PL 02 GS-02

English

Plenary Lecture Ⅱ (PL 02)

Sep. 22 (Fri), 11:20-12:00

Grand Ballroom 101-105, 1F

Chairperson(s):

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Photon-counting CT: Where Can it Make an Impact on Patient Care?

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Photon-counting detector CT (PCD-CT) differs fundamentally from conventional energy-integrating detector CT (EID-CT). Conventional CT detectors rely on a scintillating layer, which converts x-rays to light, with photodiodes converting this light into digital signals, which are proportional to the sum of all of the detected photon energies. Additionally, this process requires partitioning of detector pixels through use of reflective septae (**Figure 1**). This approach down-weights the signal of low-energy photons, which carry important contrast information. In contrast, photon-counting detectors employ semiconductors to directly convert photons to electron-hole pairs, with electrons moving to a pixelated anode that generates electrical signal proportional to the energy of each photon (**Figure 2**). PCD-CT consequently does not require reflective septae, resulting in a smaller detector size, and consequently improved spatial resolution and geometric dose efficiency. By directly recording the energy of each photon, PCD equally weights the contribution of low-energy photons, increasing the iodine signal within the image, and can utilize energy thresholds to eliminate electronic noise as well as create multi-energy images. This presentation will review evidence for patient benefit of photon-counting CT across the spectrum of diagnostic tasks in CT imaging.

Figure 1. Conventional Energy-integrating CT detector. Signal is proportional to sum of energy of all photons.

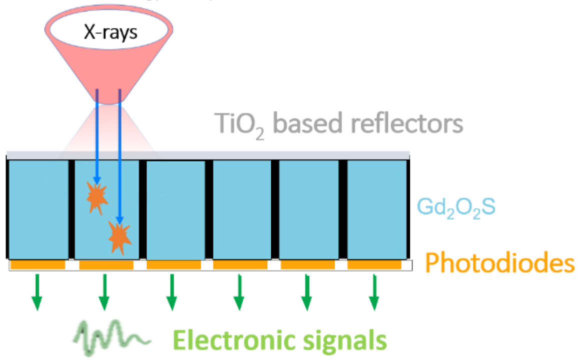
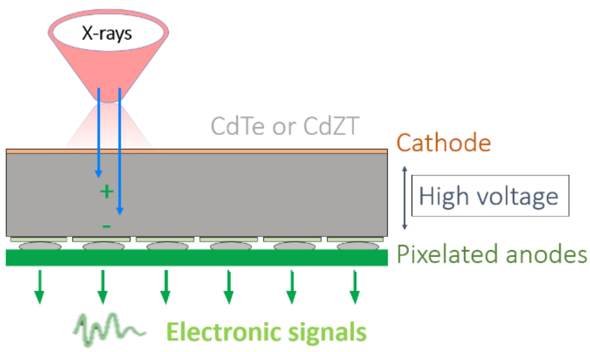
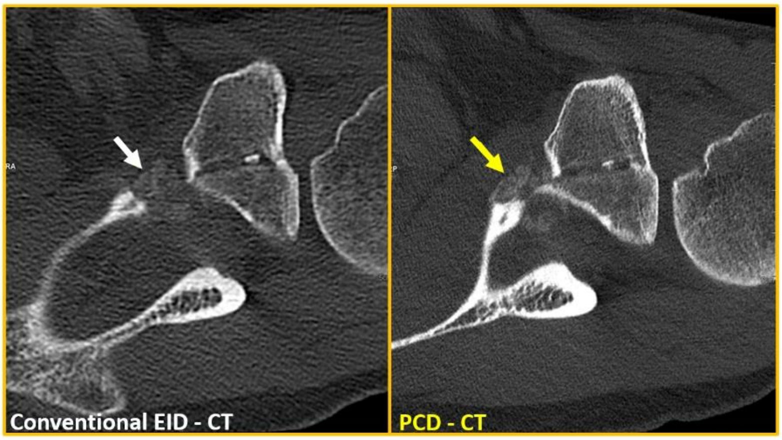


Figure 2. Photon-counting CT detector. Signal is recorded for individual photons and proportional their energy. Note absence of reflective septae.



Spatial Resolution. Increased spatial resolution is accomplished by using sharper image reconstruction kernels optimized for PCD-CT, thinner slice thicknesses, and the narrowest detector collimation permitted by a diagnostic task.

Figure 3. PCD-CT permits high resolution imaging of large joints. Note healing callus on PCD-CT despite 50% radiation dose reduction. Note reduced noise from use of energy threshold to remove electronic noise.



In musculoskeletal CT using a conventional CT system, comb filters are often used to increase spatial resolution by reducing pixel aperture but do so at the cost of additional radiation. Additionally, conventional CT system limits prohibit the use of comb filters for larger body parts such as the shoulders and hips. Using PCD-CT, which does not utilize comb filters for ultra-high resolution (UHR) imaging, large joints can be imaged with 25 - 50% radiation doe reduction (**Figure 3**), with small joints imaged using higher spatial resolution than that permitted by conventional CT with an approximate 50% reduction in radiation dose. In multiple myeloma, PCD-CT permits identification of more lytic lesions and improved visualization of pathologic abnormalities.

PCT-CT permits facilitates improve visualization of critical anatomic structures at a substantial radiation dose, which can be increased by using a tin filter. At our institution, all patients with osseous implants, and nearly all temporal bone CT exams, are performed with PCD-CT.

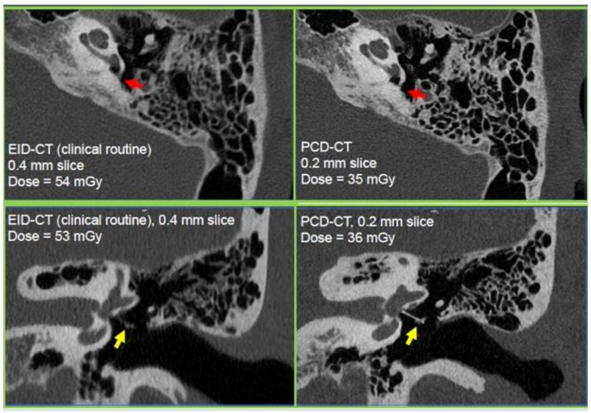


Figure 4. PCD-CT temporal bone imaging. Axial (top row) and coronal (bottom row) conventional CT and PCD-CT images.
PCD-CT improved the conspicuity of the round window (red arrows) and of a stapes prosthesis (yellow arrows) despite a 35% dose reduction.

Improved spatial resolution at PCD-CT translates into improved visualization of small bronchi and improved radiologist confidence in identifying images features of interstitial lung disease such as reticulations and traction bronchiectasis. It is also helpful in other airway diseases such as long Covid. Alternatively, routine resolution PCD-CT can be performed at reduced radiation doses compared to conventional EID-CT without a decrement in observer performance. While PCD-CT can be used for lung cancer screening or cancer surveillance with a modest dose reduction, its use in routine clinical practice can be problematic as it may identify small nodules questionably seen on prior imaging with less spatial resolution.

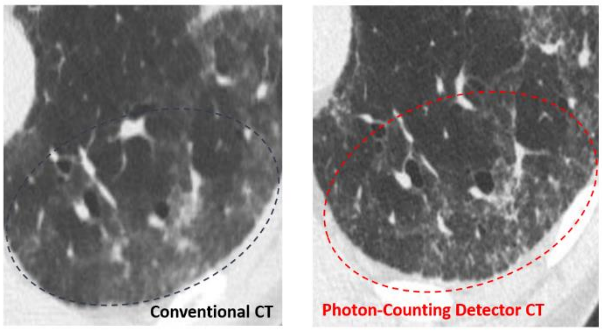
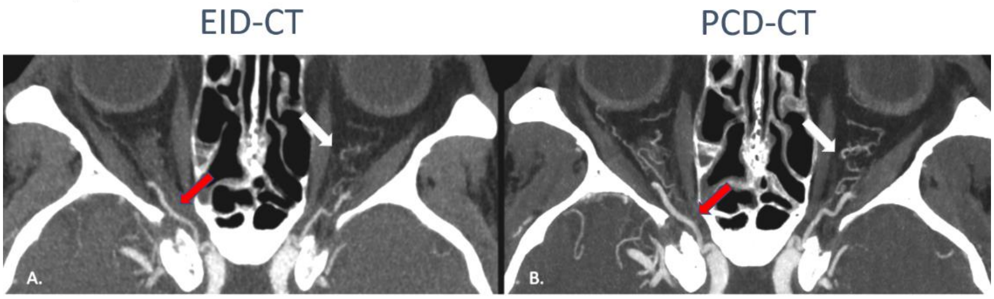


Figure 5. PCD-CT can improve diagnostic tasks in thoracic imaging that require visualization of small bronchi and image features of interstitial lung disease. In this example, ground-glass opacity is predominantly depicted on conventional CT, whereas PCD-CT reveals additional reticulation with a high degree of confidence

Spatial Resolution, Multi-energy Imaging, and Improved Iodine Signal. Routine CT angiography (CTA) permits excellent visualization of large and medium-sized vessels. Owing to improved iodine signal of PCDs coupled with increased spatial resolution and ability to reduce calcium bloom artifact, PCD-CTA can visualize small vessels not seen with conventional CTA, e.g., increased number of perforating arteries or ability to visualize critical small vessels. Improved spatial resolution combined with sharper kernels can be used to reduce the calcium bloom associated with hard and mixed plaque, as can high energy VMIs. In one study of PCD-CTA looking at below-the-knee runoff, PCD-CTA resulted in fewer occlusions due to calcific plaque, as the lumen could be visualized owing to a reduction in calcium bloom. Within-stent stenosis visualization can be improved at PCD-CTA using a similar approach. Low-energy VMIs can be used to further increase iodine signal, which neuroradiologists at our institution have utilized for decubitus PCD-CT myelography, which is identifying CSF-venous fistulas in a substantial number of patients with spontaneous intracranial hypotension who have negative digital subtraction myelography or dynamic CT myelography.

Figure 6. PCD-CTA permits visualization of small arteries not seen at conventional CTA. Note ciliary arteries visualized at PCD-CTA.



Red arrow points to ophthalmic arteries
White arrow points to ciliary arteries

See Farnsworth, Campeau, Diehn et al. Interventional Neurorad 2023 (https://doi.org/10.1177/15910199231175198)

The current impact of PCD-CT on diagnostic tasks in abdominal imaging is less pronounced than other areas, but PCD-CT can improve the detection of small contrast differences for challenging low contrast diagnostic tasks such as detection of pancreatic cancer or hepatic metastases. Because it routine generates VMIs as a standard image output, it can be used for diagnostic tasks benefitting from dual-energy CT such as evaluation of liver tumors or HCC screening or response assessment. PCD-CT better discriminate small renal stones, with use of VMIs potentially improving detection of peritoneal disease or visualization subtle nodularity within cystic tumors.

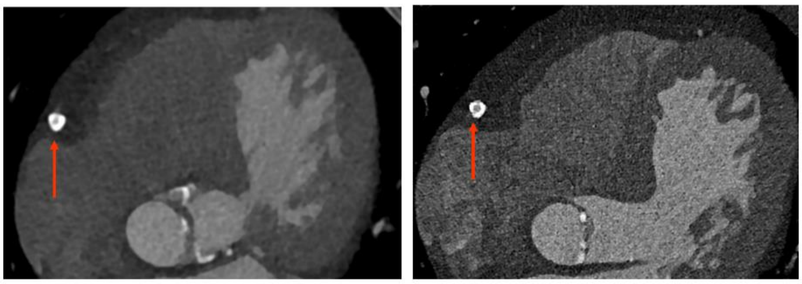


Figure 7. Calcium bloom at PCD-CT is primarily reduced using sharper reconstruction kernels and thinner slices (less partial volume averaging) and can additionally be addressed through reconstruction of higher-energy VMIs.

Multi-energy Imaging with High Temporal Resolution (dual-source PCD-CT). Dual-source PCD-CT systems can be used to permit high temporal resolution (i.e., 66 ms temporal resolution) multi-energy imaging. Compared with invasive coronary angiography, Hagar et al. estimated the performance of dual-source PCD coronary CTA to have an AUCE of 0.93 per participant and 0.92 per arterial segment in a high risk population with coronary stents and extensive coronary calcifications (https://doi.org/10.1148/radiol.223305). Coronary imaging with dual-source PCD-CT has similar advantages to PCD-CT small vessel CTA. The use of low-energy VMIs also permits diagnostic examinations with substantially lower amounts of intravenous contrast.

Dual-source PCD-CT can also perform high-pitch multi-energy CTA, which can be used to scan the adult chest in about 1 second while reducing cardiac and other motion artifact while using lower-energy VMIs to accentuate iodine signal, as well as create perfused blood volume images. This approach can be particularly useful in imaging children, as the fast table speeds minimize patient motion artifacts and VMIs can be used to increase iodine signal or reduce metal artifacts.

Figure 8. Use of high-pitch, multi-energy PCD-CT for pediatric CT enterography. Acquisition requires one second, with routine resolution multi-energy images. High-pitch, multi-energy exams are useful in pediatric patients to eliminate need for sedation.

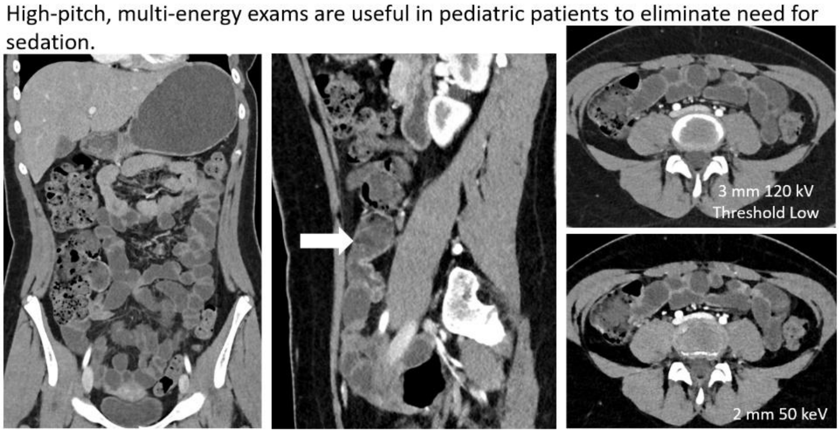
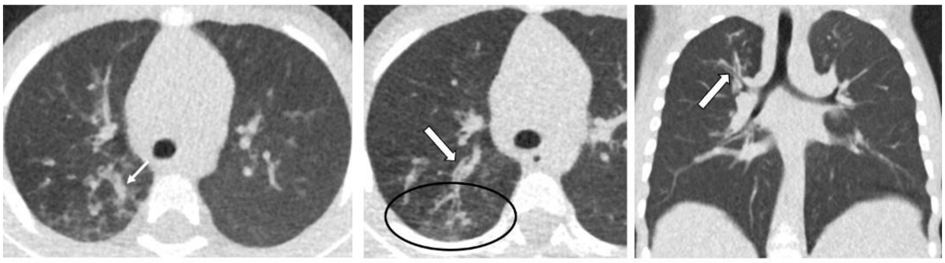


Image Noise and Radiation Dose. CT image acquisition at similar reconstruction kernel and slice thickness as conventional EID-CT will result in decreased image noise at PCD-CT; however, reducing slice thickness and employing sharper reconstruction kernels can dramatically increase image noise. This problem can be addressed by iterative reconstruction techniques to some extent, but there is generally a trade-off where increased spatial resolution can degrade image quality due to noise. Tin filtration with PCD-CT can be an especially powerful technique to substantially reduce radiation dose for many types of non-contrast CT exams.

Figure 9. PCT-CT pediatric chest CT using 100 kV with tin filter with CTDIvol 0.03 mGy, with images showing bronchial wall thickening (arrow) in segmental and subsegmental right upper lobe bronchi with scattered mucous plugging (small arrow) and small tree-in-bud nodular groundglass opacities in the right upper lobe (black oval).



Trade-offs and Limitations. UHR with the narrowest 120 x 0.2 mm detector configuration is not always possible, as this limits CT table speed, so for routine abdominal imaging, larger 144 x 0.4 mm detector configurations must be used. As mentioned, image noise can increase to an unacceptable level with very high-resolution kernels, so optimization to the diagnostic task is required. High-pitch multi-energy scanning can be performed using standard resolution (144 x 0.4 mm) but not UHR. Finally, the spectral performance of PCD-CT for VMIs and most dual-energy clinical applications is similar to conventional dual-energy CT systems but is limited for some tube potentials.

PCD-CT in a Multi-vendor Multi-specialty Radiology Practice. Introducing a PCD-CT system into a multivendor, multispecialty radiology practice requires thoughtful planning to take advantages of the technology in a way that maximizes patient benefit for each hospital or radiology practice. Consequently, radiology departments will need to compare the benefit of PCD-CT for different diagnostic tasks, and frankly discuss which types of exams should be triaged to this technology, and which exams can be performed on conventional CT systems. Triage of patients benefitting from PCDs for their CT exam may result in some practice inefficiencies. Finally, radiologist and technologist familiarity with PCD-CT systems will require dedicated training and effort and adaptation to individual radiology practices. However, these investments can yield substantial benefits to radiologists, referring clinicians, and patients.

Helpful References

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