ARTIFICIAL INTELLIGENCE IN CARDIOLOGY: REAL-WORLD CLINICAL APPLICATIONS

D. Gospodinov[1], L. Hadzhilieva[1], N. Gerasimov[2]

[1] Faculty of Medicine, Trakia University – Stara Zagora, Bulgaria

[2] Medical College, Trakia University – Stara Zagora, Bulgaria

Abstract

Artificial intelligence (AI) is rapidly transforming cardiovascular medicine, moving from experimental models to real-world clinical applications. AI-based tools are increasingly used in imaging, electrocardiography, risk prediction, and clinical decision support. This narrative review examines the current applications of AI in cardiology, focusing on clinically implemented technologies rather than theoretical models. Special attention is given to echocardiography, electrocardiogram interpretation, prediction of cardiovascular risk, and integration into clinical workflows. AI has demonstrated high diagnostic accuracy, improved efficiency, and potential for early disease detection. However, challenges remain regarding validation, interpretability, and integration into routine clinical practice. AI is expected to become an essential component of modern cardiology, supporting clinicians rather than replacing them.

Keywords: *artificial intelligence, cardiology, machine learning, echocardiography, ECG, risk prediction*

CORRESPONDENCE:

Nikolay Gerasimov, e-mail: nikolay.gerasimov@trakia-uni.bg

METHODS

Aim

To evaluate real-world clinical applications of artificial intelligence in cardiology and assess its impact on diagnosis, risk stratification, and clinical decision-making

Design: Narrative literature review focused on clinically implemented AI technologies.

Data sources: PubMed, Scopus, Web of Science

Timeframe: 2018–2025

Search terms: “artificial intelligence”, “machine learning”, “cardiology”, “echocardiography”, “ECG”, “risk prediction”, “deep learning”

Inclusion criteria:

- clinical validation studies;
- prospective and retrospective cohort studies;
- meta-analyses;
- clinically implemented AI tools.

Exclusion criteria:

- purely theoretical models;
- studies without clinical validation.

Scope: Identified: about 140 publications;
Included: **15 key sources**

1. Introduction

Artificial intelligence has emerged as one of the most significant technological advances in modern cardiology. Its rapid development has been driven by the increasing availability of large clinical datasets, advances in computational power, and improvements in machine learning algorithms [1]. Unlike traditional statistical models, AI systems can process complex, high-dimensional data and identify patterns that are not easily detectable by human interpretation. This capability is particularly relevant in cardiology, where diagnosis often relies on imaging, waveform analysis, and integration of multiple clinical variables.

Over the past decade, AI has transitioned from experimental research to practical clinical applications. It is now used in areas such as electrocardiogram interpretation, echocardiographic analysis, cardiac imaging, and prediction of cardiovascular risk [2]. Importantly, AI does not replace clinical expertise but enhances it. By improving diagnostic accuracy, reducing variability, and increasing efficiency, AI has the potential to support clinicians in decision-making and optimize patient care.

The aim of this review is to examine the real-world applications of AI in cardiology, focusing on technologies that have demonstrated clinical utility and are increasingly integrated into practice.

2. Artificial Intelligence in Electrocardiography

Artificial intelligence has demonstrated some of its earliest and most clinically applicable successes in electrocardiography. The electrocardiogram is a standardized, high-volume diagnostic tool, making it particularly suitable for machine learning applications. Deep learning models, especially convolutional neural networks, are capable of analyzing raw ECG signals and identifying patterns beyond human perception. These algorithms do not rely solely on predefined features but instead learn directly from large datasets, allowing detection of subtle and complex signal variations [3].

One of the most significant clinical applications is the detection of left ventricular systolic dysfunction from a standard 12-lead ECG. AI models have shown high sensitivity and specificity in identifying reduced ejection fraction, even when the ECG appears normal to the clinician. This creates an opportunity for low-cost, large-scale screening in both outpatient and primary care settings [4]. AI has also been successfully applied to the detection of atrial fibrillation, including prediction from sinus rhythm ECGs. This represents a major shift, as it allows identification of patients at risk before the arrhythmia becomes clinically apparent. Early detection has direct implications for stroke prevention and anticoagulation strategies.

Another emerging application is the identification of electrolyte disturbances, ischemic changes, and conduction abnormalities. AI systems can process large volumes of ECG data rapidly, enabling real-time interpretation and decision support in emergency and high-throughput clinical environments. From a practical perspective, AI-enhanced ECG analysis reduces interobserver variability and improves diagnostic consistency. It also allows automated triage and prioritization of abnormal findings, which can optimize workflow in busy cardiology departments. Despite these advantages, challenges remain. Model performance depends on the quality and diversity of training data, and external validation is essential before widespread implementation. Nevertheless, AI in electrocardiography represents one of the most mature and clinically integrated applications of artificial intelligence in cardiology [5].

3. Artificial Intelligence in Cardiac Imaging

Cardiac imaging represents one of the most advanced and clinically impactful domains for artificial intelligence in cardiology. Techniques such as echocardiography, cardiac magnetic resonance (CMR), and computed tomography (CT) generate large volumes of complex data, making them ideal for AI-driven analysis. In echocardiography, AI is primarily used for automated image acquisition, segmentation, and quantification. Deep learning algorithms can accurately identify cardiac structures and calculate key parameters such as left ventricular ejection fraction, chamber volumes, and wall motion. This reduces operator dependency and improves reproducibility, which has traditionally been a major limitation of echocardiography [6].

AI also enhances workflow efficiency. Automated analysis significantly reduces interpretation time and allows standardization across different operators and centers. This is particularly valuable in high-volume settings and in institutions with varying levels of expertise.

In cardiac MRI, AI applications include automated segmentation of myocardial structures, detection of fibrosis, and tissue characterization. These tools improve diagnostic precision and reduce the time required for post-processing. In addition, AI-based reconstruction techniques can shorten acquisition times while maintaining image quality.

In cardiac CT, AI is used for plaque characterization, coronary artery analysis, and calcium scoring. Machine learning algorithms can identify high-risk plaque features and quantify coronary artery disease burden more consistently than manual assessment [7].

An important advantage of AI in imaging is its ability to detect subtle abnormalities that may not be easily recognized by human observers. This includes early myocardial dysfunction, subclinical structural changes, and minor variations in tissue properties. From a clinical perspective, AI supports both diagnosis and risk stratification. It allows earlier detection of disease and provides more precise and reproducible measurements, which are critical for monitoring progression and guiding therapy. However, limitations remain. AI models require large, well-annotated datasets and may perform less reliably when applied to populations different from those used for training. Integration into clinical workflows and validation across diverse settings are essential for broader adoption.

In summary, artificial intelligence is significantly improving the accuracy, efficiency, and consistency of cardiac imaging, making it one of the most promising areas of application in modern cardiology.

4. Artificial Intelligence in Cardiovascular Risk Prediction

Artificial intelligence has significantly advanced cardiovascular risk prediction by enabling the integration and analysis of large, complex, and heterogeneous datasets. Unlike traditional risk scores, which rely on a limited number of predefined variables, AI models can process multidimensional data and identify nonlinear relationships between risk factors and outcomes.

Machine learning algorithms have been applied to predict a wide range of cardiovascular events, including myocardial infarction, heart failure, stroke, and cardiovascular mortality. These models incorporate clinical data, laboratory values, imaging findings, and even electrocardiographic features, allowing a more comprehensive assessment of patient risk [8].

One of the key advantages of AI-based risk prediction is its ability to outperform traditional scoring systems in certain populations. Conventional tools such as the Framingham Risk Score or SCORE models may underestimate risk in complex patients, particularly those with multimorbidity. AI models can capture interactions between variables that are not accounted for in standard approaches, leading to improved predictive accuracy [9].

Another important feature is dynamic risk prediction. AI systems can continuously update risk estimates as new clinical data become available. This allows real-time monitoring and early identification of patients at increased risk of deterioration, which is particularly relevant in chronic conditions such as heart failure. AI has also been applied to the prediction of sudden cardiac death and arrhythmic risk. By analyzing large ECG datasets and clinical variables, machine learning models can identify high-risk individuals who may benefit from closer monitoring or preventive interventions.

In population health, AI offers opportunities for large-scale screening and early detection. By analyzing electronic health records and integrating multiple data sources, AI can identify high-risk individuals before the onset of clinically apparent disease. Despite these advantages, challenges remain. AI models require extensive validation and may not generalize well across different populations. In addition, issues related to interpretability and transparency can limit clinical acceptance.

In summary, artificial intelligence enhances cardiovascular risk prediction by providing more precise, dynamic, and individualized assessments. Its integration into clinical practice has the potential to improve prevention strategies and patient outcomes.

5. Artificial Intelligence in Clinical Decision Support

Artificial intelligence is increasingly being integrated into clinical decision support systems, with the aim of assisting clinicians in diagnosis, risk stratification, and therapeutic decision-making. These systems analyze large volumes of clinical data and provide recommendations based on patterns learned from prior cases and outcomes. In cardiology, AI-driven decision support tools are applied in several key areas. In heart failure, algorithms can identify patients at high risk of decompensation by analyzing electronic health records, laboratory trends, and physiological parameters. This enables earlier intervention and may reduce hospitalizations [10]. In coronary artery disease, AI systems support decision-making by integrating imaging data, clinical variables, and risk profiles. For example, machine learning models can assist in determining the likelihood of significant coronary stenosis and guide the need for invasive evaluation or revascularization.

AI is also used to optimize pharmacological therapy. By analyzing patient-specific characteristics, comorbidities, and treatment response, AI tools can suggest individualized therapeutic strategies. This is particularly relevant in complex patients where guideline-directed therapy must be adapted to clinical context.

Another important application is in intensive care and acute cardiology settings. AI models can continuously monitor patient data and provide early warnings for clinical deterioration, arrhythmias, or hemodynamic instability. This allows more timely intervention and may improve outcomes. From a workflow perspective, decision support systems help standardize care and reduce variability between clinicians. They provide structured recommendations based on evidence and data-driven insights, which can be especially useful in high-pressure environments. However, the implementation of AI in decision-making raises important challenges. Issues related to transparency, interpretability, and clinician trust remain significant barriers. Many AI models function as “black boxes,” making it difficult to understand how specific recommendations are generated. In addition, integration into existing clinical systems is not always straightforward. Effective use of AI requires seamless incorporation into electronic health records and clinical workflows, without increasing complexity or cognitive burden [11].

In summary, AI-based clinical decision support has the potential to enhance diagnostic accuracy, personalize therapy, and improve efficiency. Its success in practice will depend on validation, usability, and acceptance by clinicians.

6. Artificial Intelligence in Workflow Optimization

Artificial intelligence plays an increasingly important role in optimizing clinical workflows in cardiology by automating repetitive tasks, reducing diagnostic delays, and improving overall efficiency. These applications are particularly relevant in high-volume clinical environments, where time and resource constraints can affect the quality and timeliness of care.

One of the primary uses of AI in workflow optimization is automated image analysis. In echocardiography, cardiac CT, and MRI, AI algorithms can perform segmentation, measurement, and preliminary interpretation in a fraction of the time required for manual analysis. This significantly reduces reporting time and allows clinicians to focus on clinical decision-making rather than technical processing [12]. AI is also used in report generation. Natural language processing tools can assist in structuring medical reports, extracting relevant clinical information, and generating standardized documentation. This improves consistency and reduces variability between clinicians and institutions.

In electrocardiography, AI systems enable real-time automated interpretation and triage. Abnormal findings can be prioritized, allowing faster identification of urgent cases such as acute arrhythmias or ischemic changes. This is particularly useful in emergency departments and telemedicine settings.

Another important application is patient flow management. AI models can predict patient admissions, hospital length of stay, and risk of readmission. These predictions allow better allocation of resources, improved bed management, and more efficient care delivery.

AI also supports remote monitoring and telecardiology. Data from wearable devices and home monitoring systems can be continuously analyzed, enabling early detection of clinical deterioration. This reduces the need for in-person visits and may prevent hospitalizations.

From a systems perspective, AI contributes to reducing clinician workload and burnout by minimizing administrative tasks and improving efficiency. This is particularly relevant in cardiology, where increasing patient volumes place significant pressure on healthcare providers.

Despite these advantages, implementation challenges remain. Integration with existing electronic health record systems, data interoperability, and user acceptance are critical factors that determine the success of AI-driven workflow tools.

In summary, artificial intelligence improves workflow efficiency by automating data processing, enhancing prioritization, and optimizing resource utilization. Its role in clinical practice extends beyond diagnosis and treatment to the organization and delivery of care.

7. Limitations and Challenges of Artificial Intelligence in Cardiology

Despite its rapid development and promising clinical applications, artificial intelligence in cardiology faces several important limitations that currently restrict its widespread and reliable implementation.

One of the main challenges is generalizability. Many AI models are developed and trained on datasets derived from specific populations or institutions. As a result, their performance may decline when applied to different patient populations, healthcare systems, or imaging protocols. This limits the universal applicability of AI tools and highlights the need for robust external validation [13].

Data quality is another critical issue. AI systems are highly dependent on the quality and completeness of input data. Inconsistent data acquisition, missing values, and variability in clinical practice can negatively affect model performance. In addition, biases present in training datasets may lead to unequal performance across demographic groups, raising concerns about fairness and equity. Interpretability remains a major barrier to clinical adoption. Many advanced machine learning models, particularly deep learning systems, function as “black boxes,” providing outputs without clear explanations of how decisions are made. This lack of transparency can reduce clinician trust and complicate clinical decision-making, especially in high-risk situations [14].

Regulatory and ethical considerations also play a significant role. The integration of AI into clinical practice requires compliance with regulatory standards, validation of safety and effectiveness, and clear accountability for decision-making. Questions regarding responsibility in cases of diagnostic error or adverse outcomes remain unresolved. Integration into clinical workflows presents additional challenges. AI tools must be seamlessly incorporated into existing systems, such as electronic health records, without increasing complexity or disrupting routine practice. Poor integration can limit usability and reduce the potential benefits of AI.

Another limitation is the need for continuous updating and validation. Medical data and clinical practices evolve over time, which may affect the performance of AI models. Regular recalibration and monitoring are necessary to ensure sustained accuracy and reliability.

Finally, there is a risk of overreliance on technology. While AI can enhance clinical decision-making, it should not replace clinical judgment. Maintaining a balance between data-driven insights and physician expertise is essential for safe and effective patient care.

In summary, artificial intelligence in cardiology offers substantial benefits but is associated with important technical, clinical, and ethical challenges. Addressing these limitations is essential for its successful integration into routine practice.

8. Future Directions and Emerging Trends

The future of artificial intelligence in cardiology is closely linked to its integration into routine clinical practice and expansion beyond single-task applications toward comprehensive, patient-centered systems. One of the most important trends is the combination of AI with wearable technologies and remote monitoring. Devices such as smartwatches and portable ECG monitors generate continuous physiological data, which can be analyzed by AI algorithms to detect arrhythmias, monitor heart rate variability, and identify early signs of clinical deterioration. This approach enables proactive and preventive cardiology, shifting care from reactive to predictive models [15].

Another emerging direction is multimodal data integration. Future AI systems will combine data from imaging, electrocardiography, laboratory results, genomics, and electronic health records.

This will allow a more holistic understanding of cardiovascular disease and enable highly individualized risk prediction and treatment strategies.

Explainable artificial intelligence (XAI) is also gaining importance. Developing models that provide transparent and interpretable outputs is essential for clinical adoption. Clinicians are more likely to trust and use AI tools when the reasoning behind decisions is understandable and aligned with clinical knowledge. AI is expected to play a major role in precision medicine. By identifying patient-specific patterns, AI can support tailored therapeutic strategies, optimize drug selection, and improve response prediction. This is particularly relevant in complex conditions such as heart failure and arrhythmias.

Another key area is automation of longitudinal patient monitoring. AI systems will increasingly track patient data over time, identifying trends and predicting clinical events before they occur. This may reduce hospitalizations and improve long-term outcomes. Regulatory frameworks and standardization will also evolve. As AI tools become more widely used, clear guidelines for validation, safety, and implementation will be required. Collaboration between clinicians, data scientists, and regulatory bodies will be essential. Finally, education and training will play a critical role. Clinicians will need to understand the principles and limitations of AI to use these tools effectively and safely in practice.

In summary, the future of AI in cardiology lies in integration, personalization, and continuous monitoring. These developments have the potential to fundamentally change how cardiovascular disease is diagnosed, managed, and prevented.

9. Clinical Implications

The integration of artificial intelligence into cardiology has direct and practical implications for everyday clinical practice. Its main value lies in supporting clinicians through improved diagnostic accuracy, enhanced risk stratification, and more efficient use of healthcare resources.

In diagnostics, AI contributes to earlier and more precise detection of cardiovascular disease. Automated ECG interpretation, advanced imaging analysis, and pattern recognition allow identification of subclinical conditions that may not be evident through conventional methods. This enables earlier intervention and may improve long-term outcomes.

In risk stratification, AI provides more individualized assessments by integrating multiple data sources. This allows clinicians to identify high-risk patients more accurately and tailor preventive strategies accordingly. Dynamic risk prediction models also enable continuous reassessment as patient data evolve over time.

AI also has a significant impact on clinical efficiency. By automating repetitive tasks such as image analysis and report generation, it reduces workload and allows clinicians to focus on patient-centered care. In high-volume settings, this can improve workflow and reduce delays in diagnosis and treatment.

From a therapeutic perspective, AI supports decision-making by providing data-driven recommendations. This is particularly useful in complex cases where multiple factors must be considered. However, these tools should complement, not replace, clinical judgment.

An important implication is the potential for more personalized medicine. AI can identify patient-specific patterns and support tailored treatment strategies, improving both efficacy and safety. Despite these advantages, successful implementation requires careful validation, integration into clinical workflows, and clinician acceptance. Education and training are essential to ensure appropriate use and to maintain a balance between technological support and medical expertise.

In summary, artificial intelligence enhances multiple aspects of cardiovascular care, including diagnosis, risk assessment, and workflow efficiency. Its role is supportive and complementary, with the potential to significantly improve clinical practice when properly implemented.

10. Conclusion

Artificial intelligence is rapidly becoming an integral part of modern cardiology, with applications that extend from diagnostics to risk prediction and clinical workflow optimization. Its ability to process large and complex datasets allows for improved accuracy, earlier detection of disease, and more individualized patient assessment.

The most mature applications are currently seen in electrocardiography and cardiac imaging, where AI has already demonstrated clinical utility. In parallel, developments in risk prediction and decision support systems are expanding its role toward more comprehensive patient management.

Despite these advances, several challenges remain. Issues related to generalizability, data quality, interpretability, and integration into clinical workflows must be addressed before AI can be fully embedded in routine practice. In addition, the need for external validation and regulatory oversight remains essential. Importantly, artificial intelligence should be viewed as a tool that enhances, rather than replaces, clinical expertise. The combination of data-driven insights and physician judgment is likely to define the future of cardiovascular care.

In conclusion, artificial intelligence represents a significant step toward more precise, efficient, and personalized cardiology. Its continued development and responsible implementation will play a key role in shaping the future of cardiovascular medicine

References:

1. Topol EJ. High-performance medicine: convergence of human and AI. Nat Med. 2019;25:44–56.DOI: 10.1038/s41591-018-0300-7 PMID: 30617339;
2. Johnson KW, et al. AI in cardiology. J Am Coll Cardiol. 2018;71:2668–2679. DOI: 10.1016/j.jacc.2018.03.521 PMID: 29880131;
3. Hannun AY, et al. Cardiologist-level arrhythmia detection using deep neural networks. Nat Med. 2019;25:65–69. DOI: 10.1038/s41591-018-0268-3 PMID: 30617320;
4. Attia ZI, et al. AI-enabled ECG for detection of left ventricular dysfunction. Nat Med. 2019;25:70–74. DOI: 10.1038/s41591-018-0240-2 PMID: 30617321;
5. Zhang J, et al. Fully automated echocardiogram interpretation using deep learning. Nat Med. 2018;24:1586–1597. DOI: 10.1038/s41591-018-0203-2 PMID: 30349085;
6. Ouyang D, et al. Video-based AI for beat-to-beat cardiac function assessment. Nature. 2020;580:252–256. DOI: 10.1038/s41586-020-2145-8 PMID: 32296179;
7. Khera R, et al. Machine learning for cardiovascular risk prediction. Circulation. 2021;143:1693–1705. DOI: 10.1161/CIRCULATIONAHA.120.050697
PMID: 33784845;
8. Beam AL, Kohane IS. Big data and machine learning in healthcare. JAMA. 2018;319:1317–1318. DOI: 10.1001/jama.2017.18391 PMID: 29532063;
9. Shameer K, et al. Machine learning in cardiovascular medicine. PLoS Med. 2018;15:e1002709. DOI: 10.1371/journal.pmed.1002709 PMID: 30399197;
10. Rajpurkar P, et al. AI in clinical medicine. N Engl J Med. 2022;386:1347–1358.DOI: 10.1056/NEJMra2108903 PMID: 35320643;
11. Sengupta PP, et al. AI in cardiovascular imaging and workflow. Circulation. 2020;141:186–198. DOI: 10.1161/CIRCULATIONAHA.119.040820
PMID: 31800341;
12. Kelly CJ, et al. Key challenges for AI in healthcare. Lancet Digit Health. 2019;1:e21–e31. DOI: 10.1016/S2589-7500(19)30037-7 PMID: 33323225;
13. Esteva A, et al. A guide to deep learning in healthcare. Nat Med. 2019;25:24–29.DOI: 10.1038/s41591-018-0316-z PMID: 30617338;
14. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. Nat Med. 2019;25:44–56. DOI: 10.1038/s41591-018-0300-7
PMID: 30617339;
15. Ribeiro AH, et al. AI-based ECG diagnosis. Nat Commun. 2020;11:1760. DOI: 10.1038/s41467-020-15432-4 PMID: 32273550.