Computed tomography

Detector technology in simultaneous spectral imaging

Philips IQon Spectral CT

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While CT has become an essential diagnostic tool worldwide, the limitations of traditional grayscale Hounsfield CT images to provide information to quantify contrast agents and discriminate between body materials are widely known. The introduction of Philips IQon Spectral CT features the first and only spectral detector CT system built from the ground up for spectral imaging. The advanced technology of the spectral detector offers significant advantages through color quantification and provides the ability to characterize structures based on material content, helping provide clinicians with additional information for their diagnosis.

How does spectral CT work?

Color quantification adds spectral resolution to image quality, delivering not just anatomical information but also the ability to identify and characterize structures based on material content.

Just as white light consists of an entire spectrum of colors, so the X-ray photon beam produced by CT scanners consists of a spectrum of photons with a range of X-ray energies from low to high. The Philips IQon spectral detector has the ability to simultaneously distinguish between X-ray photons of high and low energies. This spectral analysis allows for the discrimination of materials consisting of specific atomic numbers, such as iodine or calcium. Various elements are assigned individual colors, allowing them to be visually distinguished on CT scans.

Understanding spectral detector technology and its impact on CT imaging

The detection system is one of the three aspects that have the greatest impact on image quality in CT (the other two are the X-ray source and image reconstruction algorithms). The technology behind the Philips IQon spectral detector system is the first of its kind, allowing for color quantification and the ability to characterize structures based on material content combined with simple workflow and low dose. Other attempts at multi-energy acquisitions have relied on modification of the source (X-ray tube), which may present certain compromises that affect image quality, dose penalties and workflow practices. The Philips detector approach to multi-energy detection allows clinicians to do what they do best, which is to scan for the desired result.

IQon Spectral CT offers the clinician the ability to distinguish among body materials having similar HU values in standard CT imaging.

> With IQon, every scan can be **spectral on demand**, with superb image quality, no change to workflow, and low dose.

Importantly, due to the unique dual-layer scintillator system, high- and low-energy data can be obtained simultaneously in time and space at the detector level, cutting down on scanning time and improving data integrity, while reducing pixel shifts and spectral blurring. The use of spectral monoenergetic imaging reduces image artifacts, such as beam hardening, and enhances visualization (signal) of iodine-enhanced materials. The principal scheme of the dual-layer-based spectral detection is shown in **Figure 1**.

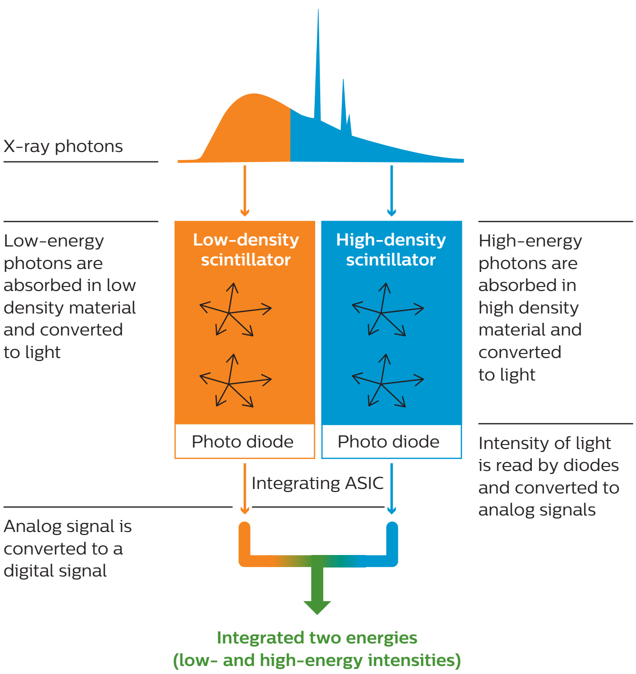

Figure 1 The principal scheme of dual-layer-based spectral detection.

The NanoPanel Prism detector

The NanoPanel Prism detector allows for simultaneous measurements of both high and low energies in the same time and space. The detector consists of a 3D tile-patterned arrangement in which each module contains three highly integrated components:

- **Scintillators**: top-layer yttrium-based garnet scintillator for detection of lower energies, and bottom-layer gadolinium oxysulphide (GOS) scintillator for detection of higher energies
- **Thin front-illuminated photodiode** (FIP), which is placed vertically (perpendicular to the detector surface); the photodiode lies beneath the anti-scatter grid as to not degrade the overall geometric efficiency of the detector
- **Integrated application-specific integrated circuit** (ASIC) for analog-to-digital conversion

The array of the NanoPanel Prism detectors on the IQon scanner currently provides 4 centimeters of detector coverage, with a minimum slice thickness of 0.625 mm at the ISO-center and supporting a rotation time as fast as 0.27 seconds.

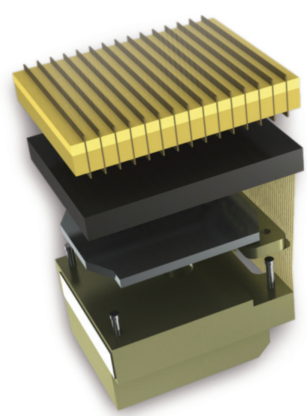

Figure 2 The NanoPanel Prism detector.

A **closer look** at NanoPanel Prism detector components

The scintillators

The scintillators convert X-rays to visible light, and the FIP converts this light into an electrical signal. The requirements for the scintillator are among the most demanding of all current medical imaging tools: they must account for optimal X-ray conversion efficiency, make a good spectral match with the photo-detector, and be easy to use. The NanoPanel Prism detector is capable of simultaneous detection in both time and space, with negligible intra-layer scatter.

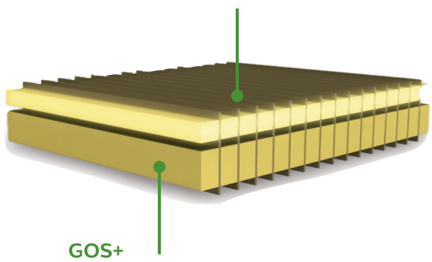

Figure 3 The scintillators of the NanoPanel Prism detector.

The design of the two scintillators' thickness is optimized for energy separation and optimal signal-to-noise ratio. The yttrium-based garnet scintillator effectively absorbs low-energy X-rays while the GOS absorbs as much as 99% of the energy spectrum. The overall stopping power of NanoPanel Prism is significantly better than that of Philips previous-generation detectors. The optimized performance and geometrical parameters of the scintillators together with the FIP usage allow 25% higher light output and 30% less cross talk than previous detectors.

Additional advantages arise from splitting the X-ray energy spectrum: as each separate energy spectrum is narrower than one that is combined, there is additional reduction in photonic noise and in beam hardening. The variance of each of the two individual spectra is also smaller than that of the combined spectrum.

Good temperature stability of the GOS and yttrium-based garnet scintillators, coupled with a robust design, help provide highly stable performance. The level of afterglow of the scintillators is low enough to be of no consequence for the CT image, therefore no additional afterglow correction is required to achieve good image quality. This is why simultaneous spectral separation can occur at 120 kVp.

The advantages of simultaneity and use of projection space data in the creation of spectral results may be realized when imaging structures are in motion, for example, during cardiovascular imaging.

Front-end electronics

Following the successful experience of NanoPanel Elite detector, the same approach was used to develop key components of the NanoPanel Prism detector electronics design. The ASIC is used in a unique concept for analog-to-digital conversion of the signals with very low power dissipation and yet low noise (both wideband and low frequency noise). The ASIC is mounted closely to the FIP for better layout, shorter lines, and better analog to digital isolation to minimize electronic noise and decrease signal drift. The electronic noise for the Philips detector is so low. This leads to significant improvements in the signal-to-noise ratio with negligible interlayer scatter, resulting in high image quality at low dose.

Other advantages of the NanoPanel Prism detector

The Philips IQon Spectral Detector CT delivers color quantification and the ability to characterize structures based on material content. With IQon Spectral CT, every scan is spectral on demand, offering the user the ability to use standard protocols to create both conventional and spectral images in the same scan.

Philips drew upon its successful experience with the 2D-tiled NanoPanel Elite detection concept when creating the state-of-the-art 3D NanoPanel Prism detector, which is a main building block of IQon scanner detection. The NanoPanel Prism demonstrates excellent characteristics in consistency, dynamic range, stability, signal uniformity, linearity, low noise characteristics, low cross-talk values, and high geometric and quantum efficiencies, which allow the IQon scanner to obtain excellent image quality.

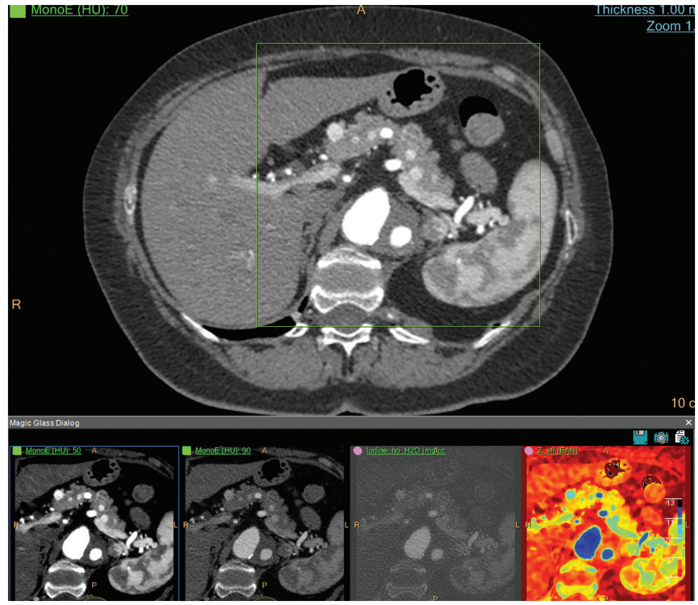

Figure 4 CTA of the abdomen with spectral results of the pancreas.

The detector system design, materials, and simultaneity of data sets can introduce a unique scanning and clinical application experience. The spectral scanning routine has minimum decision points, which means that CT scanning protocols do not need to be altered. Pre-decisions on whether to perform spectral CT scans are not required because the scans are always spectral scans.

The scanning workflow can offer CT protocols with clinical questions related to spectral results to be generated at the operating console with the choice of performing retrospective spectral image generation. Dedicated clinical applications can use the new data, allowing for clinical information interrogation and excellent image quality.

Effect of IMR on dose and image quality

For conventional scans, Iterative Model Reconstruction (IMR) can generate images that are virtually noise-free. Besides improving on the quality of conventional imaging, studies using phantoms (data on file) suggest that IMR may reduce patient dose* by 60–80% depending on the clinical task, patient size, anatomical location, and clinical practice.

Phantom studies suggest that Philips iDose[4] improves spatial resolution and/or noise reduction at low dose.

DoseWise strategies

Philips IQon Spectral CT adheres to the Philips DoseWise approach to dose management, which is an array of techniques and programs based on the ALARA (As Low As Reasonably Achievable) principle.

During scanning, tube current modulation is used to change the X-ray dose from location to location, attenuating the dose by body region.

Image quality for each diagnostic task is specified by the DoseRight Index (DRI) for various scanning regions, to allow for the appropriate dose and image quality within a single acquisition.

- **Personalized doses** for individual patients are suggested by the DoseRight automatic current selection.
- **Longitudinal dose modulation** is achieved using the DoseRight Z-DOM, which adjusts the tube current-time product (mAs) in the z-axis according to a patient's size and shape.
- **DoseRight 3D-DOM** (three dimensional dose modulation) combines angular and longitudinal patient information to modulate dose in three dimensions (x-y-z-axis). It incorporates modulation of tube current-time product (mAs) according to changes in individual patient's size and shape in the transverse (x-y-axis; angular) direction during helical scans, in addition to changes in the craniocaudal or caudocranial (z-axis; longitudinal) direction, as the tube rotates.
- **Dedicated pediatric protocols** offer high-quality conventional images at low doses, taking into account the pediatric patient's size and clinical indication.

Through the detector-based approach of the IQon Spectral CT, the user has full access to all the dose-savings tools in spectral scanning normally available in conventional scanning mode. This means that valuable tools such as dose modulation and iterative reconstruction are not discarded in order to perform spectral exams.

> "You don't have to prescribe a multi-energy acquisition mode in advance, which has a great effect on the workflow."
>
> *Zimam Romman, Clinical Scientist, Philips*

* In clinical practice, the use of IMR may reduce CT patient dose depending on the clinical task, patient size, anatomical location, and clinical practice. A consultation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task. Lower image noise, improved spatial resolution, improved ow-contrast detectability, and/or dose reduction were tested using reference body protocols. All metrics were tested on phantoms. Dose reduction assessments were performed using 0.8 mm slices, and tested on the MITA CT IQ Phantom (CCT183, The Phantom Laboratory), using human observers. Data on file.

Patient-centered CT imaging

- **iPatient** is an advanced platform that facilitates the patient-centered approach to CT imaging and has the flexibility to support future innovations. It includes methods to adapt scan protocols and techniques such as dose modulation and iterative reconstruction for individual patients and diagnostic tasks. Using patient-specific methods, iPatient facilitates optimal* management of image quality and radiation dose.

- **ExamCards** for the Philips IQon Spectral CT are individualized protocols, fully equipped with spectral capabilities, that allow planning to be based on the desired result, rather than just the scan. For each ExamCard, besides results such as axials, coronals, sagittals, MRPs, and MIPs, spectral results for the specific clinical question can be added. ExamCards can be designed for each clinical question. Results are automatically reconstructed and can be sent for viewing without any additional work from the operator. Protocols can be shared, allowing scan-to-scan consistency.

- **Scan Ruler** provides the operator with a clear interactive timeline of events during the study, such as acquisition, bolus tracking, and injection.

- **DoseRight Index** (DRI) is an image-quality reference parameter, designed to simplify adjustments to specify the required image quality for a particular diagnostic task. Increasing DRI decreases image noise and increases volume CTDI, while decreasing DRI increases image noise and decreases volume CTDI. So, for example, DRI allows a controlled increase in suggested noise levels for larger or obese patients and a decrease in noise for smaller adults. Decreasing DRI (increasing) by -1 (+1) decreases (increases) the average tube current by 12% while increasing (decreasing) the image noise by 6%, if other settings remain unchanged. DRI is a convenient tool to manage low-dose (ALARA) scans. After the appropriate number of cycles and due consideration of the results, adjustments to the DRI and iterative reconstruction settings can be incorporated into the ExamCard to manage individual patient examinations.

All of these tools are standard on the IQon Spectral CT. There is no need to alter workflow habits to obtain more clinical information.

* "Optimal" refers to the use of strategies and techniques that facilitate the management and control of both image quality and dose.

Reference

1. Gabbai, M, et al. The Clinical Impact of Retrospective Analysis in Spectral Detector Dual Energy Body CT. Radiological Society of North America 2013 Scientific Assembly and Annual Meeting, December 1 - December 6, 2013 ,Chicago IL. http://archive.rsna.org/2013/13018312.html Accessed June 24, 2014

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