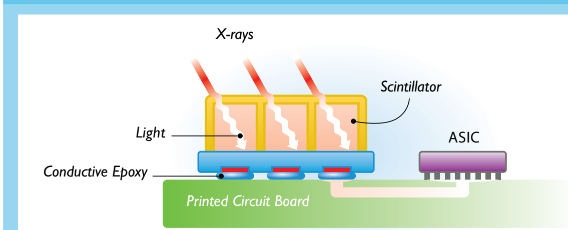


Figure 6B

Performance Result: The GOS (gadolinium oxysulfide scintillator) scintillator used in the Nano-Panel has a higher light output than $CdWO_4$ (Cadmium Tungstate) used previously. The Back Illuminated Photodiode (BIP) overcomes a historical wiring challenge and preserves signal integrity with direct connection to the electronics on the underside.

Figure 6C

Clinical Benefit: The Nano-Panel for the Brilliance CT 64-channel scanner provides four centimeters of detector coverage with a minimum slice thickness of 0.625mm and with rotation times down to 0.42 seconds (scalable to 0.28 seconds and less) as illustrated with this coronal reformatted image from a lung scan.

TACH 2 Chip

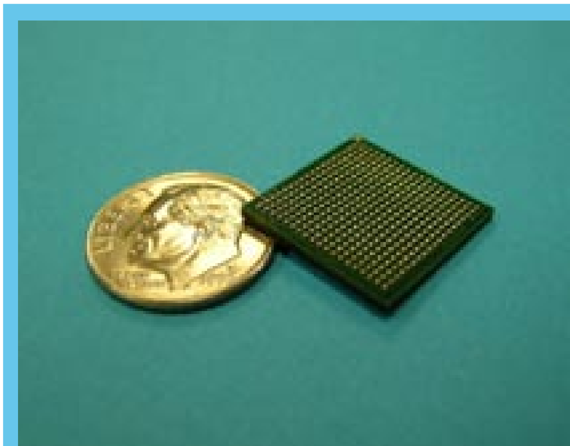


Figure 7A

Description: TACH 2 is an integrated circuit that converts the analog signal into digital (A/D) information for image reconstruction. Electronic noise is minimized by mounting it directly to the photodiode. This also decreases signal drift relative to older A/D conversion electronics. The noise reduction leads to an improvement in signal-to-noise ratio.

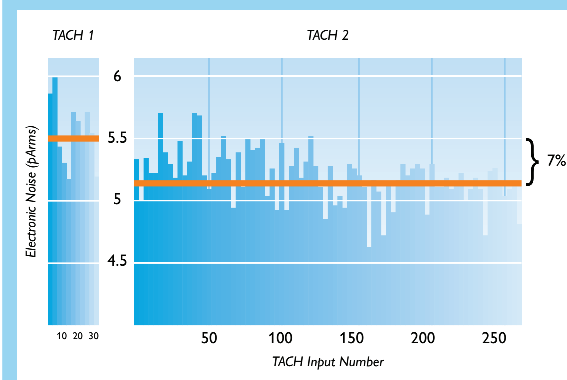


Figure 7B

Performance Result: Successive refinements of the TACH chip have lead to significant reduction in electronic noise. For instance, this graph shows that the TACH 2 chip results in a 7% high-frequency electronic noise reduction relative to the TACH 1, and is scalable to future CT scanners. The TACH 2 chip also leads to a 50% reduction in low- frequency noise.

Figure 7C

Clinical Benefit: Improved signal-to-noise ratio and less signal drift are available for all protocols. This can particularly help to optimize imaging quality when photon counts are limited such as when scanning bariatric patients (**Figure 4C)** or when lowering the X-ray dose for pediatric scans. **Figure 7C** shows a pediatric image acquired at CTDI(vol) = 28.3 mGy.

RapidView Image Reconstruction System

Advances with Essence technology also establish fast image volume reconstruction rates significantly beyond previous 2D benchmarks. The RapidView reconstruction engine (Figure 1C and 2) has been upgraded to keep pace with the image-volume-intensive trends of MDCT in Table 1. As the number of detector channels increases, the rate of raw projections generated and the number of images reconstructed increase exponentially. Scalable increases in reconstruction speed were achieved for all MDCT applications with **Quad Core processors** (Figure 11), along with a custom board dedicated to 3D back projection.

Clinically, enhancements to image-volume reconstruction speed allow the user to focus on patient care and help to streamline workflow for both routine and challenging scans, such as in the trauma setting. Increased processing speed may also, for example, decrease the time required to keep pediatric patients on the CT table while verifying images and completing the scan.

The Essence technology image reconstruction enhancements also include:

A proprietary 3D **Cone Beam Reconstruction Algorithm** (COBRA, Figure 8) for large coverage applications,

Options for high resolution scanning, including **768^2 or 1024^2 matrix reconstruction** (Figure 10), and

A sophisticated **Adaptive Multi-cycle Reconstruction** (AMR) algorithm that improves temporal resolution and reduces X-ray dose for cardiac examinations (Figure 9).

Cone Beam Reconstruction COBRA

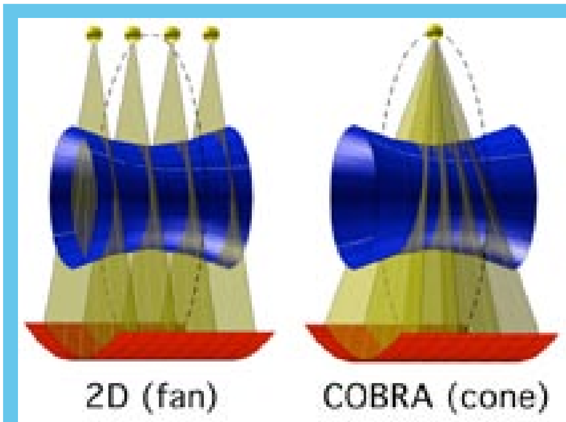


Figure 8A

Description: As the detector coverage increases to 4cm, 8cm, and more, the acquisition and reconstruction paradigm shifts from fan-based slices to cone-based image volumes. The development and implementation of a true 3D cone beam reconstruction algorithm (COBRA) was necessary to maintain virtually artifact-free images without compromising reconstruction speed relative to 2D methods.

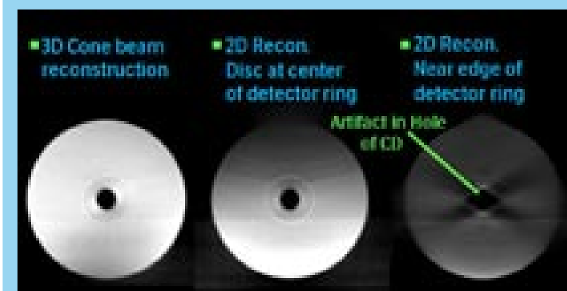


Figure 8B

Performance Result: A thin disc was scanned and reconstructed using both the 3D COBRA algorithm and an entirely 2D method (right). The 2D method had obvious artifacts when the disk was positioned near ends of the detector panel; whereas, at the center of the detector, these artifacts were not observed (center). With COBRA these types of artifacts were not observed in either location (left).

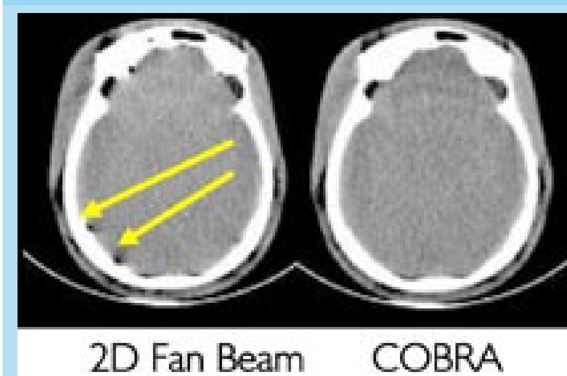


Figure 8C

Clinical Benefit: This brain scan shows that COBRA can limit potential cone-beam artifacts. COBRA is also highlighted in cardiac, single breath-hold chest, and functional imaging applications and protocols, among others where large detector coverage is needed.

Adaptive Multi-cycle Reconstruction

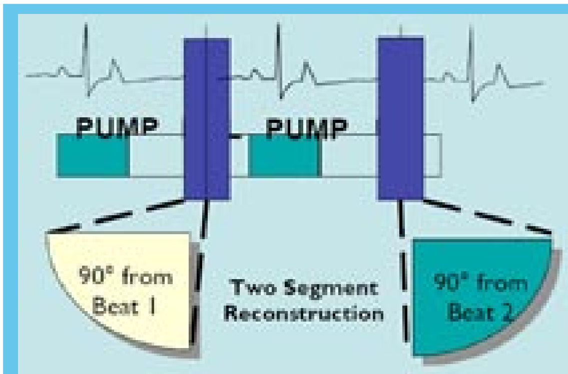


Figure 9A

Description: One way to improve temporal resolution is by combining projection data from consecutive cardiac cycles. Dedicated AMR cardiac techniques[1] significantly improve temporal resolution by combining data from as many cycles as are available, thus optimizing coronary image quality at high heart rates. Shown here is an example of AMR combining data from 90-degree segments obtained from two consecutive cardiac cycles. Combined with Philips patented Beat-to-Beat delay algorithm[2,3] which tracks a desired physiological cardiac phase of interest, consistent high-quality coronary imaging can be obtained.

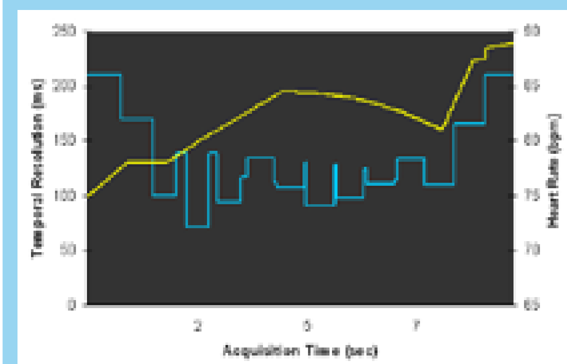


Figure 9B

Performance Result: AMR optimizes the temporal resolution by adaptively combining projection data from consecutive cardiac cycles. Figure 9B on the left is a plot displaying optimization of the temporal resolution (in blue) for varying heart rate (yellow) during a cardiac acquisition.

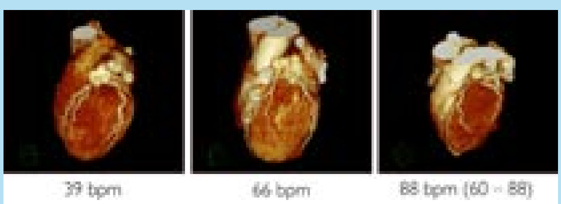


Figure 9C

Clinical Benefit: Retrospective ECG-gated cardiac CT with AMR maintains image quality over a wide range of heart rates. Shown on the left (Figure 9C) are volume rendered images obtained from scans of patients with low, medium, and high variable heart rates.

Ultra High Resolution Matrices

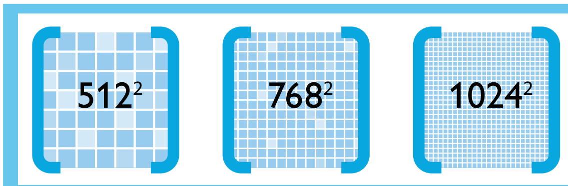


Figure 10A

Description: The RapidView reconstruction engine enables reconstruction with a matrix size of up to 1024^2 voxels. This is coupled with other component enhancements such as the Smart Focal Spot to improve spatial resolution.

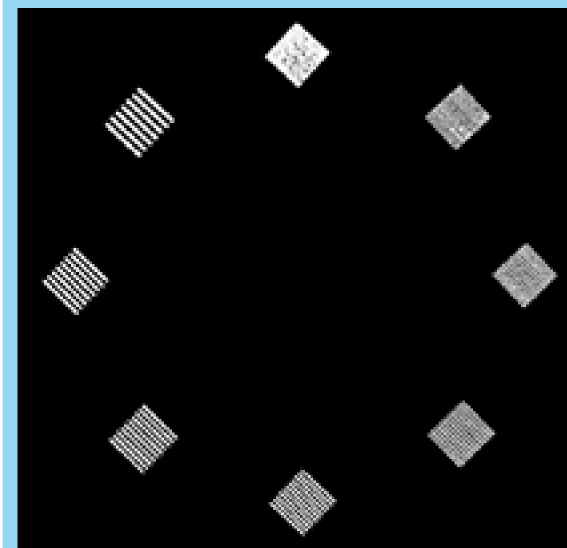


Figure 10B

Performance Result: A spatial resolution phantom demonstrates the result of 1024^2 matrix reconstruction. Two objects can be resolved with 0.22mm between them.

Figure 10C

Clinical Benefit: Improvements in spatial resolution are also highlighted with orthopedic examinations to identify bone fractures and fragments, as shown with this shaded surface view.

Quad Core processors

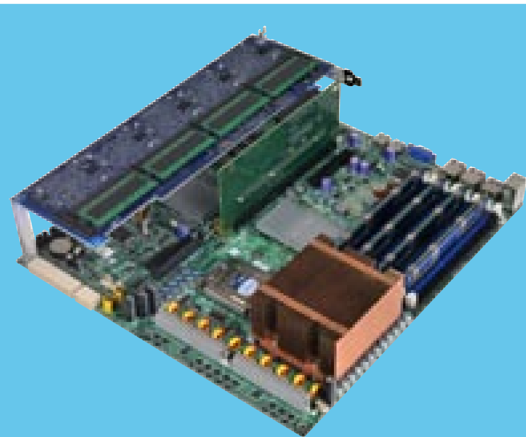


Figure 11A

Description: The reconstruction system of Essence technology makes use of Quad Core processors to achieve greater computational power.

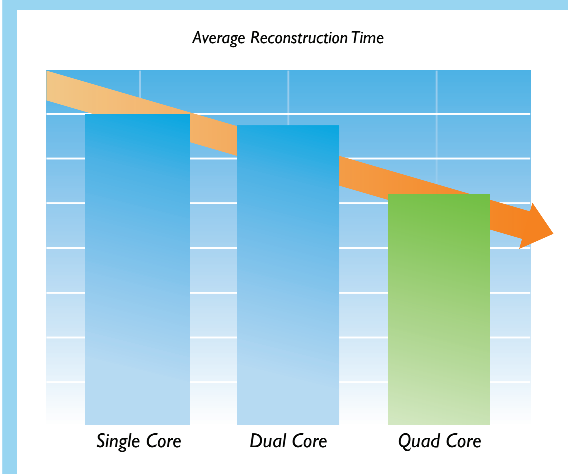


Figure 11B

Performance Result: The Quad Core processor allows greater reconstruction throughput, with an overall 35% improvement in speed relative to the Dual Core processor. This enables 75% of routine scans to be processed in under one minute.

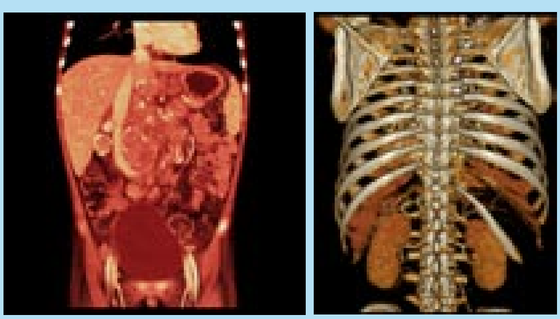


Figure 11C

Clinical Benefit: Improved reconstruction speed reduces the amount of time required to verify images. This can decrease the time required for the patient to remain stationary for time-critical examinations, such as trauma (left) or pediatric scans. Increased image reconstruction speed provides faster results for clinical management and also can increase patient throughput.

Optimizing the Image Quality of Applications with Essence technology

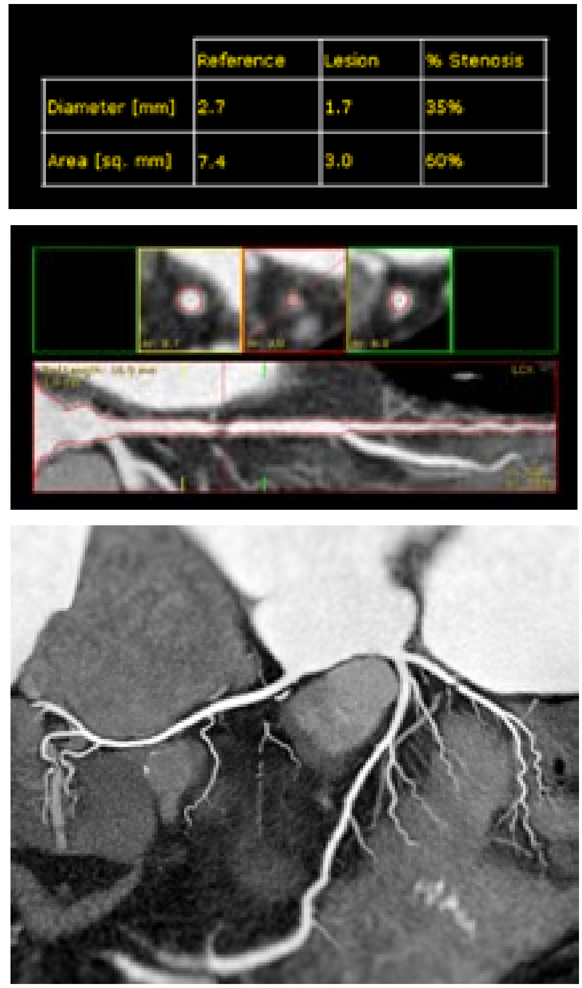
MDCT applications can have unique imaging requirements depending on anatomical region and reason for scanning, and therefore consistent image quality optimization can be challenging, especially for those procedures listed in Table 2. Essence technology can meet these challenges with synergistic performance enhancements of the entire imaging chain provided by the aforementioned components. Four clinical applications are presented below to illustrate how this can lead to application-specific optimization of image quality without trading-off other factors, as well as highlight the benefits of Essence technology for all routine applications, as summarized in Figure 16.

Cardiac CT

All aspects of Essence technology are leveraged to enhance the challenging needs of cardiac CT imaging as it becomes accessible to broader populations earlier in the care cycle. Increases in detector coverage, tube power, rotation speed, spatial and temporal resolution, along with improvements in cone beam reconstruction techniques, have significantly improved the image quality and robustness of cardiac scanning. Artifacts are prevented in the scanning and 3D reconstruction process, instead of attempting to correct the reconstructed images as with other approaches in the industry.

As part of Essence technology and the Rate Responsive Toolkit, dedicated AMR algorithms are employed in retrospective ECG-gated spiral scans and offer significant improvements in temporal resolution. These advanced algorithms, together with scalable gantry rotation speed (up to .27 sec and faster), and the patented Beat-to-Beat variable delay algorithm that tracks the quiet physiological cardiac phase, permit consistent, high quality coronary imaging.

A new prospective, ECG-triggered acquisition method, Step & Shoot Cardiac[10], is also enabled by wide Nano-Panel detector coverage and the fast acquisition time of Essence technology. The wide coverage Nano-Panel detector enables four-beats whole heart acquisition on the Brilliance CT 64-channel scanner and is scalable to less beats in the future. Step & Shoot Cardiac has also enabled motion artifact suppression and an industry-leading reduction in radiation dose of up to 80 percent without compromising cardiac image quality.



	Reference	Lesion	% Stenosis
Diameter [mm]	2.7	1.7	35%
Area [sq. mm]	7.4	3.0	60%

Figure 12: Clinical History: This asymptomatic 59-year-old male had a strong family history of coronary artery disease (CAD). A cardiac CT examination was performed for further evaluation. There is a lesion with non-calcified plaque (60% area stenosis) present in the proximal left circumflex artery. Parameters: Brilliance CT 64-channel scanner, 14 sec scan time, 140mm scan length, 0.9mm slice thickness, 0.5mm slice increment. Essence technology: AMR, Segmented Anode, Nano-Panel detectors.

Abdominal CT

The key to certain abdominal imaging exams is being able to capture high quality multi-pass, multi-planar studies obtained during specific circulatory phases. Furthermore, with improvements in temporal and spatial resolution, MDCT not only finds routine application in preoperative imaging of the liver and pancreas, but there is also a growing importance in the accurate diagnosis of acute abdominal pain and in the assessment of abdominal trauma. Also, new indications for MDCT exams of the gastrointestinal tract are being identified[5].

However, CT imaging of the abdomen presents challenges that are inherent to the disease processes which are the focus of imaging. In particular, many disease conditions can be inconspicuous on CT when viewed within, or adjacent to, the organs or tissues in which they arise[6]. This is, for example, a dominating factor in the detection of small lesions, where partial volume effects, low contrast differences, and noise can obscure the lesions themselves[7].

The synergy of Essence technology components described above also optimizes contrast resolution with wide coverage and short volume acquisition time. The **Nano-Panel detector with the TACH 2 chip** of Essence technology along with the **Smart Focal Spot** help to optimize image quality and other imaging factors needed for these examinations, especially for overweight patients where a lower photon count may be encountered. Higher in-plane and longitudinal spatial resolution allows the generation of high quality 3D images, such as the volume rendering of the abdominal vasculature shown in Figure 13.

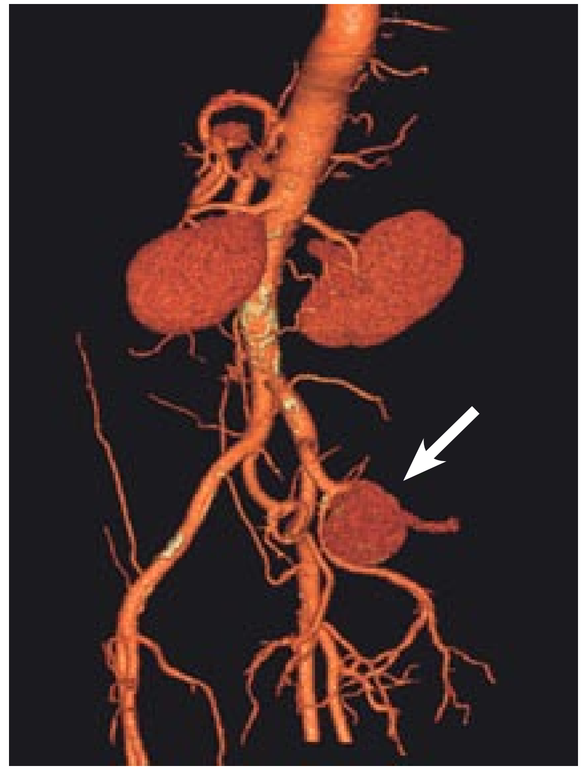


Figure 13: This 78-year-old male (history of hypertension, AV dysfunction, and prior pacemaker placement) presented with a several month history of bilateral leg edema. A CT of the abdomen and pelvis was done, showing a 4cm iliac artery pseudoaneurysm (arrow). Parameters: Brilliance CT 64-channel scanner, 6 sec scan time, 228mm scan length, 0.9mm slice thickness, 0.45mm slice increment. Essence technology: Smart Focal Spot, COBRA, Nano-Panel detectors.

High Resolution Lung CT

Pulmonary CT images have inherently higher signal-to-noise characteristics because of the air present in the lung parenchyma; however, there are challenges to pulmonary imaging despite this characteristic. Patients with breathing difficulties pose imaging challenges due to their difficulty in complying with breath-hold imaging. High spatial resolution is needed to visualize small structures such as nodules, sub-segmental pulmonary emboli, and the textural patterns of interstitial lung diseases.

The set of Essence technology components also optimizes spatial resolution with wide anatomical coverage at high rotation speeds. A Brilliance CT 64-channel scanner examination can be completed in a single breath-hold of about 5-8 seconds, thus reducing the number of patients who have trouble complying. Larger and finer reconstruction matrices, 768^2 or 1024^2, along with stability and dual-targeting capabilities of the Smart Focal Spot can further optimize the spatial resolution, up to 24 Lp/cm. High quality, 3D multiplanar reformatted (MPR) images can then be generated with isotropic resolution to evaluate subtle parenchymal abnormalities.

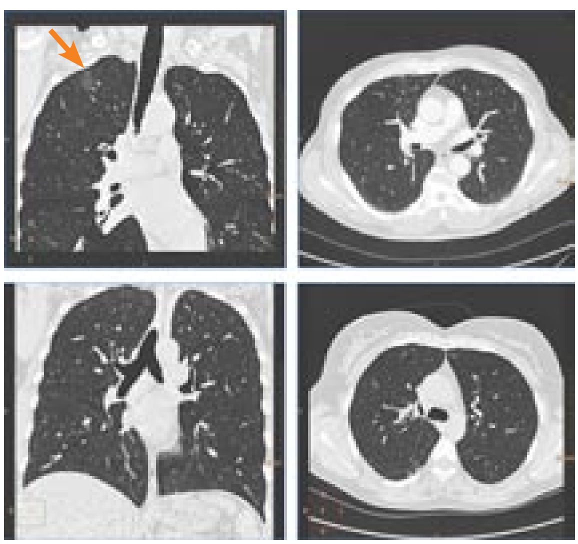


Figure 14: High resolution images of the lungs showing ground glass opacity in the right upper lung on the coronal MPR. The parenchyma and the fissures are visualized with great detail in the images. Parameters: Brilliance CT, Resolution: High, 327mm scan length, 0.8mm slice thickness, 0.4mm slice increment Essence technology: 768 reconstruction matrix, Smart Focal Spot, spiral groove bearing.

Pediatric CT

Reducing X-ray dose while maintaining optimum image quality can be challenging for pediatric patients and approaches to this reduction are inconsistent among radiology departments[4]. It is well known that lowering tube current too much for pediatric chest and abdomen CT scans will usually result in decreased image quality. Furthermore, patient restlessness may limit the amount of time available to complete the scan and cause motion artifacts.

The synergy of Essence Components - in conjunction with imaging technologies designed with the **DoseWise**[11] strategy, such as **DoseRight** Automatic Current Selection and Modulation – enables more flexibility to manage X-ray dose. The **TACH 2 chip**, with lower electronic noise characteristics, enables the optimization of image quality while lowering X-ray dose beyond fixed protocols. Also, the **RapidView reconstruction engine** with Quad Core processors, coupled with **Evolving Reconstruction** which enables real-time adjustment of display parameters on 256^2 preview images, decreases the amount of time required to reconstruct and verify the images and complete the procedure.

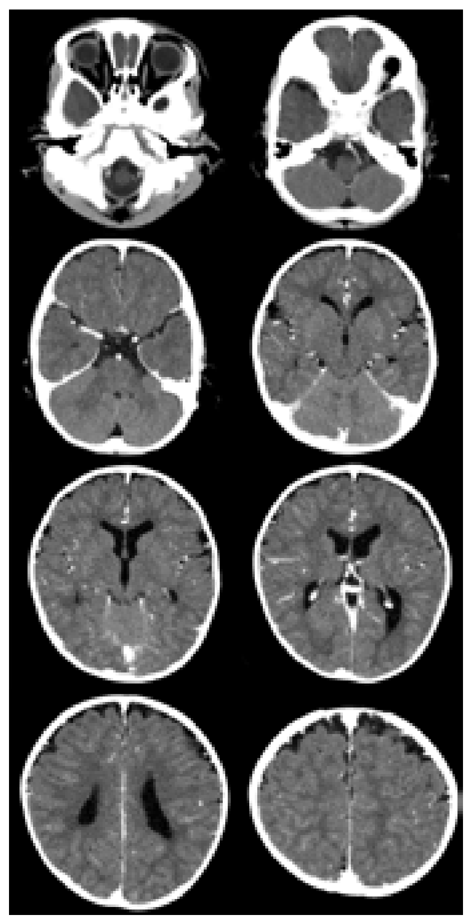


Figure 15: Low X-ray dose pediatric brain scan of 11 month old with Brilliance CT 64-channel scanner equipped with Essence technology.

Summary

Essence technology raises MDCT to a new volume imaging standard, ensuring that the number and diversity of diagnostic and therapeutic applications will continue to expand. The full scalability of Essence technology will enable further technical advances in all aspects of the imaging chain, including increases in scan speed, volume coverage, and all measures of resolution. These new levels of scan performance will continue to optimize image quality at a lower X-ray dose to improve clinical results for broader patient populations.

The scalable Essence platform will ultimately lead to the routine adoption of today's emerging MDCT examinations and further broaden the spectrum of new applications. This includes, for example, isotropic volume functional imaging, dynamic visualization of whole organs, and fast imaging of multiple parenchyma and vascular regions at a lower X-ray dose and with less contrast material. Furthermore, seamless integration of ultra-fast image reconstruction, automated image analysis, and enterprise distribution can further streamline workflow, patient throughput, and physician access to easily manage images.

In summary, Essence technology supports advances in imaging today, while providing the continuity for MDCT platform growth in the future. This scalable platform provides for optimum CT image quality and also enables better dose management and workflow solutions. Most importantly, Essence technology will ultimately facilitate scanning earlier in the care cycle and increased diagnostic accuracy, and holds promise for expanding horizons in MDCT imaging with improved patient care.

Essence technology supports imaging advances and platform continuity.

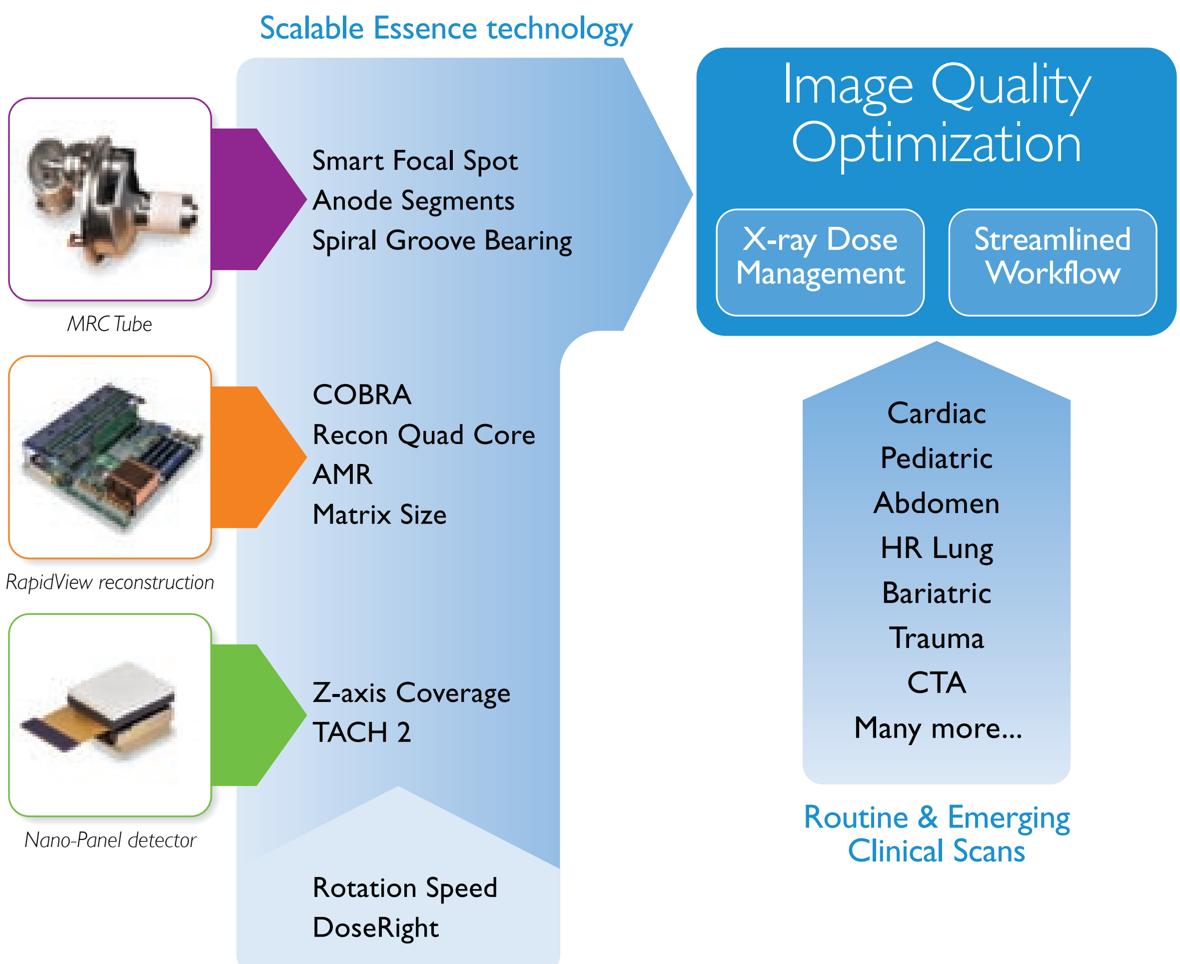


Figure 16: Essence technology enables optimization of image quality as well as facilitating X-ray dose management and streamlined workflow for routine and emerging applications.

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