S29 Photon Counting Detectors in Computed Tomography

Objectives

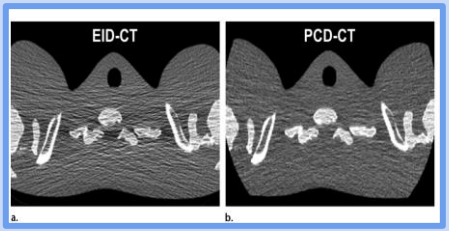
1. Define CT Photon Counting Detector (PCD)
2. Explore the advantages and challenges of a PCD

Thesis

Compared to conventional CT, CT Photon Counting Detectors provide superior spatial resolution and reduce patient dose.

What is a CT Photon Counting Detector?

- A PCD is a direct conversion technology for conversion detection that does not require a scintillator (Si-Mohamed et al., 2021, p. 2).
- PCDs count the number of individual photons exceeding specified energy levels (Leng et al., 2019, p. 731).
- The signal from a PCD carries energy information about each individually detected photon (Leng et al., 2019, p. 731).
- PCDs use semiconductor materials such as cadmium telluride, cadmium zinc telluride, silicon, and gallium arsenide (Leng et al., 2019, p. 730).



EID CT vs PCD CT shoulder section of thorax. The PCD image shows fewer streaking artifacts and a more uniform appearance, indicating less electronic noise (Leng et al, 2019).

EID-CT vs PCD-CT

EID CT (Energy Integrating Detector)

- EIDs are based on indirect conversion technology. They use a scintillator to convert X-ray photons to visible light which is then detected by a photodiode to be converted into electronic signals. This technology is currently used in conventional CT scanners (Leng et al., 2019, p. 730).

PCD CT

- PCDs use a semiconductor detector material that directly converts X-ray photons into electron-hole pairs (Leng et al., 2019, p. 730).

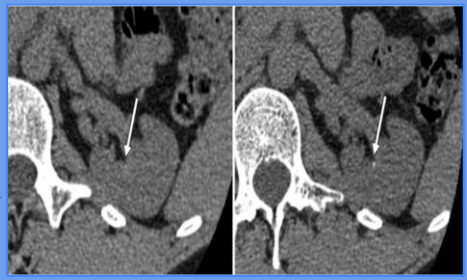
Advantages

Spatial Resolution

- Spatial resolution decreases when electronic noise is present. Electronic noise comes from analog electronic circuits in the X-ray detection system and is unrelated to the number of photons detected (Leng et al., 2019, p. 735).
- PCDs reduce electronic noise (Leng et al., 2019, p. 735).
- A reduction in electronic noise results in overall decreased image noise and improved image quality for low-dose exams (Leng et al, 2019., p.735).
- One study noted that there were no obvious differences between EID-CT and PCD in terms of overall image quality, yet PCD images were rated higher (Woeltjen et al., 2022, p. 4).
- PCD uses higher-resolution collimation. By doing this, thinner image slices with noise comparable to thicker EID-CT slices can be produced (Rajendran et al., 2022, p. 137).
  - This allows a lower dose equivalent to routine exams, thus reducing image noise and increasing spatial resolution (Rajendran et al., 2022, p. 137).

Reduce Dose

- Because PCD reduces electronic noise, exams can be performed at a lower signal intensity. This results in PCD being able to create images at a lower dose (Leng et al., 2019, p. 735).
  - Beneficial for bariatric patients because these images typically have more noise and lower signal intensity when compared to a typical patient. Therefore, less dose would be required (Leng et al., 2019, p. 735).
- Traditional CT systems have the same noise level at a higher dose level compared to PCD systems at a lower radiation dose, thus making it dose efficient (Leng et al., 2019, p. 735).
- One study noted ultra-high resolution (UHR) PCD provided higher image quality and lower levels of dose compared to high-resolution EID (Gaillandre et al., 2023, p. 5534).
- PCD can create virtual non-contrast images, which can create pre-contrast images by removing the signal from iodinated contrast agents (van der Bie et al., 2023, p. 3).
  - This eliminates pre-contrast scans and decreases patient dose.



This image demonstrates the improved spatial resolution with PCD. Kidney stone detection using EID-CT (left) and PCD (right). These small, highly contrasted structures can be detected more clearly due to PCD's increased resolution (Marcus et al, 2018).

Challenges

- A single X-ray photon can be read twice, and both times read at the incorrect energy. This is known as charge sharing (Hsieh et al., 2021, p. 442).
- Signal pile-up will happen when two independent photons are read by a singular pixel in quick succession (Hsieh et al., 2021, p. 442).
- PCDs have a limited field of view (Leng et al., 2019, p. 740).

Conclusion

- PCDs directly convert X-rays into an electrical signal and only count photons that exceed a certain energy level.
- When compared to EID-CT, PCD is superior at spatial resolution and decreasing patient dose because of its ability to suppress electronic noise. Since it can reduce electronic noise, scans can be performed at a lower signal intensity, meaning fewer X-rays are used to get the same quality images as EID-CT.
- PCD does have its challenges such as limited field of view, charge sharing, and photon pile-up.