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Review Article

Artificial intelligence in automated detection of lung nodules: a narrative review

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Abstract: Lung cancer remains a leading cause of cancer-related mortality worldwide, and early detection is essential for improving patient outcomes. This study evaluates the role of artificial intelligence (AI) in lung nodule detection, focusing on its potential to enhance the accuracy of early lung cancer diagnosis. We assess the performance of AI tools, particularly convolutional neural networks (CNNs), in identifying and segmenting lung nodules from computed tomography (CT) and X-ray images. Our findings indicate that AI systems achieve a sensitivity of 70-90%, comparable to that of experienced radiologists, while reducing false-positive rates. In pulmonary nodule detection on CT scans, AI demonstrated over 95% sensitivity with fewer than one false-positive per scan. The implementation of AI as a "second reader" significantly improved detection accuracy. Despite these advancements, challenges remain, including high false-positive rates, issues with generalizability across diverse populations, regulatory concerns, and skepticism among healthcare professionals. This study highlights the promise of AI in supporting radiologists and improving lung cancer screening while emphasizing the need for further research to enhance specificity and address existing limitations.

Keywords: Artificial intelligence, lung nodules, pulmonary nodule detection

Introduction

Lung cancer ranks among the primary causes of cancer-related mortality globally, making early detection essential for enhancing survival rates [1]. Pulmonary nodules, frequently the initial indication of lung cancer, are being detected with greater frequency via chest computed tomography (CT) scans [2]. The substantial number of scans and the risk of overlooked or misclassified nodules have prompted the creation of artificial intelligence (AI) tools to assist radiologists in detecting and characterizing lung nodules.

The application of artificial intelligence in medical imaging, especially for the analysis of lung nodules, has experienced significant expansion owing to advancements in deep learning and the accessibility of extensive imaging databases [3]. AI algorithms, particularly convolutional neural networks (CNNs), are capable of being trained to identify and segment nodules in CT and X-ray images, occasionally achieving performance levels comparable to or surpassing those of radiologists [4].

AI algorithms demonstrate enhanced sensitivity in detecting lung nodules on chest radiographs and CT scans compared to manual review. One study demonstrated that AI assistance in lung cancer screening enhanced sensitivity by 5% to 20% in the detection of actionable nodules [5].

Artificial intelligence can precisely define the margins of lung nodules, including those exhibiting irregular shapes or ground-glass characteristics [3]. Artificial intelligence has the capability to classify nodules as either malignant or benign, which may decrease the necessity for superfluous follow-up CT scans [6]. Artificial intelligence algorithms, particularly CNNs, ana-

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lyze medical images by identifying patterns indicative of lung nodules. In chest X-rays, AI enhances detection by recognizing subtle abnormalities that may be overlooked [4]. For CT scans, AI provides precise nodule segmentation and reduces false positives through advanced image processing techniques. Certain AI tools utilize characteristics like nodule morphology and growth velocity to assess the risk of malignancy [7]. Artificial intelligence can predict the malignancy risk of a nodule and may be integrated with clinical data to forecast patient prognosis [8]. Artificial intelligence tools have the capability to automate specific components of reporting and follow-up management [7]. Artificial intelligence can be employed to diminish the visibility of normal lung structures, including blood vessels, thereby facilitating the detection of nodules [9]. Artificial intelligence can facilitate the customization of screening programs according to individual risk profiles [8].

AI-based software enhances sensitivity in lung nodule detection; however, this improvement comes with a trade-off in specificity, resulting in an increase in false positive outcomes and unnecessary surveillance [5]. This indicates that although AI may identify a greater number of nodules, it may also categorize more nodules as concerning that are, in fact, benign. Research indicates that AI-assisted reading is more efficient, yet it may elevate the percentage of nodules classified as higher risk [5]. A study utilizing a chest phantom demonstrated that fully automated pulmonary nodule detection software exhibited higher sensitivity at standard dose CT in comparison to 10 and 20-fold dose reductions [1].

Numerous studies indicate that AI algorithms effectively detect pulmonary nodules on chest radiographs [4, 10, 11]. One study demonstrated that an AI algorithm attained a sensitivity of 86% and a specificity of 85% for nodule detection on chest radiographs [12]. A separate study indicated that AI-driven vessel suppression enhanced the identification of subsolid nodules on CT scans [9]. AI can analyze epidermal growth factor receptor (EGFR) gen genotypes from lung data presented in CT images [13].

Despite these advancements, challenges persist in the clinical implementation of AI tools [14]. Concerns exist about the generalizability of AI models, the transparency of AI algorithms, and the necessity for additional data on the effects of AI on radiologists' decision-making and patient outcomes [2]. The implementation of AI in clinical environments may alleviate the workload of radiologists; however, further efforts are required to enhance the specificity of AI-assisted interpretations and to mitigate bias risks [5].

In summary, AI has shown promise in enhancing the efficiency and accuracy of lung nodule detection and management; however, further research is necessary to tackle existing challenges and guarantee the safe and effective integration of these tools into clinical practice.

Methods

Study design

A comprehensive literature review was conducted to evaluate the role of AI in lung nodule detection using chest X-rays and CT scans. This study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure methodological transparency and rigor. The objective was to analyze the performance of AI algorithms, including CNNs, in detecting lung nodules and to identify associated challenges and future directions.

Search strategy

A systematic search was performed across five electronic databases: PubMed, Embase, Google Scholar, Web of Science, and the Cochrane Library. The search included articles published up to August 2024. Search terms combined Medical Subject Headings (MeSH) and free-text keywords related to AI and lung nodule detection, including 'artificial intelligence', 'deep learning', 'convolutional neural networks', 'lung nodules', 'chest X-ray', and 'CT scans'. **Table 1** details the specific search strategies employed for each database. Only peer-reviewed articles published in English were included to maintain scientific validity.

Inclusion and exclusion criteria

Two independent reviewers screened the titles and abstracts of all retrieved articles to determine their relevance. Full-text articles were assessed based on predefined eligibility crite-

Table 1. Search lines in different databases

Database	Search line
Google scholar	((“Artificial Intelligence” OR “Machine Learning” OR “Neural network*”) AND (automat* AND detect* OR character* OR diagnos* OR ident*) AND (lung AND nodul* OR pulmonary AND nodul*))
Scopus	((“Artificial Intelligence” OR “Machine Learning” OR “Neural network*”) AND (automat* AND detect* OR character* OR diagnos* OR ident*) AND (lung AND nodul* OR pulmonary AND nodul*))
Web of science	TS=(((“Artificial Intelligence” OR “Machine Learning” OR “Neural network*”) AND (automat* AND detect* OR character* OR diagnos* OR ident*) AND (lung AND nodul* OR pulmonary AND nodul*)))
PubMed	((“Artificial Intelligence”[Title/Abstract] OR “Machine Learning”[Title/Abstract] OR “Neural network*”[Title/Abstract]) AND (automat*[Title/Abstract] AND detect*[Title/Abstract] OR character*[Title/Abstract] OR diagnos*[Title/Abstract] OR ident*[Title/Abstract]) AND (lung[Title/Abstract] AND nodul*[Title/Abstract] OR pulmonary[Title/Abstract] AND nodul*[Title/Abstract]))
Embase	((“Artificial Intelligence” OR “Machine Learning” OR “Neural network*”) AND (automat* AND detect* OR character* OR diagnos* OR ident*) AND (lung AND nodul* OR pulmonary AND nodul*))
Cochrane	(((Artificial NEXT Intelligence) OR (Machine NEXT Learning) OR (Neural NEXT network*)) AND (automat* AND detect* OR character* OR diagnos* OR ident*) AND (lung AND nodul* OR pulmonary AND nodul*))

ria. Inclusion criteria were: (1) original research studies, (2) publication in English, (3) studies evaluating AI algorithms for lung nodule detection in chest X-rays and/or CT scans, and (4) studies reporting performance metrics such as sensitivity, specificity, or false-positive rates. Exclusion criteria included: (1) review articles, case reports, and letters to the editor, (2) studies unrelated to AI in lung nodule detection, and (3) non-English publications. Any discrepancies between reviewers were resolved through discussion and consensus.

Data extraction

Data extraction was performed using a standardized data collection form. Extracted information included author, publication year, study design, sample size, AI algorithm type, imaging modality (chest X-ray or CT scan), outcome measures, and main findings. The quality of randomized controlled trials (RCTs) was assessed using the Cochrane Risk of Bias tool, while the Risk of Bias in Non-randomized Studies - of Interventions (ROBINS-I) tool was used for non-randomized studies.

Observation indicators and evaluation methods

The primary observation indicators of this study included the sensitivity, specificity, and false-positive rates of AI algorithms in detecting lung nodules. Additional metrics included the accuracy of AI as a “second reader” and the impact of AI implementation on radiologists’ performance. Evaluation was performed by comparing AI performance metrics with those of human radiologists and analyzing the variability of AI effectiveness across different imaging modalities.

A narrative synthesis approach was used to analyze the extracted data, summarizing key findings with supporting evidence. The analysis focused on AI’s diagnostic performance, its role in assisting radiologists, and the challenges related to generalizability, false-positive rates, and regulatory concerns.

Results

Overview of AI in lung nodule detection

AI has been applied to the detection of lung nodules for several decades, with early applications using classic computer-aided detection (CAD) methods [4]. More recently, deep learning techniques such as CNNs have been implemented [2]. The goal of AI in this context is to improve the efficiency and accur acy of lung nodule detection, which is a critical step in the early diagnosis of lung cancer (**Figure 1**).

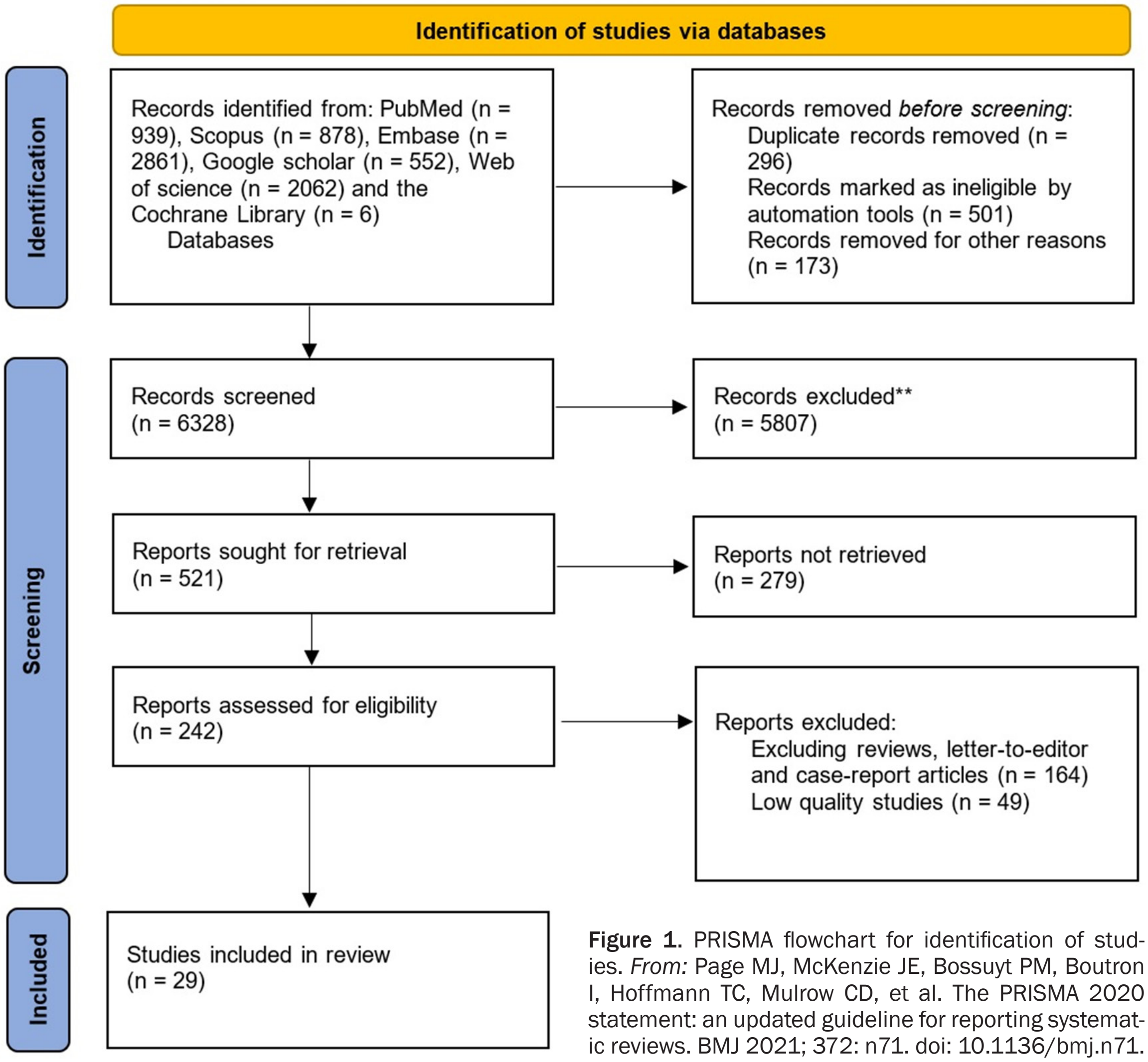

Figure 1. PRISMA flowchart for identification of studies. *From:* Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021; 372: n71. doi: 10.1136/bmj.n71.

Performance of early CAD systems

Early CAD systems for lung nodule detection on chest radiographs had variable sensitivity and high false-positive rates [4]. However, AI with modern techniques has achieved higher sensitivity (70-90%), similar to that of radiologists, and decreased false-positive rates (approximately 0.3-2.0 false positives per radiograph) [15]. AI has also shown improved results for pulmonary nodule detection on CT scans. For example, AI used as a second reader improved detection of nodules smaller than 5 mm, although with a higher number of false alerts [14]. More recent studies have shown AI applications with greater than 95% sensitivity for nodule detection on CT with less than one false-positive per scan [16].

AI performance on chest radiographs

AI algorithms are trained using large datasets of medical images, which allows them to learn to identify patterns and features associated with lung nodules [2]. These algorithms can be used to assist radiologists in the detection and characterization of pulmonary nodules on both chest X-rays and CT scans [4].

AI performance on CT scans

AI can help radiologists by acting as a “second reader” to identify potential nodules that might be missed by the human eye [8]. AI-based vessel suppression can also improve the detection of subsolid nodules (SSNs) [9]. AI algorithms can accurately segment lung nodules, which is essential for calculating volume and tracking

Table 2. AI performance in pulmonary nodule detection on CT images

Metric	Value	Reference
AUROC	0.9058	[22]
Sensitivity	89%	[22]
Specificity	86%	[22]
Sensitivity (ground-glass, standard dose CT)	70%	[1]
Sensitivity (ground-glass, 10-20x reduced dose CT)	30%	[1]
Sensitivity (solid/subsolid, standard dose CT)	100%	[1]
Sensitivity (solid/subsolid, 10-20x reduced dose CT)	92.5%	[1]
AI Detection Accuracy (malignant PNs)	92.3%	[13]
AI Detection Accuracy (benign PNs)	82.8%	[13]
Sensitivity of AI (thin-subset CT)	96.5%	[23]
Sensitivity of AI (thick-subset CT)	89.6%	[23]

Table 3. Comparison of AI and manual review in pulmonary nodule detection* [13]

Category	AI	Manual review
Pathologically Positive, Detection Positive	213	195
Pathologically Negative, Detection Positive	27	5
Pathologically Positive, Detection Negative	38	56
Pathologically Negative, Detection Negative	82	104
Accuracy (retrospective analysis)	90.3%	83.1%

*The numbers show the frequency out of 360 cases.

growth over time [17]. AI can classify nodules as either benign or malignant, potentially reducing the number of follow-up CT scans needed for less suspicious lesions [2]. AI can also differentiate between different nodule types, such as solid, part-solid, and ground-glass nodules [9]. AI can aid in risk stratification based on nodule characteristics, which is important for personalizing screening programs and determining follow-up schedules. Some AI tools can recommend Lung-Risk Assessment and Detection (RADS) classifications [15].

Discussion

The goal of the current review was to give a thorough overview of the role of AI in automated detection of lung nodules. We found 29 papers in total that satisfied our inclusion criteria, with a wide range of study trends.

AI has the potential to reduce the workload of radiologists and improve the efficiency of lung cancer screening programs [14]. AI can also help to standardize the interpretation of lung nodules by reducing inter-observer variability [11]. Some studies have shown that the use of AI can reduce radiologists' interpretation time in lung nodule detection [14]. However, it is important to consider that early CAD systems with high false-positive rates actually increased reading time [18].

Table 2 summarizes the performance of AI in detecting pulmonary nodules, highlighting the Area Under the Receiver Operating Characteristic curve (AUROC), sensitivity, and specificity. It also includes a distinction in sensitivity based on nodule type and CT dose. The table shows the detection rates for both malignant and benign pulmonary nodules. Finally, the table indicates the sensitivity achieved by AI on thin and thick-slice CT scans.

Several studies have shown that AI-assisted reading can improve sensitivity for detecting actionable nodules. However, it can also lead to reduced specificity, resulting in more false-positive results and unnecessary surveillance. AI assistance can increase the proportion of nodules allocated to higher risk categories. Therefore, more research is needed to increase the specificity of AI-assisted reading and minimize the risk of bias and applicability concerns through improved study design [5].

Table 3 compares the performance of AI versus manual review in identifying pulmonary nodules based on a pathological standard. It shows a breakdown of true positives, false positives, false negatives, and true negatives for both methods [13].

AI performance for nodule detection has been shown to be comparable to that of radiologists, and when used as a second reader, the collective performance of the radiologist and the AI is superior to either alone [14]. However, AI algorithms may struggle with certain types of nodules, such as subsolid and ground-glass nodules [19]. AI can also have false positives due to pleural thickening, peripheral vessels, scarring, artifact, and mucoid impaction [20]. AI may miss lung cancer cases that do not present as malignant pulmonary nodules [17].

A comparison with prior literature reveals a clear progression in AI's accuracy and clinical utility. Earlier CAD systems demonstrated limited sensitivity and increased the workload due to a high number of false positives [20]. More recent studies, however, have shown that advanced AI algorithms, particularly deep learning models, achieve sensitivities exceeding 95% with fewer false positives [18]. This shift underscores the substantial improvement in AI's ability to detect smaller nodules and reduce radiologist fatigue. Furthermore, while prior literature suggested that AI's performance varied significantly across different imaging protocols [18], our findings align with newer studies indicating improved generalizability of AI across various CT slice thicknesses and nodule types [21].

AI algorithms have been developed to address some of the challenges radiologists face, such as the increasing number of images per examination, and the potential for satisfaction of search [12]. AI tools can also be used to manipulate images in ways that improve radiologists' detection of pulmonary nodules, such as through vessel suppression [9].

AI-based vessel suppression can improve the detection and classification of SSNs into ground-glass nodules (GGNs) and part-solid nodules (PSNs) [9]. This can lead to more accurate Lung-RADS categorization [9]. Compared to manual detection, AI demonstrates superior sensitivity for small and subsolid nodules, but challenges persist in differentiating complex nodules and distinguishing malignant features.

Despite the promising results, there are still challenges to the widespread adoption of AI in clinical practice, including concerns about generalizability, regulatory issues, technical hurdles in implementation, and human skepticism [4]. Most AI algorithms focus narrowly on specific tasks and may not be applicable to all settings or patient populations. It is also important to validate the performance of AI tools in clinical settings and demonstrate a benefit in terms of patient-oriented outcomes.

More research is needed to determine the impact of AI on the radiologist's decision and on patient outcomes. Radiologists must actively participate in the evaluation of AI tools [2]. There is also a need to focus on the detection of cancer rather than the detection of all nodules [14]. The performance of different AI software tools may vary [21]. Significant differences between AI software tools in measuring nodule volume can lead to different Lung-RADS scores, which may result in altered patient management [21].

This study had some limitations. Limiting publications to English may create selection bias, disregarding outstanding research in other languages or from other time periods. Narrative reviews can summarize findings but lack the rigor and replicability of systematic reviews and meta-analyses, potentially introducing subjectivity in data interpretation.

Conclusions

Artificial intelligence has markedly improved the identification and efficacy of lung nodules, equaling the capabilities of radiologists and facilitating early lung cancer detection. The extensive use of AI, however promising, encounters obstacles such as generalizability, legal issues, and clinical distrust. Ongoing research is crucial to enhance AI specificity, mitigate biases, and verify its efficacy across many clinical environments. Ultimately, AI's function as a beneficial instrument to assist radiologists and enhance patient outcomes is promising, although necessitates meticulous installation and continuous assessment.

Disclosure of conflict of interest

None.

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