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Research Article

Artificial Intelligence in Cardiovascular Disease Prevention: From Risk Prediction to Precision Public Health

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Abstract: Cardiovascular Diseases (CVDs) remain the leading cause of mortality worldwide despite significant advances in diagnosis and treatment, underscoring the urgent need for more effective prevention strategies. Conventional risk assessment models and population-based interventions often fail to capture the complex interplay of genetic, behavioural, environmental and social determinants that influence cardiovascular risk. Recent advances in Artificial Intelligence (AI), including machine learning, deep learning, generative AI, foundation models and multimodal AI, have created unprecedented opportunities to transform cardiovascular disease prevention through more accurate risk prediction, early disease detection, personalized lifestyle interventions, continuous remote monitoring and data-driven clinical decision-making. By integrating diverse data sources such as electronic health records, medical imaging, wearable devices, genomics and social determinants of health, AI supports the emerging paradigm of Precision Public Health, enabling targeted interventions at both individual and population levels. This review synthesizes recent evidence on AI applications across the cardiovascular prevention continuum, including risk prediction, digital health, wearable technologies, cardiovascular imaging, big data analytics and population surveillance. It also discusses the ethical, regulatory and implementation challenges associated with AI adoption, particularly in low- and middle-income countries, while highlighting recent policy initiatives and digital health advancements. Finally, the review identifies current research gaps and future directions, emphasizing the importance of explainable, equitable and clinically validated AI solutions. The responsible integration of AI within a Precision Public Health framework has the potential to reshape cardiovascular prevention, improve health equity and substantially reduce the global burden of cardiovascular disease.

Key Words: Artificial Intelligence, Cardiovascular Disease Prevention, Precision Public Health, Machine Learning, Digital Health

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INTRODUCTION

Cardiovascular Diseases (CVDs) remain the leading cause of mortality worldwide, accounting for approximately one-third of all deaths and imposing a substantial clinical, social and economic burden. Although many cardiovascular events are preventable, their incidence continues to rise due to population ageing, urbanization, unhealthy diets, physical inactivity, tobacco use, obesity, diabetes, hypertension and other modifiable risk factors. The burden is disproportionately higher in low- and middle-income countries, including India, where rapid epidemiological transition and limited access to preventive healthcare continue to challenge effective disease control [1,2].

Despite decades of public health efforts, conventional cardiovascular prevention strategies have achieved only limited success. Traditional risk prediction models rely on a relatively small number of clinical variables and often fail to account for the complex interactions among genetic, behavioural, environmental and social determinants of health. Furthermore, population-wide prevention programmes frequently adopt a uniform approach that may overlook individual variability in risk, resulting in delayed identification of high-risk individuals and suboptimal preventive interventions [3-7].

Recent advances in digital health, coupled with the increasing availability of electronic health records, wearable devices, medical imaging and multi-omics data, have accelerated the adoption of Artificial Intelligence (AI) in cardiovascular care. AI technologies-including machine learning, deep learning, natural language processing, computer vision and generative AI-can analyse large, complex datasets to improve cardiovascular risk prediction, enable earlier disease detection, personalize preventive interventions and facilitate continuous health monitoring [8-11].

These developments have aligned closely with the emerging concept of Precision Public Health, which aims to deliver the right intervention to the right population at the right time by integrating clinical, behavioural, environmental and population-level data. In cardiovascular prevention, AI has the potential to strengthen population screening, identify vulnerable communities, support targeted lifestyle interventions, optimize healthcare resource allocation and enhance preventive decision-making while reducing health inequities [12,13].

However, successful implementation of AI in cardiovascular prevention requires addressing important challenges related to data quality, algorithmic bias, explainability, privacy, clinical validation, interoperability and ethical governance. Overcoming these barriers will be essential to ensure that AI-driven innovations translate into equitable and effective public health practice [14-19].

This review provides a comprehensive overview of the emerging role of artificial intelligence in cardiovascular disease prevention from a precision public health perspective. It critically examines recent advances, current applications, implementation challenges, ethical considerations and future directions, highlighting how AI can transform population-based cardiovascular prevention and support more personalized, equitable and proactive healthcare.

Understanding Artificial Intelligence in Healthcare

Artificial Intelligence (AI) refers to the ability of computer systems to perform tasks that typically require human intelligence, including learning, reasoning, pattern recognition, decision-making and language understanding. In healthcare, AI leverages large and diverse datasets to generate clinically meaningful insights, improve diagnostic accuracy, predict disease risk and support personalized treatment and prevention strategies. Unlike traditional statistical approaches that rely on predefined assumptions, AI continuously learns from data, enabling the identification of complex and non-linear relationships that may not be readily apparent through conventional analytical methods [9,20].

Evolution of Artificial Intelligence

The application of AI in healthcare has evolved substantially over the past few decades. Early expert systems were rule-based programs designed to replicate clinical decision-making using predefined knowledge bases; however, their dependence on manually programmed rules limited their adaptability and scalability. The advent of Machine Learning (ML) marked a paradigm shift by enabling algorithms to learn directly from data and improve performance without explicit programming [21,22].

Subsequent advances in computational power and the availability of large healthcare datasets accelerated the development of Deep Learning (DL), a subset of ML that employs multilayered neural networks to analyse complex data such as medical images, electrocardiograms and electronic health records with high accuracy. More recently, generative AI has introduced the ability to generate human-like text, images and clinical summaries, facilitating applications such as automated documentation, patient education and clinical decision support [23,24].

The emergence of foundation models, trained on massive multimodal datasets, has further expanded AI capabilities by enabling adaptation across multiple healthcare tasks with minimal additional training. Simultaneously, multimodal AI integrates information from diverse sources-including imaging, clinical records, laboratory parameters, wearable devices, genomics and environmental data-to provide a more comprehensive understanding of disease risk and health outcomes. Together, these advances have shifted AI from a supportive analytical tool to an integral component of predictive, preventive and precision healthcare [23-25] (Table 1).

Major Types of Artificial Intelligence Used in Healthcare

Several AI technologies contribute to modern healthcare, each serving distinct yet complementary functions. Machine learning identifies patterns and predicts outcomes from structured clinical data, while deep learning excels in analysing high-dimensional data such as medical imaging, electrocardiograms and physiological signals. Artificial neural networks, inspired by the structure of the human brain, form the computational foundation of many deep learning models [26,27].

Natural Language Processing (NLP) enables computers to understand and analyse unstructured clinical text, facilitating extraction of information from electronic health records, discharge summaries and scientific literature. Computer vision allows automated interpretation of medical images, including retinal photographs, echocardiograms and coronary CT scans. Reinforcement learning supports adaptive clinical decision-making by optimizing interventions based on continuous feedback from changing clinical environments [28,29].

The recent emergence of Large Language Models (LLMs) has transformed healthcare communication by assisting with literature synthesis, clinical documentation, patient counselling and decision support. Building upon these capabilities, generative AI creates new content-including clinical reports, educational materials and predictive simulations-thereby enhancing workflow efficiency and knowledge dissemination. Collectively, these technologies constitute the foundation of AI-driven healthcare and are increasingly shaping the future of cardiovascular disease prevention through precision public health [30,31] (Table 2).

Table 1: Evolution of Artificial Intelligence in Cardiovascular Disease Prevention

Era	AI Technology	Key Characteristics	Major Applications in CVD Prevention
1970s-1990s	Expert Systems	Rule-based decision support	Clinical decision support, diagnostic assistance
1990s-2010	Machine Learning	Data-driven predictive modelling	Cardiovascular risk prediction, outcome prediction
2010-2020	Deep Learning	Neural networks with automatic feature extraction	ECG interpretation, imaging, arrhythmia detection
2020-Present	Generative AI	Content generation and clinical assistance	Patient education, documentation, decision support
2023-Present	Foundation Models	Large pretrained models adaptable to multiple tasks	Multimodal clinical reasoning, workflow automation
Emerging	Multimodal AI	Integration of text, imaging, wearable and genomic data	Precision prevention and personalized cardiovascular care

Table 2: Major Artificial Intelligence Algorithms Used in Cardiovascular Prevention

Algorithm	Advantages	Limitations	Common Applications
Logistic Regression	Simple, interpretable	Limited for complex relationships	Baseline risk prediction
Decision Tree	Easy to understand	Overfitting	Clinical decision support
Random Forest	High accuracy, robust	Less interpretable	Risk prediction, classification
XGBoost	Excellent predictive performance	Computationally intensive	Cardiovascular risk prediction
LightGBM	Fast and efficient	Parameter tuning required	Large clinical datasets
CatBoost	Handles categorical variables well	Higher computational cost	Electronic health records
Artificial Neural Networks	Learns complex nonlinear relationships	Black-box nature	ECG analysis, prediction models
Deep Learning (CNN/RNN)	Superior image and signal analysis	Large datasets required	Imaging, ECG, wearable analytics

Burden of Cardiovascular Diseases

Cardiovascular Diseases (CVDs) continue to represent the greatest global public health challenge, accounting for approximately 20 million deaths annually, with nearly 80% occurring in Low- and Middle-Income Countries (LMICs). Ischemic heart disease and stroke remain the leading contributors to cardiovascular mortality, while the burden of heart failure, atrial fibrillation and peripheral arterial disease is also increasing. Population ageing, rapid urbanization and changing lifestyles have accelerated the epidemiological transition, particularly in developing nations [1,2].

India bears one of the highest burdens of CVD worldwide, with cardiovascular diseases responsible for more than one-fourth of all deaths. Alarmingly, cardiovascular events frequently occur at younger ages compared with high-income countries, leading to substantial premature mortality, disability and economic losses. Despite improvements in acute cardiac care, prevention remains inadequate because of delayed diagnosis, poor risk factor control and unequal access to healthcare services [1,32].

Current projections indicate that the global burden of CVD will continue to rise over the coming decades, driven by increasing life expectancy, obesity, diabetes, hypertension, sedentary lifestyles and environmental changes. Consequently, strengthening preventive strategies has become a public health priority.

The development of CVD is influenced by a complex interplay of traditional and emerging risk factors. Established modifiable risk factors include hypertension, diabetes mellitus, dyslipidaemia, tobacco use, unhealthy diet, physical inactivity, obesity and excessive alcohol consumption. Emerging evidence highlights the additional contribution of climate change, including heat stress and air pollution, which increase cardiovascular morbidity and mortality. Environmental exposures such as fine Particulate Matter ($PM_{2.5}$), noise pollution and occupational hazards are increasingly recognized as important cardiovascular risk determinants. Furthermore, genetic susceptibility, epigenetic modifications and family history interact with behavioural factors to influence disease risk. Social determinants-including education, income, occupation, access to healthcare, urbanization and neighbourhood characteristics-also play a critical role in shaping cardiovascular outcomes, emphasizing the need for comprehensive, multisectoral prevention strategies [33,34].

Precision Public Health

Precision Public Health (PPH) is an emerging approach that applies advanced data analytics, artificial intelligence, genomics, digital technologies and real-time population data to deliver the right intervention to the right population at the right time. Rather than replacing conventional public health, PPH enhances its effectiveness by enabling more targeted, timely and evidence-driven prevention strategies [12,35].

The concept has evolved from Precision Medicine, which focuses on individualized diagnosis and treatment based on genetic, clinical and lifestyle characteristics. While Precision Medicine primarily addresses individual patient care, Precision Public Health extends these principles to communities and populations by integrating clinical, environmental, behavioural, socioeconomic and geographic data to improve disease prevention, surveillance and health promotion. In contrast, Population Health seeks to improve health outcomes across entire populations through broad public health interventions, whereas Digital Public Health emphasizes the use of digital technologies-including electronic health records, mobile health, telemedicine and wearable devices-to strengthen healthcare delivery and public health programmes [36-38].

Artificial intelligence serves as the connecting framework across these approaches by integrating heterogeneous data sources, identifying high-risk individuals and communities, predicting disease patterns and supporting precision prevention strategies. In cardiovascular disease prevention, Precision Public Health enables personalized risk stratification, targeted screening, optimized resource allocation and proactive population surveillance, thereby improving both efficiency and health equity. As healthcare increasingly transitions toward predictive and preventive models, the integration of AI with Precision Public Health offers a transformative opportunity to reduce the global burden of cardiovascular diseases.

AI Across the Prevention Continuum

Artificial intelligence has the potential to strengthen cardiovascular disease prevention across all levels of prevention by enabling timely risk identification, personalized interventions and continuous monitoring. By integrating clinical, behavioural, environmental and digital health data, AI supports a shift from reactive disease management to proactive, precision prevention.

In primary prevention, AI identifies individuals at increased cardiovascular risk before disease onset by analysing electronic health records, wearable device data, lifestyle behaviours, family history and social determinants of health. These insights facilitate personalized lifestyle recommendations, targeted health education, smoking cessation support and optimized risk factor management.

In secondary prevention, AI enhances early detection through automated interpretation of electrocardiograms, echocardiography, retinal imaging and other diagnostic modalities. AI-powered screening tools improve the identification of subclinical disease, enabling earlier intervention and reducing the risk of adverse cardiovascular events.

For tertiary prevention, AI supports individualized disease management by predicting disease progression, monitoring treatment adherence, detecting early signs of clinical deterioration and facilitating remote patient monitoring. These applications help reduce hospital readmissions, improve medication adherence and optimize long-term clinical outcomes.

In quaternary prevention, AI contributes to safer and more efficient healthcare by minimizing unnecessary investigations, reducing overdiagnosis, identifying potentially inappropriate interventions and supporting evidence-based clinical decision-making. Explainable AI further promotes transparency and clinician confidence while improving patient safety.

Overall, AI enables a seamless continuum of cardiovascular prevention by integrating prediction, early detection, personalized intervention and long-term follow-up within a precision public health framework (Table 3).

AI for Cardiovascular Risk Prediction

Accurate cardiovascular risk prediction is fundamental to effective prevention. Conventional risk assessment tools-including the Framingham Risk Score, QRISK, Atherosclerotic Cardiovascular Disease (ASCVD) Risk Estimator and SCORE2-have been widely used to estimate future cardiovascular risk. However, these models rely on a limited number of predefined variables and assume relatively simple relationships among risk factors, which may reduce predictive performance across diverse populations [39-41].

Artificial intelligence offers a more sophisticated approach by analysing complex, high-dimensional data from electronic health records, laboratory investigations, medical imaging, genomics, wearable devices and environmental exposures. Machine learning algorithms can identify non-linear interactions and hidden patterns that are often overlooked by conventional statistical models, resulting in improved discrimination and individualized risk prediction.

Several machine learning algorithms have demonstrated promising performance in cardiovascular risk assessment. Extreme Gradient Boosting (XGBoost) effectively handles large and heterogeneous datasets while maintaining high predictive accuracy. Random Forest improves robustness by combining multiple decision trees and reducing overfitting. LightGBM and CatBoost provide efficient learning from large clinical datasets with faster computation and enhanced handling of categorical variables. Artificial Neural Networks, particularly deep learning models, excel in analysing complex multimodal data, including electrocardiograms and imaging studies [42-45].

Despite their superior predictive capability, AI models must demonstrate reliability and clinical applicability. Explainable AI (XAI) improves transparency by identifying the variables contributing to individual predictions, thereby increasing clinician trust and facilitating informed decision-making. Equally important are model calibration and external validation, which ensure that AI algorithms maintain consistent performance across different healthcare settings and populations. As evidence continues to grow, AI-based risk prediction is expected to complement rather than replace conventional cardiovascular risk scores, enabling more personalized and equitable preventive strategies.

Table 3: Artificial Intelligence Applications Across the Levels of Cardiovascular Disease Prevention

Level of Prevention	Primary Objective	Major AI Applications
Primary Prevention	Prevent disease occurrence	Risk prediction, lifestyle coaching, behavioural modification, wearable-based monitoring, personalized prevention
Secondary Prevention	Early detection	AI-assisted ECG, echocardiography, retinal imaging, automated screening, early diagnosis
Tertiary Prevention	Reduce complications	Remote monitoring, treatment optimization, prediction of readmissions, medication adherence, rehabilitation
Quaternary Prevention	Prevent overmedicalization	Clinical decision support, avoidance of unnecessary investigations, explainable AI, personalized treatment recommendations

AI and Lifestyle Modification

Lifestyle modification remains the cornerstone of cardiovascular disease prevention and artificial intelligence is transforming how preventive interventions are designed, delivered and sustained. By continuously analysing individual health data, behavioural patterns and environmental factors, AI enables personalized, adaptive and real-time lifestyle recommendations that improve engagement and long-term adherence.

AI-powered applications provide individualized guidance on healthy diet, recommending meal plans based on nutritional requirements, metabolic profile, cultural preferences and personal goals. Similarly, AI promotes physical activity by analysing wearable sensor data to generate customized exercise prescriptions, monitor activity levels and provide real-time feedback. Digital platforms also support smoking cessation and alcohol reduction through behavioural analytics, personalized reminders, motivational messaging and relapse prediction [46,47].

Beyond conventional risk factors, AI increasingly addresses sleep quality, stress management and overall mental well-being, recognizing their important contribution to cardiovascular health. Machine learning algorithms can detect behavioural changes associated with poor sleep, psychological stress or reduced activity and recommend timely interventions before these factors adversely affect cardiovascular risk.

AI-driven digital coaching, conversational chatbots and mobile health applications further enhance preventive care by delivering continuous education, behavioural counselling, medication reminders and self-management support. These systems adapt recommendations according to users' progress, preferences and adherence patterns, creating highly personalized interventions that extend preventive healthcare beyond clinical settings. Collectively, AI-powered lifestyle management represents a scalable and cost-effective strategy for promoting healthy behaviours and reducing the population burden of cardiovascular diseases [48-50].

AI and Wearables

The rapid expansion of wearable technologies has transformed cardiovascular prevention by enabling continuous, non-invasive monitoring of physiological parameters in real-world settings. When integrated with artificial intelligence, wearable devices provide real-time health insights, facilitate early detection of cardiovascular abnormalities and support personalized preventive interventions.

Modern smartwatches and wearable sensors can continuously monitor heart rate, electrocardiograms (ECG), photoplethysmography (PPG) signals, heart rate variability (HRV), physical activity, sleep patterns and increasingly, estimate blood pressure and integrate data from Continuous Glucose Monitoring (CGM) systems. AI algorithms analyse these large streams of physiological data to detect subtle changes associated with atrial fibrillation, arrhythmias, hypertension, sleep disorders, reduced physical activity and other cardiovascular risk factors, often before clinical symptoms become apparent [51-54].

AI-enabled wearables also facilitate remote patient monitoring, allowing healthcare providers to track high-risk individuals, assess treatment adherence and intervene early when deterioration is detected. This capability is particularly valuable for long-term cardiovascular risk management, cardiac rehabilitation and chronic disease follow-up.

Commercial wearable platforms such as the Apple Watch, Fitbit, Garmin, Samsung Galaxy Watch, WHOOP and Oura Ring have expanded the availability of AI-assisted cardiovascular monitoring. Recent evidence suggests that AI-integrated wearable technologies can improve early detection of cardiac rhythm abnormalities, enhance patient engagement, promote healthy lifestyle behaviours and support personalized risk assessment. Nevertheless, challenges related to measurement accuracy, data privacy, interoperability, regulatory approval and equitable access remain important considerations for their broader implementation in precision public health [52-55] (Table 4).

AI in Cardiovascular Imaging

Artificial intelligence has significantly enhanced cardiovascular imaging by improving diagnostic accuracy, reducing interpretation time and enabling earlier detection of subclinical disease. Deep learning algorithms can analyse large volumes of imaging data with high precision, assisting clinicians in identifying subtle abnormalities that may be overlooked during routine interpretation.

AI applications in electrocardiography (ECG) facilitate rapid detection of arrhythmias, myocardial ischemia, left ventricular dysfunction and other cardiac abnormalities. In echocardiography, AI automates cardiac chamber measurements, assessment of ventricular function and detection of valvular heart disease, thereby improving consistency and reducing observer variability. Similarly, AI-assisted interpretation of cardiac Computed Tomography (CT) and Magnetic Resonance Imaging

Table 4: Major AI-Enabled Wearable Devices for Cardiovascular Prevention

Device	Major Features	Cardiovascular Applications
Apple Watch	ECG, heart rate, activity, sleep	Atrial fibrillation detection, lifestyle monitoring
Fitbit	Heart rate, SpO_2, sleep, activity	Physical activity tracking, risk monitoring
Garmin	HRV, stress, fitness metrics	Exercise prescription, cardiovascular fitness
Samsung Galaxy Watch	ECG, blood pressure*, sleep	Arrhythmia detection, remote monitoring
WHOOP	HRV, recovery, strain	Recovery assessment, cardiovascular wellness
Oura Ring	Sleep, HRV, temperature	Sleep quality, stress and recovery monitoring

*Blood pressure estimation available only in selected regions after calibration

(MRI) enhances the identification of coronary artery disease, myocardial fibrosis, plaque characteristics and structural heart abnormalities [56-59].

Beyond cardiac imaging, AI has demonstrated promising applications in retinal imaging, where retinal vascular changes can serve as non-invasive biomarkers of cardiovascular risk. AI also supports automated analysis of carotid ultrasound by quantifying carotid intima-media thickness and plaque characteristics, facilitating early identification of atherosclerosis. In addition, AI improves Coronary Artery Calcium (CAC) scoring through automated image analysis, enabling faster and more standardized cardiovascular risk stratification [60-63].

Overall, AI-driven automated image interpretation enhances diagnostic efficiency, standardization and clinical decision-making while supporting large-scale cardiovascular screening and precision prevention.

AI and Big Data

The effectiveness of artificial intelligence depends largely on the availability of high-quality, large-scale health data. Advances in digital health have enabled the integration of diverse data sources, allowing AI to generate more accurate, personalized and population-level insights for cardiovascular disease prevention.

Electronic Health Records (EHRs) constitute one of the most valuable data sources, providing longitudinal clinical information including diagnoses, laboratory investigations, medications and treatment outcomes. Administrative claims databases and disease registries complement these data by offering insights into healthcare utilization, disease burden and long-term clinical outcomes at the population level [64-66].

The growing availability of biobanks, genomic, proteomic and other multi-omics datasets has further expanded opportunities for precision cardiovascular risk prediction by identifying genetic susceptibility, molecular pathways and novel biomarkers associated with disease development. AI algorithms can integrate these heterogeneous datasets with clinical and environmental information to generate individualized risk profiles and improve preventive decision-making [67,68].

Beyond clinical datasets, AI supports population surveillance by analysing real-time data from wearable devices, mobile health applications, environmental sensors and public health information systems. The emerging field of digital phenotyping uses continuous data from smartphones and wearable technologies to characterize behavioural and physiological patterns associated with cardiovascular risk. Collectively, the integration of big data and AI is transforming cardiovascular prevention by enabling more precise risk stratification, earlier intervention and data-driven public health planning [69,70].

Precision Public Health Applications

Artificial intelligence is a key enabler of Precision Public Health (PPH) by integrating clinical, demographic, environmental, behavioural and geospatial data to improve population-level cardiovascular prevention. Unlike traditional public health approaches that apply uniform interventions, AI enables more targeted, timely and data-driven strategies tailored to the needs of specific populations [71,72].

AI-powered geospatial analytics and disease mapping facilitate the identification of cardiovascular disease hotspots by combining health records with geographic, socioeconomic and environmental data. These tools enable public health authorities to detect high-risk communities, monitor temporal trends and prioritize preventive interventions. Incorporating social determinants of health, such as education, income, housing, occupation and healthcare accessibility, further improves risk stratification and supports more equitable prevention strategies [73,74].

AI also strengthens predictive surveillance by forecasting disease trends, identifying emerging risk patterns and enabling early public health responses. These predictive insights assist policymakers in optimizing resource allocation, planning workforce requirements and improving healthcare delivery. Furthermore, AI enhances population screening by identifying individuals most likely to benefit from targeted cardiovascular risk assessment, thereby improving screening efficiency and reducing unnecessary healthcare expenditure. Collectively, these applications position AI as a powerful tool for advancing precision public health while promoting health equity and more efficient population-based cardiovascular prevention [9,75].

AI in Low- and Middle-Income Countries

Artificial intelligence offers considerable potential to strengthen cardiovascular disease prevention in Low- and Middle-Income Countries (LMICs), where healthcare systems often face shortages of trained personnel, limited diagnostic facilities and a rapidly increasing burden of non-communicable diseases. In countries such as India, AI can enhance early risk assessment, support teleconsultation, improve population screening and facilitate remote monitoring, thereby extending preventive healthcare to underserved and rural populations [76].

Despite these opportunities, several challenges limit large-scale implementation. Inadequate digital infrastructure, fragmented health information systems, poor data quality and unreliable internet connectivity continue to impede AI integration in many resource-constrained settings. The digital divide, particularly among rural, elderly and socioeconomically disadvantaged populations, may further widen existing health inequities. Additionally, AI models developed using datasets from high-income countries may introduce algorithmic bias and demonstrate limited generalizability to diverse LMIC populations.

Other important barriers include affordability, limited digital literacy, multilingual healthcare environments, concerns regarding data privacy and the shortage of skilled AI professionals. Addressing these challenges requires supportive national policies, standardized health data systems and robust regulatory frameworks.

India has taken important steps toward digital health transformation through initiatives such as the Ayushman Bharat Digital Mission (ABDM), formerly known as the National Digital Health Mission (NDHM), which aims to establish an integrated digital health ecosystem through interoperable electronic health records and unique health identifiers. Coupled with the rapid expansion of telemedicine platforms, these initiatives provide a strong foundation for AI-enabled cardiovascular prevention. Continued investment in digital infrastructure, capacity building, ethical governance and locally validated AI models will be essential to ensure equitable and sustainable implementation across diverse healthcare settings.

Ethical, Legal and Regulatory Issues

The integration of artificial intelligence into cardiovascular disease prevention raises important ethical, legal and regulatory considerations that must be addressed to ensure safe, equitable and trustworthy implementation. AI algorithms trained on non-representative datasets may introduce algorithmic bias, leading to inaccurate predictions and unequal healthcare outcomes across different populations. Ensuring fairness, transparency and equitable model performance is therefore essential, particularly in diverse and resource-constrained settings.

Another major concern is the "black-box" nature of many AI models. Improving explainability enables clinicians to understand how predictions are generated, thereby increasing confidence in AI-assisted decision-making and facilitating patient acceptance. The use of large-scale health data also necessitates robust safeguards for privacy, cybersecurity and data ownership, with clear governance mechanisms to prevent unauthorized access and misuse of sensitive information. Transparent informed consent processes and clearly defined accountability for AI-supported clinical decisions remain fundamental ethical requirements [77,78].

Globally, regulatory frameworks are evolving to promote responsible AI adoption. The World Health Organization (WHO) has issued guiding principles for ethical AI in health, emphasizing transparency, inclusiveness, accountability and patient safety. Similarly, the European Union AI Act and regulatory oversight by the U.S. Food and Drug Administration (FDA) provide frameworks for evaluating AI-enabled medical technologies. In India, the Digital Personal Data Protection Act, 2023, the Ayushman Bharat Digital Mission (ABDM) and emerging national AI initiatives provide the foundation for responsible governance of AI-enabled healthcare. Strengthening ethical oversight and harmonizing regulatory standards will be essential for sustainable implementation of AI in cardiovascular prevention.

Challenges

Despite its transformative potential, several challenges continue to limit the widespread adoption of AI in cardiovascular disease prevention. Many AI models demonstrate promising performance during development but lack adequate clinical and external validation across diverse populations and healthcare settings. Ensuring generalizability remains particularly important for reducing algorithmic bias and maintaining predictive accuracy in real-world practice.

Successful implementation also depends on seamless integration of AI into existing clinical workflows and interoperable digital health systems. Limited interoperability between electronic health records, wearable devices and healthcare information systems often restricts effective data exchange and AI deployment. Furthermore, clinician acceptance remains a significant barrier, as concerns regarding reliability, interpretability, workflow disruption and medico-legal responsibility may reduce confidence in AI-assisted decision-making.

Additional challenges include the high costs of digital infrastructure, limited technical expertise, unequal access to AI technologies and the risk of widening health inequities, particularly in low-resource settings. AI-driven screening may also increase overdiagnosis and unnecessary investigations if algorithms are not appropriately validated and implemented. Addressing these technical, clinical, ethical and implementation barriers through multidisciplinary collaboration, standardized reporting and robust regulatory oversight will be critical for realizing the full potential of AI in precision cardiovascular prevention.

Future Directions

The next generation of artificial intelligence is expected to further transform cardiovascular disease prevention by enabling more predictive, personalized and proactive public health strategies. Advances in generative AI and large foundation models will enhance clinical decision support, automated documentation, patient education and evidence synthesis, while multimodal AI will integrate clinical records, imaging, wearable data, genomics and environmental information to improve individualized risk prediction.

Emerging technologies such as digital twins and population digital twins may enable virtual simulation of individual patients and entire communities, allowing prediction of disease trajectories and evaluation of preventive interventions before implementation. Federated learning offers a privacy-preserving approach by enabling collaborative model development without sharing sensitive patient data, while edge AI supports real-time analysis directly on wearable devices and smartphones, reducing latency and enhancing data security. Although still in its early stages, quantum AI has the potential to accelerate the analysis of highly complex biomedical datasets.

Future cardiovascular prevention will increasingly rely on digital biomarkers, continuous remote

Table 5: Emerging AI Technologies Shaping the Future of Cardiovascular Prevention

Technology	Potential Applications
Generative AI	Clinical documentation, patient education, decision support
Foundation Models	Multitask clinical reasoning and predictive analytics
Multimodal AI	Integration of imaging, EHRs, genomics and wearable data
Digital Twins	Personalized disease simulation and treatment planning
Population Digital Twins	Public health planning and policy evaluation
Federated Learning	Privacy-preserving collaborative AI development
Edge AI	Real-time analysis on wearable devices and smartphones
Digital Biomarkers	Continuous monitoring and early disease detection
AI Agents	Personalized health coaching and automated follow-up
Ambient Intelligence	Passive health monitoring and context-aware preventive care
Quantum AI	Advanced analysis of complex biomedical datasets (future potential)

monitoring, intelligent AI agents and ambient intelligence capable of delivering context-aware preventive recommendations with minimal user input. However, technological advancement must be accompanied by explainable and responsible AI, emphasizing transparency, fairness, accountability and ethical governance. By integrating these innovations within a precision public health framework, AI has the potential to shift cardiovascular care from reactive disease management to continuous, predictive and personalized prevention at both individual and population levels (Table 5).

Research Gaps

Despite rapid advances, the evidence supporting AI in cardiovascular disease prevention remains fragmented. Most published studies are retrospective, conducted in high-income countries and focus primarily on algorithm development rather than real-world implementation or long-term clinical outcomes. Robust prospective studies, pragmatic clinical trials and external validation across diverse populations are still limited.

Significant implementation research gaps also exist regarding the integration of AI into routine healthcare, clinician acceptance, workflow optimization and patient engagement. Evidence from Low- and Middle-Income Countries (LMICs), particularly India, remains scarce despite the disproportionate burden of cardiovascular disease. Furthermore, there is limited research evaluating AI from a public health perspective, including its impact on population screening, health equity, surveillance and resource allocation.

Another major gap is the lack of comprehensive cost-effectiveness analyses comparing AI-enabled prevention with conventional healthcare approaches. Future research should also focus on policy development, regulatory evaluation, ethical governance and standardized reporting to support safe, equitable and sustainable implementation. Addressing these gaps will be essential for translating AI innovations into meaningful improvements in cardiovascular health.

Practical Recommendations

The successful integration of AI into cardiovascular disease prevention requires coordinated efforts across multiple stakeholders. Clinicians should view AI as a decision-support tool that complements, rather than replaces, clinical judgment and should actively participate in validating AI-driven recommendations. Researchers should prioritize multicentric prospective studies, external validation, explainable AI and implementation research involving diverse populations.

Governments should strengthen digital health infrastructure, establish robust regulatory frameworks, promote interoperable health information systems and ensure equitable access to AI technologies. Public health professionals should integrate AI into cardiovascular surveillance, targeted screening, risk communication and population-level prevention programmes while addressing social determinants of health.

The healthcare industry should focus on developing transparent, interoperable, affordable and ethically designed AI solutions that meet clinical and public health needs. Finally, medical education should incorporate AI literacy, digital health, data science and ethical principles into undergraduate, postgraduate and continuing medical education to prepare future healthcare professionals for AI-enabled practice.

CONCLUSIONS

Artificial intelligence is redefining cardiovascular disease prevention by enabling more accurate risk prediction, personalized lifestyle interventions, continuous health monitoring and data-driven public health decision-making. When integrated with the principles of Precision Public Health, AI has the potential to shift healthcare from reactive disease management to proactive, predictive and personalized prevention while improving the efficiency, reach and equity of cardiovascular care.

However, realizing this potential requires more than technological innovation. Robust clinical validation, transparent and explainable algorithms, ethical governance, strong regulatory frameworks and context-specific implementation strategies are essential to ensure that AI benefits all populations, particularly those in resource-constrained settings. Continued investment in implementation research, digital health infrastructure and multidisciplinary collaboration will be critical for translating AI into sustainable public health practice.

As AI technologies continue to evolve, their greatest contribution may not simply be improving clinical prediction but transforming the way cardiovascular prevention is planned, delivered and evaluated at the population level. By responsibly integrating artificial intelligence into healthcare systems, precision public health offers a unique opportunity to substantially reduce the global burden of cardiovascular disease and move closer to the goal of equitable, preventive and patient-centred healthcare.

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