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Artificial Intelligence for Cardiovascular Risk Prediction: An Umbrella Review of Applications and Translational Challenges

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Abstract

Background: Cardiovascular diseases (CVDs) remain the leading cause of mortality worldwide. Conventional risk prediction models often demonstrate suboptimal calibration and limited generalizability across populations. Artificial intelligence (AI) approaches, including machine learning (ML) and deep learning (DL), enable integration of multimodal clinical and imaging data for individualized cardiovascular risk estimation.

Objective: To evaluate the applications, predictive performance, and translational limitations of AI models for cardiovascular risk prediction within an umbrella review framework.

Methods: PubMed, Scopus, and Web of Science were systematically searched for studies published between January 2015 and October 2025 investigating AI-based prediction of cardiovascular outcomes. Eligible designs included randomized controlled trials (RCTs), cohort studies, systematic reviews, and meta-analyses. Predictive performance was the primary outcome, mainly assessed using the area under the receiver operating characteristic curve (AUC). Methodological quality was evaluated using established risk-of-bias tools. From 3500 identified records, 48 studies (8 RCTs, 28 cohort studies, and 12 systematic reviews or meta-analyses) were included in the final analysis.

Results: AI models achieved AUC values greater than 0.90 in more than 70% of imaging-based studies. Evidence synthesis showed predominant reliance on internal validation, inconsistent calibration reporting, and limited evaluation of algorithmic fairness. Multimodal data integration improved detection of coronary artery disease (CAD) and heart failure (HF). Wearable monitoring was associated with 18-25% lower hospitalization rates compared with usual care.

Conclusion: AI improves predictive accuracy in cardiovascular risk assessment. Despite strong discrimination performance (AUC), methodological heterogeneity, insufficient calibration assessment, algorithmic bias, limited external validation, and regulatory uncertainty remain major barriers to implementation. Clinical translation requires multicenter RCTs, explainable AI frameworks, and standardized reporting guidelines such as

Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis Artificial Intelligence (TRIPOD-AI).

Keywords: artificial intelligence; cardiovascular diseases; deep learning; machine learning; precision medicine; risk assessment.

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Artificial Intelligence in Cardiovascular Medicine: Focus on Hypertension

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Abstract

Hypertension remains the most prevalent modifiable risk factor for cardiovascular morbidity and mortality worldwide, yet rates of effective blood pressure control remain persistently suboptimal despite the availability of multiple therapeutic options. This gap reflects fundamental limitations of current care models, which rely on episodic measurements, population-based treatment algorithms, and incomplete representation of the biological, behavioral, and social complexity underlying blood pressure regulation. Artificial intelligence (AI) offers a transformative framework to address these challenges by enabling the integration of longitudinal, multimodal data and modeling nonlinear, dynamic relationships that are difficult to capture with conventional approaches. This systematic review synthesizes emerging evidence on the application of AI across the hypertension care continuum, including risk prediction, phenotyping, blood pressure measurement, wearable-based monitoring, clinical trial analysis, population health modeling, detection of secondary hypertension, behavioral and adherence interventions, and multi-omics-driven precision medicine. We highlight the methodological foundations required for clinically meaningful AI, emphasizing robust ground-truth definitions, external and temporal validation, interpretability, workflow integration, and equity-aware design. The review also examines the promise and limitations of natural language processing, cuffless blood pressure technologies, and AI-guided decision support systems, alongside ethical, regulatory, and implementation challenges. Collectively, current evidence suggests that AI has the potential to shift hypertension management from a reactive, threshold-based paradigm toward a more predictive, personalized, and patient-centered model. Realizing this potential will depend on rigorous validation, thoughtful implementation, and sustained alignment with clinical, ethical, and equity principles.

Keywords: artificial intelligence; blood pressure; machine learning; precision medicine; risk factors.

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Artificial Intelligence in Sports Cardiology: Advancing Cardiovascular Screening and Diagnosis

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Abstract

Sudden cardiac death in athletes, though uncommon, remains a major concern in sports cardiology. Many responsible cardiovascular conditions, including cardiomyopathies, inherited channelopathies, valvular disease, and congenital coronary anomalies, may remain asymptomatic until intense physical exertion. Current pre-participation screening relies on clinical history, physical examination, electrocardiography, and selective cardiac imaging. While effective, these tools are limited by interobserver variability, dependence on specialist expertise, and difficulty distinguishing physiological athletic remodeling from pathological disease. These limitations have prompted growing interest in artificial intelligence (AI) as an adjunct to cardiovascular screening in athletes. This review summarizes current evidence on AI applications in sports cardiology, with a focus on electrocardiography, digital auscultation, transthoracic echocardiography, and selected imaging modalities. AI-enhanced electrocardiographic analysis has demonstrated improved sensitivity compared with traditional criteria for detecting left ventricular hypertrophy, long QT syndrome, including concealed forms, Brugada syndrome, electrolyte abnormalities, and aortic stenosis. Several deep learning models identify disease patterns even when conventional electrocardiographic parameters appear normal, addressing a key limitation of standard screening approaches. AI-assisted digital auscultation improves the detection of pathological murmurs and differentiation from benign flow murmurs, supporting earlier identification of valvular disease. In echocardiography, AI-guided image acquisition and automated analysis improve access, workflow efficiency, and measurement consistency, with diagnostic performance approaching expert interpretation. This review proposes a pragmatic AI-integrated screening framework that complements clinician judgment rather than replacing it. Although promising, limitations remain, including limited athlete-specific training data, false-positive risk related to physiological remodeling, and the need for external validation. When thoughtfully integrated into clinical workflows, AI may enhance early detection of occult cardiac disease and improve cardiovascular risk stratification in athletes.

Keywords: artificial intelligence in health care; athlete cardiovascular screening; echocardiography; electrocardiography; sports cardiology; sudden cardiac death (scd).

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High-density lipoprotein-related inflammatory ratios and coronary heart disease: A cross-sectional machine learning analysis of NHANES 2009 to 2020

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Abstract

High-density lipoprotein (HDL)-related inflammatory ratios (monocyte-to-HDL cholesterol ratio [MHR], lymphocyte-to-HDL cholesterol ratio, neutrophil-to-HDL cholesterol ratio [NHR], platelet-to-HDL cholesterol ratio) represent composite biomarkers integrating lipid metabolism and inflammatory pathways. We developed machine learning models to evaluate their utility in coronary heart disease (CHD) classification using a large population-based dataset. We analyzed data from the National Health and Nutrition Examination Survey 2009 to 2020, including 14,745 US adults aged ≥20 years (mean age 51.8 ± 17.6 years). Self-reported CHD diagnosis was the outcome variable. Machine learning models (eXtreme gradient boosting, random forest, logistic regression) were developed to evaluate cross-sectional associations between HDL-related inflammatory ratios and CHD prevalence. Self-reported CHD prevalence was 5.7% (n = 840). All HDL-related inflammatory ratios were significantly elevated in CHD patients: MHR (0.54 ± 0.35 vs 0.42 ± 0.23, P < .001), lymphocyte-to-HDL cholesterol ratio (2.05 ± 3.12 vs 1.55 ± 1.02, P < .001), and NHR (4.06 ± 2.89 vs 3.11 ± 1.77, P < .001). eXtreme gradient boosting demonstrated optimal performance with an area under the receiver operating characteristic curve of 0.8892, accuracy of 96.55%, and precision of 86.00%. SHapley Additive exPlanations analysis identified age as the most important predictor, with MHR and NHR ranking among the top 5 features. Machine learning models incorporating HDL-related inflammatory biomarkers achieved high discrimination (area under the receiver operating characteristic curve = 0.8892) for identifying cross-sectional associations with CHD prevalence. These findings reveal significant cross-sectional associations between HDL-related inflammatory ratios and CHD prevalence, rather than predictive relationships for incident events. These readily available biomarkers from routine blood tests provide substantial value for cardiovascular risk stratification. Prospective validation is warranted to establish their utility for predicting incident CHD events.

Keywords: NHANES; XGBoost; coronary heart disease; high-density lipoprotein cholesterol; inflammatory biomarkers; machine learning; monocyte-to-HDL cholesterol ratio; neutrophil-to-HDL cholesterol ratio.

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Artificial Intelligence in Cardiovascular Imaging: From Automated Acquisition to Precision Diagnostics and Clinical Decision Support

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Abstract

Cardiovascular imaging is a cornerstone of modern cardiology, yet its clinical impact is limited by operator dependence, inter-observer variability, time-consuming workflows, and unequal access to advanced expertise. Artificial intelligence (AI), particularly machine learning and deep learning, offers new opportunities to overcome these limitations. This review aims to summarize current and emerging AI applications in cardiovascular imaging and to evaluate their potential clinical value in precision diagnostics and decision support. This narrative review synthesizes clinically relevant literature on AI applications across major cardiovascular imaging modalities, including echocardiography, cardiovascular magnetic resonance, cardiac computed tomography, and nuclear cardiology. Evidence was analyzed with a focus on AI-enabled acquisition support, image segmentation, quantitative and functional assessment, workflow automation, and risk stratification, alongside key methodological and implementation considerations. Across imaging modalities, AI-driven approaches have demonstrated improved reproducibility, efficiency, and scalability of cardiovascular imaging workflows. Automated algorithms reduce operator dependence, facilitate standardized extraction of imaging biomarkers, and support advanced functional assessment and prognostic stratification. Recent developments in video-based, temporal, and multimodal models further expand AI capabilities from technical automation toward integrated disease phenotyping and personalized clinical decision support. However, translation into routine practice remains limited by heterogeneous datasets, insufficient external validation, algorithmic bias, limited interpretability, and challenges related to regulatory approval and workflow integration. Artificial intelligence has the potential to reshape cardiovascular imaging into a more efficient, reproducible, and patient-centered precision medicine tool. Real-world clinical impact will depend on outcome-driven evaluation, robust external validation, multimodal data integration, and human-in-the-loop implementation strategies that ensure safe, equitable, and clinically meaningful adoption.

Keywords: artificial intelligence; cardiac magnetic resonance; cardiovascular imaging; computed tomography; echocardiography; nuclear cardiology; precision medicine.