

# Photon-Counting Computed Tomography in Cardiovascular Imaging: Where We Are and What Lies Ahead

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Computed Tomography Angiography (CTA) has been an important asset in cardiovascular diagnosis for decades. The continuous improvement of rapid data acquisition with often higher spatial resolution has established the method as indispensable for diagnosing and managing multiple cardiovascular entities such as aneurysms, aortic dissection, and pulmonary embolism.<sup>1,2</sup> The use of CTA in heart and coronary imaging has also gained important territory and relevance.<sup>3,4</sup> Computed Tomography (CT) techniques have been advancing significantly since its introduction in the medical field. Starting with single detectors, then helicoidal scanners, multidetector scanners with high pitch, improvement of reconstruction algorithms, the appearance of dual-energy technology, and lately the ability to acquire images of the whole heart in just one heartbeat with information from the entire cardiac cycle, are incredible milestones. Fractional Flow Reserve CT (FFR-CT) is also a very promising technique.<sup>5</sup> Progression does not come without downsides: ionizing radiation is still concerning, and despite ways to reduce it such as dose modulation, some cardiovascular CTA exams still show relatively high levels of absorbed radiation, especially exams with multiple series, extremely thin slices, and retrospective reconstruction of larger parts of the cardiac cycle. Following this trend of improving image quality with less ionizing radiation as possible, a new complex technique emerged: Photon-counting CT (PCCT).

The main distinction between conventional CT and PCCT is in the detectors of X-rays. The conventional CT detector is based on receiving the X-ray photons that interact with the patient, converting them into light photons (it is an indirect system), and then converting this light into electrical signals that ultimately are going to be converted into digital signals. This system is called an Energy-Integrating Detector (EID). Basically, more light means more X-rays arriving and less interaction / more penetration in the patient's tissues. It is not possible to differentiate exactly how many X-rays are arriving, nor the different energy levels of each X-ray photon. Moreover, the septa between each of the detectors also limit the reception of X-rays.<sup>6,7</sup> On the other hand, PCCT detectors can detect separately each X-ray photon that is arriving and measure the energy of each one of the X-ray photons directly. This is

possible because the PCCT detector has a high-voltage crystal layer that relocates electrons for each X-ray photon received, and the number of electrons relocated is proportional to the energy of each X-ray. The relocated electrons generate the electrical pulse that is going to be finally converted into the digital signal. And even smaller energy X-rays can be detected, improving the image contrast-to-noise ratio. It is a direct system, and there is no septa between the detectors. In the end, less X-rays are necessary (therefore less radiation) and it is possible to separate the X-rays according to the energy of each one, leading to applications of tissue recognition (different known energy X-rays are likely to have interacted with different known tissues) functioning as a dual energy CT.<sup>8,9</sup>

As far as this new technology became available, the scientific community was excited about the advances, and interesting publications were released. In mid-2022, Esquivel *et al.*<sup>6</sup> published interesting concepts about PCCT for radiologists: “Key Points Radiologists Should Know”, which helped spread the information and knowledge amongst the international Radiology Community. The possibility of improving characterization of small vessels (e.g., distal coronary arteries, peripheral run-off arteries, artery of Adamkiewicz, and small arterial flaps) was highlighted. Still in 2022, Si-Mohamed *et al.*<sup>10</sup> published the first In-Human Results for Coronary CT Angiography with PCCT: despite being a small group of fourteen participants, this prospective study showed significant improvements in overall image quality, diagnostic quality, and diagnostic confidence in PCCT compared to an EID dual-layer CT analyzing multiple variants such as distal coronary lumen, calcification sharpness, stents – classic scenarios of partially limited evaluation with the CT technology available before PCCT.

In 2023, Cademartiri *et al* published a complete paper regarding PCCT cardiac and coronary applications.<sup>11</sup> They revised the PCCT physics, analyzed publications released up to the moment that discussed the matter, and discussed that PCCT allegedly is beneficial in evaluating coronary lumen, coronary stents, prosthetic valves, plaque composition, myocardial tissue imaging, as well as radiation dose reduction, contrast media reduction and improved contrast-to-noise ratio. The reduction in contrast media usage could be around 50%. About the radiation dose reduction, it is calculated between 19-32% according to some authors.<sup>12,13</sup>

Lately, after all these interesting improvements published in small groups of patients and pictorial essays, it is time to finally test the method in wide clinical practice. The theory and cases demonstrated so far are very promising. We have summarized the PCCT key quality improvements in Table 1. The next step is probably to publish data with larger patients' samples, more centers, and mainly, to determine if there are significant changes in patient outcomes. The experience at our Institution, where

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**Table 1 – PCCT Key Quality Improvements**

**1. Superior Spatial Resolution**

Smaller detector elements allow for sharper images with enhanced anatomic detail, benefiting applications like coronary artery visualization, but also lung imaging and inner ear for example.

**2. Enhanced Tissue Contrast and Material Differentiation**

Multi-energy detection enables material decomposition (e.g., calcium, iodine, uric acid), improving lesion characterization and reducing diagnostic ambiguity.

**3. Lower Radiation Dose**

Due to higher detector efficiency and reduced noise, diagnostic-quality images can often be achieved with significantly less radiation exposure.

**4. Reduction of Artifacts**

PCCT minimizes beam hardening and metal artifacts, improving image fidelity in challenging cases such as prosthetic valves, implants and regions near to the bones.

**5. Native Spectral Imaging Without Dose Penalty**

Unlike dual-energy CT, PCCT delivers spectral data in every scan, without requiring specialized protocols or increased dose.

we have the opportunity to work with three PCCT Scanners (one 100% dedicated to research and two for clinical assessment), is also leaning towards this direction, trying to measure differences in dose radiation, contrast media utilization, and significantly changing patient management. We have started using the PCCT scanner at the beginning of 2022. On the other hand, of course there are multiple challenges involved in PCCT worldwide: young clinical experience with the new method, optimization of protocols to extract the maximum possible of the technique (since we have multiple new protocols and Kernels available, with countless reconstruction parameters), robust / updated image viewers to deal with the extremely large number of images one single exam loads (the slice thickness can achieve up to 0.2 mm generating 11,000 images in one single Cardiac CTA) and, of course, the money invested in these novel scans. Figure 1 shows an example of a PCCT heart image acquisition of one of our patients with a prosthetic valve: notice the minimal or almost nonexistent beam hardening or blooming artifacts. Figure 2 shows the left anterior descending coronary artery of another patient scanned in our Institution with PCCT compared with a prior acquisition of the same artery in a multi-detector “conventional” CT.

Finally, we can state that there is no doubt that the new PCCT technology has brought significant advances in image quality, with ultra-high resolution images, an important improvement in the signal-to-noise ratio, and overall reduction in radiation doses, potentially increasing the accuracy of reading physicians and maximizing patient-centered care. PCCT will likely be the future of our CT scanners.



**Figure 1 – PCCT acquisition of one of our patients’ heart with a prosthetic valve: notice the minimal or almost nonexistent beam hardening or blooming artifacts.**



**Figure 2** – Left anterior descending coronary artery of another patient scanned in our Institution with PCCT (Figure 2B) compared to a few months prior acquisition of the same artery in a multi-detector “conventional” dual-source CT (2x192 detector rows) (Figure 2A). The “conventional” acquisition shows more beam hardening artifacts adjacent to a calcified plaque (hypoattenuating area – white arrow) in comparison to the PCCT acquisition- black arrow (Figure 2B). Additionally, there is also less blooming artifact of a calcified plaque in the PCCT acquisition (Figure 2B) – black asterisk - in comparison to the “conventional” acquisition (Figure 2A) – white asterisk. The blooming artifact is a known cause for luminal stenosis overestimation in calcified plaques, and indeed the plaque looks larger in the “conventional” acquisition.

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