

Beyond the Scan: The Evolving Role of Computed Tomography in Early Cancer Detection: From Early Lesion Detection to Precision Oncologic Imaging

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Abstract: ***Background:** Early cancer detection remains an important objective of modern oncology because the stage at diagnosis strongly influences treatment options and prognosis. Computed tomography (CT) has developed from a primarily anatomical imaging technique into a sophisticated platform capable of high-resolution structural assessment, quantitative tissue characterization, and increasingly automated image analysis. Its role is particularly important in lung, colorectal, pancreatic, and other abdominal malignancies. **Objective:** To review the current role of CT in early cancer detection and examine emerging developments that may improve lesion detection, characterization, and clinical decision-making. **Methods:** A narrative review of recent and established peer-reviewed literature was undertaken, with emphasis on low-dose CT screening, contrast-enhanced CT, spectral and multi-energy CT, photon-counting detector CT, radiomics, and artificial intelligence-assisted cancer detection. Recent diagnostic studies, systematic reviews, meta-analyses, and clinical guidance documents were considered. **Results:** Low-dose CT has demonstrated a mortality benefit in high-risk lung-cancer screening populations; in the National Lung Screening Trial, low-dose CT reduced lung-cancer mortality by 20% compared with chest radiography [1]. Contemporary lung-screening recommendations continue to incorporate risk-based selection and structured management of CT-detected nodules [2,3]. In colorectal cancer, CT has useful diagnostic and staging performance, although sensitivity varies according to depth of tumor invasion and clinical question [4,5]. Emerging technologies are extending CT's capabilities: spectral CT can provide iodine maps and virtual monochromatic images that may improve lesion characterization and treatment assessment [6], and photon-counting CT offers higher spatial resolution and intrinsic spectral information with potential oncologic benefits [7,8]. Artificial intelligence and radiomics may identify subtle imaging patterns before overt morphological abnormalities become apparent; recent pancreatic-cancer studies have demonstrated promising pre-diagnostic performance using quantitative CT features and deep-learning systems [9–11]. **Conclusion:** CT remains central to contemporary cancer imaging, but its future role extends beyond conventional anatomical visualization. The integration of low-dose techniques, spectral imaging, photon-counting technology, radiomics, and artificial intelligence may enable earlier and more precise detection of malignancy. However, prospective validation, standardized protocols, and clinical integration are required before emerging technologies can be routinely relied upon for cancer screening or diagnosis.*

Keywords: Computed tomography; cancer detection; early diagnosis; oncologic imaging; low-dose CT; spectral CT; photon-counting CT; radiomics; artificial intelligence

1. Introduction

Cancer continues to represent a major global health burden, and delayed diagnosis remains an important barrier to successful treatment. The clinical significance of early detection is particularly evident in cancers such as lung and pancreatic malignancies, where symptoms may develop only after substantial disease progression. Modern imaging therefore has an increasingly important role not only in confirming suspected malignancy but also in identifying abnormalities at an earlier stage.

Computed tomography has become one of the most widely used imaging techniques in oncology because of its speed, high spatial resolution, and ability to evaluate large anatomical regions. Unlike conventional radiography, CT provides cross-sectional information that can demonstrate lesion size, morphology, anatomical relationships, vascular involvement, and metastatic disease.

The role of CT in oncology has changed considerably over the past two decades. Conventional single-energy CT is now complemented by low-dose acquisition, iterative and deep-learning reconstruction, dual-energy and spectral CT, radiomics, and photon-counting detector technology. Artificial intelligence (AI) is also being investigated as an

additional layer of analysis that may assist radiologists in identifying subtle abnormalities.

This technological evolution raises an important question: can CT move from detecting established cancer to identifying imaging changes associated with cancer before the disease becomes clinically obvious?

Recent evidence suggests that the answer may increasingly be yes, particularly when conventional CT is combined with quantitative analysis and AI. However, early detection should not be confused with definitive diagnosis—imaging findings remain dependent on clinical context and, in many cases, histopathological confirmation.

This review examines the current and emerging role of CT in early cancer detection, focusing on lung, colorectal, and pancreatic cancers, and on the technologies that may shape the next generation of oncologic CT.

2. CT and the Concept of Early Cancer Detection

Early cancer detection involves identifying malignant disease before it progresses to advanced stages. From an imaging perspective, this can occur through several pathways:

- Detection of a small structural abnormality.

- Identification of a lesion with suspicious morphological characteristics.
- Recognition of abnormal enhancement or vascularity.
- Identification of quantitative tissue changes.
- Detection of subtle abnormalities using radiomics or AI before they become visually obvious.

Conventional CT primarily addresses the first three mechanisms. Spectral CT and quantitative imaging extend this capability by providing additional information about tissue composition and contrast distribution [6].

Radiomics and deep-learning approaches go further by analysing large numbers of imaging features that may not be readily appreciated during routine visual interpretation. This has generated considerable interest in cancers in which early morphological abnormalities can be subtle, particularly pancreatic cancer [9–11].

However, improved detection does not automatically mean improved patient outcomes. Any new imaging technology must ultimately demonstrate that earlier detection leads to clinically meaningful benefits, while avoiding excessive false-positive findings, unnecessary investigations, and radiation exposure.

3. Low-Dose CT and Early Detection of Lung Cancer

Lung cancer represents one of the clearest examples of CT contributing directly to early cancer detection.

The National Lung Screening Trial enrolled 53,454 individuals at high risk for lung cancer and compared three annual rounds of low-dose CT with chest radiography. Lung-cancer mortality was reduced by 20% in the low-dose CT group compared with the radiography group [1].

This landmark evidence established the clinical importance of low-dose CT in appropriately selected high-risk populations. Current recommendations continue to emphasize risk-based selection, standardized imaging, and appropriate management of detected pulmonary nodules [2,3].

The major advantage of low-dose CT is its ability to demonstrate small pulmonary nodules that may be invisible or poorly characterized on conventional chest radiography. However, screening also produces substantial numbers of indeterminate findings — the original National Lung Screening Trial reported that 96.4% of positive low-dose CT screening results were false positives [1].

This illustrates a central challenge in CT-based cancer screening: higher sensitivity can increase the number of findings requiring additional assessment.

Contemporary nodule-management approaches therefore focus on standardized assessment of nodule size, morphology, density, and growth rather than treating every detected nodule as cancer. Recent analysis of the NELSON trial has further emphasized the importance of volumetric assessment and structured management in reducing

unnecessary follow-up while maintaining diagnostic safety [3].

4. CT in Colorectal Cancer

CT has an important role in colorectal cancer evaluation, although colonoscopy remains central to direct mucosal assessment and tissue diagnosis.

Contrast-enhanced CT is particularly valuable once colorectal cancer is suspected or established because it can assess the primary tumor, regional structures, and distant metastases.

A recent systematic review and meta-analysis involving 44 studies found that CT demonstrated a pooled sensitivity of 83% and specificity of 70% for identifying pT3–T4 colon tumors [4]. Performance was lower for some more specific staging questions, demonstrating that CT should be interpreted according to the clinical objective rather than as a universal substitute for endoscopic and pathological assessment.

CT colonography provides another important application. A meta-analysis of 14 studies involving 3,578 high-risk patients reported pooled sensitivity of 87% and specificity of 90% for detecting colorectal polyps ≥ 6 mm; for lesions ≥ 10 mm, sensitivity increased to approximately 91% and specificity to 98% [5].

These findings demonstrate the ability of CT-based techniques to identify clinically relevant colorectal abnormalities, particularly larger lesions.

Nevertheless, CT cannot replace histopathology for definitive cancer diagnosis. Its greatest value lies in combining lesion detection with anatomical staging and assessment of disease distribution.

5. Pancreatic Cancer: The Next Frontier for Early CT Detection

Pancreatic ductal adenocarcinoma (PDAC) represents one of the most challenging cancers for early imaging detection. Early symptoms may be nonspecific, and an obvious mass may not be present during the earliest phase of disease.

Contrast-enhanced CT remains an important imaging modality for pancreatic cancer because it provides information about the pancreas, surrounding vessels, local extension, and metastatic disease [10].

The emerging research question is whether CT contains subtle information that precedes the development of a clearly visible pancreatic mass.

Chen et al. investigated quantitative CT imaging features in patients who subsequently developed pancreatic cancer. Their radiomic algorithms demonstrated promising predictive performance, including high area-under-the-curve values in scans obtained months to years before diagnosis [9]. These findings suggest that measurable imaging changes may exist before conventional visual diagnosis.

The implications are potentially substantial. If validated prospectively, quantitative analysis could transform selected CT examinations from retrospective diagnostic tools into opportunities for earlier risk identification.

However, the results should not be interpreted as evidence that radiomics is currently ready for population-wide pancreatic cancer screening. The study was based on retrospective data and algorithmic prediction, and clinical implementation requires independent validation.

6. Artificial Intelligence and CT-Based Cancer Detection

Artificial intelligence is rapidly becoming one of the most important developments in medical imaging.

AI systems can be trained to recognize complex imaging patterns, segment organs and lesions, estimate malignancy risk, and identify abnormalities that may be subtle during routine interpretation.

A recent systematic review of multi-reader, multi-case cancer diagnostic studies found that AI-assisted interpretation generally demonstrated higher pooled sensitivity and specificity than clinicians working without AI assistance, although substantial methodological concerns and risk of bias were present in a proportion of studies [12].

Pancreatic cancer provides a particularly interesting example. The PANORAMA study evaluated an AI system using CT examinations from 3,440 patients. In the sequestered testing cohort, the AI system achieved an AUROC of 0.92; in a reader study involving 68 radiologists, AI achieved an AUROC of 0.92 compared with 0.88 for the radiologist group [11].

These results suggest that AI may have the capacity to identify pancreatic ductal adenocarcinoma on routine CT and potentially assist with earlier detection.

However, the appropriate interpretation is augmentation rather than replacement. AI performance depends on the quality and diversity of training data, scanner characteristics, acquisition protocols, prevalence of disease, and clinical population. The recent literature on AI-assisted CT therefore supports cautious optimism rather than unrestricted clinical adoption.

7. Radiomics: Extracting More Information from CT

Radiomics refers to the extraction of large numbers of quantitative features from medical images. Traditional CT interpretation largely depends on features such as:

- Lesion size
- Shape
- Attenuation
- Enhancement pattern
- Margins
- Anatomical relationships

Radiomics can additionally evaluate quantitative characteristics related to texture, intensity distribution, spatial relationships, and heterogeneity.

This approach is particularly attractive in oncology because tumors are biologically heterogeneous. Imaging heterogeneity may contain information related to tumor biology, aggressiveness, and treatment response.

In pancreatic cancer, quantitative CT features have shown potential for predicting malignancy before conventional diagnosis [9]. Radiomics combined with spectral CT is also being investigated for tumor staging and characterization.

A 2024 study using dual-layer spectral detector CT developed a clinical-radiomics model for pancreatic ductal adenocarcinoma staging. A radiomics signature based on 40-keV virtual monochromatic images produced AUC values of 0.96 in the training cohort and 0.94 in the test cohort [13].

Although such findings are encouraging, radiomic models require external validation because performance can change when applied to different scanners, acquisition protocols, and patient populations.

8. Spectral CT and Oncologic Imaging

Spectral CT represents another important step in the evolution of CT technology.

Conventional CT primarily measures X-ray attenuation. Spectral or multi-energy CT acquires information at different energy levels and can generate additional image datasets. Important outputs include:

- Virtual non-contrast images
- Iodine maps
- Virtual monoenergetic images
- Material-specific images

These datasets can provide additional information about tumor vascularity and tissue composition.

A review of spectral CT in oncology reported that combinations of virtual non-contrast and low-energy monoenergetic images can improve lesion detection and characterization, while iodine maps may provide quantitative information relevant to tumor perfusion and treatment response [6]. This is particularly important because tumor vascularity can provide information beyond simple lesion morphology.

The development of quantitative multi-energy CT has further expanded the potential applications of CT in oncology. Quantitative biomarkers derived from dual-energy and photon-counting CT may eventually contribute to tumor characterization and assessment of treatment response [14].

9. Photon-Counting CT: A New Generation of CT Imaging

Photon-counting detector CT is among the most significant recent developments in CT technology.

Traditional CT systems use energy-integrating detectors. Photon-counting detectors directly register individual X-ray photons and can provide information about their energy. This technology offers several potential advantages, including:

- Improved spatial resolution
- Intrinsic spectral imaging
- Improved contrast-to-noise characteristics
- Improved material separation
- Potential radiation-dose reduction

A comprehensive 2025 review described photon-counting CT as a major technological development with expanding clinical applications [7].

Evidence is also emerging specifically in oncologic imaging. A systematic review and meta-analysis comparing photon-counting CT with conventional CT for lung nodules found improvements in several image-quality measures with photon-counting technology [8].

The implications for cancer imaging are considerable. Higher spatial resolution could improve visualization of small lesions, while spectral capabilities could improve lesion characterization. However, photon-counting CT remains a relatively new technology- cost, scanner availability, reconstruction requirements, clinical standardization, and the need for outcome-based validation remain important challenges.

10. Radiation Dose: Finding the Balance

The ability to detect cancer early must always be balanced against radiation exposure.

CT uses ionizing radiation, and repeated examinations may contribute to cumulative exposure. This is particularly relevant in screening populations and cancer survivors who require long-term surveillance.

The development of low-dose protocols, automated exposure control, iterative reconstruction, and AI-based reconstruction aims to maintain diagnostic image quality while reducing radiation dose.

A recent systematic review and meta-analysis of AI-based interventions in CT included five clinical validation studies involving 929 participants. AI-based approaches significantly improved reported image quality, while a favourable but statistically nonsignificant trend was observed for CT dose reduction [15].

This suggests that AI may contribute to the dose-quality balance, although dose reduction should always be evaluated alongside objective diagnostic performance. The guiding principle should therefore be: detect earlier, but do so with the lowest radiation exposure compatible with adequate diagnostic information.

11. CT as Part of a Multimodality Strategy

CT should not be viewed in isolation. Cancer diagnosis commonly requires integration of clinical assessment,

laboratory findings, ultrasound/MRI/CT, functional imaging where appropriate, and biopsy/histopathology.

Clinical assessment → Laboratory findings → Ultrasound / MRI / CT → Functional imaging (where appropriate) → Biopsy / Histopathology

CT is particularly strong in anatomical mapping and whole-body assessment. MRI may provide superior soft-tissue characterization for selected organs, while PET/CT can provide metabolic information in appropriate clinical settings.

The future of oncology is therefore likely to involve integration rather than competition between imaging modalities. For example, CT may identify a suspicious lesion, MRI may further characterize it, PET may evaluate metabolic activity, and pathology may establish the definitive diagnosis.

12. Current Challenges

Despite rapid technological development, several challenges remain.

12.1 False-positive findings

Higher sensitivity can result in more indeterminate lesions and unnecessary investigations. This remains particularly relevant in lung cancer screening [1,3].

12.2 False-negative findings

Some malignancies may initially demonstrate minimal or nonspecific morphological abnormalities. Pancreatic cancer is a prominent example [10,11].

12.3 Standardization

Radiomics and AI performance may vary according to scanner manufacturer, acquisition parameters, reconstruction method, and patient population.

12.4 External validation

A model that performs well in one institution may perform less effectively in another. Multicenter prospective validation is therefore essential.

12.5 Radiation exposure

The potential benefit of earlier diagnosis must be balanced against radiation exposure, particularly in repeated imaging and screening.

12.6 Human oversight

AI should currently be considered a decision-support technology rather than an independent replacement for radiologists.

13. Future Directions

The future of CT-based cancer detection is likely to involve the convergence of several technologies. Low-dose CT will

continue to develop, particularly in lung cancer screening. Spectral and photon-counting CT may provide more quantitative information from each examination. Radiomics may transform conventional images into quantitative biomarkers. Artificial intelligence may assist in detecting subtle lesions and prioritizing suspicious examinations. Finally, these technologies may increasingly work together rather than independently.

A future CT examination could therefore provide not only an anatomical image but also quantitative information about tissue composition, vascularity, lesion heterogeneity, and estimated malignancy risk.

The most important question, however, will remain whether these technological improvements translate into better patient outcomes. High diagnostic accuracy alone is insufficient if it results in unnecessary procedures, increased costs, or inappropriate treatment.

14. Conclusion

Computed tomography has evolved considerably from a conventional anatomical imaging modality into a technologically advanced platform for cancer detection, characterization, and staging.

Evidence from lung cancer screening demonstrates that low-dose CT can reduce lung-cancer mortality in appropriately selected high-risk populations [1]. In colorectal cancer, CT provides valuable information for tumor detection and staging, although its performance varies according to the clinical question [4,5].

The most important emerging development may be the ability to extract information that is not immediately apparent to the human observer. Radiomics and artificial intelligence have demonstrated promising results in pancreatic cancer detection, including analysis of CT examinations obtained before conventional diagnosis [9,11]. Spectral and photon-counting CT may further improve tissue characterization and lesion conspicuity [6–8].

Nevertheless, these technologies should be introduced carefully. Large prospective studies, external validation, standardized acquisition protocols, and clinically meaningful outcome assessment are required.

The future of CT in oncology is therefore unlikely to be defined simply by higher image resolution. Its greater potential lies in transforming each scan into a richer source of quantitative and clinically actionable information.

CT is moving beyond the detection of visible disease toward the identification of subtle imaging signatures of cancer- and this transition may redefine the role of computed tomography in early cancer diagnosis.

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