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ABSTRACT

Cardiac arrhythmias represent a heterogeneous group of rhythm pathologies that range from benign ectopic beats to life-threatening ventricular tachyarrhythmias, contributing substantially to global morbidity, mortality, and impaired quality of life. Over the past decade, remarkable technological advances have reshaped diagnostic strategies, transcending the limitations of conventional 12-lead electrocardiography (ECG) and Holter monitoring. High-resolution digital ECG systems, wearable devices, and long-term ambulatory monitoring platforms have enabled continuous and real-time rhythm assessment, improving detection of asymptomatic and paroxysmal arrhythmias. Implantable loop recorders, remote monitoring, and telemetry further enhance long-term surveillance and clinical decision-making. In parallel, advanced imaging modalities, such as electromechanical wave imaging and electrocardiographic imaging, combined with electroanatomic mapping systems, have refined the localization of arrhythmogenic substrates and optimized ablation outcomes. Genetic testing provides critical insights into inherited arrhythmia syndromes, facilitating personalized therapy and cascade family screening. Furthermore, artificial intelligence and machine learning algorithms—particularly deep learning models—have demonstrated high accuracy in automated arrhythmia detection, supporting integration into decision support systems and preventive healthcare strategies. Despite these advances, challenges remain regarding data privacy, algorithmic transparency, access inequities, and medico-legal responsibilities. Addressing these limitations will be essential to ensure safe, equitable, and cost-effective translation into clinical practice. Overall, the digital transformation of arrhythmia diagnostics is expected to establish multidisciplinary, data-driven, and patient-centered paradigms, positioning this field as one of the most dynamic and promising areas in contemporary cardiology.

Keywords: Artificial intelligence; Cardiac arrhythmia; Electrocardiography; Genetic testing; Electroanatomic mapping; Machine learning; Wearable electronic devices

ÖZET

Kardiyak aritmiler, benign ektopik atımlardan yaşamı tehdit eden ventriküler taşiaritmilere kadar uzanan heterojen bir ritim bozukluğu grubunu temsil etmekte olup, küresel morbidite, mortalite ve yaşam kalitesi üzerinde önemli etkilere sahiptir. Son on yılda kaydedilen dikkate değer teknolojik ilerlemeler, geleneksel 12 derivasyonlu elektrokardiyografi ve Holter monitörizasyonunun sınırlarını aşarak tanisal stratejileri köklü biçimde dönüştürmüştür. Yüksek çözünürlüklü dijital EKG sistemleri, giyilebilir cihazlar ve uzun süreli ambulator izleme platformları, asemptomatik ve paroksizmal aritmilerin saptanmasını iyileştirerek sürekli ve gerçek zamanlı ritim değerlendirmesine olanak tanımaktadır. İmplant edilebilir loop kaydediciler, uzaktan izleme ve telemetri, uzun dönemli takip ve klinik karar verme süreçlerini daha da güçlendirmektedir. Paralel olarak, elektromekanik dalga görüntüleme ve elektrokardiyografik görüntüleme gibi ileri görüntüleme modaliteleri ile elektroanatomik haritalama sistemlerinin kombinasyonu, aritmojenik substratların lokalizasyonunu hassaslaştırmış ve ablasyon sonuçlarını optimize etmiştir. Genetik testler, kalıtsal aritmi sendromlarına ilişkin kritik bilgiler sağlayarak kişiselleştirilmiş tedavi ve aile taramalarını kolaylaştırmaktadır. Ayrıca, yapay zekâ ve makine öğrenmesi algoritmaları - özellikle derin öğrenme modelleri - aritmilerin otomatik tespitinde yüksek doğruluk sergilemiş, karar destek sistemleri ve önleyici sağlık stratejilerine entegrasyonu desteklemiştir. Bununla birlikte, veri gizliliği, algoritmik şeffaflık, erişim eşitsizlikleri ve hukuki sorumluluklar gibi zorluklar devam etmektedir. Bu sınırlamaların aşılması, teknolojilerin güvenli, adil ve maliyet-etkin biçimde

For Citation:

İlhan B, Bozdereli Berikol G, Deniz T. Diagnostic Advances in Cardiac Arrhythmias. In: Karıcıoğlu Ö, editor. Advances in Emergency Medicine and Critical Care of Acute Diseases and Injuries. 1st ed. Ankara: Türkiye Klinikleri; 2025. p.179-188.

klirik uygulamaya aktarılabilmesi açısından kritik önemdedir. Genel olarak, aritmi tanısındaki dijital dönüşümün multidisipliner, veri temelli ve hasta merkezli paradigmaları yerleştirmesi beklenmekte olup, bu alan çağdaş kardiyojinin en dinamik ve umut vadeden boyutlarından biri olmaya devam etmektedir.

Anahtar Kelimeler: *Yapay zeka; Kardiyak aritmi; Elektrokardiyografi; Genetik testler, Elektroanatomik haritalama; Makine öğrenmesi; Giyilebilir elektronik cihazlar*

INTRODUCTION

Cardiac arrhythmias represent a heterogeneous spectrum of rhythm pathologies ranging from benign ectopic beats to malignant ventricular arrhythmias and constitute a major contributor to global morbidity, mortality, and impaired quality of life. Among them, atrial fibrillation (AF) is the most prevalent sustained arrhythmia, conferring a substantially increased risk of ischemic stroke, myocardial infarction, heart failure, chronic kidney disease, dementia, and all-cause mortality.¹

The diagnosis of arrhythmias has traditionally been based on conventional modalities, including 12-lead electrocardiography (ECG) and Holter monitoring. While indispensable in clinical practice, these approaches demonstrate important limitations, particularly in detecting asymptomatic or paroxysmal arrhythmias.² Moreover, the interpretation of standard ECGs is highly operator-dependent, relying heavily on physician expertise, and generally represents only a short temporal snapshot of cardiac activity.

In recent years, diagnostic approaches have been revolutionized by the convergence of digital technologies, wearable sensors, artificial intelligence (AI)-driven analytics, and device miniaturization. These innovations not only complement but also transcend traditional modalities, enabling real-time, continuous, and even predictive cardiac rhythm surveillance.^{3,4} Furthermore, the integration of advanced imaging techniques, genomic profiling, and machine learning-based algorithms has significantly enhanced our understanding of arrhythmogenic substrates and underlying pathophysiological mechanisms.³

This chapter provides a comprehensive overview of contemporary diagnostic strategies in cardiac arrhythmias. A wide range of cutting-edge modalities will be discussed, spanning advanced electrocardiographic technologies, electroanatomic mapping systems, artificial intelligence-driven analytic platforms, and genetic testing, with a particular focus on their clinical impact and translational applicability.

ADVANCES IN ELECTROCARDIOGRAPHY AND CONTEMPORARY CARDIAC MONITORING MODALITIES

The ECG continues to serve as the cornerstone of arrhythmia diagnosis. Nevertheless, the conventional 12-lead ECG is inherently constrained by its short recording duration and the challenge of capturing rhythm disturbances at the time of occurrence, often proving insufficient in the evaluation of paroxysmal arrhythmias as well as in the localization of arrhythmogenic foci and activation abnormalities.⁵ Consequently, recent technological innovations in ECG systems have markedly enhanced diagnostic yield and accuracy.

Contemporary digital ECG platforms have substantially enhanced signal resolution, enabling more precise detection of microvariations and thereby offering significant diagnostic advantages in conditions characterized by subtle electrocardiographic findings. Equipped with sophisticated preprocessing algorithms and frequency-domain analyses, next-generation ECG software can automatically classify a wide range of arrhythmias, including ventricular ectopy, atrial tachyarrhythmias, and sinus irregularities. Moreover, the capacity for long-term digital archiving facilitates advanced analyses and longitudinal comparisons, providing considerable clinical value, particularly in high-acuity settings such as emergency departments, intensive care units, and in scenarios necessitating remote cardiac monitoring.

The advances of portable ECG devices and smartwatch-based applications have empowered individuals to record and analyze their electrocardiograms in both home and ambulatory settings. These innovations have markedly advanced the detection of asymptomatic arrhythmias, with several studies reporting superior performance of smartwatch-based wearable ECGs compared to conventional Holter monitoring in identifying arrhythmias.⁶ Wearable platforms have demonstrated high sensitivity and specificity for AF and other prevalent arrhythmias.^{7,8} Beyond early de-

tection, the widespread adoption of these systems has been shown to increase pre-stroke AF diagnosis rates and to enhance long-term patient adherence.⁹

Mobile health applications and Bluetooth-enabled portable ECG devices now allow patients to record cardiac rhythms in real time and seamlessly transmit data to healthcare providers. These technologies have demonstrated potential as cost-effective and early diagnosing screening instruments for the community-based detection of subclinical arrhythmias, particularly atrial fibrillation.^{10,11}

Accordingly, smartwatch-based and smartphone-integrated ECG platforms are increasingly positioned as scalable, affordable tools for population-wide screening initiatives. Nonetheless, challenges persist, including the need for structured patient education, mitigation of false positive and negative results, and the establishment of robust data validation frameworks.

Patch-based ECG technologies, designed to overcome the limitations of conventional 24-hour Holter monitoring, offer lightweight, patient-friendly platforms capable of continuous recording for 7 to 14 days. Utilizing adhesive electrode systems, these devices have demonstrated superior efficacy in capturing asymptomatic and paroxysmal arrhythmias compared to traditional Holter monitors.^{2,12-14} Beyond enhanced diagnostic yield, patch ECGs have been associated with meaningful changes in patient management strategies and consistently outperform standard Holter systems with regard to patient comfort and adherence.¹⁵

Implantable loop recorders (ILRs) represent a new generation of long-term cardiac monitoring devices, capable of providing continuous subcutaneous ECG recordings for several years—thus overcoming the temporal limitations of conventional Holter monitoring. ILRs have proven particularly valuable in the diagnostic evaluation of unexplained syncope, cryptogenic stroke, and infrequent arrhythmias.^{16,17} Their ability to deliver uninterrupted monitoring offers significant potential to guide timely therapeutic decision-making, including interventional strategies (e.g., pacemaker or defibrillator implantation) and pharmacologic interventions (e.g., anticoagulation and antiarrhythmic therapy).¹⁸ With advancements such as wireless data transmission, automated arrhythmia detection algorithms, and miniaturized designs, next-generation ILRs are increasingly regarded as both clinician- and patient-friendly solutions.^{16,17}

In patients with implantable cardiac devices such as pacemakers and implantable cardioverter-defibrillators (ICDs), integrated rhythm detection algorithms combined with wireless data transmission now enable seamless remote monitoring. These systems confer significant clinical advantages, including the early detection of emergent arrhythmias, the facilitation of outpatient surveillance, and a reduction in complication risk.¹⁹ Moreover, next-generation devices, by enabling timely diagnosis and continuous remote follow-up, hold considerable promise in lowering overall healthcare expenditures.¹⁷

Pros and cons of ECG-based diagnostic methods are presented in Table 1.

IMAGING AND MAPPING APPROACHES IN ARRHYTHMIA DIAGNOSIS

Electrophysiological study (EPS) remains a gold-standard technique for the evaluation of cardiac arrhythmias. As a catheter-based interventional modality, EPS enables direct assessment of the heart's electrical conduction pathways and serves as the foundation not only for precise diagnosis but also for therapeutic interventions such as catheter ablation. Given that most electrophysiologic abnormalities arise from underlying structural or functional remodeling, delineation of cardiac anatomy—such as atrial and ventricular fibrosis or scar tissue—is integral to diagnostic accuracy, procedural planning, and recurrence risk stratification. Accordingly, conventional imaging modalities, including cardiac MRI and CT, have been widely incorporated into clinical practice. More recently, advances in imaging and mapping technologies have introduced significant advantages for both diagnostic and therapeutic workflows. Next-generation mapping systems, in particular, enhance diagnostic precision, improve ablation success rates, reduce procedure time, and mitigate complication risks.

Electromechanical wave imaging (EWI) is an advanced, high-frame rate ultrasound modality that enables noninvasive, high-resolution mapping of electromechanical activation in arrhythmias. By capturing the spatiotemporal propagation of myocardial activation, EWI allows arrhythmogenic substrates to be localized with greater precision than conventional electrocardiography.²⁰⁻²² Notably, it has demonstrated superior accuracy over traditional ECG interpretation in the identification of accessory pathways.²³ Owing

Table 1. ECG-based diagnostic methods: pros and cons.

Method	Pros	Cons
Conventional 12-lead ECG	<ul style="list-style-type: none"> • Widely available, inexpensive, easy to use • Cornerstone of acute arrhythmia diagnosis 	<ul style="list-style-type: none"> • Short recording duration • Limited ability to capture paroxysmal arrhythmias • Insufficient for localizing arrhythmogenic foci and activation abnormalities
Digital ECG systems	<ul style="list-style-type: none"> • High resolution, capable of detecting microvariations • Advanced algorithms allow automatic arrhythmia classification • Good integration with EHRs • Long-term digital archiving and longitudinal comparisons 	<ul style="list-style-type: none"> • Higher cost • Data management and storage burden
Wearable ECG devices / Smartwatch-based ECG	<ul style="list-style-type: none"> • Usable at home and in ambulatory settings • High sensitivity and specificity for AF and common arrhythmias • Improves long-term patient adherence • Scalable for community-based screening 	<ul style="list-style-type: none"> • Risk of false positives/negatives • Requires structured patient education • Lack of robust validation frameworks
Mobile health apps & Bluetooth-enabled ECG	<ul style="list-style-type: none"> • Real-time recording and transmission to healthcare providers • Cost-effective for community screening • Effective in detecting subclinical AF 	<ul style="list-style-type: none"> • Limited standardized validation • Data security and privacy concerns
Patch-based ECG	<ul style="list-style-type: none"> • Longer recording compared to Holter • Lightweight, comfortable, improves patient adherence • High yield in paroxysmal arrhythmia detection 	<ul style="list-style-type: none"> • Limited reusability • Relatively more expensive • May cause skin irritation
Implantable Loop Recorders (ILRs)	<ul style="list-style-type: none"> • Provides continuous multi-year recording • Superior in unexplained syncope evaluation • Gold standard for cryptogenic stroke and rare arrhythmias 	<ul style="list-style-type: none"> • Requires invasive implantation • High device cost
Cardiac implant devices (Pacemakers, ICDs) with integrated monitoring	<ul style="list-style-type: none"> • Continuous automated rhythm monitoring • Wireless data transmission • Reduces complication risks • Remote follow-up lowers healthcare costs 	<ul style="list-style-type: none"> • Applicable only to patients with devices • Potential for technical malfunction or transmission issues

ECG: Electrocardiography, ICD: Implantable cardioverter defibrillator, EHR: Electronic health records, AF: Atrial fibrillation.

to its noninvasive profile and superior mapping capability, EWI holds significant promise as a diagnostic adjunct and as a tool for guiding interventional planning in arrhythmia management.

Body surface mapping (BSM) is an advanced technique that acquires cardiac electrical signals from over 200 electrodes positioned on the torso, enabling high-resolution characterization of cardiac activation patterns.²⁴ Electrocardiographic imaging (ECGI) builds upon BSM by integrating these surface signals with CT data to reconstruct a three-dimensional map

of epicardial electrical activity. This approach allows for detailed delineation of arrhythmogenic circuits, including reentrant pathways underlying ventricular tachycardia.²⁵ A growing body of evidence highlights the utility of ECGI in arrhythmia diagnosis, risk prediction, and therapeutic decision-making.^{5,26-31} Notably, ECGI holds considerable promise for the pre-procedural assessment of complex arrhythmias, particularly those that are multifocal or transient in nature.

Three-dimensional electroanatomic mapping plat-

forms (e.g., CARTO, EnSite, Rhythmia) integrate anatomical and electrophysiological data by constructing detailed three-dimensional reconstructions of cardiac chambers. These systems permit simultaneous visualization of structural anatomy and electrical activation, offering critical guidance in the management of complex atrial tachyarrhythmias and scar-mediated ventricular tachycardia (VT). Their application spans both invasive electrophysiologic studies (EPS) and catheter ablation procedures. Importantly, in patients undergoing ICD implantation, pre-procedural ablation has been associated with prolonged freedom from refractory ventricular fibrillation/tachycardia ep-

isodes.³² Beyond their clinical utility, these systems minimize radiation exposure while enabling millimeter-level precision in catheter navigation.

Next-generation multipolar catheters (e.g., PentaRay, HD Grid), incorporating a larger array of electrodes, allow for simultaneous acquisition of signals from multiple sites. This innovation not only reduces overall mapping time but also enhances spatial resolution, yielding a more comprehensive characterization of arrhythmogenic substrates.³³

Pros and cons of advanced electrophysiology and mapping techniques are presented in Table 2.

Method	Pros	Cons
Electrophysiological Study (EPS)	<ul style="list-style-type: none"> • Gold standard for arrhythmia diagnosis • Allows direct evaluation of conduction pathways • Enables therapeutic interventions • High diagnostic and therapeutic precision 	<ul style="list-style-type: none"> • Invasive procedure • Risk of procedural complications • Requires specialized equipment and expertise
Electromechanical Wave Imaging (EWI)	<ul style="list-style-type: none"> • Noninvasive, high-resolution mapping • Superior accuracy in localizing arrhythmogenic substrates • Outperforms ECG in identifying accessory pathways • Useful for guiding interventional planning 	<ul style="list-style-type: none"> • Still emerging, limited widespread availability • Requires advanced ultrasound technology • Limited large-scale validation
Body Surface Mapping (BSM)	<ul style="list-style-type: none"> • High-resolution mapping from >200 electrodes • Provides detailed electrical activation patterns • Noninvasive method 	<ul style="list-style-type: none"> • Complex setup and patient preparation • Limited accessibility outside specialized centers
Electrocardiographic Imaging (ECGI)	<ul style="list-style-type: none"> • Combines BSM with CT for 3D epicardial mapping • Detailed visualization of arrhythmogenic circuits • Valuable for pre-procedural planning of complex arrhythmias 	<ul style="list-style-type: none"> • Requires CT (radiation exposure, cost) • Computationally intensive • Limited availability
3D Electroanatomic Mapping Systems	<ul style="list-style-type: none"> • Integrates anatomical and electrical data • Provides millimeter-level catheter navigation • Reduces radiation exposure • Improves ablation outcomes, especially in VT/atrial tachycardia 	<ul style="list-style-type: none"> • Expensive equipment • Invasive use during EPS/ablation • Requires significant operator expertise
Next-generation Multipolar Catheters	<ul style="list-style-type: none"> • Allows simultaneous signal acquisition from multiple sites • Enhances spatial resolution • Reduces mapping time • Improves characterization of arrhythmogenic substrates 	<ul style="list-style-type: none"> • Invasive tool • Higher device cost • Limited to interventional settings

ECG: Electrocardiography, CT: Computerized tomography, 3D: Three-dimensional, VT: Ventricular fibrillation, EPS: Electrophysiological study.

GENETIC APPROACHES IN ARRHYTHMIA DIAGNOSIS

A subset of cardiac arrhythmias arises from inherited conditions, including ion channelopathies, structural protein mutations, and familial cardiomyopathies. Genetic analyses have emerged as pivotal tools, offering diagnostic, prognostic, and therapeutic guidance in these patients.³⁴ For instance, in a cohort of survivors of unexplained cardiac arrest, pathogenic variants were identified in approximately 10% of cases, predominantly within cardiomyopathy-associated genes.³⁵ A wide spectrum of genetic variants has been implicated in arrhythmogenesis, and international societies now advocate their consideration in screening and risk stratification protocols.^{34,36-38} Beyond their role in guiding clinical management, genetic testing contributes to cascade family screening and personalized risk assessment, thereby advancing precision medicine in arrhythmia care.

Genetic mutations and variants influence not only arrhythmia susceptibility and treatment strategies but also interindividual variability in pharmacologic response. Polymorphisms in drug-metabolizing enzymes (e.g., CYP2D6, CYP3A4) and ion channel genotypes are particularly relevant for predicting therapeutic efficacy and adverse drug reactions.³⁹ While ongoing research continues to advance the field of genetics-driven personalized therapy, its translation into routine clinical practice remains in its infancy.

MACHINE LEARNING IN ARRHYTHMIA DIAGNOSIS

Artificial intelligence (AI) and machine learning (ML) have recently emerged as transformative technologies in cardiovascular medicine, particularly for analyzing large-scale biomedical datasets. In the context of arrhythmia diagnosis, these approaches hold considerable promise for augmenting sensitivity and specificity beyond the capabilities of conventional methods.

ML algorithms have demonstrated high accuracy in classifying arrhythmias such as atrial fibrillation, VT, bradycardia, and premature beats using standard ECG data. Among these, convolutional neural networks (CNNs) are especially noteworthy for their capacity to autonomously extract discriminative features from raw ECG signals, thereby enhancing diagnostic performance.⁴⁰⁻⁴² Furthermore, deep learning frameworks have shown robust performance in differentiating ar-

rhythmias, congestive heart failure, and normal sinus rhythm, underscoring their potential clinical utility.⁴¹⁻⁴⁴

Deep learning architectures, trained on millions of ECG recordings, have demonstrated diagnostic accuracy comparable to—or even surpassing—that of expert clinicians. When embedded within portable ECG devices, these systems are poised to revolutionize real-time arrhythmia detection and monitoring.¹⁰

Beyond ECG, data streams from electronic health records (EHRs), wearable technologies, and continuous monitoring platforms can be processed by AI algorithms and seamlessly integrated into clinical decision support systems. This integration has the potential to substantially augment clinical decision-making. In acute care settings such as emergency departments and intensive care units, as well as in home-based monitoring, automated arrhythmia detection and alerting systems can provide timely support to physicians, thereby improving efficiency and optimizing resource utilization.

Limitations and Ethical Considerations

The integration of artificial intelligence (AI) previously explained into clinical practice offers clear advantages—most notably gains in diagnostic speed and accuracy—but also raises complex challenges, including algorithmic bias, opacity of decision-making processes, data privacy concerns, and unresolved questions of legal accountability.⁴⁵ Inadequate representation within training datasets may yield erroneous outputs for specific patient subgroups, thereby exacerbating disparities in healthcare. The “black-box” nature of deep learning models further undermines clinician confidence, while reliance on vast repositories of personal health data amplifies ethical and privacy risks. Progress in explainable AI is therefore essential to enhance transparency and foster trust. Equally pressing are medico-legal uncertainties regarding responsibility when AI-assisted recommendations lead to adverse outcomes, which may hinder adoption. Resistance from healthcare professionals and unsuccessful attempts at workflow integration underscore the necessity of careful, regulation-driven, and ethically informed implementation strategies. Ultimately, sustainable incorporation of AI into patient care will demand not only technological innovation but also organizational restructuring, economic alignment, and robust frameworks for reimbursement, regulation, and standardization.

Pros and cons of artificial intelligence and machine learning in arrhythmia diagnosis are presented in Table 3.

CONCLUSION

Over the past decade, technological innovations in arrhythmia diagnostics have substantially advanced the field, enabling earlier and more precise detection of disease and fostering the evolution of individualized therapeutic strategies. High-resolution electrocardiographic platforms, extended ambulatory monitoring devices, artificial intelligence–driven algorithms, advanced imaging modalities, and genetic profiling have collectively expanded diagnostic capabilities beyond the boundaries of conventional approaches.

Nevertheless, the effective integration of these advances into routine clinical practice remains contingent upon overcoming critical challenges, including data security, disparities in access, algorithmic transparency, and cost-effectiveness. Failure to address these barriers may limit the full realization of their transformative potential.

Looking ahead, diagnostic paradigms are anticipated to evolve toward multidisciplinary, data-informed, and patient-centered frameworks. AI-enabled systems, in particular, are poised to play a pivotal role not only in diagnosis but also in shaping preventive health strategies. Accordingly, the digital revolution in arrhythmia diagnostics is likely to remain among the most dynamic and promising frontiers in contemporary cardiology.

Table 3. Artificial intelligence and machine learning in arrhythmia diagnosis: pros and cons.

Aspect	Pros	Cons
Diagnostic Accuracy	<ul style="list-style-type: none"> • High accuracy in classifying AF, VT, bradycardia, premature beats • CNNs autonomously extract features from raw ECG data • Comparable or superior performance to expert clinicians 	<ul style="list-style-type: none"> • Dependent on the quality and representativeness of training datasets • Risk of poor generalization across diverse populations
Clinical Utility	<ul style="list-style-type: none"> • Real-time arrhythmia detection when integrated into portable ECG devices • Effective in distinguishing arrhythmias, CHF, and sinus rhythm • Potential to improve decision-making in EDs, ICUs, and home monitoring 	<ul style="list-style-type: none"> • Limited clinicians’ trust due to the “black-box” nature of deep learning • Resistance to adoption in clinical workflows
Integration with Health Data	<ul style="list-style-type: none"> • Can combine ECG, EHR, and wearable data streams • Enhances clinical decision support systems • Improves efficiency and optimizes resource use 	<ul style="list-style-type: none"> • High demand for large-scale data repositories • Data privacy and security concerns
Ethical & Legal Aspects	<ul style="list-style-type: none"> • Potential for standardization and improved equity if designed well • Explainable AI research offers promise for transparency 	<ul style="list-style-type: none"> • Algorithmic bias may worsen disparities • Lack of explainability reduces clinician confidence • Legal accountability in
Implementation	<ul style="list-style-type: none"> • Scalable across healthcare systems • Supports population-wide monitoring 	<ul style="list-style-type: none"> • Requires regulation, reimbursement frameworks, and workflow integration • Risk of unsuccessful adoption without systemic restructuring

AF: Atrial fibrillation, VT: Ventricular fibrillation, CNN: Convolutional neural networks, ECG: Electrocardiography, CHF: Chronic heart failure, ED: Emergency department, ICU: Intensive care unit, EHR: Electronic health records.

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