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CdTe/CZT Detectors in Photon-Counting CT: The Enabling Technology Behind Spectral Imaging

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Abstract

Photon-counting computed tomography (PCCT) represents one of the most significant technological advances in diagnostic imaging. This narrative technical review summarizes current evidence (2013–2025) on cadmium telluride (CdTe) and cadmium zinc telluride (CZT) semiconductor detectors, which directly convert x-ray photons into electrical signals while preserving their energy information [1–3]. This direct-conversion architecture eliminates scintillation, enabling true spectral imaging by design. Compared with conventional energy-integrating CT (EICT), PCCT achieves 30–40% lower radiation dose, approximately 20% higher contrast-to-noise ratio (CNR), and sub-millimetric spatial resolution down to 0.25 mm, owing to the superior quantum efficiency (>95%) of CdTe/CZT sensors [4–8]. The integration of Quantum Iterative Reconstruction (QIR)—a physics-based, model-driven algorithm developed for direct-conversion detectors—further enhances texture fidelity, reduces electronic noise, and maintains spectral stability across energy bins [9,10]. Clinically, photon-counting CT enables intrinsic multi-energy acquisition, quantitative material decomposition, and robust virtual monoenergetic imaging (VMI), with demonstrated benefits across cardiac, thoracic, neurological, musculoskeletal, and pediatric radiology [5–8,11,12]. CdTe/CZT-based photon-counting CT thus exemplifies the convergence of high-energy physics, quantitative imaging, and multidisciplinary practice, advancing precision imaging and radiation stewardship in modern radiology [13].

Introduction

Photon-counting computed tomography (PCCT) has rapidly evolved from an experimental concept to a clinically consolidated imaging platform over the past decade. Since foundational reports on photon-counting detectors in medical CT appeared in 2013, iterative advances in semiconductor materials, front-end electronics, and reconstruction algorithms have driven the transition from laboratory prototypes to full-field clinical systems [1–5]. The core innovation is the use of cadmium telluride (CdTe) and cadmium zinc telluride (CZT) direct-conversion detectors, which transform incident x-ray photons into electrical charge while preserving energy information—thereby enabling true spectral imaging by design [4,6,7]. Compared with energy-integrating CT (EICT), early and contemporary evaluations consistently indicate 30–40% radiation dose reduction, approximately 20% CNR increase, and sub-millimetric spatial resolution down to 0.25 mm, attributable to the higher quantum efficiency and energy discrimination of CdTe/CZT sensors [5,8,11,12]. Building on detector physics, Quantum Iterative Reconstruction (QIR) provides a model-based framework tailored to direct-conversion data, balancing noise suppression with texture fidelity and maintaining spectral consistency across energy bins [9,13].Between 2023 and 2025, these technological and computational gains have translated into clinical benefits across cardiovascular, thoracic, neurological, musculoskeletal, and pediatric applications, reinforcing PCCT as a reference platform for high-resolution, low-dose quantitative imaging [10–12,15]. The effective adoption of PCCT in daily practice relies on multidisciplinary collaboration among radiologists, radiologic technologists, and medical physicists to define protocol parameters, QIR strength, and spectral presets that harmonize dose, resolution, and quantification [14,15].

Scope of this review.

This narrative technical review synthesizes current evidence (2013–2025) on (i) detector physics and mitigation of non-idealities (charge sharing, pulse pile-up, and K-fluorescence escape), (ii) the principles and role of QIR within PCCT reconstruction, and (iii) clinical implementation and workflow aspects—including automation and AI-assisted standardization—aimed at advancing precision imaging and radiation stewardship in modern radiology [16–20].

Materials and Methods

Literature Search Strategy

This article adopts a narrative technical review design, aligned with PRISMA recommendations adapted to imaging reviews to ensure transparency of search and selection processes [16,17]. A comprehensive literature search was conducted in three databases (PubMed, Scopus, and Web of Science) covering the period January 2013 to March 2025.The search strategy combined MeSH terms and free-text keywords organized into three concept groups:

1. Technology terms: "photon-counting CT" OR "photon counting computed tomography" OR "PCCT" AND "CdTe" OR "cadmium telluride" OR "CZT" OR "cadmium zinc telluride" OR "direct conversion";

RESEARCH ARTICLE

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2. Technical features: "spectral imaging" OR "virtual monoenergetic imaging" OR "energy discrimination" OR "ultra-high-resolution" OR "iterative reconstruction" OR "Quantum Iterative Reconstruction";
3. Clinical outcomes: "radiation dose reduction" OR "quantitative imaging" OR "material decomposition" OR "contrast-to-noise ratio" OR "spatial resolution".

Reference lists of key reviews and eligible primary studies were manually screened to identify additional relevant publications.

Inclusion and Exclusion Criteria

Inclusion criteria were: (i) peer-reviewed, English-language articles; (ii) reporting on CdTe/CZT-based photon-counting CT systems; (iii) presenting quantitative technical metrics (e.g., spatial resolution, modulation transfer function [MTF], radiation dose, CNR, spectral accuracy) or reproducible clinical outcomes; (iv) original research, technical reviews, or validation studies with transparent methodology. Exclusion criteria were: (i) non-peer-reviewed sources (white papers, marketing materials, conference abstracts without full data); (ii) studies lacking quantitative data or relying solely on qualitative assessment; (iii) articles focused exclusively on non-CdTe/CZT detector technologies (e.g., silicon-based systems, conventional dual-energy CT without photon-counting); (iv) opinion pieces or editorials without supporting primary evidence.

Data Extraction and Synthesis

Titles and abstracts were screened for relevance, full texts were assessed for eligibility, and data were extracted on detector architecture, acquisition parameters (including ultra-high-resolution [UHR] voxel size), reconstruction settings (including QIR level where applicable), quantitative outcomes, and key clinical endpoints. Given heterogeneity in study designs and reporting formats, findings were synthesized qualitatively across three domains: (i) detector physics and mitigation of non-idealities, (ii) reconstruction principles with emphasis on QIR, and (iii) clinical implementation and workflow—reporting ranges for performance metrics where feasible, with emphasis on recent primary evidence (2023–2025) [5,8,11–13].

Note on vendor-specific terminology:

Vendor-specific kernel names are reported together with a generic description (e.g., medium-sharp lung kernel) to preserve multi-vendor readability.

Limitations of This Review:

Owing to the heterogeneity of study designs, scanners, and reporting metrics, a formal meta-analysis was not feasible. Reported ranges (e.g., dose reduction, CNR gains) synthesize heterogeneous protocols and cohorts; they should be interpreted as indicative rather than universal benchmarks. No new human or animal data were collected; ethics approval and informed consent were not applicable. The review was not prospectively registered; methods follow PRISMA guidance adapted to narrative reviews in imaging [16,17].

Results and Technical Discussion

Detector Physics and Technological Principles

CdTe and CZT are high-atomic-number (Z = 48–52), wide-bandgap semiconductors that directly convert x-ray photons into electrical charge without intermediate scintillation, preserving per-photon energy information and enabling true spectral imaging by design [1–3]. This direct-conversion architecture minimizes electronic noise, improves quantum efficiency (>95% in the diagnostic energy range), and enables fine energy discrimination compared to conventional scintillator-based systems [4,7]. Clinical PCCT systems employing CdTe/CZT detectors achieve sub-millimetric spatial resolution with voxel sizes down to approximately 0.25 mm, supporting ultra-high-resolution (UHR) imaging protocols [5,8,11]. The superior stopping power of these high-Z materials ensures efficient photon absorption across the diagnostic energy range (20–150 keV), translating into improved dose efficiency and spectral fidelity [7,21].

Mitigation of Performance Non-Idealities

Performance limitations inherent to direct-conversion detectors—charge sharing, pulse pile-up, and K-fluorescence escape—have been largely mitigated through combined hardware and algorithmic optimization [5,12,22]. Charge sharing occurs when photon-generated charge clouds are distributed across adjacent pixels, potentially leading to energy misregistration or double-counting. This is addressed through optimized pixel pitch (approximately 0.15–0.25 mm) and advanced charge-summing or anti-coincidence logic circuits that reassign shared events to single pixels [12,22]. Pulse pile-up arises from overlapping photon events at high count rates, causing count losses or energy distortion. Modern systems manage pile-up via shorter shaping times (typically <100 ns) and adaptive energy thresholds that maintain linearity even under clinical flux conditions (>10^8 photons/mm²/s) [5,12]. K-fluorescence escape refers to the loss of characteristic x-ray photons generated within the detector material. K-fluorescence escape from Cd (Kα ≈ 23.2 keV) and Te (Kα ≈ 27.5 keV) can shift events to lower bins; calibration models and digital anti-coincidence/correction filters mitigate this effect [22].These technical refinements ensure linear count-rate behavior, stable energy calibration across the tube current range, and consistent spectral reproducibility in routine clinical use [5,12]. Recent quantitative evaluations confirm significant performance advantages relative to energy-integrating CT: 30–40% radiation dose reduction

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RESEARCH ARTICLE

at equivalent diagnostic quality [5,8,21], 15–25% improvement in contrast-to-noise ratio for soft-tissue imaging [11,23], and reproducible MTF values up to approximately 25 lp/cm in ultra-high-resolution protocols [8,12].

Quantum Iterative Reconstruction (QIR)

Quantum Iterative Reconstruction (QIR) is a vendor-specific, physics-based iterative algorithm specifically developed and optimized for photon-counting CT data acquired through direct-conversion detectors. Unlike generic iterative reconstruction methods applied to energy-integrating CT, QIR integrates an explicit forward model of detector response, energy-bin-specific noise propagation, and voxel-wise regularization tailored to the statistical properties of photon-counting data [13,16]

***Technical Framework*:**

QIR reconstructs photon-counting data using an iterative feedback loop that refines image estimates by minimizing discrepancies between measured projection data and forward-projected model predictions. Each iteration maintains deterministic control of noise suppression and spatial resolution, enabling stable and reproducible image output across acquisition conditions. The algorithm explicitly accounts for Poisson statistics in individual energy bins, ensuring that noise reduction does not compromise spectral quantification accuracy [13]. Note on Proprietary Nature: While QIR principles and clinical performance are described in peer-reviewed literature [9,10,13,16], specific implementation details (e.g., regularization weights, convergence criteria) remain proprietary. The clinical performance data presented in this review derive exclusively from peer-reviewed studies; vendor technical documentation was consulted only to clarify algorithmic nomenclature and is not cited as primary evidence.

Clinical Impact of QIR

At moderate strength settings (typically QIR levels 2–4 on a scale of 1–5), QIR shifts the noise power spectrum (NPS) toward lower spatial frequencies without suppressing fine anatomical detail, maintaining natural image granularity and edge sharpness [9,13]. This avoids the over-smoothed or "plastic" appearance typical of older iterative methods while achieving substantial noise reduction. As described by Scappatura [16], QIR represents "a transparent, self-consistent framework capable of reinventing photon-counting CT technology." QIR also harmonizes energy-bin consistency, ensuring that spectral reconstructions remain quantitatively aligned across low- and high-energy thresholds. This enhances iodine quantification accuracy, stabilizes material decomposition algorithms, and supports reproducible virtual monoenergetic imaging (VMI) [10,13]. Excessive reconstruction strength (QIR level 5) may lead to unnatural texture uniformity and should be reserved for specific low-dose applications where noise reduction is prioritized over texture preservation [13]. In clinical settings, QIR improves low-dose imaging performance, supports consistent image texture perception across patient sizes, and enhances diagnostic confidence in cardiac, thoracic, neurological, and pediatric PCCT protocols [10,12,13,16]. QIR is a physics-based, model-driven framework tailored to direct-conversion data. Claims are limited to evidence-based statements; very high strength levels may induce texture uniformity and should be avoided.

Summary of Recent Evidence

The cumulative advances between 2023 and 2025 establish PCCT as a mature technology with validated physical and clinical performance. Key findings from recent primary studies and technical reviews are summarized in Table 1.

Clinical Implementation and Applications

Building on the quantitative advantages summarized in Table 1, CdTe/CZT-based photon-counting CT (PCCT) demonstrates reproducible clinical impact across major radiologic subspecialties. The integration of direct-conversion detectors, spectral precision, and model-based reconstruction has expanded its role in diagnostic imaging by improving contrast resolution, dose efficiency, and quantitative accuracy.

Cardiovascular Imaging

PCCT enhances visualization of coronary lumens, calcified plaques, and stent structures. Energy-resolved imaging improves calcium–iodine separation, reducing blooming artifacts that obscure stent lumens in heavily calcified vessels [4,10,13]. QIR maintains high contrast and low noise even at reduced tube potentials (100–120 kV), enabling both radiation and iodine contrast dose savings [10]. However, temporal resolution remains slightly lower than dual-source energy-integrating detector (EID) systems, requiring careful heart rate control (<65 bpm) and prospective ECG-gating for optimal results [8,21].

Practical tips in cardiac PCCT: (i) use β-blockade to stabilize heart rate when feasible; (ii) prefer prospective ECG-gating with minimal padding in sinus rhythm; (iii) select medium-sharp vascular kernels and intermediate QIR levels to balance stent-lumen edge definition and noise.

Thoracic and Oncologic Imaging

In thoracic and oncologic applications, PCCT enhances detection of small pulmonary nodules and subtle vascular anomalies. Low-keV virtual monoenergetic images (VMI, typically 40–60 keV) increase iodine conspicuity, improving lesion characterization and perfusion assessment [10,11,14]. High-keV images (>100 keV) mitigate beam-hardening effects

RESEARCH ARTICLE

in mediastinal regions and reduce streak artifacts from surgical hardware. Spectral imaging also allows quantitative assessment of tumor perfusion, tissue composition, and therapy response through iodine density maps and material-specific reconstructions [11,14]. Optimal results require careful tuning of reconstruction kernels (sharp kernels [Br68–Br76] for lung parenchyma, medium kernels [Br44–Br56] for soft tissue) and moderate QIR strength (level 2–3) to avoid texture alteration [13,14].

Neuroimaging

The high spatial resolution of PCCT facilitates differentiation between contrast enhancement and acute hemorrhage, a critical distinction in stroke and post-operative imaging [11,12]. High-keV VMI (>100 keV) effectively suppresses streak artifacts from surgical hardware, improving diagnostic accuracy in neurovascular studies [12]. Enhanced spectral fidelity ensures precise tissue characterization across complex intracranial structures, with sub-millimetric depiction of cortical and vascular detail in UHR protocols [11]. A potential risk of oversmoothing at high QIR strength (level 5) necessitates moderate settings (level 2–3) to preserve natural texture [13].

Musculoskeletal Imaging

In musculoskeletal studies, photon-counting CT enables detailed evaluation of trabecular microarchitecture, subtle cortical fractures, and implant–bone interfaces through 0.25-mm voxel acquisitions [10,14]. Spectral decomposition supports analysis of bone mineral density and soft-tissue composition, while QIR's adaptive modeling preserves edge sharpness and minimizes image noise [10]. However, UHR mode inherently increases noise, requiring appropriate QIR settings (level 3–4) to balance spatial resolution with diagnostic image quality [13,14]. Clinical validation of the diagnostic impact of sub-0.3 mm resolution on specific musculoskeletal tasks remains an active area of investigation.

Pediatric Imaging

For pediatric examinations, PCCT combines spectral precision with superior dose efficiency. The high quantum efficiency (>95%) of CdTe/CZT detectors, in combination with QIR's advanced noise suppression, allows 30–50% radiation dose reduction without compromising image quality or diagnostic reliability [12,23]. This supports radiation stewardship principles in vulnerable populations requiring serial follow-up. However, validation in very low body weights (<10 kg) remains limited, and conservative energy bin selection is recommended until broader pediatric evidence is established [12].

Clinical Trade-Offs and Protocol Optimization

A comparative summary of clinical benefits, limitations, and recommended protocol strategies is provided in Table 2.

Table 1. *Recent Clinical and Technical Evidence on CdTe/CZT-Based Photon-Counting*

Year	Authors / Journal	Study Type	Focus Area	Key Findings	Relevance to PCCT
2023	Flohr T et al., Invest Radio	Technical review	Technical fundamentals	Dose ↓20–40%; QE >95%; MTF validation	Confirms CdTe/CZT as reference materials with measured performance metrics
2023	Zhan X et al., Phys Med Biol	Phantom study	Detector characterization	Spectral linearity; charge-sharing mitigation validated	Validates physical robustness and count-rate stability
2024	Ma L et al., Sci Rep	Clinical study	Vascular imaging / QIR	QIR levels 2–4 optimize CNR and texture balance	Demonstrates QIR's clinical benefit in femoral angiography
2024	Frings M et al., Eur Radiol Exp	Comparative study	Thoracic imaging	Dose ↓35%; improved UHR visibility in cystic fibrosis	Confirms efficiency and spatial resolution advantage in lung imaging
2025	Schwartz FR et al., Radiology	Comprehensive review	Clinical applications	Multi-organ validation; workflow integration	Establishes clinical maturity across cardiovascular, oncologic, neuro domains

2025	Zhang Y et al., Diagnostics	Bibliometric analysis	Cardiac imaging	Publication growth (2019–2024); expanding clinical adoption	Confirms accelerating clinical use and research interest

Abbreviations: CNR, contrast-to-noise ratio; MTF, modulation transfer function; PCCT, photon-counting computed tomography; QE, quantum efficiency; QIR, Quantum Iterative Reconstruction; UHR, ultra-high-resolution.

Table 2. *Clinical Applications*: *Benefits, Limitations, and Protocol Optimization Strategies*

Clinical Area	Technical Benefit	Trade-Off / Limitation	Recommended Protocol Strategy
Cardiac	Calcium–iodine separation; reduced blooming; improved stent–lumen visibility	Temporal resolution lower than dual-source EID CT; potential motion artifacts at high heart rates	Optimize heart rate control (<65 bpm); use medium-sharp vascular kernels*; QIR level 2–3 for noise balance; prospective ECG-gating when feasible
Thoracic / Oncologic	Low-keV VMI increases iodine conspicuity; spectral decomposition for nodule characterization	Residual artifacts if reconstruction kernel/QIR not optimized; potential noise increase at very low keV (<40 keV)	Sharp lung kernels* (e.g., Br68–Br76) for parenchyma; medium soft-tissue kernels* (e.g., Br44–Br56) for mediastinum; iodine maps for perfusion; moderate QIR (level 2–3)
Neurological	High-keV VMI reduces metal artifacts; sub-millimetric cortical detail; improved differentiation of contrast enhancement vs acute hemorrhage	Risk of oversmoothing at high QIR strength; limited validation in acute stroke protocols	UHR mode for vascular/cortical detail; high-keV VMI (>100 keV) for metal artifact reduction; moderate QIR (level 2–3) to preserve texture
Musculoskeletal	UHR protocols improve trabecular microarchitecture visibility; spectral decomposition for bone composition	Increased noise in UHR mode requires careful QIR tuning; limited evidence on clinical impact of sub-0.3 mm resolution	UHR acquisition (0.2–0.25 mm voxel); sharp reconstruction kernels*; QIR level 3–4 for noise control; validate MTF improvement for specific diagnostic tasks
Pediatric	High detector efficiency enables 30–50% dose reduction; maintains diagnostic quality at low kV	Limited validation in very low body weights (<10 kg); conservative energy bin selection needed	Weight-based protocols; QIR level 3–4 for optimal dose/quality trade-off; conservative spectral bin thresholds; document dose savings vs institutional diagnostic reference levels (DRLs)

*Vendor-specific kernel names are provided as examples; generic descriptions (e.g., sharp lung kernel, medium soft-tissue kernel) ensure multi-vendor applicability.

Abbreviations: bpm, beats per minute; DRL, diagnostic reference level; ECG, electrocardiogram; EID, energy-integrating detector; keV, kiloelectron volt; kV, kilovolt; MTF, modulation transfer function; QIR, Quantum Iterative Reconstruction; UHR, ultra-high-resolution; VMI, virtual monoenergetic imaging.

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Radiation Dose and Image Quality

The direct-conversion principle of PCCT improves quantum efficiency and signal-to-noise ratio compared to conventional energy-integrating CT. By capturing nearly all incident photons (>95% detection efficiency) and minimizing electronic noise, PCCT allows diagnostic-quality imaging at significantly lower tube potentials (100–120 kV vs 120–140 kV) [1,5,7,21]. QIR further enhances dose performance by maintaining the natural structure of the noise power spectrum (NPS) while reducing its amplitude, resulting in visually realistic texture and optimal contrast-to-noise ratio [9,13]. Multiple primary studies have reported dose reductions of 20–40% relative to conventional CT and 30–50% relative to dual-energy CT systems without loss of diagnostic performance [5,8,21,23]. The combination of photon-counting detection and model-based reconstruction supports the principles of radiation stewardship, enabling consistent low-dose imaging in routine practice and in vulnerable patient groups (pediatric, young adults) requiring serial follow-up [12,16,23].

Practical Implementation: From Theory to Clinical Practice

Protocol Selection and Optimization

Successful integration of PCCT requires systematic protocol design based on clinical indication. For cardiovascular imaging, protocol optimization focuses on balancing temporal resolution (ECG-gating strategy, heart rate control) with spectral fidelity (energy threshold selection). Low-tube-voltage protocols (100–120 kV) enhance iodine signal while maintaining acceptable noise levels through QIR adjustment (typically level 2–3) [10,13]. In thoracic imaging, sharp reconstruction kernels (Br68–Br76) maximize spatial resolution for lung nodule detection, while medium kernels (Br44–Br56) preserve soft-tissue contrast in mediastinal and vascular structures [14]. Energy bin selection should prioritize clinical objectives: low-keV VMI (40–60 keV) for iodine conspicuity, high-keV VMI (>100 keV) for metal artifact reduction, and iodine maps for quantitative perfusion assessment [11,14].

Interpretation of Spectral Data

Spectral datasets require structured interpretation workflows. Virtual monoenergetic images should be evaluated in combination with conventional (weighted-average) reconstructions to avoid misinterpretation of artifacts. Iodine density maps provide quantitative tissue enhancement but require validation against reference standards and awareness of partial-volume effects in small structures (<5 mm) [14]. Material decomposition algorithms perform optimally when energy separation exceeds 30 keV; closer bin spacing may reduce discrimination accuracy [7]. Radiologists should verify spectral calibration through periodic phantom quality assurance (QA) and remain alert to beam-hardening residuals in large patients (>100 kg) or high-attenuation regions (dense bone, metal implants) [12,22].

Workflow, Automation, and Future Perspectives

The introduction of PCCT redefines radiology workflow, demanding collaboration among radiologic technologists, radiologists, and medical physicists. Technologists are responsible for managing spectral bin selection, QIR level tuning, and acquisition protocol standardization. Radiologists interpret spectral datasets including iodine maps and material-specific reconstructions. Medical physicists oversee calibration, spectral QA, and dose monitoring [10,12,15]. Vendors are integrating artificial intelligence (AI)-driven automation and decision-support tools to streamline workflow, automatically suggesting optimal acquisition and reconstruction parameters based on patient size, clinical indication, and institutional protocols [8,18]. These systems improve reproducibility, reduce inter-operator variability, and standardize image quality across institutions [18].

Ongoing research explores novel semiconductor materials, such as edge-on silicon detectors and perovskite-based sensors, to enhance energy range and manufacturability [19,24,25]. Nevertheless, CdTe/CZT remains the technological gold standard due to its stability, high absorption efficiency (>95%), and proven clinical reliability across diverse applications [5,10,21].Emerging developments—including portable PCCT scanners, point-of-care systems, and ultra-low-dose pediatric protocols—demonstrate the expanding potential of photon-counting CT in both hospital and outpatient environments [15,20]. The fusion of advanced detector physics, quantum reconstruction algorithms, and artificial intelligence represents the next evolutionary step in diagnostic imaging, where PCCT serves as a platform for precision medicine, dose optimization, and quantitative analysis [16,18].

Glossary of Key Technical Terms

***CdTe/CZT*:** Cadmium telluride (CdTe) and cadmium zinc telluride (CZT) are high-atomic-number semiconductor materials used in direct-conversion photon-counting detectors.

***Charge sharing*:** Distribution of photon-generated charge clouds across adjacent detector pixels, potentially causing energy misregistration; mitigated through optimized pixel geometry and anti-coincidence logic.

***Direct-conversion detector*:** A detector that converts x-ray photons directly into electrical charge without intermediate scintillation, preserving individual photon energy information.

***Energy bin*:** A predefined energy range (threshold interval) used to sort detected photons by energy, enabling spectral imaging and material decomposition.

***K-fluorescence escape*:** Loss of characteristic x-ray

photons generated within the detector material, leading to undercounting or energy misregistration; mitigated through calibration and digital correction.

***MTF* (*Modulation Transfer Function*):** A quantitative measure of spatial resolution, expressed in line pairs per centimeter (lp/cm), indicating the system's ability to reproduce spatial detail.

***Pulse pile-up*:** Overlapping detection events at high photon flux, causing count losses or energy misestimation; addressed through optimized shaping times and adaptive thresholds.

***QIR* (*Quantum Iterative Reconstruction*):** A model-based iterative reconstruction algorithm specifically developed for photon-counting CT that incorporates detector physics and energy-bin-specific noise statistics.

***Quantum efficiency*:** The fraction of incident photons successfully detected and converted into useful signal; exceeds 95% for CdTe/CZT detectors in the diagnostic energy range (20–150 keV).

***UHR* (*Ultra-High-Resolution*):** Imaging mode achieving sub-millimetric voxel size (typically 0.2–0.25 mm), enabling visualization of fine anatomical structures such as trabecular bone and cortical detail.

***VMI* (*Virtual Monoenergetic Imaging*):** Synthetic images reconstructed at specific energy levels (e.g., 40 keV, 70 keV, 120 keV) from spectral data, used to optimize iodine contrast or reduce beam-hardening and metal artifacts.

Conclusions

CdTe/CZT-based photon-counting computed tomography consolidates a decade of technological progress into a clinically mature platform that is spectral by design, dose-efficient, and capable of sub-millimetric ultra-high-resolution imaging. Direct-conversion detection, combined with model-based Quantum Iterative Reconstruction, delivers consistent gains—30–40% radiation dose reduction, approximately 20% CNR increase, and reproducible 0.25-mm voxel protocols—while preserving texture and spectral stability across energy bins. Evidence from 2023–2025 confirms clinical translation across cardiovascular, thoracic/oncologic, neurological, musculoskeletal, and pediatric domains, provided that protocol parameters, reconstruction kernels, and QIR strength are harmonized through multidisciplinary collaboration. The full clinical value of PCCT depends on governance involving radiologists, radiologic technologists, and medical physicists, with standardized workflows for spectral presets, calibration, and quality control. Looking ahead, AI-assisted parameter selection, automated spectral calibration, and cross-site protocol harmonization are poised to further improve reproducibility, radiation stewardship, and diagnostic confidence. These advances will facilitate wider adoption of PCCT and strengthen its role as a reference standard for quantitative, dose-efficient imaging across diverse clinical settings.

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Institutional Review Board Statement

Not applicable. This is a narrative review of published literature; no new human or animal data were collected.

Data Availability Statement

Not applicable. All data discussed in this review are available in the cited peer-reviewed publications.

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