ISSN No: 2456-2165 https://doi.org/10.38124/ijisrt/25jul1889

Electric Frontiers: Innovations in Cardiac Electrophysiology and Arrhythmia Management

Amulya Yellamilli[1]; Bhuvaneswari Kalijavedu Ravi[1]; Deexitha Mudigonda[1]; Nabilah Subahani[2]; Hrithik Chandhar[2]; Zahra[3]

[1]Faculty of Medicine, School of Health Sciences and Public Health, University of Georgia, Tbilisi, Georgia
[2]Faculty of Medicine, Tbilisi State Medical University, Tbilisi, Georgia
[3]Faculty of Medicine, Ivane Javakishvili Tbilisi State University, Tbilisi, Georgia

Publication Date: 2025/08/07

Abstract: Arrhythmias remain a major hurdle to healthcare systems, especially atrial fibrillation (AF) and ventricular tachyarrhythmias as they pose significant risk for stroke and sudden cardiac death (SCD). Post-MI scars pose a risk for ventricular tachycardias (VTs) development due to re-entry of electric signals back into the scar tissue. Recent advancements in the field of cardiac electrophysiology enables detection and management of arrhythmias. Novel risk stratification methods such as ABC-stroke score have demonstrated higher accuracy in predicting risk of stroke in AF. Amulet implants have been recently approved as an alternative for oral anticoagulants. Innovations like pulsed field ablation (PFA) have provided a safer, tissue selective approach in managing arrhythmias. Implantable Cardioverter-Defibrillators (ICDs) along with catheter ablation (CA) techniques marked to be practical therapy for recurrent VT. Artificial Intelligence (AI) powered algorithms are utilized for interpretation of electrocardiograms (ECGs), which is more sensitive and accurate. Remote monitoring (RM) is a cornerstone for modern arrhythmia management. It includes smartwatches, patch-based ECG monitoring, and implantable loop recorders. This enables for real time monitoring, aids in early diagnosing and intervention. Robotic magnetic guided navigation during CA can overcome complex procedural complications and treat arrhythmias. Clinical trials in gene therapy show promising results in offering new scope of managing arrhythmias.

This review highlights the recent innovations in detecting and managing cardiac arrhythmias, marking a shift towards more of a technological driven approach.

Keywords: *Cardiac Arrhythmias; Atrial Fibrillation; Implantable Loop Devices; Pulsed Field Ablation; Ventricular Arrhythmias; AI-Enhanced Ecgs; Wearable Devices.*

How to Cite: Amulya Yellamilli; Bhuvaneswari Kalijavedu Ravi; Deexitha Mudigonda; Nabilah Subahani[2]; Hrithik Chandhar; Zahra (2025). Electric Frontiers: Innovations in Cardiac Electrophysiology and Arrhythmia Management. *International Journal of Innovative Science and Research Technology*, 10(7), 3186-3195. https://doi.org/10.38124/ijisrt/25jul1889

I. INTRODUCTION

Cardiac arrhythmias occur as a result of heart's atypical electric conduction which leads to abnormal heart rhythm. They can generally manifest with a slow heart beat (below 60 beats per minute), known as bradyarrhythmias, or with aberrant fast rhythm (above 100 beats per minute), known as tachyarrhythmias. They are further divided into different classification such as supraventricular and ventricular arrhythmias (VAs), based on their origin [1]. These subtypes include various kinds, mainly ventricular fibrillation (VF), ventricular tachycardia (VT) and atrial fibrillation (AF). Within them, AF continues to be the most prevalent cardiac arrhythmia [2].

AF is frequently accompanied with various comorbidities, mainly diabetes, hypertension and obesity. Without proper treatment it can lead to various complications, commonly heart failure, venous thromboembolism and stroke [3]. Therefore it requires early detection and successful management to extend patients' survivability. Reports from 2021 had recorded an astonishing 52.55 million cases and these numbers are expected to rise annually [4].

ISSN No: 2456-2165 https://doi.org/10.38124/ijisrt/25jul1889

The leading cause of sudden cardiac deaths (SCDs) are life-threatening VAs [5]. It is one of the major reasons for mortality worldwide accounting for about 25% deaths [6].

Traditional diagnostic procedures like electrocardiography (ECG), and prolonged Holter monitoring are being replaced by more technological driven wearable devices and remote monitoring (RM) systems [7]. Wearable devices such as smartwatches with ECG capability and continuous patch monitors provide features for prolonged rhythm monitoring and are able to detect either asymptomatic or intermittent arrhythmias in non-clinical environments [8]. These diagnostic innovations are further complemented by procedural advancements. Catheter ablation (CA) is one major advance that involves the ablation of targeted tissue responsible for an abnormal rhythm. Pulsed field ablation (PFA) has recently emerged as a safer and most expedient alternative to traditional thermal methods, with reduced complications which includes esophageal injury [9].

Furthermore, artificial intelligence (AI) has begun to impact the field of electrophysiology. Modern day technology offers valuable capabilities in detecting silent AF in asymptomatic high-risk populations in order to help prevent strokes and reduce costs of care in the long-term. Researchers are now able to train machine learning algorithms on extremely large datasets of ECGs to detect even subtle abnormalities in rhythm and predict risk of arrhythmia with improved precision over standard clinical tools [10].

Recent advances and improvements are altering the way that we approach arrhythmias in the acute and chronic care settings. We are advancing towards a personalized and technology based approach to care, compared to traditional methods. This review will focus on diagnostic innovations, new ablation techniques, modern device therapies, and future technologies shaping the next era of electrophysiology.

II. RECENT ADVANCEMENTS IN ARRHYTHMIAS

A. *Traditional Monitoring and Management*

Cardiac arrhythmia is diagnosed by observation of ECG, blood pressure and symptomatic presentation of palpitations, dizziness and fatigue. It is treated with implantable cardioverter defibrillator (ICD) -single or dual chambered, cardiac ablation, permanent pacemaker (PPM), antiarrhythmic medications like moricizine, flecainide, and encainide [11]. Although these modalities and methods are reliable to some extent, the development of AI technology and other developments in diagnostic techniques show promise for improved detection and treatment.

B. *Advances in Diagnosis*

The apple heart study and the FitBit heart study was found to have a 84% and high 98.2% positive predictive value for concurrent AF respectively. This accessible technology helped diagnose AF lasting greater than 30s in at least 34% of wearers proving to be a reliable first line indication of arrhythmias [12]. Machine learning (ML) algorithms trained with existing samples where a fixed length of ECG segments were analyzed and interpreted. Certain algorithms are proficient in detecting minute changes in ECGs, aiding in identifying patients at risk of arrhythmias and detects paroxysmal AF recurrence subsequent to pulmonary vein isolation (PVI). The ML model developed by Shade et al demonstrated a validation AUC of 0.82 in their cohort study [13,14].

Continuous ECG monitoring with implantable loop devices (ILDs) helps in detection of silent AF, especially as a follow up in patients with cryptogenic stroke. Anticoagulant therapy in population at risk for stroke can be tailored, and prevent excessive bleeding. ILDs have a battery life of 3 years and have the ability to keep a track of ECG snapshots. ILDs demonstrate fewer errors as they are able to monitor the heart rhythm subcutaneously [15].

C. *Application of Imaging Techniques in Ablation Procedure*

Incorporating imaging studies such as cardiac magnetic resonance (CMR) and intracardiac echocardiography (ICE) had proved to aid during the ablation procedure. Studies with CMR during the procedure have proven to be successful as CMR helped to visualize the arrhythmogenic substrate for accurate ablation [16]. ICE has enabled 3D remodeling of cardiac anatomy in real time making it efficient in early detection of complications associated with AF ablation procedure. It also enables safe entry into the left atria and observes its contact with the chamber surface [17]. The reliable operating of CA pivots on the efficacy of the mapping systems. 3D Mapping systems like CARTO, Rhythmia, NavX/EnSite have demonstrated high success rates in CA, for both AF and VF [18].

III. EMERGING STRATEGIES FOR ATRIAL FIBRILLATION

A. *Atrial Fibrillation Risk Factors, Difficulties and Healthcare Expenditure*

People with non-valvular AF have a three to five times higher risk of an ischemic stroke due to a disruption of blood flow in the left atrial appendage (LAA), which promotes the formation of a localized thrombus [19]. The combined impact of serious consequences and elevated incidence puts a significant strain on health care systems; the estimated expense of treating AF is $28.4 billion [20]. Even if obstructive sleep apnea (OSA) was taken into account, there was still a correlation between a greater body mass index (BMI) and an increased risk of AF (OR 1.40, 95% CI 1.30–1.51; $p < 0.001$) [21]. There is evidence that OSA has a major impact on the pathophysiology of AF [20]. One of the significant modifiable risk factors for AF is obesity. A 5 kg weight loss has shown to reduce the risk of AF by 12% on average; nevertheless, a 4% rise in the probability of AF is associated with a one-unit rise in

ISSN No: 2456-2165 https://doi.org/10.38124/ijisrt/25jul1889

BMI. This indicates how important it is to control body weight as an AF management strategy [22].

B. Risk Scores for Stroke Prevention

Since the majority of treatments have utilised the CHA_2DS_2-VASc(Congestive Heart Failure, Hypertension, Age ≥75 years (doubled), Diabetes Mellitus, Prior Stroke or Transient Ischemic Attack or Thromboembolism (doubled), Vascular Disease, Age 65 to 74 years, Sex Category) scale to demonstrate their effectiveness, it is typically the recommended score and is seen to be the most proven [23]. The ABC-stroke analysis takes into account health history, age, and biological markers (NT-proBNP and high-sensitivity TnT or TnI) to determine the potential risk of stroke or systemic embolism (SE) in AF. As a consequence, the application of the ABC-stroke score may help promote high-accuracy medical techniques for AF stroke prevention [24].

C. Devices for Closing the Left Atrial Appendage as An Alternative to Anticoagulation

Individuals with nonvalvular AF may benefit from interventional closure of the LAA as an alternative to over a long period anticoagulation therapy to lower the probability of stroke [19]. The AMULET IDE experiment had concluded that the Amulet implant did not require an oral anti-coagulation (OAC) therapy following the procedure, in contrast to Watchman 2.5 [25].

D. Results of Clinical Trials Comparing Rate and Rhythm Control

Early rhythm control has become common. The best primary invasive procedure for non-long-standing persistent AF cases is CA, which is supported by recent research [26]. For those suffering from AF who were diagnosed within the last 12 months, the Early Treatment of Atrial Fibrillation for Stroke Prevention Trial (EAST-AFNET 4) demonstrated that an organised approach to early rhythm control was linked to a reduced risk of cardiac events than standard treatment [27]. Patients who were randomly assigned in the EAST-AFNET 4 trial to early rhythm control treatment reported minimal cardiac issues, suggesting that rhythm control therapy might further decrease events related to cardiovascular disease [28]. The current EAST-AFNET 4 trial, which used consistent anticoagulation therapy and CA, demonstrated that early rhythm management substantially decreased stroke and cardiovascular events in comparison to rate control. In contrast, the previous Atrial Fibrillation Follow-up Investigation of Rhythm Management (AFFIRM) trial used outdated approaches such as controlled anticoagulation medications and no CA, which indicated no beneficial effects of early rhythm control [29].

E. Ablation Methods: Radiofrequency, Cryoablation, and Pulsed Field Ablation

According to Mililis et al.'s randomised controlled study, radiofrequency Ablation (RFA) and Cryo-balloon Ablation (CBA) have similar recurrence rates. Although CBA was associated with a shorter operation duration than RFA, there was no significant difference in the fluoroscopy period or the rate of complications [30]. As a potential substitute to the existing ablation techniques, such as radiofrequency and cryoablation, PFA is an innovative procedure that has become quite popular for managing AF. The safety and efficacy profile has been similar in recent clinical studies in comparison to radiofrequency and cryoablation. Early results from the Volt-AF IDE study show that the Volt PFA system is namely dependable and effective for managing both paroxysmal and chronic AF [31]. PFA's more tissue-selective ablation method may lessen the possibility of damaging collateral tissues underlying diseases, including persistent phrenic nerve numbness, atrioesophageal fistula, and pulmonary vein (PV) stenosis, while still being effective when compared to thermal approaches [32]. Throughout the whole ADVANTAGE AF trial series, PFA of persistent AF with the pentaspline catheter was linked to a reduced adverse event rate and an improved 1-year efficacy that was comparable to the prior reported result of PV isolation for paroxysmal AF [33].

Table 1 compares key ablation techniques used in AF management based on their mechanisms, benefits, limitations and supporting evidence.

Table 1 Comparison of Ablation Techniques in Atrial Fibrillation

Ablation Method	Mechanism	Advantages	Limitations	References
Radiofrequency Ablation (RFA)	Thermal energy to ablate tissue	Widely used; effective	Longer procedure duration; potential for collateral damage	[30]
Cryo-ballon Ablation (CBA)	Freezing to isolate pulmonary veins	Shorter procedure time than RFA	Similar recurrence and complication rates	[30]
Pulsed Field Ablation (PFA)	Electroporation with high-voltage pulses	Tissue-selective; reduced esophageal and phrenic nerve injury	Limited long-term outcome data	[9], [31], [32], [33]

ISSN No: 2456-2165 https://doi.org/10.38124/ijisrt/25jul1889

F. Lifestyle Changes in AF Management

RACE-3 trial found that frequent exercise and diet limitation in combination with the most effective medicine assisted patients with persistent AF in preserving their sinus rhythm. Taking it all into consideration, this underlines the significance of weight loss as a feasible risk factor of AF [21].

G. Combining Surgical Procedures with Ablation Protocols

The hybrid AF ablation technique is a combination of the advantageous factors relating to both percutaneous endocardial surgery and epicardial surgery. Some additional benefits of hybrid therapy are: The electrophysiologist (EP) can produce high-quality endocardial images to demonstrate the substrate, and the surgeon can easily see the three-dimensional orientation of the heart and create permanent epicardial lesions. Through this, people with chronic AF are advised to be aware of the success rates of hybrid AF ablation surgery [34]. Moreover, surgery ablation (SA) can potentially extend the longevity of life and prevent AF related complications [26].

IV. VENTRICULAR ARRHYTHMIAS AND SUDDEN CARDIAC DEATH

A. Ventricular Arrhythmias Associated with Ischemic Cardiomyopathy

SCD around the world is majorly caused by VAs such as VT and VF.

Absence of early detection and treatment of VAs can cause hemodynamic collapse, mainly in people with impaired heart function. VAs and SCD are mainly observed in patients with a reduced left ventricular ejection fraction (LVEF), specifically those with ischemic cardiomyopathy (ICM) [35].

B. Pathophysiology and Risk in Low Ejection Fraction

Patients with reduced LVEF, mainly those with ICM, have a higher risk of VAs and SCD. Post–myocardial infarction (MI) scar tissue disrupts usual electrical conduction and creates re-entrant circuits that predispose to sustained VT [36]. The risk of SCD goes up when LVEF drops below about 35%, which supports proactive preventive measures like putting in an ICD in this high-risk group [35,37].

C. Role of ICDs and VT Ablation

Implantable Cardioverter-Defibrillators (ICDs) represent the standard of care for preventing SCD by detecting and terminating malignant VAs in patients with low LVEF and structural heart disease [38]. Beyond ICDs, CA has become an important adjunctive therapy, particularly when VTs are recurrent or refractory to antiarrhythmic drugs [37]. A key target for VT ablation in post-MI patients is the border zone of myocardial scars, where slow conduction creates critical isthmuses for re-entrant VT circuits. Modern substrate-based ablation strategies using high-density electroanatomic mapping, help precisely identify local abnormal ventricular activities (LAVAs) and eliminate arrhythmogenic substrates without needing to induce clinical VT in every case. A prospective cohort using high-density mapping in ischemic VT reported LAVA elimination in 93.8% and VT non-inducibility in 60%, with 90% free of appropriate ICD shocks at one year and 85% at two years [38]

D. Success Rates in Idiopathic and Outflow Tract VT

Idiopathic VTs often arising from the right ventricular outflow tract (RVOT) in structurally normal hearts typically exhibit focal automaticity rather than scar-based re-entry. A single-center study describing idiopathic PVC/VT ablation found 89% procedural success and sustained 82% success, along with LV function improvement in patients with PVC-induced cardiomyopathy RVOT and other common sites of idiopathic VT benefit from excellent responsiveness to ablation due to the focal substrate and absence of scarring [35,39].

E. Inherited Arrhythmia Syndromes and Genetic Testing

Inherited channelopathies including Brugada syndrome, Long QT syndrome (LQTS), and catecholaminergic polymorphic VT (CPVT) risk of young individuals without structural heart disease to malignant VAs and SCD. These syndromes come from pathogenic variants in ion-channel genes such as SCN5A in Brugada; KCNQ1, KCNH2, SCN5A in LQTS; RYR2, CASQ2 in CPVT, leading to dysfunctional repolarization or calcium handling [40].

Genetic testing is essential for diagnosis, family screening, and risk stratification, guiding decisions on prophylactic ICD implantation, particularly in high-risk variants and symptomatic individuals. Beta-blockers remain fundamental therapy for inherited syndromes. People present at high risk utilize ICDs for either primary or secondary prevention [40].

F. Arrhythmogenic Right Ventricular Cardiomyopathy

Individuals who possess arrhythmogenic right ventricular cardiomyopathy (ARVC) have fibro-fatty tissue displacing the RV myocardium, which makes it easier for VT to occur, especially in athletes. ARVC carries a high SCD risk and due to its progressive nature, patients will often need close follow-up with serial imaging, ECG, and electrophysiological assessment. ICD implantation is often needed for secondary or primary prevention instead of long-term VT or a previous cardiac arrest [41,42].

G. Electrophysiological Evaluation Post-Cardiac Arrest

Invasive electrophysiology (EP) studies, in survivors of cardiac arrest, helps to differentiate ischemic from primary arrhythmic causes by assessing inducibility of VT/VF, substrate characterization, and mapping. EP testing guides subsequent therapies including targeted ablation or ICD placement based on underlying mechanisms and risks. This personalized EP-guided approach improves outcomes and decreases the recurring risk of arrhythmic events [35,38].

ISSN No: 2456-2165 https://doi.org/10.38124/ijisrt/25jul1889

V. CARDIAC DEVICES

A. Leadless Pace Makers

Although pacemakers and defibrillators propose a risk of fungal endocarditis [43], recent developments such as leadless permanent pacemaker (LPPM) allows patients with difficult comorbidities like limited upper venous access, recurrent or bilateral permanent pacemaker (PPM) infections, kidney failure and limited venous return to receive the benefits of transvenous implanted leads without its shortcomings. It serves as an alternative epicardial approach to patients with AF, atrioventricular (AV) block, and sinus node disease and in patients with syncope who do not show frequent ventricular pacing.

The LEADLESS trial, which analyzed LLPMs and transvenous permanent pacemakers (TV-PMs) had a comprehensive complexity-free rate of 94%, while the Leadless II trial demonstrated only 6.7% serious negative events [44]. A 2024 meta-analysis favoured LPPMs over TV-PMs due to significantly decreased likelihood of complications, dislodgement and pneumothorax. Despite this, it was found that LPPMs were unfortunately associated with an increased prospect of pericardial effusion and cardiac tamponade [45].

The Micra AV is a successor to the micra and was approved by the FDA in 2020. The Micra AV, equipped with movement sensors located within it, is placed in the RV, and is capable of making precise modifications and coordinates the ventricular pacing with atrial movement. This allows synchronous AV pacing [44].

B. Subcutaneous Implantable Defibrillators

The subcutaneous ICDs (S-ICDs) are entirely situated outside of the chest. This substantial difference allows for easy extraction, reduces procedural complexity and greatly reduces the prospect of lead fractures, systemic infections and the unpleasant complications associated with transvenous ICDs (TV-ICDs). Consequently, the S-ICDs is preferred in young patients with genetic heart diseases, hypertrophic cardiomyopathy (HCM), dilated cardiomyopathy (DCM), and genetic arrhythmia syndromes and in patients with an inaccessible transvenous route.

Present day large cohort prospective trials studies and registries demonstrate astounding short and medium term safety associated with low inappropriate shock rate. This confirmed the role of S-ICDs as a valuable alternative to TV-ICDs [46].

C. Bundle Pacing Techniques

His-bundle pacing (HBP) and left bundle pacing (LBP) are developing novelty for delivering cardiac resynchronization therapy (CRT) in heart failure (HF) patients with left bundle branch block (LBBB). In 2020, a clinical trial comprising 24 patients found HBP to be superior to biventricular epicardial (BiV-epi) pacing and biventricular endocardial (BiV-endo) pacing, providing better synchronization of heart muscles [47]. An observational study has revealed that patients undergoing CRT by left bundle branch area pacing (LBBAP) have decreased incidence of VT/VF compared to other methods such as biventricular pacing (BVP), demonstrating a p value of 0.007 [48].

The table below summarizes recent advancements in cardiac device technologies, highlighting their clinical applications, benefits and associated risks.

Table 2 Summary of Modern Cardiac Devices and Their Clinical Impact

Device/Technique	Purpose	Clinical Benefit	Complications / Risks	References
Leadless Pacemakers (LPPM)	Alternative to transvenous leads	94% complication-free rate; ideal for patients with venous access issues	Slightly increased risk of tamponade	[44], [45]
Micra AV	Synchronised AV pacing	Atrial sensing with motion sensors for improved synchrony	Still in refinement	[44]
Subcutaneous ICD (S-ICD)	SCD prevention without venous leads	Reduced infection and lead complications; suited for younger/genetic cases	Limited data in structural disease	[46]
His-Bundle / LBB Pacing	CRT in HF patients with LBBB	Superior electrical synchrony; ↓ VT/VF incidence	Need for more long-term outcomes	[47], [48]

VI. EMERGING NON-PHARMACOLOGICAL THERAPIES

A. Advancements in Ablation Techniques.

Emerging therapies include cryoablation, which produces lesions in heart tissue using extremely low temperatures, thereby gaining recognition as a less invasive alternative to conventional RFA, because it reduces the duration of the procedure, risk of AF recurrences, and cardiac complications such as pericardial effusion, cardiac tamponade, and vascular issues [1,49]. The Cryoballoon is remarkable for isolating pulmonary veins, followed by a second-generation laser balloon, as it provides precision and accuracy, thereby controlling the procedure and ensuring safety and efficacy [1].

ISSN No: 2456-2165 https://doi.org/10.38124/ijisrt/25jul1889

B. Innovations in Gene Therapy

Advances in gene therapy facilitate the identification of predisposition genes for specific arrhythmias, inform prevention strategies, and direct targeted screenings. The clustered regularly interspaced short palindromic repeats (CRISPR/ Cas9 system) has been used for therapeutic somatic genome editing of the heart [1,50].

C. Neuromodulation and Renal Denervation Therapy

Emerged as an innovative therapy for the treatment of AF, neurocardiac axis modulation has shown promise. Includes various techniques: blockade of sympathetic ganglia, renal denervation, ganglionate plexi ablation, stellate ganglion block, vagal nerve stimulation at low level, and pharmacological treatment [51].

Renal denervation (RDN) involves ablation of both the renal sympathetic efferent and afferent nerves that interact with the central nervous system, developed for treating resistant hypertension. Studies on comparing the effectiveness of RDN in conjunction with CA and PVI versus CA and PVI alone revealed that using both RDN and PVI together is more effective and increases the chances that a patient will be free of AF at 12 months, especially for patients who have uncontrolled hypertension and AF [52,53].

D. Virtual and 3d Printing for Patient-Specific Planning

Studies on virtual ablation simulation facilitate the creation of patient-specific models, enabling the estimation of ablation targets, non-inducibility confirmation, and a decrease in procedure time [54].

Patient-specific 3D models in conjunction with cardiac imaging techniques provide assessment of anatomy and functional valvular heart conditions, lowering procedure time, implant device fit and placement, safety, and efficacy [55].

E. Baroreceptor Activation Therapy

A case report on the use of baroreceptor activation therapy (BAT) for advanced heart failure with a history of arrhythmia, along with improvement of the heart condition outcome, also showed anti-arrhythmic effects [56]. Another case report on a new approach to the treatment of advanced heart failure reported a notable reduction in episodes of arrhythmia, with a decrease in need for ICD therapy, showing promising options in the management of arrhythmia episodes [57].

VII. FUTURE DIRECTIONS

A. Apple Watches

Recent advances in wearable devices are remarkable for their persistent monitoring with reduced limitations and early detection of abnormal rhythms, particularly as a Key factor for detecting arrhythmias that are asymptomatic and sporadic. Advances in wearable devices such as smartwatches have the potential to accurately detect various arrhythmias by identifying abnormal changes in heart rate and allowing users to initiate a manual ECG recording through the device, which is then reviewed by medical practitioners [58].

Bogár et al. conducted a systematic review that included various smartwatches and revealed that Apple Watches are popular and reliable device for detecting arrhythmias, especially AF [59].

B. Remote Monitoring

RM with the use of cardiac implantable electronic devices (CIEDs) provides risk stratification and early detection of arrhythmias, including VAs, AF, premature atrial complexes (PACs), and high-frequency atrial events (AHRE), as well as heart failure. RM can provide timely decisions about rhythm management, anticoagulation, and device optimization, along with improved safety, cost savings, reduced hospital visits, and high patient satisfaction compared to in-office follow-ups [60].

The Smart Emergency Medical System-Health Internet of Things (SEMS-HIOT), a new RM system, was evaluated and compared with traditional equipment on patients with different arrhythmias by Hedayati Goudarzi et al. SEMS-HIOT is used to collect remote data on vital signs heart rate, oxygen saturation, body temperature and ECG records. The study shows no notable differences in accuracy and reliability for arrhythmia detection when compared to standard devices. SEMS-HIOT can enable the identification of medical emergencies, notify both the emergency medical team and the family members [61].

C. Patch-Based ECG Monitoring

A study conducted by Abdelrazik et al. highlights the increasing role of ECG-based patch monitors in long-term monitoring and the accuracy of arrhythmia detection compared to traditional Holter monitors. Includes various studies and reports that patch monitors have feasibility, high economic value, and are reliable in clinical research fields [58].

ZioPatches can be self-applied by the patient, which records the ECG continuously for up to 14 days, and recognizes AF after an acute stroke more effectively than the Holter monitor [62].

D. Gene Therapy for Fixing Channelopathies

A study by Wang et al. emphasizes a novel gene therapy approach that utilizes SCN10A short (S10s) gene therapy to restore conduction and protect against cardiac arrhythmias, carried out on mouse models. The study reported that S10 gene therapy can be effective in treating abnormalities related to cardiac conduction, arrhythmias, enhanced action potential upstroke velocity, and rescued conduction slowing, leading to the prevention of VT [63].

E. Cell Therapy for Post-VT Scar

A study conducted by Park et al. investigated the effect of injecting mesenchymal stem cells (MSC) into the scar border zone on the risk of arrhythmias in an animal model after myocardial infarction (MI), as the ischemic scar can cause potentially fatal VT. The study found that MSC injection has not increased the risk of VT and restoration of Connexin 43 expression with improved signal conduction [64].

F. Robotic and Remote Ablation Procedures

A study by Khairy et al. highlights that vascular distortions and surgical repairs pose challenges that Robotic Magnetic-guided Navigation (RMN) can overcome for CA for arrhythmias in patients with complex congenital heart disease, where manual ablation is not feasible and without specific safety concerns [65].

According to a study by Ijaz et al., although remote magnetic navigation (RMN) has a longer procedure time and a similar freedom from AF recurrence to manual catheter navigation (MCN), it can provide a reduction in fluoroscopy length and decreased complications [66].

VIII. CONCLUSION

As the field of electrophysiology moves towards improved techniques like high-resolution 3D mapping, more recent ablation procedures, and AI-enhanced ECG monitoring, it results in providing more accurate and individualised care. Recent clinical studies have shown PFA as safer and efficient alternative due to its tissue selective nature, along with its ability to manage both chronic and sporadic arrhythmias. Modern risk stratification tools like ABC stroke score, have high accuracy in preventing AF. CRT performed with LBBAP has demonstrated decreased incidence of VT/VF in patients with heart failure (HF). Implantable loop devices and wearable devices are reforming the outlook of arrhythmia detection and cardiac monitoring as they enable for continuous real time monitoring outside clinical setting, allowing early detection of sporadic arrhythmias, which could be overlooked in a clinical setting. Recent innovations in gene editing and cardiac-specific delivery systems have shown a promise in developing a curable approach to inherited cardiac arrhythmias.

These technological and procedural advances had not only improved the outcomes, but also long-term patient care due to reduced arrhythmia recurrence rate and corresponding death. Ongoing trials and further studies are required to optimize and improve their efficacy.

➢ *Declarations*

- *Funding:*

No funding was received for the publication of this article.

- *Conflicts of Interest/Competing Interests:*

The authors declare that they have no conflicts of interest.

- *Ethics Approval:*

Not applicable (this is a narrative review based solely on previously published literature).

- *Consent to Participate:*

Not applicable.

- *Written Consent for Publication:*

Not applicable.

- *Availability Of Data And Material:*

All data referenced are publicly available in the cited literature. No original datasets were generated or analyzed during the writing of this manuscript.

- *Code Availability:*

Not applicable (no software or custom code was used in this study).

- *Authors' Contributions:*

A.Y. conceptualized the study, designed the structure, coordinated the literature review process, and edited the full manuscript.

B.K.R., D.M., N.S., Z., and H.C. contributed to the literature review and drafting of assigned sections.

A.Y. reviewed and finalized the entire manuscript.

All authors read and approved the final version. All data referenced are publicly available in the cited literature. No original datasets were used.

REFERENCES

[1]. Nagpal AK, Pundkar A, Singh A, Gadkari C. Cardiac Arrhythmias and their Management: An In-Depth Review of current practices and emerging therapies. Cureus. 2024. https://doi.org/10.7759/cureus.66549

[2]. Lippi G, Sanchis-Gomar F, Cervellin G. Global epidemiology of atrial fibrillation: An increasing epidemic and public health challenge. Int J Stroke. 2020;16(2):217–221. https://doi.org/10.1177/1747493019897870

[3]. Kornej J, Börschel CS, Benjamin EJ, Schnabel RB. Epidemiology of Atrial fibrillation in the 21st century. Circ Res. 2020;127(1):4–20. https://doi.org/10.1161/circresaha.120.316340

ISSN No: 2456-2165 https://doi.org/10.38124/ijisrt/25jul1889

[4]. Cheng S, He J, Han Y, Han S, Li P, Liao H, et al. Global burden of atrial fibrillation/atrial flutter and its attributable risk factors from 1990 to 2021. EP Europace. 2024;26(7). https://doi.org/10.1093/europace/euae195
[5]. Järvensivu-Koivunen M, Tynkkynen J, Oksala N, Eskola M, Hernesniemi J. Ventricular arrhythmias and haemodynamic collapse during acute coronary syndrome: increased risk for sudden cardiac death? Eur J Prev Cardiol. 2024;31(18):2117–2124. https://doi.org/10.1093/eurjpc/zwae074
[6]. Srinivasan NT, Schilling RJ. Sudden cardiac death and arrhythmias. Arrhythm Electrophysiol Rev. 2018;7(2):111. https://doi.org/10.15420/aer.2018:15:2
[7]. Bokhari SFH, Waseem AB, Raza H, Iqbal A, Javaid S, Idrees B, et al. Advancing cardiac arrhythmia management: The integration of wearable technology and remote monitoring. World J Cardiol. 2025;17(7). https://doi.org/10.4330/wjc.v17.i7.106841
[8]. Lubitz SA, Faranesh AZ, Selvaggi C, Atlas SJ, McManus DD, Singer DE, et al. Detection of atrial fibrillation in a large population using wearable devices: the Fitbit Heart Study. Circulation. 2022;146(19):1415–1424. https://doi.org/10.1161/circulationaha.122.060291
[9]. Reddy VY, Neuzil P, Koruth JS, Petru J, Funosako M, Cochet H, et al. Pulsed field ablation for pulmonary vein isolation in atrial fibrillation. J Am Coll Cardiol. 2019;74(3):315–326. https://doi.org/10.1016/j.jacc.2019.04.021
[10]. Attia ZI, Noseworthy PA, Lopez-Jimenez F, Asirvatham SJ, Deshmukh AJ, Gersh BJ, et al. An artificial intelligence-enabled ECG algorithm for the identification of patients with atrial fibrillation during sinus rhythm: a retrospective analysis of outcome prediction. Lancet. 2019;394(10201):861–867. https://doi.org/10.1016/S0140-6736(19)31721-0
[11]. Fu D. Cardiac arrhythmias: diagnosis, symptoms, and treatments. Cell Biochem Biophys. 2015;73(2):291–296. https://doi.org/10.1007/s12013-015-0626-4
[12]. Babu M, Lautman Z, Lin X, Sobota MH, Snyder MP. Wearable Devices: Implications for precision medicine and the future of health care. Annu Rev Med. 2023;75(1):401–415. https://doi.org/10.1146/annurev-med-052422-020437
[13]. Nagarajan VD, Lee S, Robertus J, Nienaber CA, Trayanova NA, Ernst S. Artificial intelligence in the diagnosis and management of arrhythmias. Eur Heart J. 2021;42(38):3904–3916. https://doi.org/10.1093/eurheartj/ehab544
[14]. Shade JK, Ali RL, Basile D, Popescu D, Akhtar T, Marine JE, et al. Preprocedure Application of Machine Learning and Mechanistic Simulations Predicts Likelihood of Paroxysmal Atrial Fibrillation Recurrence Following Pulmonary Vein Isolation. Circ Arrhythm Electrophysiol. 2020;13(7):e008213. https://doi.org/10.1161/CIRCEP.119.008213
[15]. Bisignani A, De Bonis S, Mancuso L, Ceravolo G, Bisignani G. Implantable loop recorder in clinical practice. J Arrhythm. 2018;35(1):25–32. https://doi.org/10.1002/joa3.12142
[16]. Bauer BK, Meier C, Bietenbeck M, Lange PS, Eckardt L, Yilmaz A. Cardiovascular Magnetic Resonance-Guided radiofrequency ablation. JACC Clin Electrophysiol. 2022;8(2):261–274. https://doi.org/10.1016/j.jacep.2021.11.017
[17]. Kuwahara T. Intracardiac Echocardiography in Catheter Ablation for Atrial Fibrillation: It Is Better to See What You Are Doing? J Atrial Fibrillation. 2015;7(6):1215. https://doi.org/10.4022/jafib.1215
[18]. Bazoukis G, Elkholey K, Stavrakis S, Heist EK, Armoundas AA. Efficacy of commonly used 3D mapping systems in acute success rates of catheter ablation procedures. Heart Int. 2024;18(1). https://doi.org/10.17925/hi.2024.18.1.3
[19]. Lakkireddy D, Thaler D, Ellis CR, Swarup V, Sondergaard L, Carroll J, et al. Amplatzer Amulet Left Atrial Appendage Occluder versus Watchman Device for Stroke Prophylaxis (Amulet IDE): a randomized, controlled trial. Circulation. 2021;144(19):1543–1552. https://doi.org/10.1161/circulationaha.121.057063
[20]. Na J, Garapati SS, Lador A. Obesity and Atrial Fibrillation: A Comprehensive review. Methodist Debakey Cardiovasc J. 2025;21(2):35–43. https://doi.org/10.14797/mdcvj.1516
[21]. Ardissino M, Reddy RK, Slob EAW, Patel KHK, Ryan DK, Gill D, et al. Sleep disordered breathing, obesity and atrial fibrillation: a Mendelian randomisation study. Genes. 2022;13(1):104. https://doi.org/10.3390/genes13010104
[22]. Edpuganti S, Thomas KS, Ponnuri SSA, Tomar RK, Kapuge PH. Obesity and metabolic syndrome: Pathophysiological mechanisms driving cardiovascular risk. Junior Researchers. 2025;3(3):20–35. https://doi.org/10.52340/jr.2025.03.03.03
[23]. Joglar JA, Chung MK, Armbruster AL, Benjamin EJ, Chyou JY, Cronin EM, et al. 2023 ACC/AHA/ACCP/HRS Guideline for the Diagnosis and Management of Atrial Fibrillation: A report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. Circulation. 2023;149(1). https://doi.org/10.1161/cir.0000000000001193
[24]. Xing LY, Diederichsen SZ, Højberg S, Krieger DW, Graff C, Frikke-Schmidt R, et al. The ABC-Stroke Risk Score and Effects of Atrial fibrillation screening on stroke prevention: results from the randomized LOOP study. J Am Heart Assoc. 2024;13(4). https://doi.org/10.1161/jaha.123.032744

ISSN No: 2456-2165 https://doi.org/10.38124/ijisrt/25jul1889

[25]. Frazzetto M, Sanfilippo C, Costa G, Contrafatto C, Giacalone C, Scandura S, et al. Watchman vs. Amulet for Left Atrial Appendage Closure: Current Evidence and Future Perspectives. J Clin Med. 2024;13(16):4651. https://doi.org/10.3390/jcm13164651
[26]. Kowalewski M, Dąbrowski EJ, Kurasz A, Święczkowski M, Raffa GM, Kawczyński M, et al. Surgical ablation of atrial fibrillation with concomitant cardiac surgery. A state-of-the-art review. Eur J Cardiothorac Surg. 2025. https://doi.org/10.1093/ejcts/ezaf187
[27]. Jensen M, Suling A, Metzner A, Schnabel RB, Borof K, Goette A, et al. Early rhythm-control therapy for atrial fibrillation in patients with a history of stroke: a subgroup analysis of the EAST-AFNET 4 trial. Lancet Neurol. 2022;22(1):45–54. https://doi.org/10.1016/s1474-4422(22)00436-7
[28]. Willems S, Borof K, Brandes A, Breithardt G, Camm AJ, Crijns HJGM, et al. Systematic, early rhythm control strategy for atrial fibrillation in patients with or without symptoms: the EAST-AFNET 4 trial. Eur Heart J. 2021;43(12):1219–1230. https://doi.org/10.1093/eurheartj/ehab593
[29]. Zhu W, Wu Z, Dong Y, Lip GYH, Liu C. Effectiveness of early rhythm control in improving clinical outcomes in patients with atrial fibrillation: a systematic review and meta-analysis. BMC Med. 2022;20(1). https://doi.org/10.1186/s12916-022-02545-4
[30]. Mililis P, Kariki O, Saplaouras A, Bazoukis G, Dragasis S, Patsiotis IG, et al. Radiofrequency versus cryoballoon catheter ablation in patients with persistent atrial fibrillation: A randomized trial. J Cardiovasc Electrophysiol. 2023;34(7):1523–1528. https://doi.org/10.1111/jce.15965
[31]. Lo M, Gambhir A, Sundaram S, Sanders P, DeLurgio D, Trivedi A, et al. Safety and effectiveness of a novel Balloon-in-Basket pulsed Field ablation catheter for the treatment of paroxysmal and persistent AF: VOLT-AF IDE Trial acute results. Heart Rhythm. 2025. https://doi.org/10.1016/j.hrthm.2025.04.037
[32]. Reddy VY, Calkins H, Mansour M, Wazni O, Di Biase L, Bahu M, et al. Pulsed field ablation to treat paroxysmal atrial fibrillation: Safety and effectiveness in the ADMIRE pivotal trial. Circulation. 2024;150(15):1174–1186. https://doi.org/10.1161/circulationaha.124.070333
[33]. Reddy VY, Gerstenfeld EP, Schmidt B, Andrade JG, Nair D, Natale A, et al. Pulsed field ablation of persistent atrial fibrillation with continuous ECG monitoring Follow-Up: ADVANTAGE AF-Phase 2. Circulation. 2025. https://doi.org/10.1161/circulationaha.125.074485
[34]. Van Der Heijden CAJ, Aerts L, Chaldoupi S, Van Cruchten C, Kawczynski M, Heuts S, et al. Hybrid atrial fibrillation ablation. Ann Cardiothorac Surg. 2024;13(1):54–70. https://doi.org/10.21037/acs-2023-afm-0129
[35]. Zeppenfeld K, Tfelt-Hansen J, De Riva M, Winkel BG, Behr ER, Blom NA, et al. 2022 ESC Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death. Eur Heart J. 2022;43(40):3997–4126. https://doi.org/10.1093/eurheartj/ehac262
[36]. Suryanarayana P, Garza HK, Klewer J, Hutchinson MD. Electrophysiologic considerations after sudden cardiac arrest. Curr Cardiol Rev. 2018;14(2):102–108. https://doi.org/10.2174/1573403x14666180507164443
[37]. Ammar A, Sharief M, Abouelmagd K, Riad O, Ibrahim M. Outcomes of catheter ablation of ventricular tachycardia in non-ischemic idiopathic dilated cardiomyopathy: A systematic review and meta-analysis. Front Cardiovasc Med. 2022;9. https://doi.org/10.3389/fcvm.2022.1007392
[38]. Da Silva GL, Cortez-Dias N, Carpinteiro L, Pinto FJ, De Sousa J. Outcome of ventricular tachycardia catheter ablation in ischemic heart disease patients using a high-density mapping substrate-based approach: A prospective cohort study. Rev Port Cardiol. 2022;41(4):325–335. https://doi.org/10.1016/j.repc.2021.02.026
[39]. Oomen AWGJ, Dekker LRC, Meijer A. Catheter ablation of symptomatic idiopathic ventricular arrhythmias. Neth Heart J. 2018;26(4):210–216. https://doi.org/10.1007/s12471-018-1085-5
[40]. Kim JA, Chelu MG. Inherited arrhythmia syndromes. Tex Heart Inst J. 2021;48(4). https://doi.org/10.14503/thij-20-7482
[41]. Krahn AD, Wilde AA, Calkins H, La Gerche A, Cadrin-Tourigny J, Roberts JD, et al. Arrhythmogenic right ventricular cardiomyopathy. JACC Clin Electrophysiol. 2022;8(4):533–553. https://doi.org/10.1016/j.jacep.2021.12.002
[42]. Kirkels FP, Van Osta N, Rootwelt-Norberg C, Chivulescu M, Van Loon T, Aabel EW, et al. Monitoring of myocardial involvement in early arrhythmogenic right ventricular cardiomyopathy across the age spectrum. J Am Coll Cardiol. 2023;82(9):785–797. https://doi.org/10.1016/j.jacc.2023.05.065
[43]. Edpuganti S. Fungal endocarditis: Microbial insights, diagnostic and therapeutic challenges in the modern era. Explor Cardiol. 2025;3:101264. https://doi.org/10.37349/ec.2025.101264
[44]. Vouliotis AI, Roberts PR, Dilaveris P, Gatzoulis K, Yue A, Tsioufis K. Leadless pacemakers: Current achievements and future perspectives. Eur Cardiol Rev. 2023;18. https://doi.org/10.15420/ecr.2022.32
[45]. Oliveira VMR, Rivera A, Oliveira IC, De Sousa AM, Nishikubo MEP, Serpa F, et al. The effectiveness and safety of leadless pacemakers: An updated meta-analysis. Curr Cardiol Rep. 2024;26(8):789–799. https://doi.org/10.1007/s11886-024-02079-6
[46]. Guarracini F, Preda A, Bonvicini E, Coser A, Martin M, Quintarelli S, et al. Subcutaneous implantable cardioverter defibrillator: A contemporary overview. Life. 2023;13(8):1652. https://doi.org/10.3390/life13081652

ISSN No: 2456-2165 https://doi.org/10.38124/ijisrt/25jul1889

[47]. Strocchi M, Lee AW, Neic A, Bouyssier J, Gillette K, Plank G, et al. His-bundle and left bundle pacing with optimized atrioventricular delay achieve superior electrical synchrony over endocardial and epicardial pacing in left bundle branch block patients. Heart Rhythm. 2020;17(11):1922–1929. https://doi.org/10.1016/j.hrthm.2020.06.028
[48]. Herweg B, Sharma PS, Cano Ó, Ponnusamy SS, Zanon F, Jastrzebski M, et al. Arrhythmic risk in biventricular pacing compared with left bundle branch area pacing: results from the I-CLAS study. Circulation. 2023;149(5):379–390. https://doi.org/10.1161/circulationaha.123.067465
[49]. Fortuni F, Casula M, Sanzo A, Angelini F, Cornara S, Somaschini A, et al. Meta-Analysis Comparing cryoballoon versus radiofrequency as first ablation procedure for atrial fibrillation. Am J Cardiol. 2020;125(8):1170–1179. https://doi.org/10.1016/j.amjcard.2020.01.016
[50]. Moore OM, Ho KS, Copeland JS, Parthasarathy V, Wehrens XHT. Genome editing and cardiac arrhythmias. Cells. 2023;12(10):1363. https://doi.org/10.3390/cells12101363
[51]. Karatela MF, Fudim M, Mathew JP, Piccini JP. Neuromodulation therapy for atrial fibrillation. Heart Rhythm. 2022;20(1):100–111. https://doi.org/10.1016/j.hrthm.2022.08.011
[52]. Nawar K, Mohammad A, Johns EJ, Abdulla MH. Renal denervation for atrial fibrillation: a comprehensive updated systematic review and meta-analysis. J Hum Hypertens. 2022;36(10):887–897. https://doi.org/10.1038/s41371-022-00658-0
[53]. Steinberg JS, Shabanov V, Ponomarev D, Losik D, Ivanickiy E, Kropotkin E, et al. Effect of renal denervation and catheter ablation vs catheter ablation alone on atrial fibrillation recurrence among patients with paroxysmal atrial fibrillation and hypertension. JAMA. 2020;323(3):248. https://doi.org/10.1001/jama.2019.21187
[54]. Trayanova NA, Pashakhanloo F, Wu KC, Halperin HR. Imaging-based simulations for predicting sudden death and guiding ventricular tachycardia ablation. Circ Arrhythm Electrophysiol. 2017;10(7). https://doi.org/10.1161/circep.117.004743
[55]. Cernica D, Benedek I, Polexa S, Tolescu C, Benedek T. 3D printing—A cutting edge technology for treating post-infarction patients. Life. 2021;11(9):910. https://doi.org/10.3390/life11090910
[56]. Wang D, Veltmann C, Bauersachs J, Duncker D. Antiarrhythmic effects of baroreceptor activation therapy in chronic heart failure: a case report. Eur Heart J Case Rep. 2023;7(11). https://doi.org/10.1093/ehjcr/ytad520
[57]. Robles-Mezcua A, Villaescusa-Catalán JM, Melero-Tejedor JM, García-Pinilla JM. A new approach to the treatment of advanced heart failure: a case report. Eur Heart J Case Rep. 2021;5(2). https://doi.org/10.1093/ehjcr/ytaa541
[58]. Abdelrazik A, Eldesouky M, Antoun I, Lau EYM, Koya A, Vali Z, et al. Wearable devices for arrhythmia detection: advancements and clinical implications. Sensors. 2025;25(9):2848. https://doi.org/10.3390/s25092848
[59]. Bogár B, Pető D, Sipos D, Füredi G, Keszthelyi A, Betlehem J, Pandur AA. Detection of arrhythmias using smartwatches—A systematic literature review. Healthcare. 2024;12(9):892. https://doi.org/10.3390/healthcare12090892
[60]. Preda A, Falco R, Tognola C, Carbonaro M, Vargiu S, Gallazzi M, et al. Contemporary advances in cardiac remote monitoring: a comprehensive, updated mini-review. Medicina. 2024;60(5):819. https://doi.org/10.3390/medicina60050819
[61]. Goudarzi MTH, Marzouni HZ, Tarkhan F, Bijani A, Babagoli M, Shadifar A, Alipour JA. A new remote monitoring system: evaluation of the efficiency and accuracy of the Smart Emergency Medical System-Health Internet of Things device. Galen Med J. 2024;13:e3376. https://doi.org/10.31661/gmj.v13i.3376
[62]. Jena N, Singh P, Chandramohan D, Garapati HN, Gummadi J, Mylavarapu M, et al. Wearable technology in cardiology: advancements, applications, and future prospects. Rev Cardiovasc Med. 2025;26(6). https://doi.org/10.31083/rcm39025
[63]. Wang J, Verkerk AO, Wilders R, Zhang Y, Zhang K, Prakosa A, et al. SCN10A-short gene therapy to restore conduction and protect against malignant cardiac arrhythmias. Eur Heart J. 2025. https://doi.org/10.1093/eurheartj/ehaf053
[64]. Park E, Kim J, Seong E, Lee E, Chang K, Choi Y. Effects of mesenchymal stem cell injection into healed myocardial infarction scar border zone on the risk of ventricular tachycardia. Biomedicines. 2023;11(8):2141. https://doi.org/10.3390/biomedicines11082141
[65]. Khairy P, Dyrda K, Mondésert B, Aguilar M, Dubuc M, Cadrin-Tourigny J, et al. Overcoming access challenges to treat arrhythmias in patients with congenital heart disease using robotic magnetic-guided catheter ablation. J Clin Med. 2024;13(18):5432. https://doi.org/10.3390/jcm13185432
[66]. Ijaz R, Singh A, Qazi M, Kachhadia M, Qayoom L, Riaz S, et al. Comparison between efficacy and safety of remote magnetic navigation and manual catheter navigation for atrial fibrillation ablation: an updated meta-analysis and systematic review. J Innov Cardiac Rhythm Manage. 2025;16(6):6307–6328. https://doi.org/10.19102/icrm.2025.16065