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Commentary

Photon Counting Computed Tomography: A Breakthrough in Imaging Technology

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INTRODUCTION

Photon counting computed tomography (PCCT) is an emerging imaging technology that has been under development for several years. There are numerous benefits and applications of photon-counting computed tomography (CT) machines that have created a significant buzz in the healthcare community.

Compared to traditional CT, PCCT technology has a superior spectral and spatial resolution, resulting in a stronger image resolution. It is also much faster than traditional CT and it uses lower radiation. Patient size and even movement are not a factor when worrying about motion artifacts or blurriness.

I will begin by explaining the foundation of the technology behind this breakthrough in imaging.

A CT machine is a medical imaging device that uses a series of X-rays and a detector to produce detailed images of the internal structures of the body, generating a more detailed view than a traditional X-ray. Traditional CT machines utilize an energy-integrated-detector (EID). Within these detectors, the X-ray illuminates a scintillator layer, emitting light impulses, that are measured by a photodiode. These light impulses are then converted into an electrical signal that we process into a CT image.

When the light pulses are emitted, "dead spaces" arise in the detector due to its physical limitations and the fact that we cannot keep up with the measurement of individual photons coming in before the next pulse. With a traditional CT, we take all 30,000 photons and measure them collectively as a whole.

"*Initial technical challenges were primarily posed by cross-talk between the detector elements and the extremely fast detector readout required to separately count each incident X-ray photon*".[1]

There have been limitations to advancements in this field because, it was not possible to focus on resolution, speed, and spectral information—at the same time. Traditional CT users are forced to compromise between high spatial resolution or low dose, high-speed acquisition, or spectral information. Photon Counting CT technology is able to eliminate the need to choose.

"*Clinicians no longer have to compromise*," said Fuld.[2] "*They used to have to choose between high resolution or low dose, fast acquisition or spectral resolution. … it's yes to everything – higher resolution, low dose, speed and spectral information. It's pushing the boundaries of what CT can provide*".

This is due, in large part to the way the photons are read with PCCT technology.

PCCTs utilize a crystal semiconductor instead of a ceramic scintillator (as in traditional CT). This creates an electric charge first as opposed to light. As a result, each of the 30,000 photons can be counted individually.

The benefits that arise from this technology are; high resolution with lower radiation, better tissue differentiation, and greater speed.

High-Resolution Images with Lower Radiation

The correction of beam-hardening artifacts, and alternative contrast agent protocols create opportunities to generate high-resolution images all while maintaining a lower dose of radiation. This produces a higher contrast-to-noise ratio, improved spatial resolution, and optimized spectral imaging.

One of the first locations to utilize this technology was at University Hospital Ausberg in Germany in April of 2021.

"*The important thing to me is seeing better and seeing more, due to the intrinsic spectral separation that photon counting allows*," … said Thomas Kröncke, director of the hospital's department of diagnostic and interventional radiology.[3]

The lower radiation dose is particularly important for imaging children and young adults, who are more susceptible to the harmful effects of radiation.

Tissue Differentiation

The ability to differentiate between different tissue types based on their energy absorption properties is advantageous in many ways. This ability can be particularly useful in identifying early stages of cancer, as well as in evaluating the efficacy of certain cancer treatments. This technology proved especially useful in a recent prospective study of coronavirus disease-2019 (COVID-19) patients: "*Photon-counting detector (PCD) CT revealed subtle lung abnormalities in symptomatic participants with persistent COVID-19 symptoms that were not detectable on EID CT but may be indicative of irreversible fibrosis*", wrote Benedikt H. Heidinger, MD.[4]

"*Photon-counting detector CT outperformed energy-integrating detector CT with regard to visualization of subtle post-COVID-19 lung abnormalities and image quality*".[5]

Speed and Accuracy

The Photon counting CT's gantry spins at 250 milliseconds per rotation. EID CTs contain a gantry with a rotational spin of 400-500 milliseconds. That is nearly halving the rotational speed of the current technology.

PCCT machines have the potential to improve the accuracy of diagnoses by providing more detailed information about the internal structures of the body.

In cardiovascular imaging, for example, PCCT machines can detect plaque build-up in the arteries, which can be a precursor to heart disease. PCCT machines can provide more detailed information about the brain, making it useful for neuroimaging applications as well.

For these coronary applications; the quality of the image obtained at these speeds, often obviates the need for invasive angiography. This saves money, time and patient risk.

There are also several other potential applications of PCCT machines, including uses in; dental imaging, forensic investigations, and materials science.

Dental imaging: Dental imaging can provide high-resolution images of the teeth, allowing for better diagnosis of dental conditions. Forensic investigations: used to identify hidden weapons, explosives, or other objects. Materials science: used to study the internal structure of materials, which can be useful for developing new materials with specific properties.

Despite the benefits that are possible with this emerging technology, there are also some challenges that will need to be addressed before it becomes more widely available. These challenges are primarily, price justification and software restraints.

Price

One of the main challenges is the development of cost-effective photon-counting detectors that can be used in a clinical setting. These detectors must be able to handle the high X-ray flux and provide accurate energy measurements, which is currently a major technological hurdle, resulting in an increased cost of ownership.

The current price point is upwards of $2.3 million, which is a delta of over $1 million when compared with traditional CT.

One method to overcome this larger price would be to quantify the increase of patient throughput that results in additional exams. Another option that is available would be to run clinical studies on the equipment. This technology is still new, so white papers will be in high demand.

There are other indirect savings that would be associated with this technology when it comes to better imaging, such as the lower need for biopsies, angiographies, etc.

Software

There is a need here to develop new reconstruction algorithms that can take advantage of the unique features of PCCT data. The energy-resolved data generated by PCCT machines is more complex than the data generated by conventional CT machines and requires new computational methods for image reconstruction.

"*In portal venous abdominal photon-counting detector CT, an iterative reconstruction algorithm (QIR; Siemens Healthcare) at high strength levels improved image quality by reducing noise and improving contrast-to-noise ratio and lesion conspicuity without compromising image texture or CT attenuation values*".[6]

This hurdle is being addressed by the continual development of stronger algorithms and software, as they are pushed forward in subsequent generations of the technology. The algorithms also engage in "learning" from previous actions and datasets acquired, which result in stronger performance.

According to Manuel Algara López, MD:

"*…But this is where deep learning comes in – the algorithm can be continuously improved when more data becomes available*".[7]

CONCLUSION

In conclusion, photon-counting CT machines have the potential to revolutionize medical imaging by providing high-resolution images with a lower dose of radiation.

This technology has a wide range of potential applications in the medical field, as well as the dental, forensic, and materials science fields.

However, there are still several technical and cost-related challenges that need to be addressed before PCCT machines become widely available. With continued research and development, PCCT machines have the potential to significantly improve the accuracy and safety of medical imaging, leading to better patient outcomes.

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