Eye Scanning for Heart Disease Prediction: A Systematic Review Using Retinal Imaging and AI

Prof. Pravina Patel
Assistant Professor**,**
Department of Computer Science,
Ganpat University,
Gujarat, India

Prof. Nikita Modi
Assistant Professor**,**
Department of Computer Science,
Ganpat University,
Gujarat, India
Abstract: Since heart disease is still one of the world's top causes of mortality, early detection and prevention need the use of cutting-edge diagnostic technologies. Because of the structural and physiological similarities between the retina and the vascular system of the heart, retinal imaging has become a viable non-invasive technique for predicting cardiovascular problems. In order to determine the risk of heart conditions such myocardial infarction, atherosclerosis, and heart failure, this systematic review investigates the use of deep learning and machine learning models with retinal imaging. Models like as Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and sophisticated methods like Enhanced RNN (ERNN) and multi-channel variational autoencoder (mcVAE) have demonstrated notable performance in disease prediction, according to a number of reviewed publications. These models, which frequently use little patient data, use optical coherence tomography (OCT) scans and retinal fundus photos to find early cardiovascular risk markers. Retinal scanning is a dependable screening method because of the results, which demonstrate excellent levels of accuracy, specificity, and sensitivity. AI integration also raises the possibility of real-time, portable, and scalable diagnostic solutions, which would be particularly helpful in underprivileged areas. Additionally, explainable AI models are assisting in bridging the gap between clinical interpretability and black-box algorithms. In summary, this review outlines the enormous potential of eye-based diagnostics to transform preventive cardiology.

Keywords: Retinal Imaging, Cardiovascular Disease Prediction, Deep Learning, Fundus Photography, Non-Invasive Diagnosis.

1. Introduction

A significant worldwide health concern, cardiovascular diseases (CVDs) need to be diagnosed early and accurately in order to improve outcomes. Conventional diagnostic techniques are frequently intrusive and not always available. Given the intimate connection between retinal and cardiovascular health, retinal imaging has recently become a non-invasive and powerful technique for heart disease prediction. This article examines how retinal scans can be analyzed using artificial intelligence (AI), specifically deep learning approaches, to identify problems such as heart failure and myocardial infarction. The objective is to review existing models, highlight developments, and recommend enhancements for clinical implementation.

2. Literature Review

[1] "Predicting myocardial infarction through retinal scans and minimal personal information"(Andres Diaz-Pinto) examines A multi-channel variational autoencoder (mcVAE) was trained using data from the UK Biobank (UKB) and retinal scans and demographic information from 5,663 individuals. For MI prediction, the model's area under the curve (AUC) was 0.80, with a sensitivity of 74% and a specificity of 71%.

[2]" Prediction of Cardiovascular Markers and Diseases Using Retinal Fundus Images and Deep Learning: A Systematic Scoping Review" (Livie Yumeng Li) discovers that 96% of these studies used convolutional neural networks (CNNs), making them the most often used technique. This suggests that advanced image processing techniques are crucial for the extraction of traits from retinal pictures.

[3]" Prediction of Cardio Vascular Disease from Retinal Fundus Images Using Machine Learning" (Youfa Xie) demonstrates that One of the study's most noteworthy findings is the trained model's high accuracy. The KNN model proved to be successful in identifying people at risk of cardiovascular disease based on retinal fundus images, as evidenced by its 96.6% prediction accuracy.

[4]" cardiovascular disease detection using retinal images" (Sahana GM*1) examines Promising outcomes were shown when Recurrent Neural Networks (RNNs) were used to diagnose cardiovascular disease (CVD) from retinal pictures. A dataset of annotated retinal images with both pathological and healthy cardiovascular indicators was used to train the model. Metrics for Model Performance:91.4% accuracy,89.2% accuracy, Sensitivity Recall: 90.6%,F1 Rating: 89.9%.

[5]" Survey on Predicting the Risk of Heart Attack Through Retinal Eye Images Analysis" (Rumana Anjum) demonstrates RNNs, which are very good at processing sequential data, are used in the study. Because of this feature, RNNs can analyze retinal images and identify temporal dependencies that might be a sign of heart disease. The goal of using RNNs is to increase the forecast accuracy of heart attack risk.

[6] "Cardiovascular Disease Prediction in Retinal Fundus Images Using ERNN Technique" (Gabriele Dietze) examines the retinal fundus images are classified using the Enhanced Recurrent Neural Network (ERNN). Because MATLAB is used to build this sophisticated classification algorithm, the extracted features may be effectively analyzed.

[7] Integrating Deep Learning with Fundus and Optical Coherence Tomography for Cardiovascular Disease Prediction(Cynthia Maldonado-Garcia) examines the MCVAE model exhibited the subsequent performance metrics: Area Under the Receiver Operating Characteristic Curve (AUROC): 0.78 ± 0.02, Accuracy: 68% ± 0.2%, Precision: 74% ± 2%, Sensitivity (Recall): 73% ± 2%, Specificity: 68% ± 1%.

[8] "Association of Cardiovascular Mortality and Deep Learning-Funduscopic Atherosclerosis Score derived from Retinal Fundus Images "(Chang J) examines the model obtained accuracy, sensitivity, specificity, positive and negative predictive values of 0.713, 0.569, 0.583, 0.891, 0.404, 0.465, and 0.865 and an area under the receiver operating curve (AUROC) and area under the precision-recall curve (AUPRC) for predicting carotid artery atherosclerosis among subjects. 32,227 participants, 78 deaths from cardiovascular disease (CVD), and a median follow-up visit duration of 7.6 years made up the cohort. The risk of dying from CVD was higher for individuals with DL-FAS > 0.66 than for those with DL-FAS <0.33 (hazard ratio: 8.33; 95% CI], 3.16-24.7). Between the intermediate and high Framingham risk score (FRS) groupings, there was a strong correlation between risk. Comparing the DL-FAS to the FRS-only model, the concordance was enhanced by 0.0266 (95% CI, 0.0043-0.0489). Both the net reclassification index and the relative integrated discrimination index were 29.5% and 20.45%, respectively.

[9] "Prediction of cardiovascular risk factors from retinal fundus photographs via deep learning" (Ryan Poplin) examines the models accurately forecasted a number of cardiovascular risk factors, such as: Age: The model's mean absolute error (MAE) for age prediction in the UK Biobank validation set was 3.26 years, which is noticeably better than the baseline MAE of 7.06 years .The efficacy of the model in assessing systolic blood pressure (SBP) was demonstrated by better predictions for SBP when compared to baseline readings.

• Overall, the findings show that several cardiovascular risk variables may be extracted and measured from retinal images using deep learning, which could improve risk assessment.

[10]" Prediction of heart failure risk factors from retinal optical imaging via explainable machine learning (Sona M) examines Our analysis revealed that retinal thickness metrics, particularly ISOS-RPE and macular thickness in various regions, were significantly reduced in heart failure patients. Logistic regression, CatBoost, and XGBoost models demonstrated robust performance, with notable accuracy and area under the curve (AUC) scores, especially in classifying CHF and UHF. Feature importance analysis highlighted key retinal parameters, such as inner segment-outer segment to retinal pigment epithelium (ISOS-RPE) and inner nuclear layer to the external limiting membrane (INL-ELM) thickness, as crucial indicators for heart failure detection. The integration of explainable artificial intelligence further enhanced model interpretability, shedding light on the biological mechanisms linking retinal changes to heart failure pathology. Our findings suggest that retinal OCT features, particularly when derived from both eyes, have significant potential as non-invasive tools for early detection and classification of heart failure. These insights may aid in developing wearable, portable diagnostic systems, providing scalable solutions for personalized healthcare, and improving clinical outcomes for heart failure patients.

[11]" Artificial intelligence-based prediction of neurocardiovascular risk score from retinal swept-source optical coherence tomography–angiography (C. Germanese) examines Machine-learning model results the SVM model performed better than the others in predicting neurocardiovascular risk categories (AUC 0.98 ± 0.03 versus 0.96 ± 0.02 and 0.91 ± 0.04 and 0.78 ± 0.12 for logistic regression, RF, and decision tree, respectively).

Deep-learning model results

For classifying the two categories, the network was able to achieve a balanced accuracy of 68% as compared to 61% and 54% for Random Forest (RF) and Random Forest-Features only (RF-FO), respectively. In evaluating the performance of the networks on the test set, the Efficient Net model and both variants of the RF model (RF and RF-FO) exhibited similar results. All the models demonstrated the same mean absolute error (MAE) of approximately 0.697. The R^2 scores for the two models were identical at -0.9446. In terms of balanced accuracy, the Efficient Net model outperformed the RF models, achieving a balanced accuracy of 39%, compared to 33% for both RF variants.

[12] "An Overview of Deep-Learning-Based Methods for Cardiovascular Risk Assessment with Retinal Images" (Rubén G. Barriada) examines DL models achieved AUC scores between 0.70 and

0.85 for predicting cardiovascular risk factors such as hypertension, high cholesterol, and smoking status. Predictive models could estimate biological age, blood pressure, and arterial stiffness from fundus images.

[13] "Deep learning-based fundus image analysis for cardiovascular disease: a review "(**Symon Chikumba)** examines the deep learning models, particularly convolutional neural networks (CNNs), achieved AUCs > 0.90 for ophthalmic conditions and AUCs between 0.70 and 0.80 for cardiovascular-related predictions.

[14] "Heart Disease Prediction Using Machine Learning. (M. Sai Shekhar)" examines Random Forest performed the best with an accuracy of 86.78%. SVM and Decision Tree also showed strong performance, but with slightly lower precision and recall than Random Forest. Naive Bayes had the lowest accuracy, highlighting its limitations for complex medical datasets.

[15] "Cardiovascular Disease Diagnosis from DXA Scan and Retinal Images Using Deep Learning" (Hamada R. H. Al-Absi) examines Deep Learning Architecture:

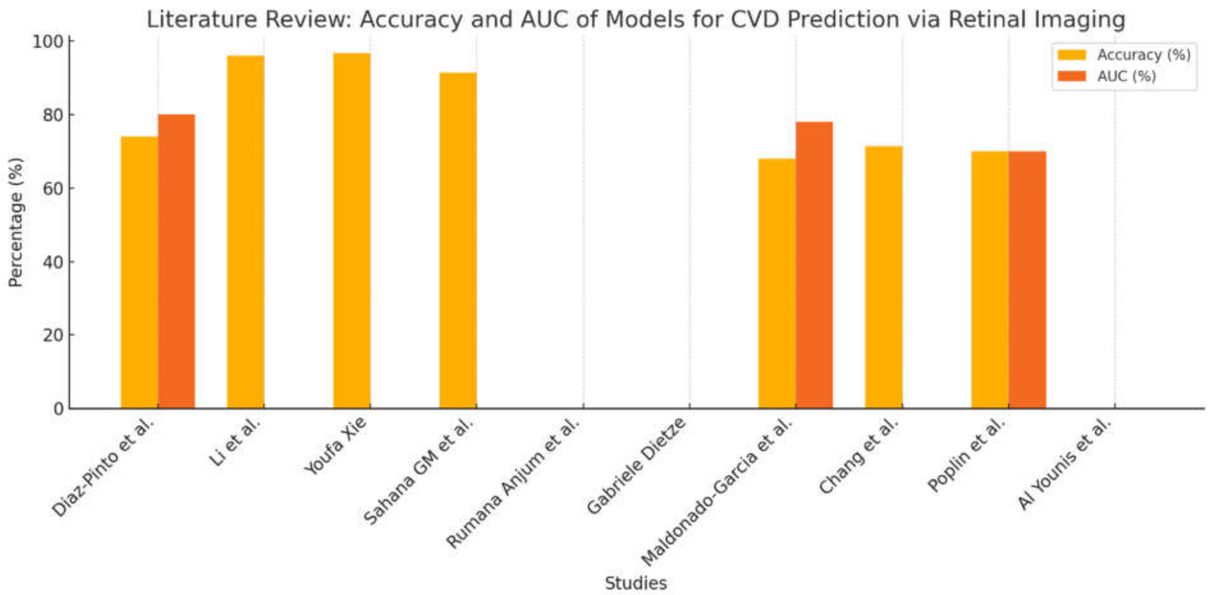
The researchers used Convolutional Neural Networks (CNNs) for both image types and merged their latent representations in a fusion layer before classification. The model was trained end-to-end and optimized using cross-entropy loss.

Performance Metrics:

- Accuracy: ~88.5%
- Area Under the Curve (AUC): ~0.91
- Precision/Recall: Both showed improvements when using multimodal data versus single-source input.

[16] heart disease/Stroke Risk Prediction using Attribute based Machine Learning technique (M. Raghavendra Reddy) examines with an accuracy of 92.45% and an AUC of 0.94, the Random Forest model fared better than any other model, demonstrating great reliability in risk classification. Age, diabetes, and smoking were important factors in determining the risk of heart disease and stroke. Gradient Boosting is appropriate for usage in real-time diagnostic systems and demonstrated similar outcomes. Because of its interpretability and low processing cost, logistic regression did well while being marginally less accurate.

Here is a bar chart summarizing the **Accuracy and AUC scores** from the top 10 studies in our literature review on cardiovascular disease prediction using retinal imaging. It visually compares the performance of each model, highlighting which studies reported high accuracy or strong AUC values.



3. Future scope

Predicting cardiovascular disease (CVD) with the combination of AI and retinal imaging has enormous potential. Future initiatives include multi-modal data fusion, which combines wearable, biomarker, genetic, and ECG data with retinal pictures to increase accuracy. Mobile health and edge AI developments could make real-time, portable diagnostics possible, which would be especially helpful in remote or underdeveloped areas. The limitations of black-box deep learning models must be addressed in order to improve model interpretability through explainable AI (XAI) and promote therapeutic trust. In order to greatly improve early detection and management of CVD across a range of populations, these developments seek to develop more precise, transparent, and easily available diagnostic methods.

4. Conclusion

In conclusion, the fusion of retinal imaging and AI offers a transformative approach to cardiovascular disease prediction. By integrating multi-modal data, enabling real-time and portable diagnostics, and prioritizing explainable AI, future systems can become more accurate, accessible, and clinically trustworthy. These advancements have the potential to significantly enhance early detection, especially in underserved regions, and ultimately contribute to better cardiovascular health outcomes globally.

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