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DIAGNOSTIC ACCURACY OF ULTRA-LOW-DOSE CT VS. STANDARD-DOSE CT FOR PULMONARY NODULE DETECTION: A SYSTEMATIC REVIEW AND META-ANALYSIS

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Abstract
Background: Standard dose computed tomography (CT) is a primary modality for detecting pulmonary nodules (PNs), but the health risk from cumulative radiation exposure has prompted the emergence of ultra-low-dose CT (ULDCT) as an alternative to reduce this dose, because its diagnostic accuracy remains variable, this systematic review and meta-analysis aims to synthesize the existing evidence to determine the diagnostic accuracy and effective radiation dose of ULDCT for pulmonary nodule detection.
Methods: Following PRISMA guidelines, a systematic search was conducted in PubMed, Cochrane Library, and Ovid MEDLINE for original research published between 2015 and 2025 that evaluated the diagnostic accuracy of ULDCT for PN detection, for which a meta-analysis using random-effects models was performed to calculate the pooled sensitivity for nodule detection and the pooled mean effective radiation dose, with a subgroup analysis conducted to assess the impact of different reconstruction algorithms.
Results: Forty-two studies comprising 15,792 patients were included, from which a meta-analysis of 11 studies demonstrated a pooled sensitivity of 91.9% (95% CI: 84.6%–97.1%) for PN detection with heterogeneity (I^2=93.0%), and a pooled mean effective dose from 12 studies of 0.22 mSv (95% CI: 0.11–0.33 mSv), a level comparable to standard chest radiography, while subgroup analysis revealed a trend towards higher sensitivity with advanced reconstruction algorithms (96.7%) compared to standard iterative reconstruction (87.9%) that was not statistically significant

(p=0.091), and a narrative synthesis confirmed ULDCT's accuracy for solid nodules but identified reduced sensitivity for subsolid, ground-glass, and small (<6 mm) nodules, with performance limited in patients with a high body mass index (BMI).
Conclusion: ULDCT combined with advanced reconstruction techniques offers high diagnostic accuracy for the detection of solid pulmonary nodules and reduces radiation exposure to levels approaching that of a chest X-ray, but its utility is limited for detecting subsolid and small nodules and in obese patients, making protocol standardization and patient-specific considerations essential to optimize its clinical implementation.

Keywords: Ultra-Low-Dose CT, Pulmonary Nodule, Diagnostic Accuracy, Systematic Review, Meta-Analysis, Radiation Dose.

INTRODUCTION

When evaluating patients with suspected pathology in the chest, imaging modalities with the most optimal diagnostic accuracy and limited risks for the patients are preferred [1]. Computed Tomography (CT) is a non-invasive imaging technique used for diagnosing a wide range of conditions by detecting lesions with the help of an X-ray tube that rotates around the patient [2]. CT provides detailed visualization of the lung parenchyma and has become a well-established modality for evaluating the thorax [1].

Non-transparent pulmonary lesions measuring ≤ 3 cm in diameter on imaging that are encased by lung parenchyma are considered pulmonary nodules (PNs) [3, 4, 5]. When the diameter of the PNs is between 6 and 8 mm, frequent CT follow-up is required, as recommended by the Fleischner Society recommendations [6, 7].

However, CT examinations are linked to radiation exposure with lifetime dose and an associated cancer risk accumulating with repeated examinations [8]. Improvements in third-generation CT scanners with novel reconstruction algorithms, filtering techniques, and detectors have resulted in the potential for considerable reductions in radiation dose by up to 95% for various indications of chest CTs, termed ultra-low-dose CT (ULDCT) [1, 9, 10, 11. The performance of ULDCT has been investigated for the detection of acute COVID-19 pneumonia [12, 13, 14], as well as for the evaluation of specific lung abnormalities, such as pulmonary nodules, pulmonary emphysema, and pneumonia[15, 16, 17, 18].

Systematic reviews have been conducted to evaluate low dose (LD)-CT for lung cancer screening, and studies have found ULD-CT to be an acceptable diagnostic modality for pathology in the chest[1, 19, 20, 21], but the higher radiation doses required for CT imaging, compared to traditional radiography, requires continuous efforts to reduce exposure while maintaining high diagnostic quality [22, 23, 24]. Compared to the normal-dose CT guidance, the radiation dose can be reduced by 81–92% by using low-dose CT, without reducing the overall diagnostic accuracy [25, 26, 27, 28, 29]. Although major dose reduction can exacerbate noise and decreased image quality, use of iterative reconstruction techniques can reduce the image noise and provide better overall image quality [7, 26].

Advances in CT scanners have enabled dose-reduction and image quality improvement, while maintaining an acceptably high diagnostic accuracy for detection of pathology in the chest. Diagnostic modalities like low-dose CT and ultra-low-dose CT (LD- and ULD-CT) have been described by studies for examination of various chest pathologies [30, 31, 32]. To previous knowledge no specific effective dose has yet been set for LD- and ULD-CT, however some studies suggest that the effective dose of LD-CT is <2.5 mSv [1, 33, 34].

A reduction in radiation dose is often accompanied by an increase in image noise and a deterioration in image quality. Therefore, minimizing the radiation dose while maintaining image quality is highly valued [35]. The radiation dose for a single chest scan is about 3-7 mSv for standard-dose CT (SDCT) and 1.5 mSv for low-dose CT (LDCT) [36, 37, 38]. The recent introduction of ULDCT has the potential to reduce radiation exposure through advanced hardware and sophisticated image reconstruction algorithms [38] which highlight the potential of ULDCT in the safe detection and evaluation of lung nodules [39].

While Tække r et al. provided a systematic review on the diagnostic accuracy of LDCT and ULDCT for chest pathologies including lung nodules covering studies from 2002 to 2019 [1], a lack of meta-analyses and systematic reviews on ULDCT has emerged in the last 5 years, a modality which, informed by findings from Jiang et al. and Carey et al., is commonly characterized by doses ranging from 0.13 to 0.49 mSv [40, 41].

Problem Statement and Research Gap

ULDCT has emerged as a promising alternative, using advanced hardware and reconstruction algorithms to reduce radiation (as low as 7.7% of SDCT) while maintaining high nodule detection rates (86.1–100%) [39, 42], but variability in diagnostic accuracy (75–91% for malignancy) and inconsistent reconstruction techniques across studies highlight unresolved challenges [41, 42]. Iterative and deep learning-based reconstruction methods (e.g., ADMIRE) improve image quality in low-dose settings, but optimal dose-reduction thresholds remain unclear, particularly in diverse patient populations [42]. Prior reviews have focused on lung cancer screening, but no systematic review has evaluated the diagnostic accuracy of ULDCT specifically for pulmonary nodule detection across broader clinical settings [1], therefore, this gap underscores the need for an updated synthesis of evidence to guide clinical decision-making and protocol standardization.

Aim of the Study:
This systematic review and meta-analysis (SRMA) aim to synthesize existing evidence on the diagnostic accuracy of ULDCT for pulmonary nodule detection, evaluating its sensitivity, specificity, and clinical applicability as a standalone modality.
PICO Framework:
This review's PICO framework defined the population as patients undergoing evaluation for pulmonary nodules, the intervention as ULDCT, and, with no direct comparator, evaluated outcomes of diagnostic accuracy, including sensitivity and specificity, nodule detection rates, and technical feasibility.
Objectives:
Primary Objective:
To determine the pooled sensitivity and specificity of ULDCT for pulmonary nodule detection.
Secondary Objectives:
To analyse nodule detection rates stratified by size (<5 mm, 5–10 mm, >10 mm).
To evaluate the impact of reconstruction algorithms on diagnostic performance.
To quantify radiation dose ranges and their relationship with image quality/diagnostic confidence.
To identify patient- or protocol-related factors influencing ULDCT accuracy.

METHODOLOGY

Study Design:
This SRMA follows the Preferred Reporting Items for Systemic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [43]. The review protocol was registered with International Prospective Register of Systematic Reviews (PROSPERO; registration number CRD420251060219). This review did not require review or approval by the ethics committee as it used previously published data.
Search Strategy
A literature search was conducted across PubMed, OVID MEDLINE, and the Cochrane Library from their inception until July 2025, employing a search strategy with key terms and Medical Subject Headings (MeSH) related to ULDCT and pulmonary nodule detection, using the specific search string: (((Pulmonary nodules) OR (lung nodules)) OR (chest pathology)) OR (sensitivity) OR (accuracy)) AND (Ultra-Low-Dose CT).
Selection Criteria
Inclusion criteria encompassed original research studies such as randomized controlled trials (RCTs), cohort studies, and cross-sectional analyses published in English between 2015 and 2025 that reported diagnostic accuracy metrics for ULDCT in pulmonary nodule detection, while exclusion criteria comprised case reports, review articles, editorials, conference abstracts, studies focused on non-pulmonary pathologies or not published in English.
Data Extraction:
Four independent reviewers extracted data on study details including design and sample size, ULDCT protocols, and outcomes such as sensitivity, specificity, nodule size-specific detection, and radiation dose.
Quality Assessment:
The methodological quality of included studies was assessed using the Newcastle-Ottawa Scale (NOS) for cohort and observational studies, which evaluates selection, comparability, and outcome, and the Cochrane Risk of Bias 2 (RoB 2) tool for randomized controlled trials [44].
Data Synthesis and Analysis
A narrative synthesis was performed and structured around the review's pre-defined key outcomes, and because of significant clinical and methodological heterogeneity among the included studies, such as varying ULDCT protocols, reconstruction techniques, and reference standards, the findings are presented descriptively and organized into thematic areas based on the review's results:
Comparative Diagnostic Performance: Synthesis of studies comparing ULDCT to standard-dose CT, focusing on overall and size-specific nodule detection rates which addresses the results on comparable accuracy for solid nodules and reduced sensitivity for subsolid and small nodules.
Radiation Dose Analysis: Quantitative synthesis of reported radiation dose metrics (effective dose in mSv) from included studies to demonstrate the achievement of dose reduction to near-chest X-ray levels.
Technical Analysis: Synthesis of evidence on the impact of different reconstruction algorithms (iterative reconstruction, deep learning) and AI-based CAD systems on diagnostic performance and image quality. This section is dedicated to the findings on the role of advanced reconstruction and AI.
Expanded Clinical Utility: Analysis of studies reporting on the incidental findings and utility of ULDCT in other clinical scenarios (e.g., pneumonia, COPD, biopsy guidance), supporting the outcome on clinical applications beyond nodule detection.
Limitations and Gaps: A summary of the frequently reported study limitations and identified gaps in the literature, such as the need for standardization and studies in obese populations, reflecting the outcome on limitations and challenges.

Quantitative Synthesis (Meta-Analysis)

To provide a quantitative summary of the key outcomes, several meta-analyses were performed using R (version 4.5.1) with the meta and metafor packages. A meta-analysis of proportions was conducted to calculate the pooled sensitivity of ULDCT for pulmonary nodule detection. Data from studies reporting the number of true positive nodule detections and the total number of positive nodules were included. The Freeman-Tukey double arcsine transformation was used to stabilize variances. A random-effects model was chosen a priori due to anticipated heterogeneity across studies in terms of patient populations, ULDCT protocols, and nodule characteristics. The Hartung-Knapp-Sidik-Jonkman method was applied to calculate confidence intervals for the pooled estimate.

A meta-analysis of means was performed to estimate the pooled mean effective radiation dose (ED) of the ULDCT protocols, using study-specific mean EDs, standard deviations, and patient numbers, for which a random-effects model was applied to account for variations in CT protocols and scanner technologies, and where heterogeneity was assessed using the Cochrane's Q statistic and quantified using the I^2 statistic, with values representing low, moderate, and substantial heterogeneity.

Publication bias was evaluated through visual inspection of funnel plot asymmetry and tested using Egger's linear regression test, where $p < 0.05$ indicated significant asymmetry, while a subgroup analysis and meta-regression were performed on the sensitivity data to explore the impact of advanced reconstruction algorithms by categorizing studies based on their use of "Standard Iterative Reconstruction (IR)" (e.g., ASIR, AIDR) or "Advanced IR" (e.g., Deep Learning IR [DLIR], Model-Based IR [MBIR]), with the difference between subgroups tested for statistical significance.

RESULTS

Figure 1 depicts the PRISMA flow diagram outlining the process of literature identification, screening, and study inclusion, a process which commenced with the identification of 157 articles through electronic database searches, from which 25 duplicate records were removed, leading to 118 unique articles for title and abstract screening, from which 105 were advanced to a full-text review for eligibility assessment, after which 63 studies were excluded for not meeting the predefined inclusion criteria, resulting in the 42 studies that satisfied all eligibility criteria and were included in this systematic review. The 42 included studies, published between 2015 and 2025, represented a total pooled sample size of 15,792 patients.

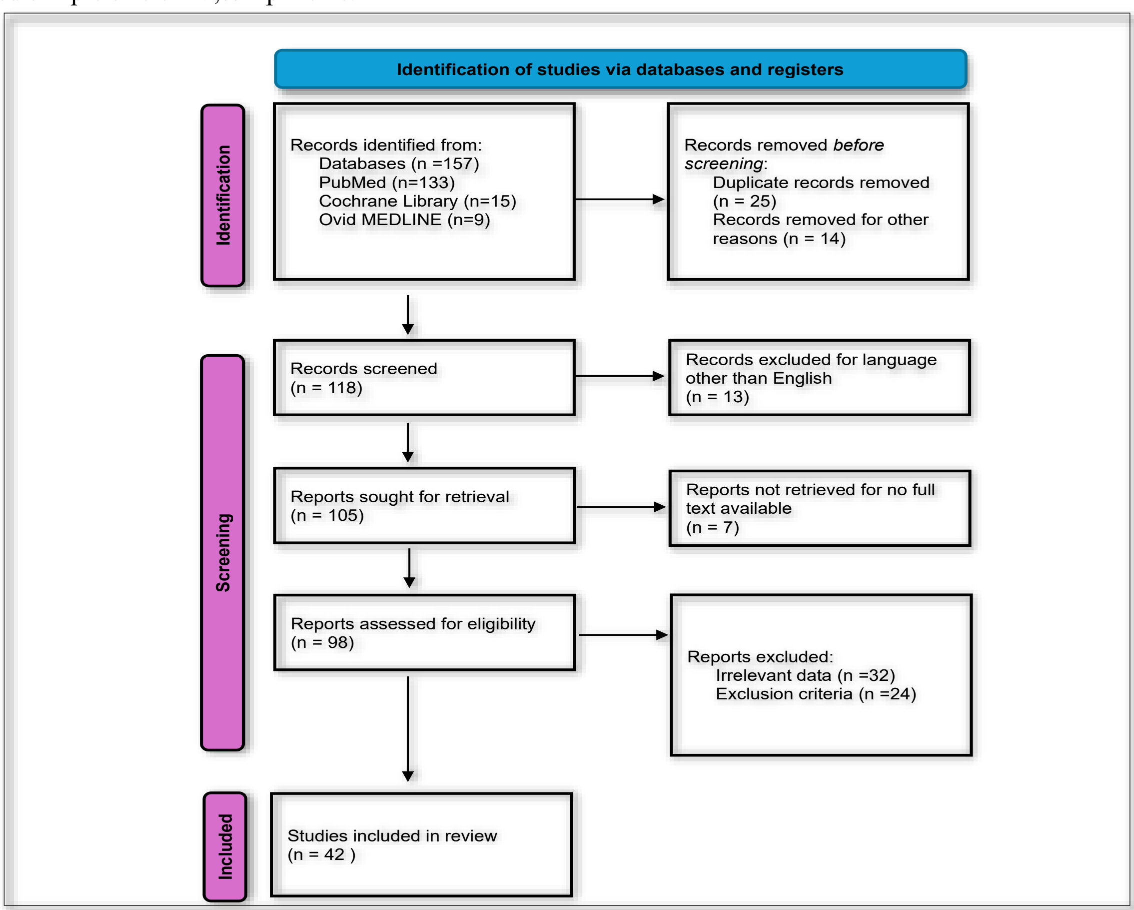

Figure 1:PRISMA Flow Diagram

Quantitative Synthesis (Meta-Analysis)

Sensitivity of ULDCT for Pulmonary Nodule Detection

Eleven studies, comprising a total of 2,251 nodules, were included in the meta-analysis for sensitivity, for which the random-effects model demonstrated a pooled sensitivity of 91.9% (95% CI: 84.6%–97.1%) for pulmonary nodule detection using ULDCT, with individual study sensitivities ranging from 70.2% to 100% (Figure 2) and observed heterogeneity across the studies ($I^2 = 93.0\%$; Q=143.36, $p < 0.0001$), while Egger's test for funnel plot asymmetry was not statistically significant ($p = 0.083$), suggesting no strong evidence of publication bias for this outcome (Figure 3).

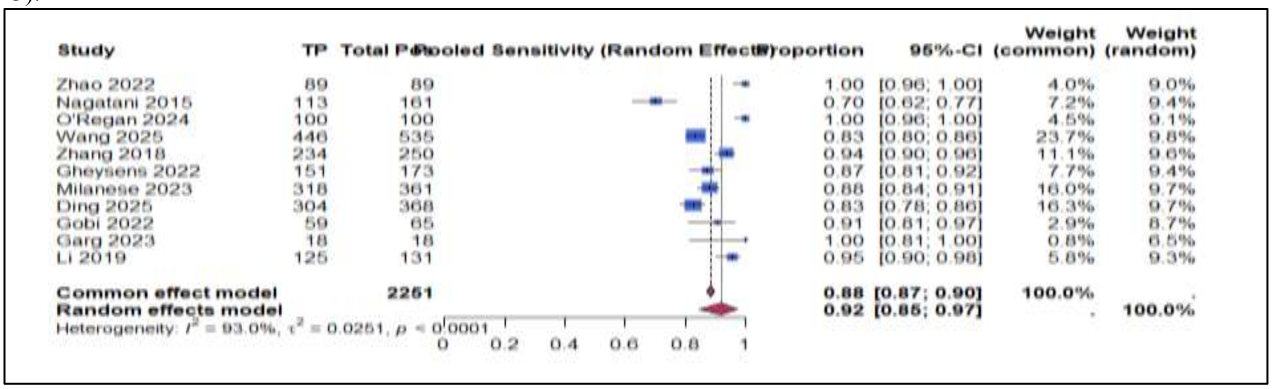

Figure 2: Forest plot of the pooled sensitivity of ULDCT for pulmonary nodule detection

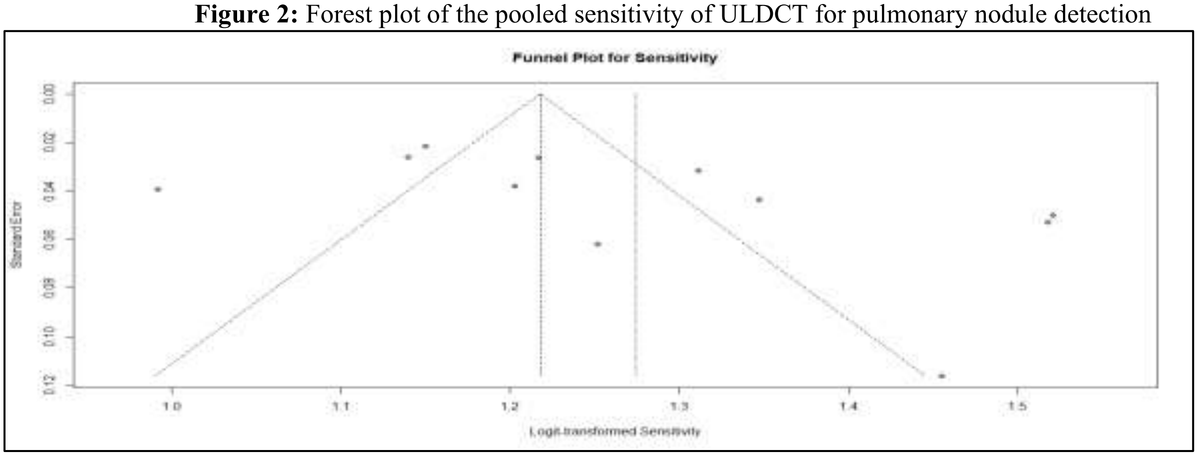

Figure 3: Funnel plot for the assessment of publication bias in the sensitivity analysis

Mean Effective Dose

Twelve studies reporting on 1,805 patients were included in the meta-analysis of effective radiation dose, for which the random-effects model estimated a pooled mean effective dose of 0.22 mSv (95% CI: 0.11–0.33 mSv), with a wide range of doses from 0.05 mSv to 0.67 mSv across the included studies (**Figure 4**) and extremely high heterogeneity ($I^2 = 100.0\%$; Q=40104.65, $p < 0.0001$) reflecting variability in ULDCT protocols, while Egger's test revealed significant funnel plot asymmetry ($p = 0.0002$), indicating publication bias or small-study effects where smaller studies tended to report lower effective doses (**Figure 5**).

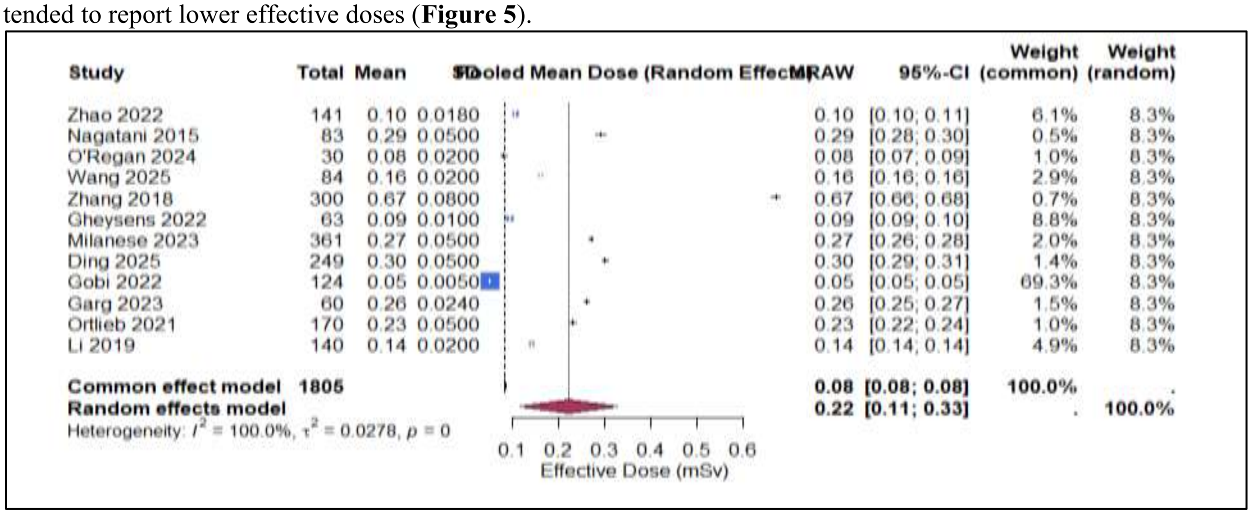

Figure 4: Forest plot of the pooled mean effective dose (mSv) of ULDCT protocols

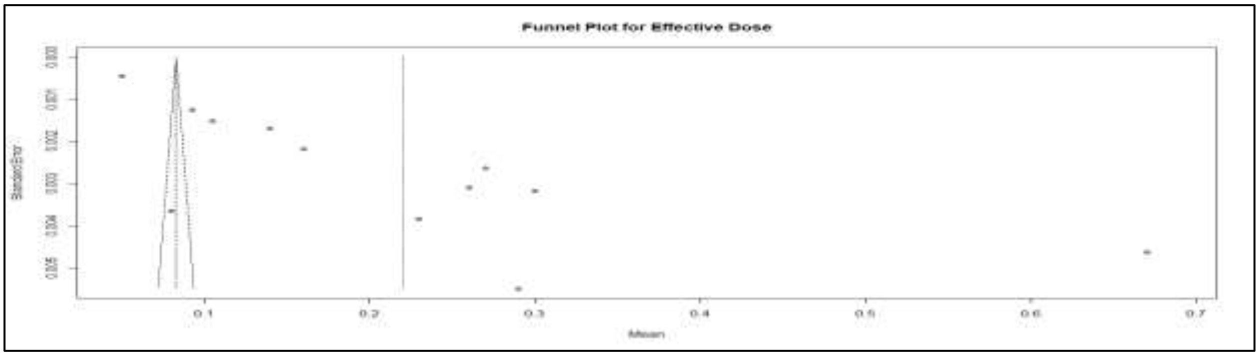

Figure 5: Funnel plot for the assessment of publication bias in the effective dose analysis

Subgroup Analysis: Impact of Reconstruction Algorithm on Sensitivity

A subgroup analysis was performed based on the type of reconstruction algorithm used to investigate a potential source of heterogeneity.

Standard IR (7 studies): The pooled sensitivity was **87.9%** (95% CI: 78.6%–94.9%).

Advanced IR (DLIR/MBIR) (4 studies): The pooled sensitivity was **96.7%** (95% CI: 79.4%–100.0%).

Although studies using advanced reconstruction algorithms demonstrated a trend towards higher pooled sensitivity, the test for subgroup differences was not statistically significant (p = 0.091). The forest plot for the subgroup analysis is presented in **Figure 6**.

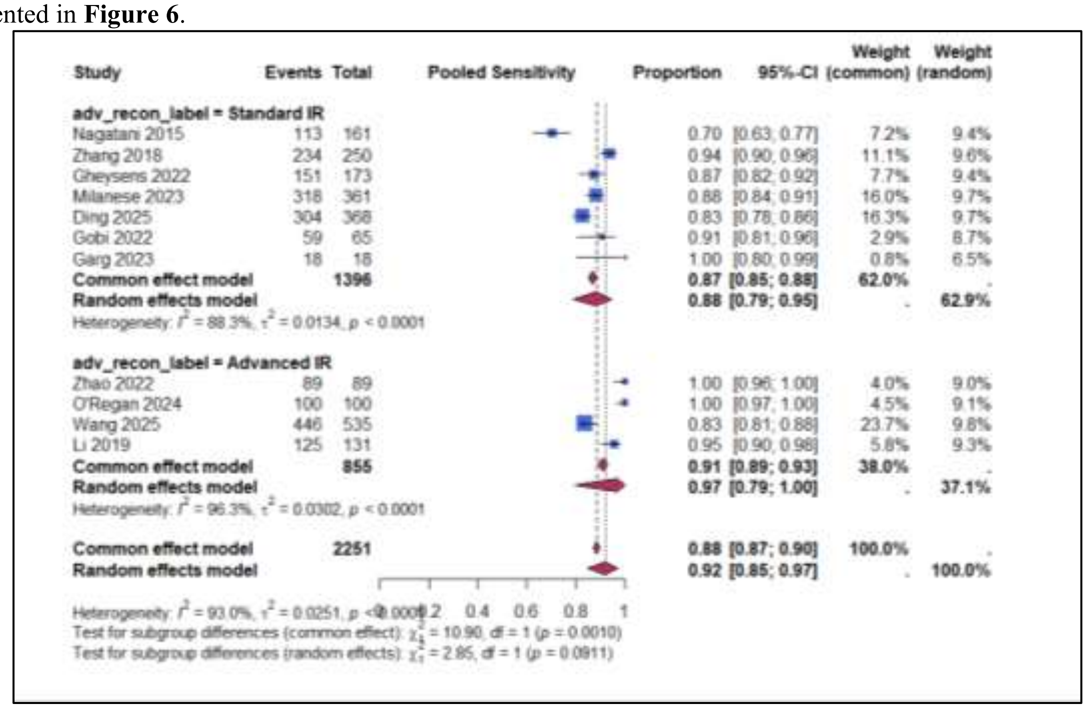

Figure 6: Subgroup forest plot of sensitivity based on reconstruction algorithm type (Standard IR vs. Advanced IR).

Synthesis of Results

A narrative synthesis was conducted, organized around the key themes identified from the included literature.

Quality assessment:

Among the studies included, 4 (10%) of 42 studies were regarded as having a moderate risk of bias, and 2 (5%) of 42 were rated as low quality. However, the majority, 34 studies (85%), presented a high overall methodological quality. The most common strengths cited across studies were prospective design, clear and detailed CT protocols, the use of advanced iterative or deep learning reconstruction (DLR) techniques, and objective outcome measures. The primary limitations contributing to a lower score were retrospective design, lack of reference standards, and small sample sizes. Furthermore, the two identified randomized controlled trials (RCTs) were assessed using the Cochrane Risk of Bias (RoB 2) tool (Figure 2). The large multicenter RCT by van den Berk et al. (2023) compared ULDCT to chest X-ray in the emergency department (n=2,418). Its overall risk of bias was judged as "Some Concerns" primarily due to the open-label design (lack of blinding) which could influence outcome assessment, though the randomization process and completeness of outcome data were low risk. The second RCT by Milanese et al. (2023) prospectively compared ULDCT protocols for lung cancer screening (n=361) and was also rated as having "Some Concerns" for overall risk of bias (Figure 7). This was mainly due to potential issues in the measurement of the outcome (D4), as the same radiologists read both the standard and ultra-low-dose scans and different reconstruction kernels were used, creating a potential for detection bias.

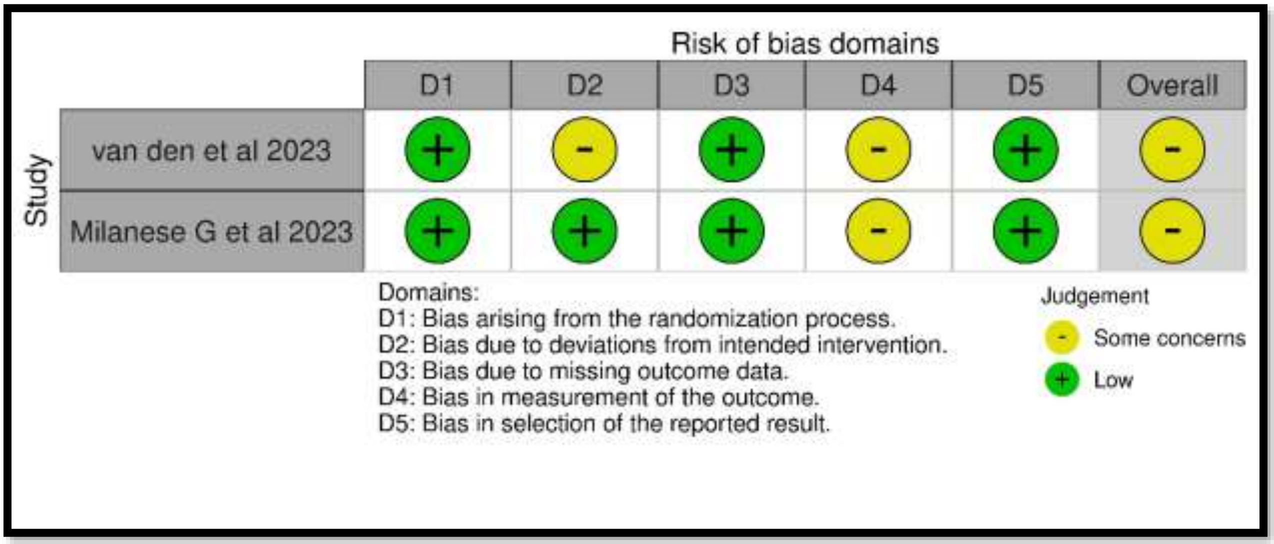

Figure 7: Risk-of-bias evaluation of the RCT studies using the RoB 2

Key findings

A synthesis of the evidence from the 42 included studies is presented in **Table 1**, which summarizes the key findings organized into seven thematic categories as it captures the primary outcomes related to the diagnostic accuracy of ULDCT for pulmonary nodules, its advanced quantitative capabilities, limitations, achieved radiation dose reductions, the pivotal role of AI and reconstruction, its broader clinical applications, and the persistent challenges for implementation.

Table1: Summary of Key Findings from Included Studies on ULDCT

Theme	Study (Citation)	Key Outcome Measured	Main Findings
Diagnostic Accuracy for Solid Nodules	Milanese et al. (2023)	LungRADS agreement, detection rate	Excellent agreement with LDCT (κ=0.87-0.91), 88% nodule detection at 0.27 mSv (70% dose reduction).
	Nagatani et al. (2016)	AUC for nodule detection	No significant difference in AUC between ULDCT (0.844) and LDCT (0.876) at 0.29 mSv.
	O'Regan et al. (2024)	Nodule characterization	Achieved 97.6% dose reduction with non-inferior performance for solid nodule characterization.
	Wang et al. (2025)	Nodule detection/measurement	DLIR improved detection and accuracy at extreme low doses (0.07–0.14 mSv).
Advanced Quantitative Analysis	Autrusseau et al. (2021)	Radiomic feature concordance	Good agreement in radiomic features and malignancy prediction between ULDCT and full-dose CT.
	Zhou et al. (2023)	Nodule volumetry accuracy (phantom)	Excellent measurement accuracy (ICC >0.95) at doses of 0.23-0.59 mSv.
	Zhao et al. (2022)	RECIST measurement variability	Minimal variability (±2.3%) and near-perfect correlation (r=0.999) for lesion sizing at 0.07-0.14 mSv.
	Lancaster et al. (2022)	Negative Predictive Value (NPV)	AI volumetry on LDCT showed 99.8% NPV for cancer risk in nodules <100 mm³.
Reduced Sensitivity for Subsolid/Small Nodules	Ding et al. (2025)	GGN and small nodule detection	Reduced sensitivity for pure GGNs (85.5%) and small solid nodules (78.3–82.6%); 34 missed GGNs <6mm.
	Ortlieb et al. (2021)	Impact of BMI on image quality	Higher BMI significantly reduced image quality (ρ = -0.325) and sensitivity for emphysema.
Radiation Dose Reduction	Van Den Berk et al. (2023)	Diagnostic accuracy in ED (vs. CXR)	ULDCT (0.22 mSv) superior to CXR for pulmonary diagnoses (RR 1.09, 95% CI 1.04–1.14).
	Li et al. (2019)	CT-guided biopsy accuracy	92.1% dose reduction (to 0.14 mSv) with 95.4% accuracy for biopsies of lesions <3cm.
	Kepka et al. (2023)	Pneumonia detection in ED (vs. CXR)	Superior pneumonia detection (SMD=0.36) without increasing ED length of stay.
Role of AI & Re	Hamabuchi et al. (2023)	Deep Learning (DLR) vs. Iterative (IR)	DLR achieved superior AUCs (0.97-1.00) vs. IR (0.91-0.97) at 0.8 mGy.

	Afshar et al. (2022)	AI for COVID-19 diagnosis	AI achieved human-level diagnosis from LDCT (0.3-1.5 mSv), identifying cases without clear imaging findings.
	Gheysens et al. (2022)	Scoutless acquisition protocol	Maintained 88.2% nodule detection at 0.14 mGy CTDIvol without scout scan.
Clinical Applications Beyond Nodules	Devkota, Garg, et al. (2022-2024)	COVID-19 pattern detection	ULDCT reliably detected COVID-19 patterns (92-98% of findings) with 94-95% dose reduction.
	Klug et al. (2025)	Pneumonia in immunocompromised	High sensitivity (92.1%) and specificity (90.2%) for pneumonia at 0.24 mSv.
	Liang et al. (2021)	CT-guided biopsy success	95% technical success rate for biopsies at a dose of ~0.19 mGy.
Limitations & Challenges	Gobi et al. (2022)	Effect of BMI on diagnostic quality	Image quality was diagnostic in only 96.77% of cases and worsened with increasing BMI.
	Ingbritsen, Ludwig et al. (2019-2025)	PET/CT image texture degradation	ULDCT protocols <0.8 mSv caused quantifiable degradation in PET image texture features.

Abbreviations: ULDCT: Ultra-low-dose computed tomography; LDCT: Low-dose CT; CXR: Chest X-ray; GGN: Ground-glass nodule; AUC: Area under the curve; DLIR: Deep learning image reconstruction; ICC: Intraclass correlation coefficient; NPV: Negative predictive value; ED: Emergency department; RR: Risk ratio; CI: Confidence interval; SMD: Standardized mean difference.

Diagnostic Accuracy of ULDCT for Solid Pulmonary Nodules

Recent evidence robustly demonstrates that ULDCT achieves diagnostic accuracy comparable to SDCT for solid pulmonary nodules when utilizing advanced reconstruction techniques. The prospective randomized trial by Milanese et al. (2023) (n=361) found excellent agreement between ULDCT and LDCT for LungRADS classification (κ=0.87-0.91) with 88% nodule detection at 0.27 mSv (70% dose reduction) [45], while Nagatani et al. (2016) (n=83) reported no significant difference in AUC (0.844 vs 0.876) at 0.29 mSv using AIDR 3D reconstruction [46].

Also, studies confirm that advanced algorithms enable dose reduction without compromising diagnostic integrity, as O'Regan et al. (2024) achieved a 97.6% dose reduction with MBIR while maintaining non-inferior performance for nodule characterization [47], and Wang et al. (2025) demonstrated that DLIR improved detection rates and measurement accuracy at doses of 0.07-0.14 mSv [48], findings which indicate that ULDCT protocols incorporating spectral shaping and advanced reconstruction provide clinically acceptable diagnostic accuracy for solid pulmonary nodules.

Advanced Quantitative Analysis of Solid Nodules in ULDCT

Recent studies indicate that ULDCT provides high concordance with standard-dose CT for quantitative and radiomic assessment of solid pulmonary nodules as Autrusseau et al. (2021) demonstrated good agreement in radiomic features and malignancy prediction indices in 170 patients [49], while phantom research such as Zhou et al. (2023) confirmed high measurement accuracy (ICC>0.95) at doses of 0.23–0.59 mSv using advanced reconstruction techniques [50]. A prospective clinical study by Zhao et al. (2022) on 141 patients showed RECIST-comparable measurements at 0.07–0.14 mSv with near-perfect correlation (r=0.999) [51]. In screening contexts, Zhang et al. (2017) reported 93.8% sensitivity for all nodules and perfect detection for nodules >6 mm at sub-millisievert doses [52], while analysis of the NELSON trial (n=15,792) showed that solid nodules <100 mm³ were associated with a 99.8% NPV for lung cancer [53]. These findings support ULDCT enhanced by AI as a precise tool for nodule assessment and reducing unnecessary follow-ups in lung cancer screening programs.

Reduced Sensitivity for Subsolid and Small Nodules

ULDCT demonstrates limitations in detecting subsolid and small pulmonary nodules, particularly ground-glass nodules (GGNs) and lesions <6 mm. Ding et al. (2025) reported that while ULDCT (0.3 mSv) achieved 97.1% detection for part-solid nodules, pure GGNs showed reduced detection (85.5%) with 34 missed GGNs <6 mm, and solid nodules demonstrated lower sensitivity (78.3-82.6%) for smaller lesions [54]. Also, Aiello et al. (2022) found AI-based segmentation performed comparably between ULDCT and conventional CT for COVID-19 lesions but did not specifically evaluate small or subsolid nodules [55]. Body habitus impacts performance, as Ortlieb et al. (2021) demonstrated higher BMI significantly reduced ULDCT image quality (ρ = -0.325) and sensitivity for emphysema detection [56]. For interstitial lung disease, Hata et al. (2019) showed ULDCT with MBIR provided acceptable quality but was inferior to standard-dose CT in noise reduction [57] which indicate that while ULDCT is adequate for solid and part-solid nodules, caution is warranted for small GGNs and obese patients, where sensitivity may be compromised.

Radiation Dose Reduction to Near-Chest X-ray Levels

Modern ULDCT achieves near-CXR doses while preserving diagnostic value as in a multicenter RCT, it outperformed CXR for emergency pulmonary diagnoses [58]. Advances like tin filtration [59], optimized 100 kVp protocols [60], and dose-reduced interventional scans enabled sub-0.2 mSv imaging with high accuracy [61]. Clinically, ULDCT proved superior for pneumonia detection [62], effective for systemic disease monitoring [63], and reliable for nodule detection at CXR-equivalent doses [64]. Novel reconstruction methods improved performance with 96% sensitivity for pneumonia at 0.18 mSv [65], confirming ULDCT as a safe, low-dose alternative to CXR.

Role of Advanced Reconstruction and AI in ULDCT

Advanced reconstruction techniques and AI have enhanced ULDCT, enabling diagnostic performance rivalling standard-dose imaging as in paediatric applications, AI denoising improved image quality for pneumonia detection at extremely low doses [66], while DLR achieved superior AUCs (0.97-1.00) versus iterative reconstruction at 0.8±0.1 mGy, nearly matching standard-dose performance for lung texture detection [67]. Adaptive statistical iterative reconstruction (ASiR-V) at higher blending levels (70-90%) ensured excellent consistency in radiomic feature analysis [68], and AI algorithms achieved human-level COVID-19 diagnosis from low-dose scans, even identifying infections lacking clear imaging findings [69]. Technical innovations including scoutless fixed-dose techniques maintaining 88.2% nodule detection at 0.14 mGy [38] and high-speed protocols reducing motion artifacts **(**Bae et al., 2024**)** demonstrate how the synergy of sophisticated algorithms, AI-driven analysis, and optimized acquisition techniques is pushing the boundaries of low-dose thoracic imaging.

Clinical Applications Beyond Nodule Detection

ULDCT has demonstrated clinical utility beyond nodule detection, proving valuable across diverse scenarios including COVID-19 management, high-risk population monitoring, and procedural guidance. For COVID-19 evaluation, ULDCT protocols (0.22-0.28 mSv) reliably detect characteristic parenchymal patterns and post-COVID sequelae with 92-98% sensitivity and excellent interobserver agreement (κ=0.85), despite somewhat reduced sensitivity for specific findings like ground-glass opacities (72.7%) in obese patients [70, 71, 72, 73]. In high-risk populations, ULDCT maintains high diagnostic performance for immunocompromised patients (92.1-95.45% sensitivity for infections at 0.24-0.43 mSv) and asbestos-exposed individuals (95.7% sensitivity for pleural plaques at 0.14-0.8 mSv) [74, 75, 76, 77] . For procedural guidance, ULDCT enables CT-guided biopsies with 95% success at 0.19 mGy, bronchoscopic navigation with 83-88% detection at 0.19 mSv, and pulmonary embolism diagnosis with 96.7% sensitivity at 1.1 mSv, establishing it as a capable low-dose guidance modality [78, 79, 80, 81].

Limitations and Challenges

A major issue is maintaining image quality, which decreases with increasing BMI, resulting in specific challenges in the management of obese patients while remaining diagnostic in only 96.77% of cases, even though there is reasonable sensitivity associated with consolidation (97%) and solid nodules (91%) [82]**.** The increase in noise within the ULDCT images may introduce interpretation bias, and work looking at optimization for PET/CT has suggested that protocols with less than 0.8 mSv impair PET texture features while offering reasonable quantitative precision [83, 84]**.** Also, generalizability is restricted due to the abundance of single-center studies with heterogeneous methodologies and vendor-specific reconstruction algorithms. The absence of longitudinal clinical outcome data also presents a gap when looking to understand the clinical impact of ULDCT beyond a dose reduction, as well as whether it will downgrade apparent diagnostic performance for subtle findings, as might occur with ground-glass opacities.

Substantial statistical heterogeneity observed in the sensitivity (I^2=93.0%) and effective dose (I^2=100%) analyses indicates that the pooled estimates should be interpreted as an average of a wide range of differing effects rather than a single true effect, a phenomenon stemming from the considerable variability in patient populations, nodule characteristics, CT scanner models, and acquisition and reconstruction protocols across the included studies.

The meta-analysis for effective dose showed significant funnel plot asymmetry ($p = 0.0002$), suggesting a small-study effect or publication bias that indicates smaller studies reporting lower radiation doses may be overrepresented in the literature, a situation that could lead to an underestimation of the true average dose used in broader clinical practice.

DISCUSSION

This systematic review synthesizes current evidence on the diagnostic performance of ULDCT for pulmonary nodule detection as the findings demonstrate that with advanced reconstruction techniques such as MBIR, DLIR, and ASiR-V, ULDCT achieves diagnostic accuracy for solid pulmonary nodules that is comparable to standard LDCT while reducing radiation exposure by 70–97.6% [1, 9, 10, 11]. Milanese et al. (2023) and Nagatani et al. (2016) reported excellent agreement (κ=0.87–0.91) and non-inferior AUC values (0.844 vs. 0.876 for LDCT) at doses as low as 0.27–0.29 mSv [15, 16, 17, 18, 45] which supports ULDCT as a viable option for routine nodule detection and LungRADS classification, aligning with reviews that found ULDCT acceptable for chest pathology evaluation [1, 19, 20, 21], but the performance is highly contingent on advanced reconstruction algorithms to mitigate noise, underscoring the necessity of technological integration for maintaining diagnostic integrity at sub-millisievert doses [7, 26, 35].

Significant limitations persist, particularly in the detection of subsolid and small nodules as Ding et al. (2025) reported reduced sensitivity for pure GGNs (85.5%) and solid nodules <6 mm, with 34 missed GGNs in their cohort [54] which is compounded by patient-specific factors, as Ortlieb et al. (2021) and Gobi et al. (2022) found that increasing BMI degrades image quality and diagnostic confidence, limiting ULDCT's generalizability in obese populations [56, 82] which highlight that while ULDCT is adequate for solid and part-solid nodules, its application for subtle findings like small GGNs requires caution. This variability in diagnostic performance, especially for malignancy, echoes the unresolved issues noted in earlier studies and emphasizes the need for protocol optimization tailored to nodule characteristics and patient habitus [41, 42].

ULDCT has shown substantial promise across diverse clinical scenarios, reducing radiation to levels near conventional CXR without compromising diagnostic utility as Van Den Berk et al. (2023) demonstrated in a multicenter RCT that ULDCT (0.22 mSv) outperformed CXR for emergency pulmonary diagnoses [58], while Kepka et al. (2023) reported superior pneumonia detection in elderly patients without prolonging ED stays [62]. In specialized settings, ULDCT guided interventions such as CT-guided biopsies with 95.4% accuracy at 0.14 mSv (Li et al., 2019) and bronchoscopic navigation with 83–88% success at 0.19 mSv [81], validate its clinical robustness [25, 26, 27, 28, 29]. Also, applications in COVID-19 (Devkota et al., 2024) and immunocompromised patients (Klug et al., 2025) underscore its versatility, with doses as low as 0.24–0.28 mSv maintaining high sensitivity for infectious and fibrotic changes [12, 13, 14] which position ULDCT as a transformative modality for broad clinical use, from screening to complex procedural guidance.

The integration of AI and deep learning has been pivotal in overcoming traditional dose-quality trade-offs as Hamabuchi et al. (2023) and Afshar et al. (2022) revealed that DLIR enhances image quality and enables human-level diagnosis in challenging cases, such as COVID-19 with occult imaging findings [30, 31, 32]. AI-driven volumetry, as demonstrated in the NELSON trial analysis (Lancaster et al., 2022), achieved a 99.8% NPV for cancer risk stratification, reducing unnecessary follow-ups [30, 31, 32], but the predominance of single-center studies and vendor-specific algorithms limits generalizability, and the lack of long-term outcomes data remains a gap [1, 42], therefore, future efforts must focus on standardizing protocols, validating AI tools in multi-center trials, and establishing dose thresholds for specific clinical tasks.

Also, this systematic review provides the first quantitative estimate of ULDCT performance through a formal meta-analysis as the results consolidate the findings of individual studies, demonstrating a high pooled sensitivity of 91.9% for pulmonary nodule detection which provides strong quantitative support for the utility of ULDCT as a diagnostic tool, confirming that it maintains high accuracy despite significant dose reductions.

Meta-analysis calculated a pooled mean effective dose of 0.22 mSv as this value, which is comparable to a standard two-view chest X-ray, underscores the radiation dose reduction achievable with modern ULDCT protocols. The heterogeneity (I^2 = 100%) highlights the lack of protocol standardization across institutions, with reported doses varying more than tenfold (0.05 mSv to 0.67 mSv) which emphasizes the need for optimized, consensus-based protocols to ensure that radiation exposure is kept low.

Subgroup analysis explored the role of advanced reconstruction algorithms as the trend towards higher sensitivity with Advanced IR (96.7%) compared to Standard IR (87.9%) did not reach statistical significance ($p = 0.091$), but this is due to the limited number of studies in the Advanced IR subgroup which aligns with the conclusions from Wang et al. (2025) and Zhao et al. (2022), which demonstrate that DLIR and MBIR qualitatively and quantitatively improve nodule detection and measurement accuracy which suggests that as more studies on advanced reconstruction are published, a statistically significant benefit will emerge.

CONCLUSION

ULDCT represents an advancement in thoracic imaging, achieving diagnostic performance comparable to standard low-dose CT for solid pulmonary nodules while reducing radiation exposure by 70-97.6% through advanced reconstruction techniques and AI integration, and it demonstrates strength in quantitative nodule assessment, emergency medicine applications, and procedural guidance at radiation doses approaching conventional chest X-ray levels, but its utility is limited for detecting subsolid nodules and small lesions (<6 mm), with performance further compromised in obese patients due to image quality degradation, and because current evidence remains constrained by single-center studies, vendor-specific algorithms, and a lack of long-term outcome data, future implementation requires protocol standardization, validation in multi-center trials, and careful consideration of patient-specific factors to ensure optimal diagnostic performance across diverse clinical scenarios and populations.

AUTHOR CONTRIBUTIONS

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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DISCLOSURES

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

REFERENCES

- M. Tække, B. Kristjánsdóttir, O. Graumann, C. B. Laursen, and P. I. Pietersen, "Diagnostic accuracy of low-dose and ultra-low-dose CT in detection of chest pathology: a systematic review," Clin Imaging, vol. 74, pp. 139–148, Jun. 2021, doi: 10.1016/J.CLINIMAG.2020.12.041.
- K. Lee, K. Nam, J. Jang, H. K.-A. Sciences, and undefined 2021, "Feasibility of the quantitative assessment method for CT quality control in phantom image evaluation," mdpi.comKB Lee, KC Nam, JS Jang, HC KimApplied Sciences, 2021•mdpi.com, Accessed: May 30, 2025. [Online]. Available: https://www.mdpi.com/2076-3417/11/8/3570
- J. Du, Y. F. Fu, and Y. N. Lv, "Preoperative localization for lung nodules: a meta-analysis of bronchoscopic versus computed tomography guidance," Wideochirurgia I Inne Techniki Maloinwazyjne, vol. 17, no. 4, pp. 601–610, 2022, doi: 10.5114/WIITM.2022.119586.
- Y. Li, K. Z. Chen, and J. Wang, "Development and validation of a clinical prediction model to estimate the probability of malignancy in solitary pulmonary nodules in Chinese people," Clin Lung Cancer, vol. 12, no. 5, pp. 313–319, Sep. 2011, doi: 10.1016/J.CLLC.2011.06.005.
- K. Chen et al., "Development and validation of machine learning-based model for the prediction of malignancy in multiple pulmonary nodules: Analysis from multicentric cohorts," Clinical Cancer Research, vol. 27, no. 8, pp. 2255–2265, Apr. 2021, doi: 10.1158/1078-0432.CCR-20-4007.
- H. MacMahon et al., "Guidelines for management of incidental pulmonary nodules detected on CT images: from the Fleischner Society 2017," pubs.rsna.orgH MacMahon, DP Naidich, JM Goo, KS Lee, ANC Leung, JR Mayo, AC Mehta, Y OhnoRadiology, 2017•pubs.rsna.org, vol. 284, no. 1, pp. 228–243, Jul. 2017, doi: 10.1148/RADIOL.2017161659.
- Y. Zhao, K. Xiong, and Y. N. Lv, "Systematic review and meta-analysis of low-dose CT-driven biopsy for pulmonary nodules," Videosurgery and other Miniinvasive Techniques, vol. 18, no. 4, p. 603, 2023, doi: 10.5114/WIITM.2023.131563.
- C. Brower, M. R.-T. B. journal of radiology, and undefined 2021, "Radiation risk issues in recurrent imaging," academic.oup.comC Brower, MM RehaniThe British journal of radiology, 2021•academic.oup.com, Accessed: May 30, 2025. [Online]. Available: https://academic.oup.com/bjr/article-abstract/94/1126/20210389/7477317
- P. Kalmar, F. Quehenberger, J. Steiner, … A. L.-E. journal of, and undefined 2014, "The impact of iterative reconstruction on image quality and radiation dose in thoracic and abdominal CT," Elsevier, Accessed: May 30, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0720048X1400254X
- F. M. Braun, T. R. C. Johnson, W. H. Sommer, K. M. Thierfelder, and F. G. Meinel, "Chest CT using spectral filtration: radiation dose, image quality, and spectrum of clinical utility," SpringerFM Braun, TRC Johnson, WH Sommer, KM Thierfelder, FG MeinelEuropean radiology, 2015•Springer, vol. 25, no. 6, pp. 1598–1606, Jun. 2015, doi: 10.1007/S00330-014-3559-1.
- Y. Ohno, H. Koyama, S. Seki, … Y. K.-E. journal of, and undefined 2019, "Radiation dose reduction techniques for chest CT: principles and clinical results," Elsevier, Accessed: May 30, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0720048X18304546
- G. Argentieri, L. Bellesi, A. Pagnamenta, G. V.- Medicine, and undefined 2021, "Diagnostic yield, safety, and advantages of ultra-low dose chest CT compared to chest radiography in early stage suspected SARS-CoV-2 pneumonia: A retrospective ," journals.lww.comG Argentieri, L Bellesi, A Pagnamenta, G Vanini, S Presilla, F Del Grande, M MarandoMedicine, 2021•journals.lww.com, Accessed: May 30, 2025. [Online]. Available: https://journals.lww.com/md-journal/fulltext/2021/05280/Diagnostic_yield,_safety,_and_advantages_of.35.aspx?context=LatestArticles
- J. Greffier, A. Hoballah, … A. S.-… I. in M., and undefined 2021, "Ultra-low-dose chest CT performance for the detection of viral pneumonia patterns during the COVID-19 outbreak period: a monocentric experience," pmc.ncbi.nlm.nih.govJ Greffier, A Hoballah, A Sadate, F De Oliveira, PG Claret, H De Forges, P LoubetQuantitative Imaging in Medicine and Surgery, 2021•pmc.ncbi.nlm.nih.gov, Accessed: May 30, 2025. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC8250025/
- Agostini et al., "Proposal of a low-dose, long-pitch, dual-source chest CT protocol on third-generation dual-source CT

using a tin filter for spectral shaping at 100 kVp for CoronaVirus ," SpringerA Agostini, C Floridi, A Borgheresi, M Badaloni, P Esposto Pirani, F Terilli, L OttavianiLa radiologia medica, 2020•Springer, vol. 125, no. 4, pp. 365–373, Apr. 2020, doi: 10.1007/S11547-020-01179-X.

- V. Vardhanabhuti, C. Pang, S. Tenant, … J. T.-E. journal of, and undefined 2017, "Prospective intra-individual comparison of standard dose versus reduced-dose thoracic CT using hybrid and pure iterative reconstruction in a follow-up cohort of," Elsevier, Accessed: May 30, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0720048X1730150X
- Y. Nagatani, M. Takahashi, M. Ikeda, … T. Y.-A., and undefined 2017, "Sub-solid nodule detection performance on reduced-dose computed tomography with iterative reduction: comparison between 20 mA (7 mAs) and 120 mA (42 mAs)," Elsevier, Accessed: May 30, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1076633217300508
- H. Wisselink, G. Pelgrim, M. Rook, … K. I.-E. J. of, and undefined 2021, "Ultra-low-dose CT combined with noise reduction techniques for quantification of emphysema in COPD patients: an intra-individual comparison study with," Elsevier, Accessed: May 30, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0720048X21001261
- C. Wassipaul et al., "Ultra-low-dose vs. standard-of-care-dose CT of the chest in patients with post-COVID-19 conditions—a prospective intra-patient multi-reader study," Eur Radiol, vol. 34, no. 11, pp. 7244–7254, Nov. 2024, doi: 10.1007/S00330-024-10754-Z/TABLES/5.
- T. Snowsill, H. Yang, E. Griffin, and H. Long, "Low dose computed tomography for lung cancer screening in high-risk populations: a systematic review and economic evaluation2018 ",, Accessed: May 30, 2025. [Online]. Available: https://ore.exeter.ac.uk/repository/handle/10871/32880
- K. L. Huang, S. Y. Wang, W. C. Lu, Y. H. Chang, J. Su, and Y. T. Lu, "Effects of low-dose computed tomography on lung cancer screening: a systematic review, meta-analysis, and trial sequential analysis," SpringerKL Huang, SY Wang, WC Lu, YH Chang, J Su, YT LuBMC pulmonary medicine, 2019•Springer, vol. 19, no. 1, Jul. 2019, doi: 10.1186/S12890-019-0883-X.
- L. L. Humphrey et al., "Screening for lung cancer with low-dose computed tomography: a systematic review to update the US Preventive services task force recommendation," acpjournals.orgLL Humphrey, M Deffebach, M Pappas, C Baumann, K Artis, JP Mitchell, B Zakher, R FuAnnals of internal medicine, 2013•acpjournals.org, vol. 159, no. 6, pp. 411–420, 2013, doi: 10.7326/0003-4819-159-6-201309170-00690.
- K. B. Lee and H. W. Goo, "Comparison of quantitative image quality of cardiac computed tomography between raw-data-based and model-based iterative reconstruction algorithms with an ," SpringerKB Lee, HW GooPediatric Radiology, 2020•Springer, vol. 50, no. 11, pp. 1570–1578, Oct. 2020, doi: 10.1007/S00247-020-04741-X.
- S. Sayed, M. Irfan, and M. Yusof, "Techniques and Strategies to Minimize Radiation Exposure in Pediatric Computed Tomography (CT) Abdominal Examinations: A Review," cureus.comIS Sayed, MIM YusofCureus, 2024•cureus.com , 2024, doi: 10.7759/cureus.67494.
- B. Lee, S. M. Kim, J. T. Yoon, Y. Ahn, and K. H. Do, "Radiation dose reduction and image quality enhancement for patients unable to elevate their arms in chest CT: A comparative study," Eur J Radiol, vol. 188, Jul. 2025, doi: 10.1016/j.ejrad.2025.112120.
- H. M. Zhang, X. B. Huo, H. L. Wang, X. Zhang, and Y. F. Fu, "Computed tomography-guided cutting needle biopsy for lung nodules: A comparative study between low-dose and standard dose protocols," Medicine (United States), vol. 100, no. 3, p. E24001, Jan. 2021, doi: 10.1097/MD.0000000000024001.
- E. L. Li, A. L. Ma, T. Wang, Y. F. Fu, H. Y. Liu, and G. C. Li, "Low-dose versus standard-dose computed tomography-guided biopsy for pulmonary nodules: a randomized controlled trial," SpringerEL Li, AL Ma, T Wang, YF Fu, HY Liu, GC LiJournal of Cardiothoracic Surgery, 2023•Springer, vol. 18, no. 1, p. 86, Dec. 2023, doi: 10.1186/S13019-023-02183-8.
- C. Li, B. Liu, H. Meng, W. Lv, and H. Jia, "Efficacy and Radiation Exposure of Ultra-Low-Dose Chest CT at 100 kVp with Tin Filtration in CT-Guided Percutaneous Core Needle Biopsy for Small Pulmonary Lesions Using a Third-Generation Dual-Source CT Scanner," Journal of Vascular and Interventional Radiology, vol. 30, no. 1, pp. 95–102, Jan. 2019, doi: 10.1016/J.JVIR.2018.06.013.
- Y. Y. Huang, H. Cheng, and G. C. Li, "Computed tomography-guided core needle biopsy for lung nodules: Low-dose versus standard-dose protocols," Wideochirurgia I Inne Techniki Maloinwazyjne, vol. 16, no. 2, pp. 355–361, 2021, doi: 10.5114/WIITM.2021.103303.
- Y. F. Fu, G. C. Li, Q. S. Xu, Y. B. Shi, C. Wang, and T. Wang, "Computed tomography–guided lung biopsy: a randomized controlled trial of low-dose versus standard-dose protocol," SpringerYF Fu, GC Li, QS Xu, YB Shi, C Wang, T WangEuropean radiology, 2020•Springer, vol. 30, no. 3, pp. 1584–1592, Mar. 2020, doi: 10.1007/S00330-019-06464-6.
- R. Manser et al., "Screening for lung cancer," cochranelibrary.com, vol. 2013, no. 6, Jun. 2013, doi: 10.1002/14651858.CD001991.PUB3/ABSTRACT.
- C. O'Brien, H. Kok, B. Kelly, K. Kumamaru, A. S.-C. Imaging, and undefined 2019, "To investigate dose reduction and comparability of standard dose CT vs ultra-low dose CT in evaluating pulmonary emphysema," Elsevier, Accessed:

May 30, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0899707118302808
- C. M. Dorneles et al., “Ultra-low-dose chest computed tomography without anesthesia in the assessment of pediatric pulmonary diseases,” SciELO BrasilCM Dorneles, GS Pacini, M Zanon, S Altmayer, G Watte, MC Barros, E MarchioriJornal de Pediatria, 2020•SciELO Brasil, vol. 96, no. 1, pp. 92–99, 2020, doi: 10.1016/j.jped.2018.07.010.
- F. J. Larke et al., “Estimated radiation dose associated with low-dose chest CT of average-size participants in the National Lung Screening Trial,” ajronline.orgFJ Larke, RL Kruger, CH Cagnon, MJ Flynn, MM McNitt-Gray, X Wu, PF Judy, DD CodyAmerican Journal of Roentgenology, 2011•ajronline.org, vol. 197, no. 5, pp. 1165–1169, Nov. 2011, doi: 10.2214/AJR.11.6533.
- C. Rampinelli, D. Origgi, M. B.-C. imaging, and undefined 2013, “Low-dose CT: technique, reading methods and image interpretation,” pmc.ncbi.nlm.nih.govC Rampinelli, D Origgi, M BellomiCancer imaging, 2013•pmc.ncbi.nlm.nih.gov, Accessed: May 30, 2025. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC3569671/
- Sarma, M. E. Heilbrun, K. E. Conner, S. M. Stevens, S. C. Woller, and C. G. Elliott, “Radiation and chest CT scan examinations: What do we know?” Chest, vol. 142, no. 3, pp. 750–760, 2012, doi: 10.1378/CHEST.11-2863.
- D. E. Wood et al., “NCCN Guidelines Version 1.2025 Lung Cancer Screening Continue NCCN Guidelines Panel Disclosures,” 2024, Accessed: May 30, 2025. [Online]. Available: https://www.nccn.org/home/member-
- M. Vonder, M. D. Dorrius, and R. Vliegenthart, “Latest CT technologies in lung cancer screening: Protocols and radiation dose reduction,” Transl Lung Cancer Res, vol. 10, no. 2, pp. 1154–1164, Feb. 2021, doi: 10.21037/TLCR-20-808.
- G. Gheysens et al., “Detection of pulmonary nodules with scoutless fixed-dose ultra-low-dose CT: a prospective study,” SpringerG Gheysens, W De Wever, L Cockmartin, H Bosmans, W Coudyzer, S De Vuysere, M LefereEuropean Radiology, 2022•Springer, vol. 32, no. 7, pp. 4437–4445, Jul. 2022, doi: 10.1007/S00330-022-08584-Y.
- Z. Pan et al., “Detection, measurement, and diagnosis of lung nodules by ultra-low-dose CT in lung cancer screening: a systematic review,” BJR Open, vol. 6, no. 1, p. tzae041, Jan. 2024, doi: 10.1093/BJRO/TZAE041.
- B. Jiang et al., “Deep learning reconstruction shows better lung nodule detection for ultra–low-dose chest CT,” pubs.rsna.orgB Jiang, N Li, X Shi, S Zhang, J Li, GH de Bock, R Vliegenthart, X XieRadiology, 2022•pubs.rsna.org, vol. 303, no. 1, pp. 202–212, Apr. 2022, doi: 10.1148/RADIOL.210551.
- S. Carey et al., “Comparison of conventional chest x ray with a novel projection technique for ultra-low dose CT,” Wiley Online LibraryS Carey, S Kandel, C Farrell, J Kavanagh, TB Chung, W Hamilton, P RogallaMedical Physics, 2021•Wiley Online Library, vol. 48, no. 6, pp. 2809–2815, Jun. 2021, doi: 10.1002/MP.14142.
- Y. Xu et al., “Effect of iterative reconstruction techniques on image quality in low radiation dose chest CT: a phantom study,” Diagnostic and Interventional Radiology, vol. 25, no. 6, p. 442, Nov. 2019, doi: 10.5152/DIR.2019.18539.
- M. J. Page et al., “The PRISMA 2020 statement: An updated guideline for reporting systematic reviews,” BMJ, vol. 372, Mar. 2021, doi: 10.1136/BMJ.N71.
- “Risk of Bias 2 (RoB 2) tool | Cochrane Methods.” Accessed: Aug. 28, 2025. [Online]. Available: https://methods.cochrane.org/risk-bias-2
- G. Milanese et al., “Ultra-low dose computed tomography protocols using spectral shaping for lung cancer screening: Comparison with low dose for volumetric LungRADS classification,” Eur J Radiol, vol. 161, Apr. 2023, doi: 10.1016/j.ejrad.2023.110760.
- Y. Nagatani et al., “Lung nodule detection performance in five observers on computed tomography (CT) with adaptive iterative dose reduction using three-dimensional processing (AIDR 3D) in a Japanese multicenter study: Comparison between ultra-low-dose CT and low-dose CT by receiver-operating characteristic analysis,” Eur J Radiol, vol. 84, no. 7, pp. 1401–1412, Jul. 2015, doi: 10.1016/J.EJRAD.2015.03.012,.
- P. W. O’Regan et al., “Ultra-low-dose chest computed tomography with model-based iterative reconstruction in the analysis of solid pulmonary nodules: A prospective study,” World J Radiol, vol. 16, no. 11, p. 668, Nov. 2024, doi: 10.4329/WJR.V16. I11.668.
- Wang et al., “Deep learning reconstruction improves computer-aided pulmonary nodule detection and measurement accuracy for ultra-low-dose chest CT,” BMC Med Imaging, vol. 25, no. 1, pp. 1–12, Dec. 2025, doi: 10.1186/S12880-025-01746-6/FIGURES/7.
- P. A. Autrusseau et al., “Radiomics in the evaluation of lung nodules: Intrapatient concordance between full-dose and ultra-low-dose chest computed tomography,” Diagn Interv Imaging, vol. 102, no. 4, pp. 233–239, Apr. 2021, doi: 10.1016/J.DIII.2021.01.010.
- X. Zhou et al., “Ultra-low-dose spectral-detector computed tomography for the accurate quantification of pulmonary nodules: an anthropomorphic chest phantom study,” Diagnostic and Interventional Radiology, vol. 29, no. 5, pp. 691–703, Sep. 2023, doi: 10.4274/DIR.2023. 232233.
- Zhao et al., “Measurement Accuracy and Repeatability of RECIST-Defined Pulmonary Lesions and Lymph Nodes in Ultra-Low-Dose CT Based on Deep Learning Image Reconstruction,” Cancers (Basel), vol. 14, no. 20, Oct. 2022, doi: 10.3390/CANCERS14205016.
- Zhang, W. Qi, Y. Sun, Y. Jiang, X. Liu, and N. Hong, “Screening for lung cancer using sub-millisievert chest CT with iterative reconstruction algorithm: image quality and nodule detectability,” Br J Radiol, vol. 91, no. 1090, p. 20170658, 2017, doi: 10.1259/BJR.20170658.

- H. L. Lancaster et al., "Outstanding negative prediction performance of solid pulmonary nodule volume AI for ultra-LDCT baseline lung cancer screening risk stratification," Lung Cancer, vol. 165, pp. 133–140, Mar. 2022, doi: 10.1016/j.lungcan.2022.01.002.
- L. Ding et al., "Ultra-low dose dual-layer detector spectral CT for pulmonary nodule screening: image quality and diagnostic performance," Insights Imaging, vol. 16, no. 1, pp. 1–12, Dec. 2025, doi: 10.1186/S13244-024-01888-1/FIGURES/6.
- Aiello et al., "Evaluation of AI-Based Segmentation Tools for COVID-19 Lung Lesions on Conventional and Ultra-low Dose CT Scans," Dose-Response, vol. 20, no. 2, p. 15593258221082896, Mar. 2022, doi: 10.1177/15593258221082896.
- C. Ortlieb, A. Labani, F. Severac, M. Y. Jeung, C. Roy, and M. Ohana, "Impact of morphotype on image quality and diagnostic performance of ultra-low-dose chest ct," J Clin Med, vol. 10, no. 15, Aug. 2021, doi: 10.3390/JCM10153284.
- Hata, M. Yanagawa, O. Honda, T. Miyata, and N. Tomiyama, "Ultra-low-dose chest computed tomography for interstitial lung disease using model-based iterative reconstruction with or without the lung setting," Medicine (United States), vol. 98, no. 22, May 2019, doi: 10.1097/MD.0000000000015936.
- A. H. Van Den Berk et al., "Ultra-low-dose CT versus chest X-ray for patients suspected of pulmonary disease at the emergency department: A multicentre randomised clinical trial," Thorax, vol. 78, no. 5, pp. 515–522, May 2023, doi: 10.1136/THORAXJNL-2021-218337.
- E. S. Choi, J. S. Kim, J. K. Lee, H. A. Lee, and S. Pak, "Prospective evaluation of low-dose multiphase hepatic computed tomography for detecting and characterizing hepatocellular carcinoma in patients with chronic liver disease," BMC Med Imaging, vol. 22, no. 1, p. 219, Dec. 2022, doi: 10.1186/S12880-022-00947-7.
- R. D. eedar A. Khawaja et al., "Ultra-low-dose chest CT using filtered back projection: comparison of 80-, 100- and 120 kVp protocols in a prospective randomized study," Eur J Radiol, vol. 83, no. 10, pp. 1934–1944, Oct. 2014, doi: 10.1016/J.EJRAD.2014.06.024.
- Li, B. Liu, H. Meng, W. Lv, and H. Jia, "Efficacy and Radiation Exposure of Ultra-Low-Dose Chest CT at 100 kVp with Tin Filtration in CT-Guided Percutaneous Core Needle Biopsy for Small Pulmonary Lesions Using a Third-Generation Dual-Source CT Scanner," Journal of Vascular and Interventional Radiology, vol. 30, no. 1, pp. 95–102, Jan. 2019, doi: 10.1016/J.JVIR.2018.06.013,.
- S. Kepka et al., "Organizational Benefits of Ultra-Low-Dose Chest CT Compared to Chest Radiography in the Emergency Department for the Diagnostic Workup of Community-Acquired Pneumonia: A Real-Life Retrospective Analysis," Medicina 2023, Vol. 59, Page 1508, vol. 59, no. 9, p. 1508, Aug. 2023, doi: 10.3390/MEDICINA59091508.
- Tore et al., "Ultra-Low-Dose Whole-Body Computed Tomography Protocol Optimization for Patients with Plasma Cell Disorders: Diagnostic Accuracy and Effective Dose Analysis from a Reference Center," Front Oncol, vol. 11, p. 769295, Nov. 2021, doi: 10.3389/FONC.2021.769295.
- H. Kwon et al., "The adaptive statistical iterative reconstruction-V technique for radiation dose reduction in abdominal CT: comparison with the adaptive statistical iterative reconstruction technique," Br J Radiol, vol. 88, no. 1054, p. 20150463, Oct. 2015, doi: 10.1259/BJR.20150463.
- F. Sanchez Tijmes et al., "Chest CT at X-Ray Dose Using a Noise-Mitigating Weighted Projection: The Thoracic Tomogram. Diagnostic Performance for Pneumonia Detection in Hemato-Oncology Patients," Canadian Association of Radiologists Journal, vol. 75, no. 3, pp. 621–630, Aug. 2024, doi: 10.1177/08465371231215670.
- S. Brendlin et al., "AI Denoising Improves Image Quality and Radiological Workflows in Pediatric Ultra-Low-Dose Thorax Computed Tomography Scans," Tomography 2022, Vol. 8, Pages 1678-1689, vol. 8, no. 4, pp. 1678–1689, Jun. 2022, doi: 10.3390/TOMOGRAPHY8040140.
- Hamabuchi et al., "Effectiveness of deep learning reconstruction on standard to ultra-low-dose high-definition chest CT images," Jpn J Radiol, vol. 41, no. 12, pp. 1373–1388, Dec. 2023, doi: 10.1007/S11604-023-01470-7.
- Ye, M. Chen, Q. Zhu, Y. Lu, and H. Yuan, "Effect of adaptive statistical iterative reconstruction-V (ASiR-V) levels on ultra-low-dose CT radiomics quantification in pulmonary nodules," Quant Imaging Med Surg, vol. 11, no. 6, Jun. 2021, doi: 10.21037/QIMS-20-932.
- Afshar et al., "Human-level COVID-19 diagnosis from low-dose CT scans using a two-stage time-distributed capsule network," Sci Rep, vol. 12, no. 1, pp. 1–11, Dec. 2022, doi: 10.1038/S41598-022-08796-8; SUBJMETA=1647,245,2514,255,631,692,699; KWRD=IMAGING, VIRAL+INFECTION.
- F. Zarei et al., "Evaluation of Ultra-Low-Dose Chest Computed Tomography Images in Detecting Lung Lesions Related to COVID-19: A Prospective Study," Iran J Med Sci, vol. 47, no. 4, p. 338, Jul. 2022, doi: 10.30476/IJMS.2021.90665.2165.
- M. Garg et al., "Ultra-Low Dose CT Chest in Acute COVID-19 Pneumonia: A Pilot Study from India," Diagnostics, vol. 13, no. 3, p. 351, Feb. 2023, doi: 10.3390/DIAGNOSTICS13030351.
- S. Devkota et al., "Evaluating Lung Changes in Long COVID: Ultra-Low-Dose vs. Standard-Dose CT Chest," Br J Biomed Sci, vol. 81, 2024, doi: 10.3389/BJBS.2024. 13385.
- Wassipaul et al., "Ultra-low-dose vs. standard-of-care-dose CT of the chest in patients with post-COVID-19 conditions-a prospective intra-patient multi-reader study," Eur Radiol, vol. 34, no. 11, pp. 7244–7254, Nov. 2024, doi: 10.1007/S00330-024-10754-Z.
- M. Schaal, F. Severac, A. Labani, M. Y. Jeung, C. Roy, and M. Ohana, "Diagnostic Performance of Ultra-Low-Dose

Computed Tomography for Detecting Asbestos-Related Pleuropulmonary Diseases: Prospective Study in a Screening Setting," PLoS One, vol. 11, no. 12, p. e0168979, Dec. 2016, doi: 10.1371/JOURNAL.PONE.0168979.

- C. P. Murray et al., "Ultra-low dose CT screen-detected non-malignant incidental findings in the Western Australian Asbestos Review Programme," Respirology, vol. 21, no. 8, pp. 1419–1424, Nov. 2016, doi: 10.1111/RESP.12826.
- D'Errico et al., "Diagnostic Accuracy in Detecting Fungal Infection with Ultra-Low-Dose Computed Tomography (ULD-CT) Using Filtered Back Projection (FBP) Technique in Immunocompromised Patients," Journal of Clinical Medicine 2024, Vol. 13, Page 1704, vol. 13, no. 6, p. 1704, Mar. 2024, doi: 10.3390/JCM13061704.
- Klug et al., "Denoised Ultra-Low-Dose Chest CT to Assess Pneumonia in Individuals Who Are Immunocompromised," Radiol Cardiothorac Imaging, vol. 7, no. 2, Apr. 2025, doi: 10.1148/RYCT.240189; ISSUE: ISSUE: 10.1148/CARDIOTHORACIC.2025.7.ISSUE-2; WGROUP: STRING: RSNA.
- Macri et al., "Value of ultra-low-dose chest CT with iterative reconstruction for selected emergency room patients with acute dyspnea," Eur J Radiol, vol. 85, no. 9, pp. 1637–1644, Sep. 2016, doi: 10.1016/j.ejrad.2016.06.024.
- S. Brendlin et al., "Diagnostic performance of a contrast-enhanced ultra-low-dose high-pitch ct protocol with reduced scan range for detection of pulmonary embolisms," Diagnostics, vol. 11, no. 7, Jul. 2021, doi: 10.3390/DIAGNOSTICS11071251.
- J. S. Eom, G. Lee, J. Roh, H. S. Chung, and Y. J. Jeong, "Feasibility of Ultra-Low-Dose CT for Bronchoscopy of Peripheral Lung Lesions," Medicina (B Aires), vol. 56, no. 9, p. 479, Sep. 2020, doi: 10.3390/MEDICINA56090479.
- T. Liang et al., "Ultra-low-dose CT-guided lung biopsy in clinic: radiation dose, accuracy, image quality, and complication rate," Acta radiol, vol. 62, no. 2, pp. 198–205, Feb. 2021, doi: 10.1177/0284185120917622.
- K. Gobi, V. K. Arunachalam, R. K. Varatharajaperumal, M. Cherian, G. Periaswamy, and S. Rajesh, "The role of ultra-low dose computed tomography in the detection of pulmonary pathologies: a prospective observational study," Pol J Radiol, vol. 87, no. 1, p. e597, 2022, doi: 10.5114/PJR.2022.121433.
- Ludwig et al., "Detection of pulmonary nodules: A clinical study protocol to compare ultra-low dose chest CT and standard low-dose CT using ASIR-V," BMJ Open, vol. 9, no. 8, Aug. 2019, doi: 10.1136/BMJOPEN-2018-025661.
- J. Ingbritsen, J. Callahan, H. Morgan, M. Munro, R. E. Ware, and R. J. Hicks, "Optimisation of low and ultra-low dose scanning protocols for ultra-extended field of view PET in a real-world clinical setting," Cancer Imaging, vol. 25, no. 1, Dec. 2025, doi: 10.1186/S40644-025-00823-X.