Technological Advances Transforming the Clinical Practice of Atrial Fibrillation

Os Avanços Tecnológicos que estão a Transformar a Prática Clínica da Fibrilhação Auricular

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Abstract

Atrial fibrillation (AF) is the most common arrhythmia causing stroke, myocardial infarction, and heart failure. An early diagnosis and treatment are crucial to reduce AF recurrence, progression of the disease and to improve prognosis. Thus, an opportunistic screening is recommended in people older than 65 years.

With the advent of digital medicine, there are a vast variety of wearables to enable an ECG-based or photoplethysmography-based notification for an irregular heart rhythm. Adopting digital health platforms facilitates remote monitoring of these notifications and integrating data from wearable devices, smartphones, and patient-reported outcomes, allowing healthcare providers to track AF in real-time and adjust management strategies proactively, leading to prompt and personalized treatment. However, there are some challenges to overcome such as managing an overwhelming volume of information, and storing health data raises concerns about patient privacy and data that we further develop in this revision.

Indeed, the complexity of AF requires a comprehensive, patient-centered management strategy for optimal outcomes. The AF-CARE pathway simplifies the approach and focuses on managing comorbidities and risk factors, anticoagulation, rate, and rhythm control, and continuous patient reassessment.

Rhythm control strategies employed in the past decade, including the safer use of antiarrhythmic drugs and catheter ablation, have been shown to provide significant symptomatic improvement and reduce cardiovascular mortality and morbidity when initiated early. Technological advances in catheter ablation have enabled a paradigm shift towards single-shot procedures, using specialized catheters that deliver energy to isolate the pulmonary veins in a single application ("single shot"). These ablation techniques, incorporating cryoablation and more recently pulsed field ablation, represent an advancement in the treatment of atrial fibrillation, offering improved outcomes and safety for patients.

As consequence of the benefit and safety of catheter ablation, the 2024 European guidelines state that catheter ablation can be recommended as a first-line option within a shared decision-making rhythm control strategy for patients with paroxysmal AF to reduce symptoms, recurrence, and progression of AF.

Keywords: Atrial Fibrillation/diagnosis; Atrial Fibrillation/surgery; Catheter Ablation; Cryosurgery

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Resumo

A fibrilhação auricular (FA) é a arritmia mais comum que causa acidente vascular cerebral, enfarte do miocárdio e insuficiência cardíaca. O diagnóstico e tratamento precoces são cruciais para reduzir a recorrência da FA, a progressão da doença e melhorar o seu prognóstico. Assim, recomenda-se um rastreio oportunista em pessoas com pelo menos 65 anos.

Com o advento da medicina digital, há uma grande variedade de *wearables* que permitem o rastreio desta doença através de uma notificação baseada em ECG ou fotopletismografia de um ritmo cardíaco irregular. A adoção de plataformas digitais de saúde facilita a monitorização remota dessas notificações e integra dados de dispositivos *wearables, smartphones* e resultados relatados pelos doentes, permitindo que os profissionais de saúde diagnostiquem a FA em tempo real, levando a um tratamento rápido e personalizado. No entanto, existem alguns desafios a ultrapassar, como a gestão de um volume esmagador de informações e o armazenamento de dados de saúde que suscitam preocupações sobre a privacidade dos doentes, assuntos estes que desenvolvemos nesta revisão.

Efetivamente, a FA é uma arritmia complexa cujo tratamento adequado deverá ser holístico e centrado no doente. A mnemónica AF-CARE simplifica a abordagem terapêutica, focando-se no controlo das comorbilidades e fatores de risco acompanhantes, anticoagulação, controlo de ritmo e frequência cardíaca, mantendo uma reavaliação regular do doente.

As estratégias de controlo de ritmo utilizadas ao longo da última década, com ênfase no uso com segurança de fármacos antiarrítmicos e na disponibilidade da ablação por catéter, vieram demonstrar não só melhoria significativa dos sintomas, como também redução de morbimortalidade cardiovascular quando utilizadas precocemente. Os avanços tecnológicos na ablação por cateter permitiram uma mudança de paradigma para procedimentos "*single-shot*", utilizando cateteres especializados que fornecem energia para isolar as veias pulmonares numa única aplicação ("*single-shot*"). Estas técnicas de ablação, incorporando a crioablação e, mais recentemente, a eletroporação, representam um avanço no tratamento da FA, oferecendo aos doentes melhores resultados e segurança.

Como consequência do benefício e da segurança da ablação por cateter, as *guidelines* europeias de 2024 recomendam a ablação por cateter como opção de primeira linha para controlo do ritmo de doentes com FA paroxística, a fim de reduzir os sintomas, a recorrência e a progressão da FA.

Palavras-chave: Ablação por Catéter; Criocirurgia; Fibrilhação Auricular/cirurgia; Fibrilhação Auricular/diagnóstico

Introduction

Atrial fibrillation (AF) is the most common heart rhythm disorder, affecting millions of people worldwide. Data from the Framingham Heart Study demonstrated that the lifetime risk of developing AF in individuals of European ancestry at an index age of 55 years is 1 in 3.[1,2] In fact, AF prevalence in Portuguese population aged ≥ 40 years is estimated to be 2.5%, reaching 9% in people ≥ 65 years.[3] Increasing age is a prominent AF risk factor, but increasing burden of comorbidities including hypertension, diabetes mellitus, obesity, heart failure, coronary artery disease, among others play a significant role.[4]

AF leads to symptoms such as fast or chaotic heartbeat, fatigue, shortness of breath, and chest pain. Notably, it has been associated with a 2-fold increase in myocardial infarction, 5-fold increase in stroke[5] and heart failure,[6] as well as dementia and cognitive decline.[7] The observed impact of clinical risk factor burden suggest that an early intervention and modifiable risk factor control could reduce incident AF.

Taking into consideration the increasing prevalence and all the above stated complications, efforts have been made to reduce the healthcare burden by use of AF screening, leading to an early AF treatment and improvement of long-term prognosis of patients.

With this paper, we aim to demonstrate the exponential growth of knowledge in the screening and treatment assessment of AF, reviewing the major novelties in this area.

Screening Assessment of AF

Traditionally, diagnostic evaluation of AF patients included intermittent ECGs, Holter monitoring, etc. demonstrating at least 30 seconds of AF tracing. However, public health screening has enhanced dramatically over the last few years owing to the need and desire to address the growing burden of AF. The advent of new technologies has enabled a more accurate and continuous monitoring techniques improving the screening of this arrhythmia. A recent meta-analysis with a total of 35 836 participants demonstrated that screened participants had a reduction in stroke when compared to no screening (RR 0.91, 95% CI 0.84–0.99).[8] Thus, the 2024 European Society of Cardiology (ESC) guidelines on AF management recommend opportunistic screening for AF in persons aged ≥ 65 years.[9]

1. Innovations in AF Screening Methods

Digital health uses information and communication technologies in medicine to manage illnesses and health risks to promote wellness. It includes several areas such as wearable devices with more than 400 wearable activity monitors currently available (ex. smartwatches and patches, some examples depicted in Table 1), mobile health (mHealth), telehealth, health information technology, and telemedicine with promising tools for early AF detection and initiation of prompt treatment.[10]

Table 1. Screening methods for AF

Type of screening	Characteristics	Examples
Wearable devices	Smartwatches equipped with photopletysmography (PPG) sensors that can detect irregular heart rhythms suggestive of AF. Some models also include ECG capabilities that allow users to capture a single-lead ECG, which can be reviewed by healthcare providers to confirm AF. These wearables enable continuous or intermittent monitoring, increasing the likelihood of detecting AF, mainly in asymptomatic patients.	Apple watch (uses PPG and ECG), Fitbit Sense and Fitbit Charge 5 (uses ECG), Samsung Galaxy watch (uses ECG), Garmin Venu 2 plus (uses PPG), Withings ScanWatch (uses PPG and ECG)
Handheld ECG devices	Portable devices which provide a quick and easy way for patients to record an ECG by putting their fingers on the device's electrodes. The recorded ECG can be analyzed in real-time by algorithms that detect AF or may be sent to a healthcare provider for further analysis. These portable devices are user friendly and can be used anytime, anywhere, making them a convenient option for AF screening.	AliveCor, KardiaMobile
Patch monitors	Adhesive patches that can be worn on the chest for continuous ECG monitoring over extended periods, typically 14 days. These patches are particularly useful to detect paroxysmal/intermittent AF episodes that could not be captured in shorter monitoring windows. Collected data is then analyzed to identify AF and other arrhythmias, providing a detailed report that can guide further clinical decisions.	Zio Patch by iRhythm
Community-based screening programs	Several initiatives use mobile ECG devices and public health outreach to screen older adults in the community for AF. These programs typically target high-risk patients, such as patients ≥ 65 years with stroke risk factors and involve large scale ECG screening followed by confirmatory tests and appropriate clinical follow-up for those found to have AF. These community efforts are crucial in detecting undiagnosed AF, particularly in populations that may have limited access to healthcare facilities.	STROKESTOP[11] study in Sweden

In the last decade, large software companies have been increasingly investing in wearables for AF detection due to the growing demand for personalized healthcare and the potential to leverage their technological expertise in this rapidly expanding market. One of such companies is Apple, which recruited 419 197 participants over 8 months in the Apple Heart Study[12] with 0.5% of participants receiving an irregular pulse notification. Subsequent 1-week ECG patch monitoring revealed AF in 34% of monitored patients. In addition, the Huawei Heart Study[13] included 186 956 participants using a wristband or wristwatch with photoplethysmography, of whom 0.23% received a "suspected AF" notification and 87% were confirmed as having AF. A majority (95%) of the participants successfully integrated the AF management program by using a mobile AF app (mAFA, depicted in Fig. 1).

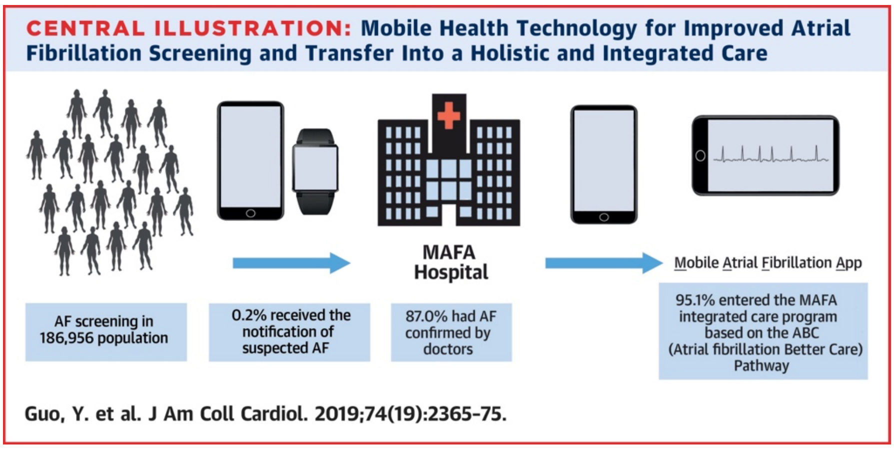

Figure 1. Mobile health technology for improved AF screening and transfer into a holistic and integrated care.[13]

When AF is detected by a screening tool, including mobile or wearable devices, a single-lead ECG or 12-lead ECG showing AF analyzed by a physician with expertise in ECG rhythm interpretation, is necessary to establish a definitive diagnosis of AF.[4] These devices and integrated digital AF management enable long-term, non-invasive monitoring, improving the detection of paroxysmal or asymptomatic AF episodes that could otherwise be unnoticed in clinical settings. The adoption of digital health platforms facilitates remote monitoring and patient engagement, integrates data from wearable devices, smartphones, and patient-reported outcomes, allowing healthcare providers to track AF in real-time and adjust management strategies proactively.

Additionally, the development of high-resolution ECGs and the application of machine learning algorithms have enhanced the accuracy and reliability of AF detection, even in large populations.[14]

2. Challenges on the Management of AF Screening Data

The use of cloud-based analytics enables the aggregation and analysis of vast amounts of health data, providing insights into AF patterns and risk factors that were previously difficult to establish. This approach not only increases the accessibility of AF screening, but also supports personalized medicine, tailoring interventions based on individual patient data. However, this vast amount of digital data generated from AF screening should be properly filtered and integrated into clinical practice, presenting several challenges that should be taken into consideration. Firstly, digital health platforms generate a continuous stream of data, leading to an overwhelming volume of information for healthcare providers to manage. Evaluating all the data looking for clinically relevant information can be time-consuming and labor-intensive.[15] To minimize these efforts, machine learning algorithms should be developed to filter and prioritize data, highlighting significant events such as irregular heart rhythms or increased heart rates, while excluding the noise from less relevant data. Secondly, AF screening data from different smartwatches, smartphones, and other wearable devices should be integrated into electronic health record systems, overcoming different data formats from different devices. The adoption of standardized data formats could help to integrate data from different sources, ensuring healthcare providers have a comprehensive view of a patient's health. Thirdly, after data being filtered and properly integrated, healthcare providers must interpret and make informed clinical decisions. The potential false positives or inconclusive results may become a challenge in this process.[15] Artificial intelligence can assist, by analyzing trends, and detecting patterns, helping healthcare providers distinguish between significant and insignificant findings. Fourthly, the collection and storage of health data raise concerns about patient privacy and data security.[16] Encryption methods, secure data storage solutions, and rigorous access controls to protect patient data should be implanted.

At the end of the process, physicians should always interpret the information and provide the best-personalized treatment for the patient. The detection of AF in its early stages and subsequent treatment at the right time, reduces morbidity, mortality, and societal healthcare costs.[17]

Comprehensive Approach to Atrial Fibrillation

The complexity of AF requires a comprehensive, patient--centered approach for optimal management. This approach should focus not only on the arrhythmia itself but also on accompanying comorbidities, risk factors, presenting symptoms, and the risk of thromboembolism. Actively involving patients in their AF care, alongside healthcare professionals, has been shown to improve outcomes in oral anticoagulation and arrhythmia management.[18]

The most recent ESC guidelines on AF have adopted the AF--CARE pathway to ensure optimal management and integration into routine clinical care.[9] The AF-CARE approach includes [C] comorbidity and risk factor management, [A] avoidance of stroke and thromboembolism, [R] reduction of symptoms through rate and rhythm control, and [E] evaluation and dynamic reassessment of implemented strategies. All these elements should be delivered in a patient-centered manner, with appropriate education provided to patients, families, and other healthcare professionals, while ensuring equal access to healthcare across different genders, ethnicities, and socioeconomic statuses.

Common comorbidities associated with AF include hypertension, diabetes, heart failure, and obstructive sleep apnea. Modifiable risk factors such as smoking, physical inactivity, excessive alcohol consumption, and obesity are also frequently present and should be addressed. Each of these conditions can exacerbate the burden of AF and promote adverse atrial remodeling that perpetuates the arrhythmia. A holistic approach, including optimal pharmacological treatment, lifestyle changes, and regular monitoring, can help reduce AF episodes and prevent its progression.[19] The HEAD-2-TOES scheme (Table 2) provides a practical summary of risk factors and suggested treatment targets for preventing a first episode of AF (primary prevention) or AF recurrences (secondary prevention).

Table 2. The HEAD-2-TOES scheme: modifiable risk factor targets to prevent AF.

Acronym	Risk factor	Primary prevention targets	Secondary prevention targets
H	Heart failure (with reduced ejection fraction)	ACE inhibitor or ARB, β-blocker, MRA, SGLT2 inhibitor	ACE inhibitor or ARB, MRA
E	Exercise (physical inactivity)	≥150 min per week MVPA	≥200 min/per week MVPA
A	Arterial hypertension	BP <130/80 mmHg	BP <130/80 mmHg (rest) and <200/100 mmHg (exercise)
D2	Diabetes mellitus type 2	HbA1c <6.5%	Dietary changes and HbA1c <6.5%
T	Tobacco smoking	Complete cessation	Complete cessation
O	Obesity	BMI ≤25 kg/m^2	10% weight reduction; BMI ≤27 kg/m^2
E	Ethanol consumption	≤1 standard drink[a] per day	≤3 standard drinks[a] per week
S	Sleep apnoea	AHI <15	AHI <15 without CPAP; CPAP for AHI ≥30 or AHI ≥20 with hypertension

Reproduced from Elliot, *et al.*[19]

ACE, angiotensin-converting enzyme; AF, atrial fibrillation; AHI, apnoea–hypopnoea index; ARB, angiotensin receptor blocker; BP, blood pressure; CPAP, continuous positive airway pressure; HbA1c, glycated haemoglobin; MRA, mineralocorticoid receptor antagonist; MVPA, moderate-to-vigorous physical activity; SGLT2, sodium–glucose cotransporter 2. [a] One standard drink contains 12 g of alcohol (1.5 units).

Furthermore, AF is a major risk factor for thromboembolism, particularly ischemic stroke, regardless of whether it is paroxysmal, persistent of permanent. All patients should have their thromboembolic risk assessed using validated risk scores, such as CHA2DS2-VA, and appropriate anticoagulation initiated when indicated.[9] Oral anticoagulation should be considered for patients with a CHA2DS2-VA score of 1 and is recommended for all patients with a CHA2DS2-VA score of 2 or greater. Most importantly, antiplatelet therapy, such as acetylsalicylic acid or clopidogrel, is not an alternative to oral anticoagulation, as it fails to adequately protect against ischemic stroke, whilst not being considerably safer.[20]

Direct oral anticoagulants (DOACs) – apixaban, dabigatran, edoxaban and rivaroxaban –, are the drugs of choice for most patients, except for those with mechanical heart valves and moderate-to-severe mitral stenosis. Compared to warfarin, standard, full-dose DOAC treatment reduces the risk of stroke or systemic embolism by approximately 20%, all-cause mortality by around 10%, and intracranial bleeding by about 50%, with no significant differences in other major bleeding.[21] Special attention should be paid to appropriate dose reduction criteria and concomitant drug therapy to avoid over- or under-dosing and significant drug-drug interactions.

Most patients with symptomatic AF will benefit from medical therapy to control heart rate during AF episodes (rate control strategy), using beta-blockers, non-dihydropyridine calcium channel antagonists, or digoxin. Additionally, in selected patients with paroxysmal or persistent AF, pharmacological therapy and/or interventions are often considered to restore and maintain sinus rhythm (rhythm control strategy). Rhythm control strategies have significantly evolved due to an increasing experience in the safe use of antiarrhythmic drugs, consistent use of oral anticoagulation, advancements in ablation technology, and the identification and management of comorbidities.[9]

While landmark trials published over 20 years ago indicated that the primary reason for pursuing long-term rhythm control was symptomatic improvement, more recent evidence suggests that rhythm control, when pursued early (within 12 months) after AF diagnosis, can reduce the composite risk of cardiovascular death, stroke, or hospitalization (as demonstrated in the EAST-AFNET 4 trial[22]). A significant benefit in terms of mortality and hospitalization for heart failure was also demonstrated when rhythm control using catheter ablation was pursued in selected patients with paroxysmal or persistent AF and concomitant heart failure with reduced ejection fraction (HFrEF).[23]

Overall, the landscape of AF rhythm control strategies is rapidly evolving, driven by new drugs and technological advances that enhance the precision, safety, and efficacy of treatment options. In the following sections, we will further discuss how these technological innovations can help refine the routine clinical care of AF.

1. Antiarrhythmic Drug Therapy

Antiarrhythmic drugs (AADs) are often used as part of a rhythm control strategy, either alone or in conjunction with catheter ablation. The selection of an AAD for long-term rhythm control requires careful evaluation of factors such as the presence of structural heart disease, coronary artery disease, atrioventricular block, QRS or QT interval prolongation, and renal or hepatic failure.[24] This is due to the risk of serious adverse effects, including pro-arrhythmia, when AADs are not used appropriately. In the absence of the above-mentioned contraindications, propafenone or flecainide is recommended to prevent the recurrence and progression of AF.[9] In fact, these were the most used antiarrhythmics in the EAST-AFNET 4 trial.[22] Amiodarone should be reserved for patients with HFrEF, coronary artery disease, or severe valvular heart disease who require long-term AAD therapy to prevent AF recurrence, with careful monitoring for extracardiac toxicity.[9]

2. Catheter Ablation

Catheter ablation prevents AF recurrences, reduces AF burden, and improves quality of life in symptomatic paroxysmal or persistent AF, especially when the patient is intolerant or does not respond to AADs.[9,25] The recent European guidelines state that catheter ablation can be recommended as a first-line option within a shared decision-making rhythm control strategy for patients with paroxysmal AF to reduce symptoms, recurrence, and progression of AF.[9] Recent evidence shows that catheter ablation, particularly cryoballoon ablation, significantly improves quality of life, reduces arrhythmia recurrence, and decreases healthcare resource usage, without increasing the risk of adverse events compared to an initial AAD strategy.[26] Electrical isolation of the pulmonary veins (PVI) remains the cornerstone of AF catheter ablation. Additional ablation targets, such as non-pulmonary vein triggers, linear lesions, or posterior left atrial wall isolation, are sometimes used on a case-by-case basis in persistent forms of AF or during re-do procedures.[25]

In the past decade, we have witnessed the emergence of several innovations in catheter ablation, ranging from adjunctive imaging to new ablation tools, which are already transforming our approach to AF ablation.

2.1 Innovations in Pre-Procedural Imaging Methods for AF Ablation

Pre-procedural imaging with cardiac computed tomography (CCT) is useful for characterizing the anatomy of the left atrium and pulmonary veins, ruling out intracardiac thrombus, and identifying the relative positions of the esophagus and the right phrenic nerve.[27] CCT imaging can then be integrated with conventional three-dimensional mapping systems, enabling faster procedures, and reducing fluoroscopic usage.

In addition, ultrasound equipment for guiding femoral venous access should be available, as it reduces puncture time, minimize inadvertent arterial puncture, and lower the risk of vascular complications.[28] Routine use of ultrasound guidance is recommended, especially in an era where AF ablation is increasingly performed with uninterrupted anticoagulation.[25]

Intracardiac echocardiography (ICE) is also currently available, and its use has been shown to enhance procedural safety, reduce fluoroscopy time, and increase efficiency during AF ablation, although it does lead to an increase in procedural costs.[25]

2.2 Innovations in Mapping Technologies

Mapping and AF ablation require precise navigation within the left atrium. Electroanatomical mapping (EAM) systems allow for three-dimensional visualization of the chamber's anatomy, delineate arrhythmia circuits, and visualize real-time catheter localization without the use of fluoroscopy. Several EAM systems, along with their corresponding multipolar mapping catheters, are currently on the market and have seen significant improvements over time. These enhancements include higher spatial resolution, better quality of automatic electrogram annotation, automated algorithms to help identify arrhythmia circuits, and the ability to incorporate intracardiac echocardiography (ICE), CCT, or cardiac MRI imaging.[25]

EAM systems have also evolved to incorporate specific indicators for radiofrequency (RF) ablation, such as power, duration, contact force, and impedance shifts. These parameters can indicate an effective ablation lesion, which can then be tagged in the anatomical map.

2.3 Innovations in Ablation Technology – Single-Shot Ablation

Traditionally, AF ablation was based on point-by-point radiofrequency (RF) thermal ablation, using catheters with contact-force sensors and integrated algorithms to measure ablation lesion quality and to achieve durable PVI. These methods would require left atrium 3D-mapping and would lead to long-time procedures with patients under deep sedation (Fig. 2). Novel catheters equipped with multiple tissue thermal sensors, such as the QDOT Micro by Biosense Webster, have been developed. These allow for specific high-power or very high-power/short-duration RF ablation protocols, reducing procedure times to close to or less than one hour while maintaining similar safety and efficacy profiles compared to traditional RF protocols.[25,29] Another recent development in AF ablation technology is a larger footprint, single-tip ablation catheter. Unlike the conventional 3-4 mm tip, this new catheter features a lattice spherical structure with a 9 mm diameter, capable of delivering temperature-controlled, contact-sensing-facilitated RF lesions. A pilot study demonstrated a very high incidence of durable PVI using this catheter.[30]

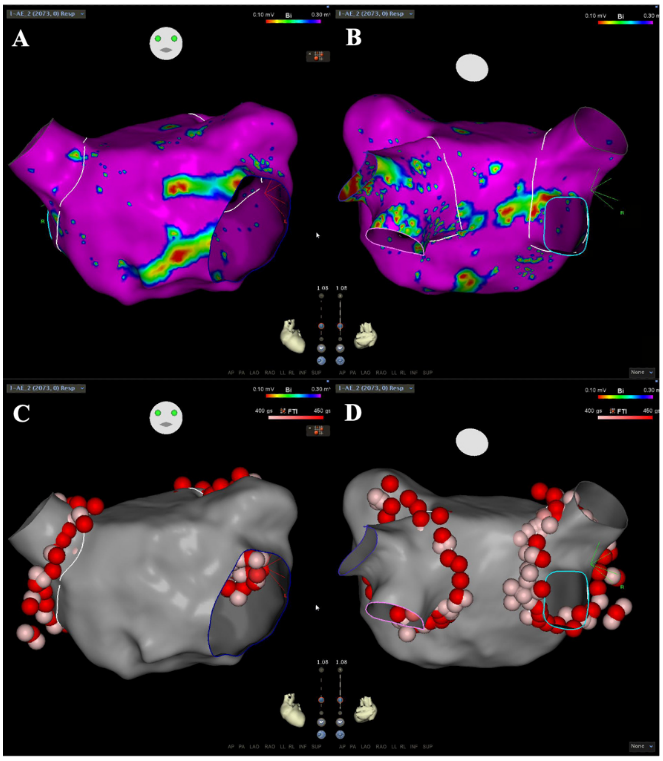

Figure 2. AF ablation using point-by-point RF-based ablation. A and B illustrate invasive electroanatomic map of the left atrium with 4 pulmonary veins (AP and PA views, respectively); C and D demonstrate the final ablation setting isolating the 4 pulmonary veins (each red tag indicates an ablation lesion; AP and PA views, respectively).

Due to the increasing prevalence of AF and the benefits of ablation therapies, we are going through a vertiginous development of new technology to enable safe, effective, simple, and fast ablation procedures. We have witnessed a paradigm shift in what AF ablation is regarded with a novel single shot approach. With these new ablation methods, specialized catheters can deliver energy to isolate the pulmonary veins in a single application ("single shot"), rather than requiring multiple applications as with point-by-point RF ablation. The single-shot approach makes the procedure more efficient, significantly reducing procedure time, provides more uniform and consistent lesions, and reduces the risk of complications as we will discuss below.

Cryoablation ablation, in the other end of the thermal ablation spectrum, uses a balloon catheter that delivers cryothermal energy (extreme cold) to create lesions around the pulmonary veins, effectively isolating them. The balloon is inflated and positioned at the pulmonary vein opening, and the cold energy is applied to freeze the tissue (illustrated in Fig. 2). These catheters use freezing temperatures to create effective ablation lesions, showing comparable efficacy to RF-based ablation.[31] While these single-shot devices enable shorter procedure times (124 min for cryoablation versus 141 min for RF ablation, $p<0.001$[32]), they require increased use of fluoroscopy. Recent data supporting first-line ablation for paroxysmal AF, as opposed to a trial of AADs, comes from cryoballoon-based ablation studies, which underscore both its efficacy and safety.[26]

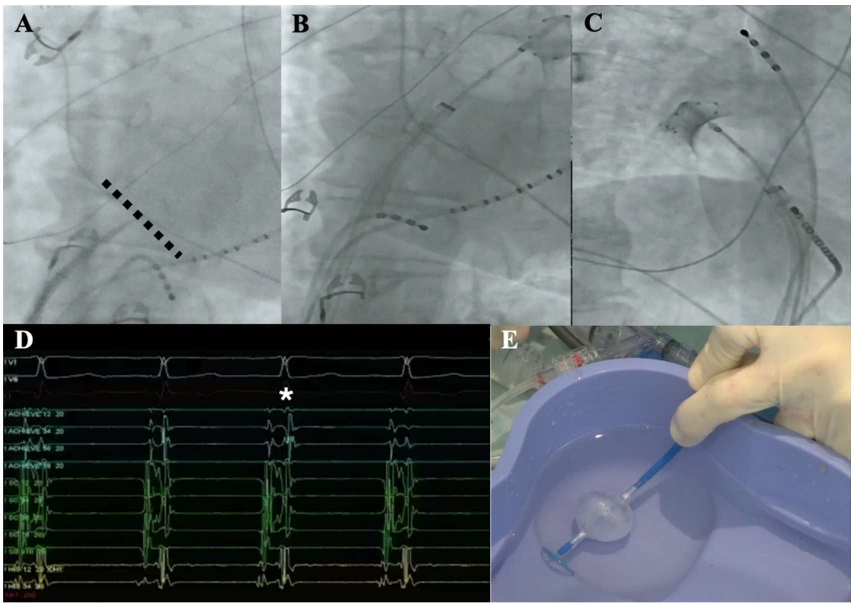

Figure 3. AF ablation with a single-shot cryoballoon. A. Transseptal puncture between right and left atrium using SL-1 sheath and transeptal needle (dashed line indicating interauricular septum); B. Left superior pulmonary vein isolation using an inflated cryoballoon with contrast retention inside the vein demonstrating a good contact to the pulmonary vein; C. Right superior pulmonary vein isolation with contrast retention inside the vein. Quadripolar catheter in the superior vena cava for phrenic nerve pacing to prevent phrenic nerve palsy during cryoablation. D. Pulmonary vein signals monitored with a circular mapping catheter inside the pulmonary vein isolation. The * emphasizes a sharp pulmonary vein signal (in blue) that disappears in the following beat during cryoablation, demonstrating pulmonary vein isolation. E. Inflated cryoballoon and multipolar circular catheter.

The new "kid in the block" regarding single shot ablation uses a different source of energy - pulsed-field ablation (PFA). Instead of applying thermal energy (either RF or cryoenergy), PFA uses an electrical field to disrupt cell membrane integrity, leading to cell death and replacement by fibrosis, a process known as electroporation.[33] Because this electrical field can be selectively directed to affect only cardiomyocytes, there is a significant reduction in collateral damage to extracardiac structures, such as the esophagus, phrenic nerve, and surrounding vascular structures.[25] However, some cases of coronary arterial spasm and hemolysis have been reported. PFA can currently be delivered using large footprint, "single-shot" devices, with average procedure times of less than one hour for AF ablation. Recent studies comparing PFA to thermal ablation (either RF or cryoablation) have shown comparable efficacy and safety.[34]

Overall, the single-shot approach in AF catheter ablation represents a significant advancement in the treatment of atrial fibrillation, offering improved outcomes and safety for patients.

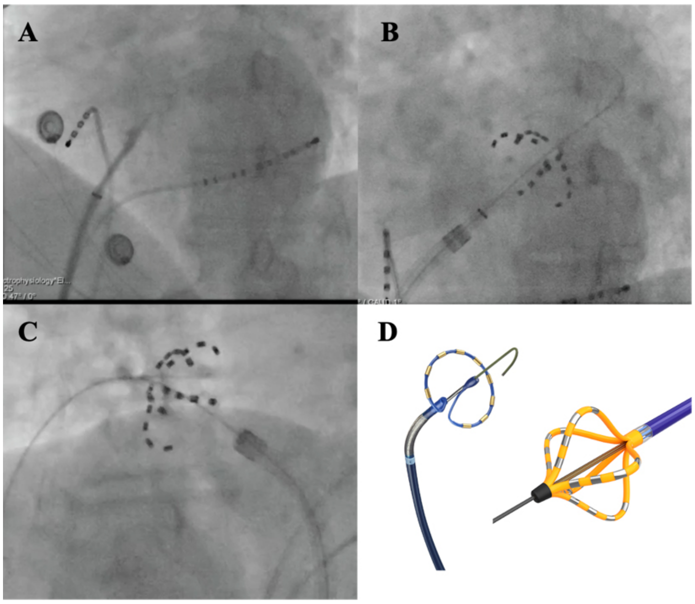

Figure 4. AF ablation using single-shot electroporation. A. Transseptal puncture between right and left atrium using SL-1 sheath and transeptal needle; B. Left superior pulmonary vein isolation using electroporation catheter; C. Right superior pulmonary vein isolation. D. Electroporation catheters commercially available (left - PulseSelect®, right – Farapulse®)

2.4 Artificial Intelligence Guiding AF Ablation

Artificial intelligence-based (AI) algorithms have been developed that can perform real-time analysis of electrograms recorded by multipolar catheters and automatically identify spatiotemporal electrogram dispersion. This capability may identify relevant ablation targets besides pulmonary vein isolation, particularly in patients with persistent AF. The recently presented TAILORED AF trial demonstrated that a strategy of PVI plus ablation targeting these AI-identified areas resulted in significantly higher rates of freedom from AF at 12 months compared to PVI alone in patients with long-standing persistent AF.[35]

Conclusion

Atrial fibrillation is the most common arrhythmia and its early diagnosis and personalized treatment improve patients' symptoms and prognosis. Screening using wearables based on ECG or photoplethysmography enable the continuous monitoring of an irregular rhythm and early diagnosis of AF. Patient-centered management of AF with novel ablation technologies promote a safe and effective treatment of the disease.

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References

1. Magnussen C, Niiranen TJ, Ojeda FM, Gianfagna F, Blankenberg S, Njølstad I, et al. Sex differences and similarities in atrial fibrillation epidemiology, risk factors, and mortality in community cohorts: Results from the biomarcare consortium (Biomarker for cardiovascular risk assessment in Europe). Circulation. 2017;136:1588-97. doi:10.1161/CIRCULATIONAHA.117.028981
2. Staerk L, Wang B, Preis SR, Larson MG, Lubitz SA, Ellinor PT, et al. Lifetime risk of atrial fibrillation according to optimal, borderline, or elevated levels of risk factors: Cohort study based on longitudinal data from the Framingham Heart Study. BMJ. 2018;361. doi:10.1136/bmj.k1453
3. Monteiro P. The SAFIRA study: A reflection on the prevalence and treatment patterns of atrial fibrillation and cardiovascular risk factors in 7500 elderly subjects. Rev Port Cardiol. 2018;37:307-13. doi:10.1016/j.repc.2017.08.006
4. Hindricks G, Potpara T, Kirchhof P, Arbelo E, Bax JJ, Blomström-Lundqvist C, et al. 2020 ESC Guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the European Association for Cardio-Thoracic Surgery (EACTS). Eur Heart J. 2021;42:373-498. doi:10.1093/eurheartj/ehaa612
5. Wolf PA, Abbott RD, Kannel WB. Original Contributions Atrial Fibrillation as an Independent Risk Factor for Stroke: The Framingham Study. Stroke. 1991;22:983-8. doi: 10.1161/01.str.22.8.983.
6. Gopinathannair R, Chen LY, Chung MK, Cornwell WK, Furie KL, Lakkireddy DR, et al. Managing atrial fibrillation in patients with heart failure and reduced ejection fraction: a scientific statement from the American Heart Association. Circ Arrhythm Electrophysiol. 2021;14:E000078. doi:10.1161/HAE.0000000000000078
7. Rivard L, Friberg L, Conen D, Healey JS, Berge T, Boriani G, et al. Atrial fibrillation and dementia: a report from the AF-SCREEN International Collaboration. Circulation. 2022;145:392-409. doi:10.1161/CIRCULATIONAHA.121.055018
8. McIntyre WF, Diederichsen SZ, Freedman B, Schnabel RB, Svennberg E, Healey JS. Screening for atrial fibrillation to prevent stroke: a meta-analysis. Eur Heart J Open. 2022;2. doi:10.1093/ehjopen/oeac044
9. Van Gelder IC, Rienstra M, Bunting KV, Casado-Arroyo R, Caso V, Crijns HJ, et al. 2024 ESC Guidelines for the management of atrial fibrillation developed in collaboration with the European Association for Cardio-Thoracic Surgery (EACTS). Eur Heart J. 2024:ehae176. doi: 10.1093/eurheartj/ehae176.
10. Hermans ANL, Gawalko M, Dohmen L, van der Velden RM, Betz K, Duncker D, et al. Mobile health solutions for atrial fibrillation detection and management: a systematic review. Clin Res Cardiol. 2022;111:479-91. doi:10.1007/s00392-021-01941-9
11. Svennberg E, Friberg L, Frykman V, Al-Khalili F, Engdahl J, Rosenqvist M. Clinical outcomes in systematic screening for atrial fibrillation (STROKESTOP): a multicentre, parallel group, unmasked, randomised controlled trial. Lancet. 2021;398:1498-506. doi:10.1016/S0140-6736(21)01637-8
12. Perez MV, Mahaffey KW, Hedlin H, Rumsfeld JS, Garcia A, Ferris T, et al. Large-Scale Assessment of a Smartwatch to Identify Atrial Fibrillation. N Engl J Med. 2019;381:1909-17. doi: 10.1056/NEJMoa1901183.
13. Guo Y, Wang H, Zhang H, Liu T, Liang Z, Xia Y, et al. Mobile photoplethysmographic technology to detect atrial fibrillation. J Am Coll Cardiol. 2019;74:2365-75. doi:10.1016/j.jacc.2019.08.019
14. 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;394:861-7. doi:10.1016/S0140-6736(19)31721-0
15. Ilyas MH, Sharih AM, Tukur Jido J, Ali AR, Khoshnaghsh A, Nadeem M, et al. Screening for atrial fibrillation: risks, benefits, and implications on future clinical practice. Curr Treat Options Cardiovasc Med. 2024;26:233--42. doi:10.1007/s11936-024-01047-1
16. Khatiwada P, Yang B, Lin JC, Blobel B. Patient-Generated Health Data (PGHD): Understanding, Requirements, Challenges, and Existing Techniques for Data Security and Privacy. J Pers Med. 2024;14. doi:10.3390/jpm14030282
17. Markides V, Schilling RJ. Atrial fibrillation: classification, pathophysiology, mechanisms and drug treatment. Heart. 2003;89:939-43. doi: 10.1136/heart.89.8.939.
18. Chung MK, Fagerlin A, Wang PJ, Ajayi TB, Allen LA, Baykaner T, et al. Shared decision making in cardiac electrophysiology procedures and arrhythmia management. Circ Arrhythm Electrophysiol. 2021;14:E007958. doi:10.1161/CIRCEP.121.007958
19. Elliott AD, Middeldorp ME, Van Gelder IC, Albert CM, Sanders P. Epidemiology and modifiable risk factors for atrial fibrillation. Nat Rev Cardiol. 2023;20:404-17. doi:10.1038/s41569-022-00820-8
20. Lip GY. The role of aspirin for stroke prevention in atrial fibrillation. Nat Rev Cardiol. 2011;8:602-6. doi:10.1038/nrcardio.2011.112
21. Carnicelli AP, Hong H, Connolly SJ, Eikelboom J, Giugliano RP, Morrow DA, et al. Direct oral anticoagulants versus warfarin in patients with atrial fibrillation: patient-level network meta-analyses of randomized clinical trials with interaction testing by age and sex. Circulation. 2022;145:242-55. doi:10.1161/CIRCULATIONAHA.121.056355
22. Kirchhof P, Camm AJ, Goette A, Brandes A, Eckardt L, Elvan A, et al. Early Rhythm-Control Therapy in Patients with Atrial Fibrillation. N Engl J Med. 2020;383:1305-16. doi: 10.1056/NEJMoa2019422.
23. Marrouche NF, Brachmann J, Andresen D, Siebels J, Boersma L, Jordaens L, et al. Catheter Ablation for Atrial Fibrillation with Heart Failure. New Engl J Med .2018;378:417-27. doi:10.1056/nejmoa1707855
24. Dan GA, Martinez-Rubio A, Agewall S, Boriani G, Borggrefe M, Gaita F,et al. Antiarrhythmic drugs-clinical use and clinical decision making: A consensus document from the European Heart Rhythm Association (EHRA) and European Society of Cardiology (ESC) Working Group on Cardiovascular Pharmacology, endorsed by the Heart Rhythm Society (HRS), Asia-Pacific Heart Rhythm Society (APHRS) and International Society of Cardiovascular Pharmacotherapy (ISCP). Europace. 2018;20:731-2. doi:10.1093/europace/eux373
25. Tzeis S, Gerstenfeld EP, Kalman J, Saad EB, Shamloo AS, Andrade JG, et al. 2024 European Heart Rhythm Association/Heart Rhythm Society/Asia Pacific Heart Rhythm Society/Latin American Heart Rhythm Society expert consensus statement on catheter and surgical ablation of atrial fibrillation. Heart Rhythm. 2024;21:e31-e149. doi: 10.1016/j.hrthm.2024.03.017.
26. Andrade JG. Ablation as first-line therapy for atrial fibrillation. Eur Cardiol Rev. 2023;18. doi:10.15420/ECR.2023.04
27. Deneke T, Kutyifa V, Hindricks G, Sommer P, Zeppenfeld K, Carbucicchio C, et al. Pre- and post-procedural cardiac imaging (computed tomography and magnetic resonance imaging) in electrophysiology: a clinical consensus statement of the European Heart Rhythm Association and European Association of Cardiovascular Imaging of the European Society of Cardiology. Europace. 2024;26:euae108. doi: 10.1093/europace/euae108. Erratum in: Europace. 2024;26:euae166. doi: 10.1093/europace/euae166.
28. Sobolev M, Shiloh AL, Di Biase L, Slovut DP. Ultrasound-guided cannulation of the femoral vein in electrophysiological procedures: A systematic review and meta-analysis. Europace. 2017;19:850-5. doi:10.1093/europace/euw113
29. Lee AC, Voskoboinik A, Cheung CC, Yogi S, Tseng ZH, Moss JD, et al. A Randomized Trial of High vs Standard Power Radiofrequency Ablation for Pulmonary Vein Isolation: SHORT-AF. JACC Clin Electrophysiol. 2023;9:1038--47. doi:10.1016/j.jacep.2022.12.020
30. Reddy VY, Anter E, Rackauskas G, Peichl P, Koruth JS, Petru J, et al. Lattice-Tip Focal Ablation Catheter That Toggles Between Radiofrequency and Pulsed Field Energy to Treat Atrial Fibrillation: A First-in-Human Trial. Circ Arrhythm Electrophysiol. 2020;13:E008718. doi:10.1161/CIRCEP.120.008718
31. Andrade JG, Champagne J, Dubuc M, Deyell MW, Verma A, Macle L, et al. Cryoballoon or radiofrequency ablation for atrial fibrillation assessed by continuous monitoring: a randomized clinical trial. Circulation. 2019;140:1779-88. doi:10.1161/CIRCULATIONAHA.119.042622
32. Kuck KH, Brugada J, Fürnkranz A, Metzner A, Ouyang F, Chun KR, et al. Cryoballoon or Radiofrequency Ablation for Paroxysmal Atrial Fibrillation. N Engl J Med. 2016;374:2235-45. doi: 10.1056/NEJMoa1602014.

33. Verma A, Asivatham SJ, Deneke T, Castellvi Q, Neal RE. Primer on pulsed electrical field ablation: understanding the benefits and limitations. Circ Arrhythm Electrophysiol. 2021;14:E010086. doi:10.1161/CIRCEP.121.010086

34. Reddy VY, Gerstenfeld EP, Natale A, Whang W, Cuoco FA, Patel C, et al. Pulsed field or conventional thermal ablation for paroxysmal atrial fibrillation. New Engl J Med. 2023;389:1660-71. doi:10.1056/nejmoa2307291

35. Deisenhofer I, Albenque JP, Busch S. LB-469805-01 Tailored cardiac ablation procedure for persistent atrial fibrillation guided by artificial intelligence: the tailored-af randomized clinical trial. Heart Rhythm. 2024;21:1199. doi:10.1016/j.hrthm.2024.04.025