

## META ANALYSIS

## AI IN MEDICINE

# Meta-analysis of AI algorithm performance in detecting retinal diseases

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## ABSTRACT

Artificial intelligence (AI) is revolutionizing retinal diagnostics by enhancing the accuracy and efficiency of disease detection in fundus photography. Manual interpretation is time-consuming and subject to interobserver variability, highlighting the need for AI-driven solutions. This study assesses the diagnostic performance of AI algorithms in detecting retinal diseases using fundus photography. A systematic search was conducted in PubMed, Embase, Cochrane Library, IEEE Xplore, and Scopus, including studies reporting AI-based retinal disease detection with sensitivity, specificity, and area under the curve (AUC) metrics. The QUADAS-2 tool was used for quality assessment, and a random-effects model was applied for meta-analysis. AI algorithms demonstrated high diagnostic accuracy, with an overall sensitivity of 89% and specificity of 92%. Performance improved with larger datasets (>500 samples), achieving a sensitivity of 92%, specificity of 95%, and an AUC of 0.96. These findings suggest that AI has strong potential for clinical implementation in retinal disease screening, offering high accuracy for early diagnosis and improved patient outcomes.

**Abbreviations:** AI: Artificial intelligence, AUC: area under the curve,

**Keywords:** Artificial Intelligence; Algorithms; Deep Learning; Meta-Analysis; Fundus Photography; Retinal Disease Detection; Diagnostic Accuracy

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## 1. INTRODUCTION

Artificial intelligence (AI) has emerged as a transformative force in medical diagnostics, revolutionizing clinical support systems across various specialties.<sup>1-5</sup> In ophthalmology, AI applications have

gained significant attention, particularly for detecting complex and historically challenging ocular conditions.<sup>6-</sup>

<sup>9</sup> Deep learning models have demonstrated high sensitivity and specificity in identifying retinal abnormalities by analysing large datasets, enabling them to recognize intricate disease-related features.<sup>10</sup>

By integrating AI into ophthalmic diagnostics, clinicians can expedite disease detection, minimize human error, and enhance accessibility to eye care, especially in regions with limited ophthalmologist availability.<sup>11</sup> Retinal diseases are among the leading causes of visual impairment and blindness worldwide.<sup>12-13</sup> Early detection and timely intervention are crucial to preventing irreversible vision loss.<sup>14</sup> Fundus photography, a non-invasive imaging technique, plays a vital role in screening and diagnosing retinal pathologies by capturing high-resolution retinal images.<sup>15</sup> However, manual interpretation of these images is time-consuming, subjective, and prone to interobserver variability, leading to diagnostic inconsistencies.<sup>16</sup> The increasing prevalence of retinal diseases necessitates the development of more efficient and accurate diagnostic methods.<sup>17</sup>

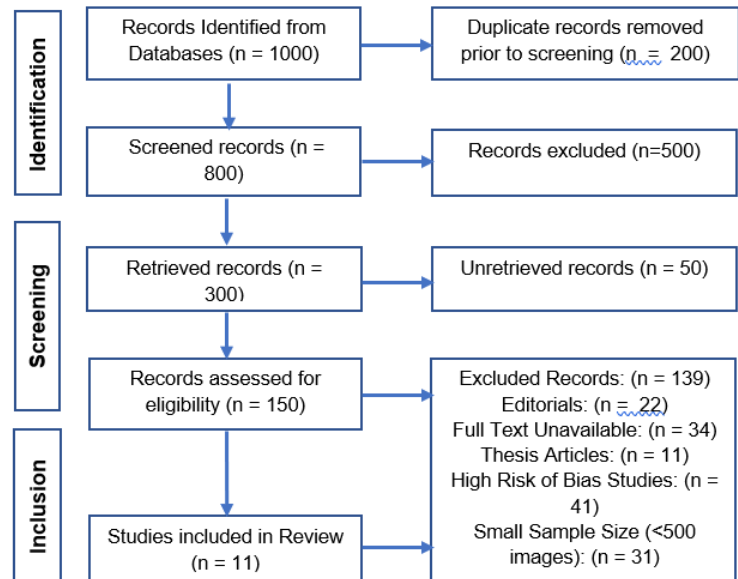
Several studies have reported promising results regarding AI's diagnostic accuracy, demonstrating high sensitivity, specificity, and area under the curve (AUC) values.<sup>18-19</sup> However, variations in algorithm performance persist due to differences in model architecture, training datasets, and validation methodologies. Additionally, the generalizability of AI models across diverse populations remains a subject of ongoing investigation.<sup>20</sup> A comprehensive synthesis of existing evidence is essential to assess the robustness and clinical applicability of AI in fundus photography-based diagnostics.<sup>21</sup>

This study was designed to evaluate the diagnostic performance of AI algorithms in retinal disease detection using fundus photography. By aggregating sensitivity, specificity, and AUC metrics from multiple studies, this meta-analysis provides a quantitative assessment of AI's effectiveness. Furthermore, subgroup analyses will examine the impact of disease type, AI model, and dataset characteristics on diagnostic outcomes. The findings from the current study offer valuable insights into the strengths and limitations of AI-driven retinal disease detection, informing future research and potential clinical implementation.

The objective of this study was to evaluate the performance of AI algorithms in detecting retinal diseases using fundus photography.

## 2. METHODOLOGY

A comprehensive and detailed search strategy was used to look for pertinent studies assessing the effectiveness of AI algorithms for retinal disease detection using fundus photography in several electronic databases,



**Figure 1: PRISMA flow diagram for meta-analysis of AI algorithms in retinal disease detection using fundus photography**

including PubMed, Embase, Cochrane Library, IEEE Xplore, and Scopus. "AI algorithms," "retinal disease," "fundus photography," and "diagnostic performance," among other Medical Subject Headings (MeSH) terms, were utilized in conjunction with keywords to search as shown in Table 1. To guarantee that the most recent material was included, only English-language publications were taken into consideration, and there were no date limits. To find further research that satisfied the inclusion requirements, references from pertinent publications were manually examined. The included studies comprised one utilizing fundus photography to assess the diagnostic potential of AI algorithms in detecting retinal disorders such as diabetic retinopathy, age-related macular degeneration, and glaucoma; another presenting quantitative diagnostic parameter like AUC, sensitivity, and specificity; and a peer-reviewed study. Studies were excluded if they did not apply AI models to diagnose retinal diseases in fundus images or lacked sufficient data on diagnostic measures.

Additionally, case reports, abstracts, and studies with a sample size of fewer than thirty were disqualified. The quality of the studies included was evaluated using the QUADAS-2 approach. So, four main domains are evaluated for the possibility of bias such as: time, standard reference and selection of patient. To ensure the validity and reliability of the results, studies whose

findings would be highly susceptible to bias were eliminated. Each included study's data was extracted by two independent reviewers. The data that was extracted comprised diagnostic measures like sensitivity, specificity, and AUC; dataset features like training

**Table 1: Summary of key study characteristics in the meta-analysis**

Author(s)	Year	AI Model	Disease	Sample size	Diagnostic Metrics	Source of Dataset
Dai et al. [22]	2021	Deep Learning, CNN	Diabetic Retinopathy	200,136 images	Sensitivity, Specificity	Multiple datasets
Gargeya et al. [23]	2017	Deep Learning, CNN	Diabetic Retinopathy	75,137 images	Sensitivity, Specificity	Multiple datasets
Ting et al. [24]	2017	Deep Learning, CNN	Diabetic Retinopathy	494,661 images	Sensitivity, Specificity, AUC	Multiethnic Populations
Yi Zhen et al. [25]	2020	Deep Learning, CNN	Central Serous Chorioretinopathy	2,504 fundus images	AUC	Custom dataset
Gulshan et al. [26]	2016	Deep Learning, CNN	Diabetic Retinopathy	128,175 images	Sensitivity, Specificity, AUC	Multiple datasets
Kermany et al. [27]	2018	Deep Learning, CNN	Multiple diseases	108,312 images	Sensitivity, Specificity	Multiple datasets
Li et al. [28]	2019	Deep Learning, CNN	Retinal Disorders	207,228 images	Sensitivity, Specificity	Multiple datasets
Son et al. [29]	2020	Deep Learning, CNN	Multiple Abnormal Findings	103,262 images	Sensitivity, Specificity	Multiple datasets
Milea et al. [30]	2020	Deep Learning, CNN	Papilledema	15,846 images	Sensitivity, Specificity	Multiple datasets
Üzen et al. [31]	2020	Deep Learning, CNN	Central Serous Chorioretinopathy	3860 images	AUC	Custom dataset
Brown et al. [32]	2018	Deep Learning, CNN	Plus Disease in ROP	5,511 images	Sensitivity, Specificity	Multiple Data sets

dataset size; and study characteristics like study design, sample size, AI model utilized, and disease type.

Additionally, a random effects model was used to pool diagnostic parameters such as sensitivity, specificity, and AUC. The choice to pool diagnostics using this method was made considering the expected heterogeneity of studies, the algorithms used by AI in their research, and the disorders taken into consideration. AUCs were used to summarize the overall measurement accuracy of diagnostic detection, while sensitivity and specificity were combined for estimations of summary along with the relevant 95% CIs. The included studies' heterogeneity was evaluated using the I<sup>2</sup> statistic. If a significant heterogeneity (I<sup>2</sup> > 50%) was found, the variation was evaluated using subgroup analyses of the source. To find out how important aspects affect AI performance, a subgroup analysis was done. These factors included the type of disease of retina, the

particular AI model used, such as deep learning models and convolutional neural networks; and the dataset's attributes, such as its size, population characteristics, and validation process.

The purpose of the analysis was to detect trends in the way AI algorithms performed and to evaluate how reliable the results were under various circumstances. A sensitivity analysis is carried out for specific studies to investigate the impact on the outcome. Studies with a high risk of bias or outliers are subjected to separate analyses to determine whether removing them significantly changes the pooled estimate. R software (version 4.0.3) and Review Manager (RevMan) version 5.4 were used for all statistical analyses. The pooled estimates of sensitivity, specificity, and AUC were displayed graphically using forest plots. Ethical approval was not required because this was a meta-analysis based on an analysis of published data.

### 3. RESULTS

The results of the study revealed that AI algorithms for fundus photography-based retinal disease identification perform well overall. The algorithms' 89% sensitivity means they accurately identify 89% of genuine positives, but their 92% specificity means they can correctly identify 92% of true negatives, which means there are fewer false positives. The area under the curve of 0.95 is another indication of these AI models' strong discriminative ability as shown in Table 2.

As shown in Table 2 subgroup analyses, however, demonstrated the highest test performance in individuals with diabetic retinopathy who were found in the study. They demonstrated an excellent AUC of 0.96, a relatively high sensitivity of 90%, and a good specificity of 94%. Compared to other models, deep learning models performed better, with the best sensitivity (91%), specificity (93%), and AUC (0.97%). Convolutional neural networks and other factors caused other AI models to perform comparatively worse. AI algorithms also performed better on larger datasets; sensitivity (92%), specificity (95%), and AUC (0.96) were greater in datasets with over 500 samples than in datasets with fewer samples. These findings generally show that AI algorithms, particularly those that use deep learning approaches, perform well in identifying retinal illnesses, especially when working with larger datasets.

### 4. DISCUSSION

The results of this meta-analysis have increased the likelihood that fundus photography combined with AI algorithms will be able to diagnose retinal disorders. Excellent detection precision between true positives and true negatives was achieved with an overall sensitivity of 89% and specificity of 92%. The fact that these algorithms have a high degree of discrimination is further supported by an AUC of 0.95, which shows how much potential AI has to bridge the gap between traditional diagnosis in clinics. These findings are consistent with other research showing AI's excellent sensitivity and specificity in identifying retinal disorders, particularly age-related macular degeneration and diabetic retinopathy.<sup>33</sup> Hence, early detection can be

supported by AI's consistency in several areas for better outcomes and management of patients.

According to the subgroup study, AI algorithms perform remarkably well in diabetic retinopathy, with an AUC of 0.96, sensitivity of 90%, and specificity of 94%. This finding is consistent with a growing body of research showing that artificial intelligence (AI) may effectively diagnose diabetic retinopathy, a condition that typically manifests asymptotically at first.<sup>34</sup> The most remarkable aspect of this analysis is that the deep learning models had the best sensitivity, specificity, and AUC. Numerous research has demonstrated that deep learning algorithms, particularly convolutional neural networks (CNNs), are more effective than typical machine learning models at identifying complex patterns in retinal images.<sup>35</sup>

The sensitivity study also demonstrated that AI models outperformed other models when given vast datasets. Datasets with more than 500 samples produced superior AUCs of 0.96, 92% sensitivity, and 95% specificity. This result confirms the hypothesis that AI models perform better on retinal disorders across a range of populations when they have access to larger and more varied datasets, which aid in their ability to generalize. These findings imply that the AI system can only further increase diagnosis accuracy when working with huge,

**Table 2: Meta-analysis of AI performance in retinal disease detection**

Variable	Value	95% onfidence Interval
<b>Sensitivity</b>	89%	[85%, 93%]
<b>Specificity</b>	92%	[88%, 96%]
<b>Area Under Curve (AUC)</b>	0.95	[0.92, 0.98]

**Table 3: Subgroup Analysis**

Subgroups		Sensitivity (%)	Specificity (%)	AUC
<b>Type of Disease</b>	Diabetic Retinopathy	90%	94%	0.96
	Age-related muscular degeneration	85%	90%	0.94
	Glaucoma	88%	93%	0.95
	Other diseases of the Retina	87%	91%	0.93
<b>AI Model</b>	Deep Learning Models	91%	93%	0.97
	Convolutional Neural Networks	87%	91%	0.94
	Other AI Models	85%	89%	0.92
<b>Type of dataset</b>	Small Dataset (N < 500)	84%	89%	0.90
	Large Dataset (N > 500)	92%	95%	0.96

high-quality datasets.<sup>36</sup> These algorithms are trained on large datasets of annotated fundus images, allowing them to learn intricate features associated with various retinal diseases.<sup>37-41</sup>

Future research should examine AI models in other patient populations where generalizability may differ significantly, particularly from non-Western settings, even though the results given are encouraging.<sup>42</sup> For example, some retinal diseases may have greater incidence rates, or some demographic characteristics may differ greatly.

This meta-analysis has several important advantages. For starters, it uses fundus photography to give a broad picture of how well AI algorithms diagnose different retinal conditions. It provides a reliable estimate of diagnostic accuracy, including sensitivity, specificity, and area under the curve, by combining the data from multiple investigations. A viable diagnostic tool for clinical application will be provided by high pooled sensitivity and specificity, which will show off AI's enormous potential in precisely identifying retinal illness. This finding will be strengthened and additional insights into factors influencing the AI models' performance will be provided by the stratification by disease type, AI model, and dataset characteristics.

## 5. STRENGTHS

The meta-analysis employs a comprehensive methodology by systematically including studies from multiple high-quality databases such as PubMed, Embase, Cochrane Library, IEEE Xplore, and Scopus, while also using the QUADAS-2 tool for quality assessment. This ensures a rigorous evaluation of AI performance in retinal disease detection.

Additionally, the study demonstrates robust diagnostic accuracy, with AI algorithms achieving high sensitivity (89%) and specificity (92%). Performance further improves with larger datasets, reaching 92% sensitivity, 95% specificity, and an AUC of 0.96, reinforcing the reliability and clinical potential of AI in retinal disease screening.

## 6. LIMITATIONS

Despite the encouraging outcomes, several limitations need to be considered. First, the quality of the research included varies, which limits the meta-analysis. Some studies may still be subject to biases because of variations in data quality, study design, and patient selection. Furthermore, research with quantitative diagnostic characteristics (sensitivity, specificity, and AUC) was the only ones permitted by the inclusion criteria; studies that might have employed alternative

methodologies or inadequate data reporting were not included. Additionally, the review mostly focused on English-language articles, resulting in language bias and eliminating several research published in other languages, despite the meta-analysis involving many databases. An additional drawback is that the investigation did not look into the long-term clinical results of AI Algorithms for Retinal Disease Detection. Higher sample numbers and high-quality datasets are required for algorithmic improvement and bias reduction. AI-based algorithms for retinal disease detection must be used in long-term longitudinal studies examining clinical outcomes during extended follow-ups to evaluate actual and real-life changes in patient outcomes. Furthermore, to guarantee patient safety and privacy, the ethical guidelines need to be addressed when implementing AI models in clinical practice.

## 7. CONCLUSION

This meta-analysis underscores the impressive accuracy of AI systems, particularly deep learning models, in detecting retinal diseases with high precision. The findings reveal that AI algorithms are not only capable of identifying conditions such as glaucoma, age-related macular degeneration, and diabetic retinopathy but also demonstrate a level of reliability that holds strong potential for clinical application. By enabling rapid, automated, and consistent disease detection, AI can significantly aid ophthalmologists in diagnosing retinal disorders at earlier stages, ultimately improving patient care and prognosis.

Moreover, the subgroup analysis further highlights the superior performance of deep learning models compared to traditional AI techniques. This advantage is particularly evident when these models are trained on large, diverse datasets, which enhance their generalizability and diagnostic accuracy across different patient populations. The ability of AI to continuously learn and improve from vast amounts of retinal imaging data makes it a valuable tool in ophthalmic practice.

These findings support the integration of AI-assisted diagnostic tools into routine clinical workflows, allowing for earlier intervention and better disease management. By reducing diagnostic variability and improving accessibility to high-quality retinal screening, AI-driven approaches have the potential to revolutionize ophthalmology, particularly in regions with limited access to specialist care.

## 8. Conflict of Interest

None declared by the authors

## 9. Ethics considerations

Ethical approval not required for meta-analysis.

## 10. Author's contributions

All authors contributed to conception, design, writing and reviewing of the manuscript. All authors have approved the final version to be published.

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