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Advances in Low-Dose CT Protocols and Their Impact on Diagnostic Accuracy: A Systematic Review

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Abstract

Background: Advancements in low-dose computed tomography (CT) protocols have revolutionized medical imaging by enhancing diagnostic accuracy while reducing radiation exposure, a critical concern in radiology. CT imaging, a cornerstone of diagnostic practices, is invaluable for detecting and monitoring diseases such as cancer, cardiovascular conditions, and pulmonary disorders.

Aim: To explore the advances in low-dose CT protocols, their impact on diagnostic accuracy.

Methods: This is an updated systematic analysis of papers conducted between 2020 and 2024 that specifically examine the interventions of the advances in low-dose CT protocols, their impact on diagnostic accuracy. Using the databases from Google Scholar, Web of Science, Cochrane, and PubMed, we searched the literature for pertinent studies on our subject. Various combinations of the terms "Advances, low-dose, CT protocols, impact, and diagnostic accuracy" were utilized. Additionally, a review of original studies that assessed the advances in low-dose CT protocols, their impact on diagnostic accuracy was done. Based on full-text articles, the inclusion criteria were developed.

Results: Only eight of the 55 articles that were gathered met the criteria for inclusion. The papers used included six prospective studies and two single-center prospective randomized controlled trial. Two studies included patients presenting with suspected appendicitis, another study involved patients with clinically suspected diverticulitis. Additionally, one study involved oncologic patients, while another study included patients with ground-glass opacities, and one further study enrolled confirmed COVID-19. Finally two studies patients randomized into low-dose and standard-dose CT-guided biopsy groups.

Conclusion: Low-dose CT imaging has become one of the revolutionary techniques for diagnostic imaging whereby the requirements for correct image and the concerns made to minimize the radiation dose. Beginning with acute appendicitis, to oncologic imaging, and procedural guidance emerging literature supports its safety and effectiveness. Reconstruction algorithms improve its capabilities and potential technological advancements make it suitable for application in clinics. Future studies offer the potential for forming more sophisticated low-dose CT systems with AI and machine learning to enhance the working

performance of diagnosis and diseased treatment and to enlarge the application fields of low-dose CT systems in various medical specialties.

Keywords: Advances, low-dose, CT protocols, impact, and diagnostic accuracy

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INTRODUCTION

Low-dose computed tomography (CT) is a novel medical imaging technique that has gradually replaced conventional diagnostic imaging because it provides accurate and efficient diagnostics without posing significant risks in terms of radiation exposure to the patient [1]. CT imaging is deemed a traditional and fundamental modality of diagnosis since it is capable of diagnosing cancer, cardiovascular diseases, and pulmonary diseases, among others [2]. Nevertheless, its associated radiation has brought about innovations in attempting to minimize ionizing radiation exposure while retaining the required diagnostic capacities of imaging. These developments are especially pressing when it comes to safety and the shift towards more personalized treatments [3].

The latest advancement in low-dose CT (LDCT) involves the reconstruction of images using advanced methods such as the iterative reconstruction (IR) and deep learning-based reconstruction (DLR) [4]. These technologies provide excellent image quality at much lower radiation doses compared to traditional technologies. Specifically, DLR has been shown to either have no loss or even an increase in image quality compared with standard-dose protocols, making it a cornerstone of modern radiology [5]. For instance, the use of deep learning has been described as improving the detection of small lung nodules while not compromising on the diagnostic quality even with as low as 25% radiation emission [6]. This highlights that LDCT has the ability of offering favorable diagnostic results while at the same time protecting the safety of patients.

Current applications of LDCT are rapidly growing, and the consequences are quite notable in lung cancer screening and emergency practices [7]. Both low-dose and ultra-low-dose CT are equally beneficial as standard-dose CT in terms of diagnosing severe conditions, including pulmonary embolisms and post-COVID symptoms, while posing minimal radiation hazards. These protocols have changed patient management paradigms and have enabled the decrease in unnecessary hospital admissions and follow-up by improving imaging accuracy and safety [8].

However, some barriers still exist; there is variance in protocols between and within institutions, and the results need to be reproduced in real-world settings with various patient types [9]. Combating these concerns necessitates the implementation of multi-disciplinary approaches involving radiologists, technologists, and industry partners in terms of disseminating low-dose approaches and increasing availability.

Aim of Work:

To explore the advances in low-dose CT protocols, their impact on diagnostic accuracy.

METHOD AND SEARCH STRATEGY

This systematic review adheres to the PRISMA checklist recommendations for systematic reviews and meta-analyses [10]. Google Scholar, Web of Science, Cochrane, and PubMed were the databases that were analyzed. We searched the four databases for literature pertaining to our main topic; "the advances in low-dose CT protocols, their impact on diagnostic accuracy”. The included studies were published between 2020 and 2024.

The search technique included using several keywords such as “Advances, low-dose, CT protocols, impact, and diagnostic accuracy". Furthermore, the pertinent keywords were used to gather all applicable articles. As a consequence of this preliminary investigation, all titles were revised.

ELIGIBILITY CRITERIA

After analyzing the titles, only publications specifically addressing the advances in low-dose CT protocols, their impact on diagnostic accuracy were eliminated. This exclusion was limited to papers published between 2020 and 2024. In the second step, we focused on choosing only authentic studies written in English that specifically addressed the advances in low-dose CT protocols, their impact on diagnostic accuracy. This selection process required carefully reviewing the abstracts of the remaining papers. However, review articles, editor letters, and case reports were excluded. The last phase included authentic English-language literature that explored the advances in low-dose CT protocols, their impact on diagnostic accuracy. The articles underwent further scrutiny to eliminate duplicates, articles without full-text, and articles with unacceptable material, such as data that was overlapped or incomplete. Figure 1 provides a comprehensive illustration of the search methodology

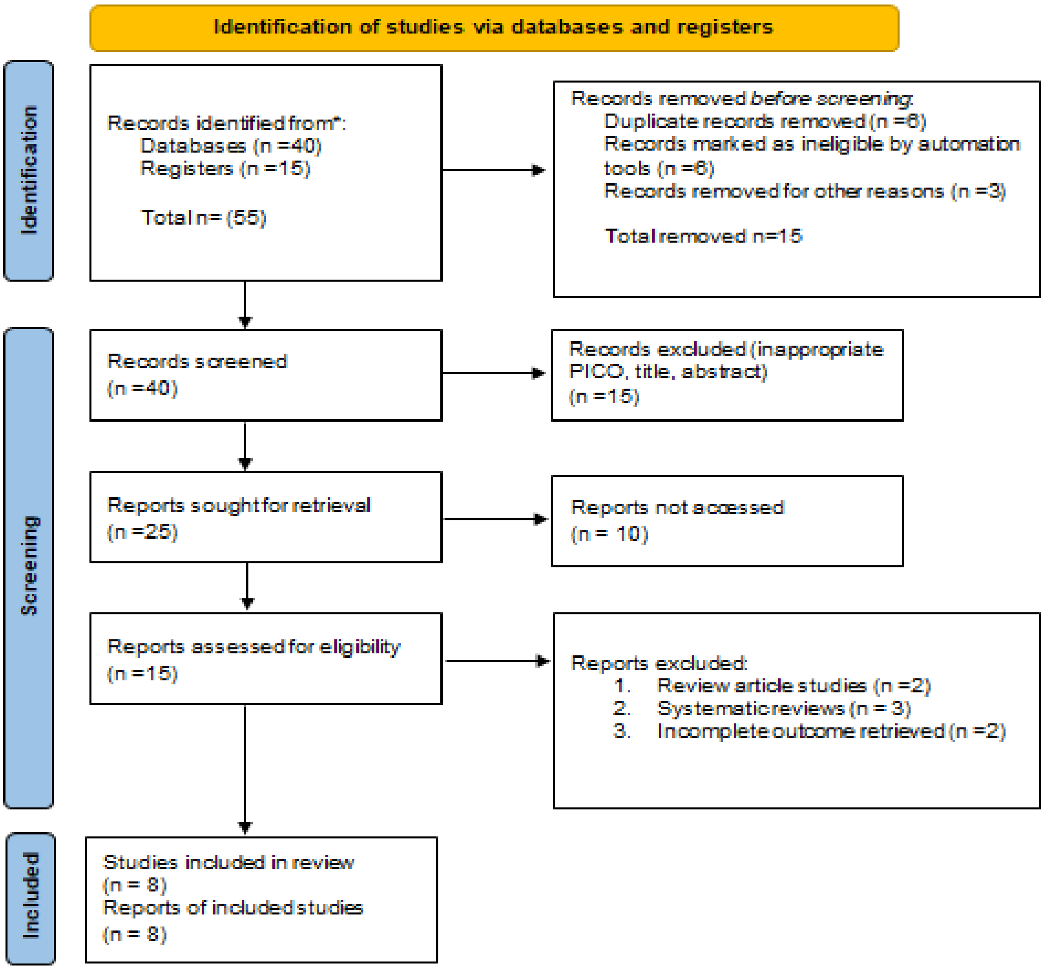

Fig1: Planning of Eligible criteria

DATA REVIEWING AND ANALYSIS

The full text and abstracts of the publications were assessed in order to extract the pertinent data and transfer it to a pre-existing excel spreadsheet. The selected data were then modified in the excel spreadsheet, and the data were merged to condense the information for the purpose of facilitating data analysis.

RESULTS

Eight papers [11- 18] met the inclusion criteria of this systematic review (table 1). The papers used included six prospective studies [11- 16] and two single-center prospective randomized controlled trial [17, 18]. The papers were either published in 2020 [12, 13, 16, 17], 2021 [11], 2023 [18] and 2024 [14, 15]. Two studies [11, 12] included 856 and 60 patients aged 16 years or older presenting with suspected appendicitis, another study [13] involved 149 patients with clinically suspected diverticulitis. Additionally, one study [14] involved 50 oncologic patients, while another study [15] included 101 patients with ground-glass opacities, and one further study [16] enrolled 50 confirmed COVID-19. Finally two studies [17, 18] included 280 and 200 randomized into low-dose and standard-dose CT-guided biopsy groups.

Two studies [11, 12] assessed the diagnostic effectiveness of low-dose vs standard-dose CT for suspected acute appendicitis, while another research [13] examined the diagnostic reliability of unenhanced low-dose CT for identifying acute diverticulitis. Furthermore, one study [14] evaluated the diagnostic efficacy of low-dose liver CT, another study [15] investigated the effectiveness of low-dose dual-input targeted perfusion CT in distinguishing benign from malignant ground-glass opacities (GGOs), and a third study [16] compared the diagnostic reliability of a low-dose chest CT protocol (30 mAs) against a standard-dose protocol (150 mAs) for the detection of COVID-19 pneumonia. Two trials evaluate the diagnostic accuracy of low-dose vs standard-dose CT-guided lung biopsy [17] and for pulmonary nodules [18].
Low-dose CT exhibited diagnostic accuracy equivalent to normal CT in identifying acute appendicitis and distinguishing between simple and complex cases. It also accomplished a substantial decrease in radiation dosage [11]. Both low-dose and standard-dose CT efficiently diagnosed appendicitis and differentiated between simple and difficult cases. Low-dose CT markedly decreased radiation exposure and is advised as the routine imaging strategy, especially for individuals with a BMI under 30 kg/m^2 [12]. Low-dose CT demonstrated significant diagnostic precision for acute diverticulitis. Nevertheless, the potential to miss indicators of complex illness requires standard-dose CT in instances when complications are anticipated [13].
Low-dose CT-guided lung biopsy attained diagnostic accuracy equivalent to standard-dose guidance while markedly decreasing radiation exposure for lung biopsy and pulmonary nodules [17, 18].

The low-dose CT procedure demonstrated efficacy in detecting COVID-19 pneumonia in standard clinical practice, resulting in a substantial decrease in radiation exposure and related cancer risks [16]. Low-dose dual-input perfusion CT demonstrated significant diagnostic efficacy, with fractional extraction product (FEP) being especially adept at differentiating malignant GGOs [15]. DLIR algorithms demonstrated enhanced diagnostic accuracy relative to iterative reconstruction, particularly in identifying hypovascular liver lesions, notably those measuring ≤0.5 cm [14].

DISCUSSION

Computed Tomography (CT) imaging has become an indispensable tool in the diagnosis of various conditions, particularly for its ability to offer high spatial resolution and detailed anatomic images. However, the standard use of CT involves relatively high radiation doses, which raise concerns about the associated long-term risks, particularly cancer. In recent years, there has been a shift toward developing LDCT protocols that aim to maintain diagnostic accuracy while minimizing radiation exposure. This systematic review explores the advances in low-dose CT protocols, their impact on diagnostic accuracy.

Regarding the diagnosing acute appendicitis and differentiating between simple and complicated cases, our findings indicated that LDCT showed diagnostic accuracy comparable to standard CT. Additionally, it achieved a significant reduction in radiation dose, supporting previous findings [19, 10]. Furthermore, compared to standard-dose imaging, the median radiation dosage linked to low-dose CT was lower. Clinical practice is rapidly adopting non-operative care of CT-confirmed uncomplicated acute appendicitis due to mounting evidence of its safety, effectiveness, feasibility, and cost advantages [21, 22].

Furthermore, our findings showed that LDCT had a notable level of diagnostic accuracy for acute diverticulitis. In a prior research [23], the LDCT technique was shown to be sensitive for the identification of both diverticulitis and diverticular abscess, albeit abscess size was not recorded. It also demonstrated comparable accuracy to SDCT in patients with suspected acute diverticulitis.

When compared to iterative reconstruction, DLIR algorithms showed improved diagnostic accuracy, especially when it came to detecting hypovascular liver lesions, especially those that were less than 0.5 cm in size. Abdominal studies are usually fairly sensitive to radiation dose because of the inherent low contrast differences between various abdominal organs, and the possibility of sensibly reducing radiation exposure without compromising the diagnostic yield of a CT examination depends solely on the particular clinical task [24]. Specifically, liver imaging requires good picture quality to detect and properly describe liver lesions, particularly tiny ones, whose assessment may be hampered by slight reductions in radiation dosage that are not offset by iterative reconstruction procedures [25]. In this sense, DLIR, which has previously been shown to be successful in preserving noise texture and sufficient low contrast liver lesion detectability at low dose settings [26], may allow for more dose optimization in abdominal CT without impairing diagnostic results.

Significant diagnostic effectiveness was shown by low-dose dual-input perfusion CT, with FEP particularly good at distinguishing malignant GGOs. Vascular endothelial growth factor and other angiogenic factors cause malignant nodules to have greater neovascularization, immature blood vessel development, incomplete vessel walls, and enhanced capillary permeability. On the other hand, benign nodules exhibit reduced vessel-wall permeability, comparably mature vasculature, and substantially straighter vessel branching [27]. Thus, in line with the results of earlier research, the FEP was larger for the malignant nodules than for the benign nodules [28].
Furthermore, the current findings showed that LDCT-guided lung biopsy significantly reduced radiation exposure for lung biopsies and pulmonary nodules while achieving diagnostic accuracy comparable to standard-dose guidance. Compared to standard-dose CT, low-dose CT had comparable technical success rates, needle route counts, and procedure durations, despite the fact that the standard-dose CT produced much superior picture quality. Moreover, unlike traditional diagnostic pictures, biopsy images do not need to show every detail of the lesion; instead, they just need to show the lesion and the needle tip in clearly visible areas [17]. These results could suggest that low-dose CT scans produced using our settings can also meet PN biopsy requirements.
The capacity to achieve a definitive diagnosis by biopsy is often indicated by diagnostic yield [29, 30, 31]. We discovered that the low-dose CT did not lower the CT-guided biopsy's diagnostic yield. Additionally, both groups' diagnostic yield rates (68% and 65%) were comparable to earlier findings of CT-guided biopsy for PNs [30]. Likewise, low-dose CT did not lower the diagnostic yield for spine biopsies, according to Shpilberg et al. [29].

CONCLUSION

Based on the results outlined in the present systematic review, low-dose CT protocols demonstrate significant potential in reducing radiation exposure without compromising diagnostic accuracy in various medical applications. Across diverse patient populations and clinical scenarios—including the evaluation of acute appendicitis, pulmonary nodules, liver lesions, and COVID-19 pneumonia—low-dose CT has proven to be as effective as standard-dose CT in diagnosing and differentiating conditions. While its reliability is underscored in most cases, cautious application is recommended in contexts where identifying complex or subtle pathology is critical. These findings advocate for integrating low-dose CT as a standard practice in appropriate clinical settings to enhance patient safety while maintaining diagnostic efficacy.

APPENDIX

Table 1

Author and Publication year	**Study design**	**Population, Sample Size, and Characterization**	**Main points**	**Results and main findings**
1. Haijanen et al. 2021 [11]	Prospective cohort study	856 patients aged 16 years or older presenting with suspected appendicitis. The study assessed the diagnostic precision of contrast-enhanced low-dose and standard-dose CT protocols, tailored to imaging based on BMI, allowing direct comparisons for individuals with a BMI below 30 kg/m²..	To compare the diagnostic efficacy of low-dose versus standard-dose CT for suspected acute appendicitis.	Both low- and standard-dose CT effectively identified appendicitis and distinguished between uncomplicated and complicated cases. Low-dose CT significantly reduced radiation exposure and is recommended as the standard imaging protocol, particularly for patients with a BMI below 30 kg/m².
2. Sippola et al. 2020 [12]	Prospective study	60 patients with suspected acute appendicitis and a BMI below 30 kg/m² underwent both standard and low-dose contrast-enhanced CT scans.	Conducted as part of the OPTICAP trial phantom phase, the study aimed to compare the diagnostic performance of contrast-enhanced low-dose CT to standard CT in patients with suspected acute appendicitis.	Low-dose CT demonstrated diagnostic accuracy comparable to standard CT in diagnosing acute appendicitis and differentiating uncomplicated from complicated cases. It also achieved significant radiation dose reduction.

3.	**Thorisson et al. 2020 [13]**	Prospective study	149 patients with clinically suspected diverticulitis underwent low-dose CT followed by standard-dose CT between January and October 2017.	To evaluate the diagnostic reliability of unenhanced low-dose CT for detecting acute diverticulitis.	Low-dose CT exhibited high diagnostic accuracy for acute diverticulitis. However, the possibility of overlooking signs of complicated disease necessitates standard-dose CT for cases where complications are suspected.
4.	**Caruso et al. 2024 [14]**	Prospective study	50 oncologic patients underwent contrast-enhanced CT scans with images reconstructed using deep learning image reconstruction (DLIR) algorithms at three intensity levels and ASiR-V with strength levels ranging from 10% to 100%.	To assess the diagnostic utility of low-dose liver CT.	DLIR algorithms showed superior diagnostic accuracy compared to iterative reconstruction, particularly for detecting hypovascular liver lesions, especially those ≤0.5 cm.
5.	**Hu et al. 2024[15]**	A prospective study was conducted of patients with GGOs who underwent CT perfusion imaging from January 2022 to October 2023	101 patients with ground-glass opacities (GGOs) underwent CT perfusion imaging between January 2022 and October 2023, including 43 benign and 58 malignant nodules.	To explore the effectiveness of low-dose dual-input targeted perfusion CT in differentiating benign from malignant GGOs.	Low-dose dual-input perfusion CT exhibited high diagnostic capability, with fractional extraction product (FEP) being particularly effective for distinguishing malignant GGOs.

6.	**Tabatabaei et al. 2020 [16]**	Prospective study	50 confirmed COVID-19 patients aged 50 years or older with normal same-day chest X-rays participated.	To compare the diagnostic reliability of a low-dose chest CT protocol (30 mAs) versus a standard-dose protocol (150 mAs) for detecting COVID-19 pneumonia.	The low-dose CT protocol proved effective for identifying COVID-19 pneumonia in routine clinical practice, with a significant reduction in radiation dose and associated cancer risks.
7.	**Fu et al. 2020 [17]**	single-center, single-blind, prospective, randomized controlled trial	Among 280 enrolled patients, 271 underwent randomized allocation to low-dose (n=135) or standard-dose (n=136) CT-guided lung biopsy interventions.	To compare the diagnostic accuracy of low- versus standard-dose CT-guided lung biopsy.	Low-dose CT-guided lung biopsy achieved diagnostic accuracy comparable to standard-dose guidance while significantly reducing radiation exposure.
8.	**Li et al. 2023 [18]**	a single-center prospective randomized controlled trial	200 patients were randomized into low-dose (n=100) and standard-dose (n=100) CT-guided biopsy groups, all achieving technical success and definitive diagnoses.	To assess the safety and diagnostic performance of low-dose CT-guided biopsy for pulmonary nodules.	Low-dose CT-guided biopsy was equally safe and diagnostically accurate compared to the standard-dose protocol, with significant reductions in radiation exposure.

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