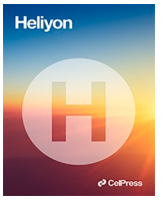
Heliyon 10 (2024) e34205

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Review article

Factors predicting the recurrence of atrial fibrillation after catheter ablation: A review

Degang Mo [a,1], Mengmeng Wang [b,1], Peng Zhang [b], Hongyan Dai [c,**], Jun Guan [c,*]

[a] Qingdao Municipal Hospital, School of Medicine, Qingdao University, Qingdao, 266011, China
[b] Department of Cardiology, Qingdao University, Qingdao, 266011, China
[c] Department of Cardiology, Qingdao Municipal Hospital, Qingdao, 266011, China

ARTICLE INFO

Keywords:
Predictors
Predict
Recurrence
Atrial fibrillation
Catheter ablation

ABSTRACT

Atrial fibrillation (AF) is the most common and clinically significant type of cardiac arrhythmia. Although catheter ablation (CA) can restore sinus rhythm in patients with AF, some patients experience recurrence after the procedure. This requires us to find a simple and effective way to identify patients at a high risk of recurrence and to intervene early in the high-risk population to improve patient prognosis. The mechanism of AF recurrence is unclear, but it involves several aspects including patient history, inflammation, myocardial fibrosis, and genes. This article summarizes the current predictors of AF recurrence after CA, including myocardial fibrosis markers, inflammatory markers, MicroRNAs, Circular RNAs, AF recurrence scores, and imaging indicators. Each predictor has its own scope of application, and the predictive capacity and joint application of multiple predictors may improve the predictive power. In addition, we summarize the mechanisms involved in AF recurrence. We hope that this review will assist researchers understand the current predictors of AF recurrence and help them conduct further related studies.

1. Introduction

Atrial fibrillation (AF) is the most common and clinically significant type of cardiac arrhythmia. It is associated with high morbidity and mortality rates. The most serious consequences of AF are stroke and heart failure [1]. Therefore, improved methods are required to predict the complications of AF and for early intervention. Currently, the treatment of AF mainly focuses on the prevention of thrombosis and control of rhythm [2]. Catheter ablation (CA) is recommended for symptomatic AF and reduced left ventricular ejection fraction [2]. The success rate of CA is 70 % in patients with paroxysmal AF and approximately 50 % in those with persistent AF [3]. However, Hsieh et al. [4] reported a major problem with high recurrence rates, particularly within 6 months after ablation. Although the recurrence rate of AF after CA has decreased with technological advancements, it remains an unresolved social and public health issue [5].

Therefore, early identification of patients with high risk of AF recurrence after CA is essential. Currently, biomarkers related to cardiac fibrosis, myocardial injury, inflammation, and oxidative stress can be used to predict AF recurrence after CA [6–12]. With further research, some new predictors have emerged in recent years. This article reviews the identified and potential predictors of AF

* Corresponding author.
** Corresponding author.
E-mail addresses: daihy9@163.com (H. Dai), guanjunqd@163.com (J. Guan).
[1] The first two authors contributed equally to this work.

https://doi.org/10.1016/j.heliyon.2024.e34205
Received 12 March 2024; Received in revised form 26 May 2024; Accepted 4 July 2024
Available online 6 July 2024
2405-8440/© 2024 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

recurrence after CA. This article will assist researchers to further explore the predictors of AF recurrence after CA. In clinical practice, identification and early intervention in patients at high risk for AF recurrence can improve their quality of life.

2. Biomarkers of myocardial fibrosis

2.1. Transforming growth factor-β1 (TGF-β1)

TGF-β1 is a key cytokine that initiates and promotes the synthesis and metabolism of atrial interstitial collagen. TGF-β1 plays a substantial role in cardiovascular diseases, such as post-ischemic conditions, dilated and hypertrophic cardiomyopathies, valvular diseases, and arrhythmias, particularly AF [13].

Many studies have shown that the TGF-β1 level is an independent predictor of AF recurrence [6,14,15]. However, Kishima et al. reported that a lower TGF-β1 level in patients with AF could be a cause of AF recurrence after CA [16]. Their study contradicted most previous studies. In recent years, more and more studies have indicated that TGF-1 can promote the occurrence of AF through various pathways. A recent study found that TGF-β1 can induce the proliferation, differentiation, and collagen production of cardiac fibroblasts [17]. Several pathways are involved in myocardial fibrosis pathogenesis. Sox9 was either overexpressed or depleted in cultured atrial fibroblasts using adenovirus or siRNA, followed by the addition of recombinant human TGF-β1. Wang et al. reported that myocardial fibrosis may be mediated by the TGF-β1/Sox9 pathway [18]. Liu et al. discovered that the Slit2-Robo1 signaling pathway interferes with the TGF-β1/Smad pathway and promotes cardiac fibrosis [19].

In conclusion, TGF-β1 contributes to AF recurrence through various molecular pathways. Thus, high levels of TGF-β1 can be used to predict recurrence after AF ablation.

2.2. Galectine-3 (Gal-3)

Gal-3, a β-galactoside-binding lectin secreted primarily by activated macrophages, plays a role in various biological functions such as inflammation, apoptosis, angiogenesis, adhesion, and migration [20]. It promotes myocardial fibrosis via the Gal-3/TGF-β1/α-smooth muscle actin (SMA)/collagen I (Col I) pathway [21].

A recent study by Ruan et al. demonstrated that AF recurrence after radiofrequency catheter ablation (RFCA) is associated with a higher baseline Gal-3 level and that a higher preoperative circulating Gal-3 level is an independent predictor of AF recurrence in patients undergoing RFCA [22]. A meta-analysis concluded that higher preprocedural Gal-3 levels may be associated with an increased risk of AF recurrence in patients undergoing CA [23]. Galectin-3 facilitates electrical and structural remodeling during AF progression by stimulating fibroblast activation and differentiation, leading to myocardial fibrosis, remodeling, cellular dysfunction, and eventual onset of AF [24]. However, some researchers believe that high Gal-3 levels are not associated with AF recurrence. Kornej et al. reported that body mass index, but not AF, was associated with Gal-3 levels [25]. They believed that Gal-3 level is affected by cardiometabolic comorbidities, and it is not useful for predicting the rhythm outcome of RFCA. In another study, the authors concluded that Gal-3 level cannot predict arrhythmia recurrence after CA [26].

In brief, most studies support the use of Gal-3 to predict AF recurrence, but some controversy remains, warranting further research.

2.3. Fibroblast growth factor-23 (FGF-23)

FGF-23 is a bone-derived hormone that promotes urinary phosphate excretion and regulates vitamin D metabolism [27]. It has been associated with heart failure, myocardial infarction, and AF [28–30].

Mizia-Stec et al. found that high serum FGF-23 level is associated with episodes of AF, and FGF-23 is a potent predictor of AF recurrence following pulmonary vein isolation (PVI) [31]. Similarly, a prospective, controlled, cohort study conducted by Begg et al. concluded that FGF-23 is associated with arrhythmia recurrence [32]. Dong et al. observed that cardiac fibroblasts treated with recombinant FGF-23 show enhanced interactions between STAT3 and SMAD3. These findings suggest that in patients with AF, FGF23 promotes atrial fibrosis by enhancing reactive oxygen species (ROS) production, which then activates the STAT3 and SMAD3 signaling pathways [33]. This may be the mechanism underlying the AF recurrence. In conclusion, FGF-23 is a powerful biomarker for predicting AF and its recurrence after CA.

2.4. Soluble suppression of tumorigenicity 2 (sST2)

Suppression of tumorigenicity 2 (ST2) is a member of the IL-1 receptor family that plays an important role in immune and inflammatory responses. ST2 receptor exists in the two following forms: a transmembrane receptor and a soluble receptor (sST2). The ligand for ST2 (ST2L) is interleukin-33 (IL-33), which exerts antihypertrophic, antifibrotic, and antiapoptotic functions. sST2 can bind with high affinity to IL-33, interrupting the interaction between IL-33 and ST2L, consequently abrogating their cardioprotective effects [34].

Tan et al. found that increased sST2 levels can serve as biomarkers of AF recurrence after radiofrequency ablation (RFA) [35]. Fan et al. also concluded that elevated sST2 levels in patients with AF considerably increases risk of recurrence after RFA [36]. According to the above studies, we can consider sST2 as a biomarker for predicting AF recurrence after RFA. One possible explanation for how ST2 contributes to the recurrence of AF is that soluble ST2 binds tightly to IL-33, disrupting the IL-33/ST2L interaction, and potentially diminishing its cardioprotective effects [34].

However, the opposite conclusion was reached in another prospective study. Using multivariate regression analysis Badoz et al. demonstrated that sST2 levels do not appear to have any prognostic value in assessing the risk of AF recurrence up to 1 year after CA [37]. Further prospective large-scale clinical trials are required to verify the role of sST2 in AF recurrence. In conclusion, sST2 is a potential biomarker for predicting AF recurrence after CA.

2.5. Other biomarkers of myocardial fibrosis

AF is also associated with myocardial fibrosis [38]. Other biomarkers associated with myocardial fibrosis can also be used to predict the occurrence and recurrence of AF. The N-terminal propeptide of procollagen I type and N-terminal propeptide of procollagen III type are associated with heart remodeling and an increased risk of AF [39]. Matrix metalloproteinases (MMPs), such as MMP-1, MMP-2, MMP-3, and MMP-9, play crucial roles in the occurrence and recurrence of AF [40–42]. The cellular and molecular mechanisms of myocardial fibrosis are complex, and more biomarkers will hopefully be discovered in the future to predict AF recurrence. Table 1 demonstrates myocardial fibrosis biomarkers that predict AF recurrence after CA.

3. Inflammatory biomarkers

3.1. C-reactive protein (CRP)

Although the pathogenesis of AF remains unclear, inflammatory responses play an important role [43]. CRP, a systemic inflammatory marker, is widely used to predict the risk of cardiovascular disease. In a prospective study involving 202 patients with AF, researchers found that the CRP level before CA is a biomarker for AF recurrence after RFA [44].

However, there are opposing opinions. In 2010, Marott et al. performed Mendelian randomization (MR) including 47, 000 individuals from the general population. They found that high plasma CRP levels are associated with AF but genetically elevated CRP levels are not. This suggests that elevated plasma CRP levels do not increase the risk of AF [45]. In a recent study, Li et al. reached similar conclusions. They suggested that the causal effects of CRP on AF are not supported by MR [46].

In conclusion, previous studies have shown that elevated serum CRP levels are positively associated with AF incidence. However, MR studies does not support this finding. Therefore, further research is required to confirm the relationship between CRP level and AF.

3.2. Interleukin (IL) family

ILs are the most important inflammatory factors involved in the inflammatory response. Among the IL family, interleukin-6 (IL-6) is currently one of the most studied members in AF. In a meta-analysis, the authors concluded that IL-6 is a powerful predictor of AF recurrence [10]. The specific mechanism by which IL-6 promotes AF recurrence is not fully understood, but it likely involves a combination of structural and electrical remodeling of the atrium [47]. However, some studies have not supported this conclusion. Stavroula et al. conducted a prospective study including 80 patients with first AF episodes and found that IL-6 is not reliable for

Table 1
Biomarkers of myocardial fibrosis for predicting atrial fibrillation recurrence after catheter ablation.

Biomarkers	Reference	Biological Functions	Prognostic impact after catheter ablation
Transforming growth factor-β1 (TGF-β1)	Kimura et al. [14] Wu et al. [15]	Key cytokine that initiates and promotes the synthesis and metabolism of atrial interstitial collagen.	TGF-β1 participates in the occurrence and recurrence of atrial fibrillation through various molecular pathways.
Galectin-3 (Gal-3)	Isola et al. [20] Ruan et al. [22] Pranata et al. [23]	Many biological functions: inflammation, apoptosis, angiogenesis, adhesion, and migration.	A higher circulating Gal-3 level is an independent predictor of atrial fibrillation recurrence.
Fibroblast growth factor-23 (FGF-23)	Mathew et al. [27] Mizia-Stec et al. [31] Dong et al. [33]	FGF-23 is a bone-derived hormone that promotes urinary phosphate excretion and regulates vitamin D metabolism.	FGF-23 is a powerful biomarker for predicting atrial fibrillation and recurrence after catheter ablation.
Soluble suppression of tumorigenicity 2 (sST2)	Pascual-Figal et al. [34] Tan et al. [35] Fan et al. [36]	A member of IL-1 receptor (IL-1R) family which plays an important role in immune and inflammatory responses.	sST2 can be used to predict the recurrence of atrial fibrillation after catheter ablation but there are dissenting voices [37].
N-terminal propeptide of procollagen I type (PINP) and III type (PIIINP)	Ionin et al. [39]	PINP and PIIINP, play crucial roles in tissue repair and fibrotic processes.	PINP and PIIINP are associated with heart remodeling and they can increase the risk of atrial fibrillation.
Matrix metalloproteinases (MMPs): MMP-1, MMP-2, MMP-3, and MMP-9	Buckley et al. [40] Lewkowicz et al. [41] Lombardi et al. [42]	They are involved in the degradation of the extracellular matrix and are regulated at both the transcriptional and extracellular levels.	They play a crucial role in the occurrence and recurrence of atrial fibrillation.

predicting AF relapse [48]. Another study suggested that IL-6 levels cannot predict AF recurrence [49]. In summary, further clinical research is required to predict AF recurrence of using IL-6 levels.

Other members of the IL family, such as IL-2 and IL-18, have also been confirmed to be associated with AF. Cabrera-Bueno et al. studied 44 patients with paroxysmal AF who underwent PVI and found that IL-2 is an independent predictive factor of AF recurrence [50]. Liu et al. found that high IL-18 levels are related to the severity of AF and its recurrence after cryoablation [51]. In addition, many members of the IL family may be associated with AF and require further investigation.

3.3. Tumor necrosis factor-α (TNF-α)

TNF-α is a versatile cytokine that exhibits a diverse array of biological effects. It plays a role in influencing vascular endothelium, stimulating the production of other cytokines, exerting antiviral effects, promoting bone resorption, facilitating angiogenesis, and stimulating the growth of fibroblasts [52]. A recent prospective study suggests that preprocedural serum TNF-α levels can predict AF recurrence [53]. TNF-α can cause electrical remodeling of the atria by inducing remodeling of ion channels and gap junctions in cardiomyocytes. This leads to the abnormal propagation of action potentials and transmission of calcium ions [54]. Overall, TNF-α plays an important role in the development of AF. However, relatively little research has been conducted on AF recurrence after CA and larger clinical trials are required.

3.4. Neutrophil/lymphocyte ratio (NLR), platelet/lymphocyte ratio (PLR) and systemic immune-inflammatory index (SII)

NLR, a novel systemic inflammatory biomarker, is a prognostic indicator of adverse cardiovascular diseases [55,56]. It is also an important predictor of AF. The level of NLR, before or after CA, is associated with an increased risk of AF recurrence or occurrence [56–59]. In recent years, progress has been made in understanding the relationship between NLR level and AF. Consistent with previous studies, Bazoukis et al. found that NLR levels can predict AF recurrence in patients who underwent CA [60]. Yano et al. also demonstrated that changes in NLR levels before ablation can predict AF recurrence after CA [61]. Thus, NLR is a strong predictor of AF recurrence after CA.

PLR is a repeatable and easily obtainable novel biomarker of systemic inflammatory burden [62]. In a recent retrospective study involving 638 cases of AF, Huang et al. found that PLR is an independent biomarker of long-term AF recurrence after CA [63]. Further studies are required to verify the relationship between PLR and AF recurrence after CA.

Hu et al. proposed that SII, defined as platelet count × neutrophil count/lymphocyte count, is a novel inflammation and immune marker, which has a prognostic value in different types of cancer [64]. Previous studies have confirmed that SII can predict AF

Table 2
Biomarkers of inflammatory for predicting atrial fibrillation recurrence after catheter ablation.

Biomarkers	Reference	Biological Functions	Prognostic impact after catheter ablation
C-reactive protein (CRP)	Hiram et al. [43] Carballo et al. [44]	It plays a crucial role in host defense, inflammation, and autoimmunity, and has been associated with cardiovascular events.	Elevated serum CRP levels are positively associated with atrial fibrillation but Mendelian Randomization studies does not support this result [45,46].
Interleukin (IL) family IL-6, IL-2, IL-18	Cabrera-Bueno et al. [50] Liu et al. [51]	A group of molecules produced by monocytic cells, plays a crucial role in immune responses and the development of immunopathological disorders.	They are potential markers for predicting atrial fibrillation recurrence. Many members of the IL family may be associated with atrial fibrillation and require further investigation.
Tumor necrosis factor-α (TNF-α)	Semenzato et al. [52] AlKassas et al. [53]	It plays a role in influencing vascular endothelium, stimulating the production of other cytokines, exerting antiviral effects, promoting bone resorption, facilitating angiogenesis, and stimulating the growth of fibroblasts.	TNF-α plays an important role in the occurrence and development of atrial fibrillation. However, there is relatively little research on the recurrence of atrial fibrillation after catheter ablation, and larger clinical trials are needed.
Neutrophil/lymphocyte ratio (NLR)	Adamstein et al. [56] Bazoukis et al. [60] Yano et al. [61]	NLR, a novel systemic inflammatory biomarker, is a prognostic indicator of adverse cardiovascular diseases.	NLR is a strong predictor of atrial fibrillation recurrence after catheter ablation.
Platelet/lymphocyte ratio (PLR)	Huang et al. [63]	PLR is a repeatable and easily obtainable novel biomarker of systemic inflammatory burden.	Future studies are needed to verify the relationship between PLR and atrial fibrillation recurrence.
Systemic immune-inflammatory index (SII)	Zhao et al. [66] Kaplan et al. [67]	SII, a novel inflammation and immune marker defined as platelet count × neutrophil count/lymphocyte counts.	It can be easily obtained from blood routine and have strong predictive value.
NLRP3 inflammasome	Swanson et al. [68] Butts et al. [69] Takahashi et al. [70]	It plays a vital role in the innate immune system by initiating the production of inflammatory cytokines, as well as inducing pyroptotic cell death.	There have no clinical trials directly demonstrating the potential use of NLRP3 inflammasome as a predictor of atrial fibrillation recurrence.

recurrence after concomitant cryoMAZE and mitral valve surgery [65]. In two recent studies, SII was observed to be independently and positively associated with AF recurrence after RFCA or cryoablation [66,67].

In conclusion, NLR, PLR, and SII can be easily obtained from routine blood tests and have strong predictive values, making them valuable candidates for promotion and application in clinical practice.

3.5. NLR family pyrin domain containing 3 (NLRP3) inflammasome

NLRP3 inflammasome plays a vital role in the innate immune system by recognizing various signals, initiating the production of inflammatory cytokines, and inducing pyroptotic cell death [68]. Its involvement has been documented in heart diseases such as heart failure (HF), acute myocardial infarction, and arrhythmia [69–71].

Colchicine is a drug that can inhibit the expression of NLRP3 inflammasome [72]. In a randomized controlled trial [73], 161 patients who underwent ablation for AF were treated with colchicine for 3 months following the procedure. The findings of this study indicated that the recurrence rate of AF was significantly lower in the colchicine group than in the placebo group, suggesting that NLRP3 inflammasome can be used to predict AF recurrence. Yao et al. found that the constitutive activation of the cardiomyocyte NLRP3 inflammasome in an animal model resulted in ectopic activity and the production of re-entry substrate conducive to AF development [71]. This mechanism may explain how NLRP3 contributes to AF recurrence.

To date, no clinical trial has directly demonstrated the potential use of NLRP3 inflammasome as a predictor of AF recurrence after CA. Future randomized controlled trials are essential to assess the effectiveness of NLRP3 inflammasome as a predictor of AF recurrence after CA. Inflammatory biomarkers predicting AF recurrence after CA are shown in Table 2.

4. MicroRNAs and circular RNAs

4.1. MicroRNAs

MicroRNAs (miRNAs) are small, non-coding RNAs, composed of approximately 22 ribonucleotides that regulate gene expression at the post-transcriptional level [74]. A prospective study conducted by Zhou et al. [75] demonstrated that circulating miR-21 corresponds to left atrial low-voltage areas and is associated with procedural outcomes in patients with persistent AF undergoing CA. A recent study also reported that the level of miRNA-21 is higher in left atrial blood than in peripheral blood, which may be related to the severity and recurrence of AF after cryoablation [51]. Plasma miRNA-155 levels is elevated in patients with recurrence of AF [76,77]. Conversely, some miRNAs can negatively regulate atrial fibrosis. Harada et al. demonstrated that the expression of miR-20b-5p and miR-330-3p is decreased in patients with AF recurrence [78]. Lage et al. showed that miRNA-451a is downregulated in patients with AF recurrence [79]. In conclusion, some miRNAs can promote the development of AF, whereas others can inhibit the development of AF; therefore, the specific pathogenesis requires further study.

Table 3
MicroRNAs and Circular RNAs for predicting atrial fibrillation recurrence after catheter ablation.

Biomarkers	Reference	Biological Functions	Prognostic impact after catheter ablation
miRNA-21	Bartel et al. [74] Zhou et al. [75]	MiRNA-21, a small non-coding RNA, has been implicated in a range of biological processes and diseases.	Elevated miRNA-21 is associated with new onset atrial fibrillation, severity of atrial fibrillation, and recurrence.
miRNA-155	Zhang et al. [76] He et al. [77]	MiRNA-155, a small non-coding RNA, has been implicated in infectious diseases, cancer, and central nervous system.	Plasma miRNA-155 is elevated in patients with recurrence of atrial fibrillation.
miR-20b-5p	Harada et al. [78]	MiRNA-20b-5p has been identified as a tumor suppressor in renal cell carcinoma, with potential as a biomarker and therapeutic target.	The expression of the miRNA-20b-5p is decreased in patients with atrial fibrillation recurrence.
miR-330-3p	Harada et al. [78]	MiRNA-330-3p has been identified as a key regulator in various cancers, including liver cancer, glioma, and cutaneous malignant melanoma.	The expression of miRNA-330-3p is decreased in patients with atrial fibrillation recurrence.
miRNA-451a	Lage et al. [79]	MiRNA-451a has been identified as a potential diagnostic marker for glioma, with decreased expression in patients with this cancer.	MiRNA-451a is downregulated in recurrent patients.
CircRNA-81906-RYR2	Zhu et al. [81]	CircRNA-81906-RYR2 as one of the highly expressed circRNAs in the human heart.	Increased CircRNA-81906-RYR2 is an independent risk factor for late atrial fibrillation recurrence.
hsa_circ_0002665 hsa_circ_0001953 hsa_circ_0003831 hsa_circ_0040533	Liu et al. [82]	They play an important role in different tumor diseases.	The elevated Circ-RNAs are predicted to play potential regulatory roles in the pathogenesis of late recurrences of atrial fibrillation.

4.2. Circular RNAs

Circular RNAs (CircRNAs) have emerged as a novel type of non-coding RNA involved in gene regulation and have attracted much research attention in the past decade [80]. In a recent prospective clinical study involving 136 patients, multivariate analysis revealed that increased CircRNA-81906-RYR2 is an independent risk factor for late AF recurrence [81]. A recent bioinformatics study identified several CircRNAs that can be used to predict AF recurrence, including hsa_circ_0002665, hsa_circ_0001953, hsa_circ_0003831, and hsa_circ_0040533 [82]. Currently, most research on CircRNAs is focused on bioinformatics, with limited number of clinical trials on this topic. Epanding research in this area is promising, and more clinical trials should be conducted to reveal the clinical predictive role of CircRNAs.

Table 3 lists the miRNAs and CircRNAs used to predict AF recurrence after CA.

5. Risk scores to predict AF recurrence

5.1. CHA2DS2-VASc score

The CHA2DS2-VASc score is a 10-point scale used to assess the risk of stroke in patients with non-valvular AF [83]. The risk factors included in this scoring system are congestive heart failure (points awarded 1), hypertension (points awarded 1), age≥75 years (points awarded 2), diabetes mellitus (points awarded 1), stroke (points awarded 2), vascular disease (points awarded 1), age 65–74 years (points awarded 1), female sex (points awarded 1). The highest score of the entire scoring system is nine points [84].

Kisheva et al. followed 101 patients with AF for 1 year and concluded that the CHA2DS2-VASc score is a significant predictor of AF recurrence [85]. Rordorf et al. conducted a prospective study involving 3313 patients [86], categorized into the low-risk and high-risk groups based on CHA2DS2-VASc scores 0–1 and ≥2, respectively. After 36 months of follow-up, they found that a higher CHA2DS2-VASc score is a significant predictor of AF recurrence [86]. These studies have shown that the CHA2DS2-VASc score is a good predictor of short- and long-term AF recurrence and has good predictive power.

5.2. C2HEST score

The C2HEST score takes several medical conditions into account, such as coronary artery disease (1 point), chronic obstructive pulmonary disease (1 point), hypertension (1 point), old age (age ≥75 years, 2 points), systolic heart failure (2 points), and thyroid disease (hyperthyroidism, 1 point).

The C2HEST score, a simple clinical tool, has demonstrated its effectiveness in predicting the development of AF in different populations. Specifically, in post-stroke patients, it showed superior discrimination and performance than those of other risk scores [87]. It can successfully identify individuals at high risks of AF across different age groups, indicating its potential for targeted AF screening [88]. Additionally, the score proved its predictive value in clinical outcomes, such as incident AF, in patients with HF with preserved ejection fraction, with higher scores correlating with increased risk [89]. Moreover, compared to the CHA2DS2-VASc score, it exhibits stronger predictive abilities for AF recurrence after PVI in patients with paroxysmal AF [90]. In another prospective study including 189 patients with AF, Özmen et al. found that the C2HEST score has greater predictive power than the CHA2DS2-VASc score [91]. Collectively, these findings strongly support the usefulness of the C2HEST score in predicting AF and its related outcomes after CA. In conclusion, the C2HEST score is a good predictor of AF recurrence after CA, and its predictive ability may be superior to that of the CHA2DS2-VASc score. It merits consideration for clinical application.

5.3. HATCH score

The HATCH score utilizes a patient's clinical history and considers factors such as hypertension, age, transient ischemic attack or stroke, chronic obstructive pulmonary disease, and HF [92].

The HATCH score has demonstrated its significance in predicting AF after coronary artery bypass graft surgery, with higher scores indicating a higher risk of AF, as demonstrated in a study conducted by Selvi et al. [93]. It has also been established as a predictor of AF recurrence after RFCA, particularly when the score is 2 or higher, as shown in a study conducted by Dandan et al. [94]. In a retrospective analysis including 322 patients with AF, Han et al. discovered that the areas under the receiver operating characteristic curve for predicting AF recurrence were 0.773 for the C2HEST score and 0.801 for the HATCH score [95]. The study found no significant difference between the two scoring systems in their ability to identify patients with AF recurrence, indicated by a DeLong test p-value of 0.36 [95]. In conclusion, the HATCH score can be used to predict AF recurrence; however, its predictive power needs to be further validated in future clinical trials.

5.4. Coronary artery calcium score (CACS)

CACS, particularly using the Agatston score, has been shown to be a valuable predictor of future cardiovascular risk [96,97]. In a recent prospective study that included 311 patients with AF, researchers found that CACS ≥100 is associated with an increased risk of AF recurrence (hazard ratio = 1.7; 95 % confidence interval: 1.0–2.8; p = 0.039) [98]. In a cross-sectional study, Fernandes et al. indicated that performing an opportunistic assessment of the CACS during ablation can serve as an important tool to enhance cardiovascular risk stratification [99]. These findings have substantial clinical and therapeutic implications. Collectively, these findings

suggest that CACS is a valuable tool for predicting AF recurrence.

5.5. Other risk scores for predicting AF recurrence

In recent years, researchers have continued to explore new scoring systems with the goal of more accurately predicting the risk of AF recurrence after CA and improving the management of high-risk risk patients in advance. The following section discussed some of the new scoring systems that have been discovered by researchers in recent years.

The scoring system, known as the PAT2C2H score, is determined by assigning 1 point to each of the following conditions: chronic obstructive pulmonary disease (P), left atrial dilatation ≥45 mm (A), and hypertension (H). Additionally, 2 points were given for a history of transient ischemic attack or stroke (T), and congestive heart failure (CHF). Cay et al. found that the PAT2C2H score has a better clinical predictive capability for AF recurrence than the HATCH and CHA2DS2-VASc scores [100]. Since relatively few studies have been conducted on the PAT2C2H score, further clinical trials are needed to validate the results of previous studies.

The MB-LATER score, which includes male sex, bundle branch block, left atrial size, type of AF, and early recurrent AF, has been validated in several studies for its ability to predict AF recurrence after various treatments. Potpara et al. [101] reported that a higher MB-LATER score is linked to late AF recurrence after CA. Another study conducted by Kornej et al. [102] reiterated the correlation between the MB-LATER score and arrhythmia recurrence, specifically late recurrence, following CA. Mujović et al. [103] also emphasized that the MB-LATER score exhibits superior predictive ability for very late AF recurrence after RFCA. Collectively, these findings suggest that the MB-LATER score is a valuable tool for predicting AF recurrence, particularly after cardiac arrest and electrical cardioversion.

Peigh et al. [104] developed the SCALE-CryoAF score, which includes structural heart disease, coronary artery disease, left atrial diameter, left bundle branch block, early return of AF, and non-paroxysmal AF as predictors of very late recurrence of AF after CA. A retrospective analysis of 241 cases concluded that the SCALE-CryoAF score is a good predictor of AF recurrence and is superior to the MB-LATER and CHA2DS2-VAS scores [105]. Sano et al. reached the same conclusion that the SCALE-CryoAF score is superior to other scores, such as the MB-LATER score [106]. In conclusion, the SCALE-CryoAF score is stronger than the other scores in predicting distant recurrence of AF.

In summary, each scoring system has its own scoring criteria and target population. Further investigation is required to determine which score exhibits superior predictive ability than the others. Risk scores for predicting AF recurrence after CA are shown in Table 4. In addition, Table 5 shows the predictive ability of some indicators in this article.

Table 4
Risk scores for predicting atrial fibrillation recurrence after catheter ablation.

Risk scores	Reference	Classic using of the risk scores	Prognostic impact after catheter ablation
CHA2DS2-VASc	Kisheva et al. [85] Rordorf et al. [86]	The CHA2DS2-VASc score is a 10-point scale used to assess stroke risk in patients with non-valvular atrial fibrillation	CHA2DS2-VASc score is a good predictor of short- and long-term atrial fibrillation recurrence, and has good predictive power.
C2HEST	Li et al. [87] Lip et al. [88] Liang et al. [89]	The C2HEST score has demonstrated its effectiveness in predicting the development of atrial fibrillation in different populations.	C2HEST scoring system is a good predictor of atrial fibrillation recurrence and its predictive ability may be superior to the CHA2DS2-VASc score.
HATCH	Shibata et al. [92] Selvi et al. [93] Miao et al. [94] Han et al. [95]	It is possible to predict that paroxysmal atrial fibrillation can progress to persistent atrial fibrillation and the risk of atrial fibrillation after atrial flutter ablation.	HATCH score can be used to predict atrial fibrillation recurrence. However, its predictive ability needs to be further validated compared to C2HEST.
Coronary artery calcium score (CACS)	Lopes Fernandes et al. [98] Fernandes et al. [99]	CACS, particularly using the Agatston score, has been shown to be a valuable predictor of future cardiovascular risk.	It is associated with the recurrence of atrial fibrillation.
PAT2C2H	Cay et al. [100]	A new score to predict the recurrence of atrial fibrillation.	A new score shows superior efficiency compared to HATCH and CHA2DS2-VASc scores.
MB-LATER	Potpara et al. [101] Kornej et al. [102] Mujović et al. [103]	It has been validated in several studies for its predictive ability in the atrial fibrillation recurrence after various treatments.	MB-LATER score exhibited superior predictive ability for very late atrial fibrillation recurrence.
SCALE-CryoAF	Peigh et al. [104] Nayak et al. [105] Sano et al. [106]	A novel risk model for very late return of atrial fibrillation.	A good predictor of atrial fibrillation recurrence and is superior to MB-LATER and CHA2DS2-VAS scores.

Table 5
Prediction models for various indicators.

Indicators	Reference	HR (95 % CI)	P value	AUC	Cut-off value	Sensitivity	Specificity
TGF-β1	Kishima et al. [16]	1.073 (1.018–1.138)	0.0083	0.6553	12.56 ng/mL	44.4 %	81.8 %
Galectine-3	Ruan et al. [22]	1.280 (1.040–1.560)	0.0200	0.636	14.57 pg/mL	65.3 %	77.5 %
sST2	Tan et al. [35]	1.038 (1.017–1.060)	<0.001	0.748	39.25 ng/mL	74.0 %	77.0 %
CRP	Ding et al. [59]	1.137 (1.029–1.257)	0.012	0.584	2.025 mg/L	41.4 %	78.8 %
NLR	Ding et al. [59]	1.438 (1.036–1.995)	0.030	0.603	2.33	31.4 %	84.5 %
SII	Kaplan et al. [67]	2.326 (1.359–3.981)	0.002	0.880	532	71.4 %	67.9 %
CHA2DS2-VASc	Rordorf et al. [86]	1.330 (1.100–1.600)	0.003	0.580	2	45.8 %	58.0 %
C2HEST	Ozmen et al. [91]	3.792 (1.784–8.062)	0.001	0.760	2	51.5 %	91.6 %
MB-LATER	Potpara et al. [101]	1.230 (1.080–1.400)	0.002	0.620	2	42.9 %	74.2 %

Note: Transforming growth factor-β1 (TGF-β1); Soluble suppression of tumorigenicity 2 (sST2); C-reactive protein (CRP); Neutrophil/lymphocyte ratio (NLR); Systemic immune-inflammatory index (SII); Hazard ratio (HR); Confidence interval (CI); Area Under Curve (AUC).

6. Imaging for predicting AF recurrence

6.1. Cardiac ultrasound

Cardiac ultrasonography is a simple and effective diagnostic method for predicting AF recurrence. Left atrial diameter (LAD) has been shown to correlate with AF recurrence. Jin et al. analyzed 13 studies including 2825 patients and concluded that LAD is significantly associated with AF recurrence [107]. A recent study suggested that left atrial volume (LAV) is an independent predictor of PVI outcomes [108]. In addition, left atrial strain (LAS) is a predictor of AF recurrence. Nielsen et al. reported that left atrial contractile strain can be used to predict the recurrence of atrial tachyarrhythmia after CA [109]. Hauser et al. [3] also reported that the peak atrial longitudinal strain and peak atrial contraction strain can independently predict incident AF in the general population [110]. Increasing evidence suggests that left atrial appendage flow velocity (LAAFV) is associated with AF recurrence after CA. Chen et al. [111] concluded that LAAFV is associated with an increased risk of AF recurrence after CA. Diastolic early transmitral flow velocity/mitral annular velocity (E/e') is another indicator of AF recurrence. Masuda et al. evaluated the association between E/e' and left atrial low-voltage-area existence [112]. They found that patients undergoing AF ablation who had a high E/e' on preablation echocardiography had a left atrial substrate that was prone to arrhythmias. Additionally, a high E/e' is associated with unfavorable procedural outcomes following PVI [112]. In summary, some indicators of cardiac ultrasound, such as LAD, LAV, LAS, LAAFV, and E/e', can be used to predict AF recurrence after CA.

6.2. Cardiac magnetic resonance imaging (CMRI)

CMRI, a noninvasive diagnostic modality, is also valuable in predicting recurrence of AF. It can be used to assess the level of fibrosis in the heart, which is associated with AF recurrence. Many studies have shown that left atrial (LA) fibrosis assessed using CMRI is associated with an increased risk of AF recurrence. Ghafouri et al. conducted a meta-analysis of nine studies and found that every 10 % increase in LA fibrosis was associated with a 1.54-fold increase in post-ablation AF recurrence [113]. The left atrial appendage (LAA) is a triggering site that is not located in the pulmonary veins. One study revealed that the extent of LAA structural remodeling identified using late gadolinium enhancement magnetic resonance imaging is associated with arrhythmia recurrence after AF ablation [114]. Given that PVI is the cornerstone of AF ablation, the existence of considerable fibrosis outside the pulmonary veins, as indicated by preablation CMRI, may explain the occurrence of AF recurrence despite successful execution of PVI [115]. The correlation between AF recurrence and circumferential pulmonary vein fibrosis induced by cryoballoon ablation was evaluated using late gadolinium-enhanced (LGE) CMRI. Acha et al. found that circumferential pulmonary vein fibrosis assessed using gadolinium-enhanced CMRI is associated with AF recurrence [116]. In conclusion, CMRI can predict recurrence after AF ablation by assessing the level of fibrosis in different parts of the atria.

7. Mechanisms of AF recurrence after CA

Various factors influence AF recurrence, including the primary disease, duration of AF, manner in which CA is performed, and skill level of the operator [117]. AF is a complex process involving systemic inflammation, oxidative stress injury, and atrial fibrosis as the primary mechanisms [118]. These mechanisms also play a crucial role in AF recurrence, as illustrated in Fig. 1.

Inflammation significantly increases in patients with AF after CA. Al-Ani et al. [119] examined CRP and white blood cell (WBC) counts in 55 patients with AF before and a day after CA. They found that inflammatory markers significantly increased in patients who underwent AF ablation [119]. Different CA methods cause inflammatory indicators to increase to varying degrees, which may be related to the risk of AF recurrence after CA. Yin et al. argued that the recurrence rate of AF positively correlates with an increase in the percentage of WBC and neutrophil counts after CA [120]. Wei et al. recruited 152 patients for AF treatment, including 90 patients undergoing RFA and 64 patients undergoing cryoballoon ablation, and concluded that post-ablation inflammation is greater in RFA than in cryoballoon ablation, which is related to higher inflammation in RAF [121]. These studies [120,121] have shown that AF recurrence is related to surgical procedure, which produces greater inflammatory factors, subsequently leading to higher recurrence

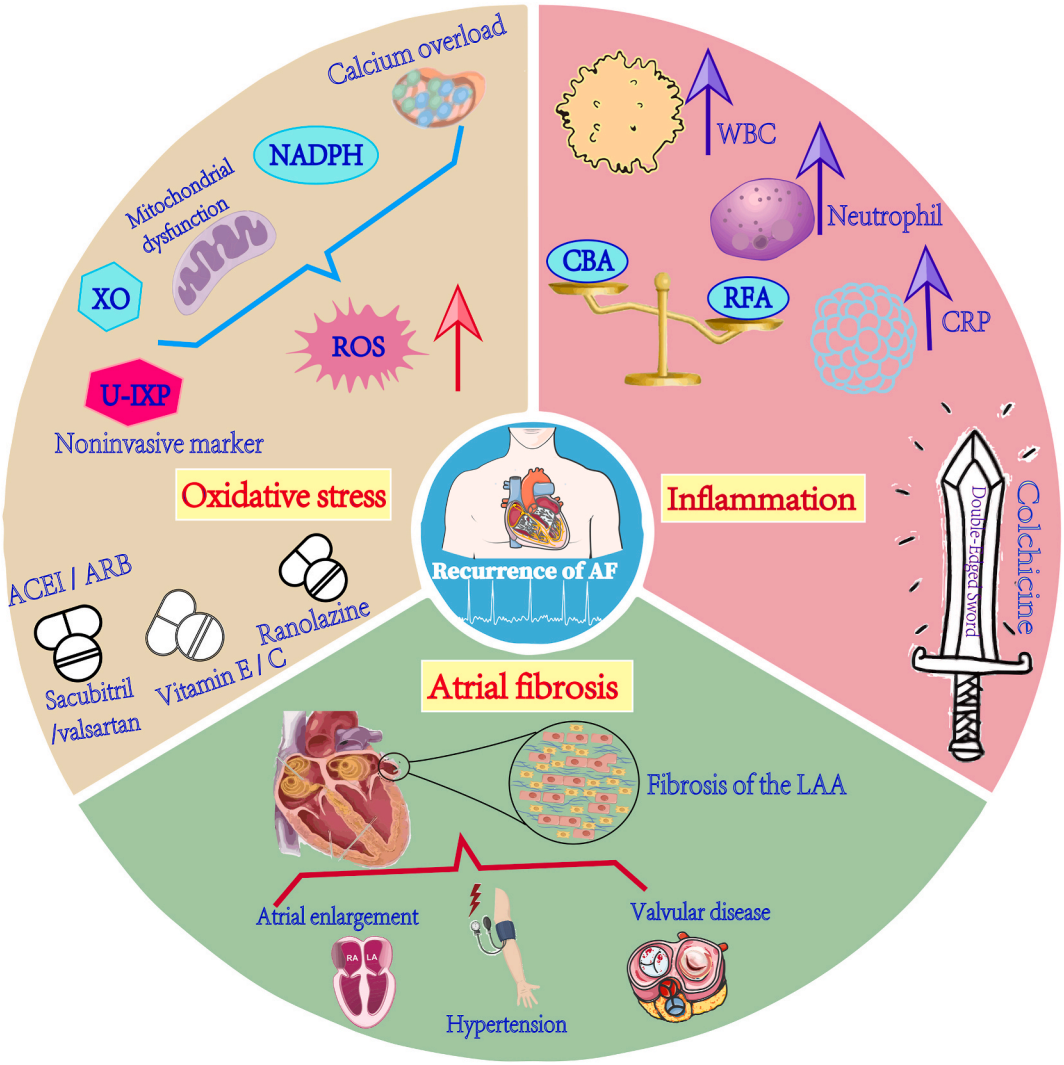


Fig. 1. Fig. 1 illustrates three mechanisms of atrial fibrillation (AF) recurrence including inflammation, oxidative stress injury, and atrial fibrosis. During AF ablation, inflammatory biomarkers such as white blood cells (WBC), neutrophil and C-reactive protein (CRP), are significantly elevated. The degree of inflammation varies among different surgical methods, and the inflammation after radiofrequency ablation (RFA) is more severe than that after cryoballoon ablation (CBA). Anti-inflammatory therapy is a double-edged sword, requiring a balance between its benefits and side effects. Secondly, oxidative stress plays an important role in the recurrence of AF. Oxidative stress is potentially involved in the development of AF through various pathways, including xanthine oxidase (XO), nicotinamide adenine dinucleotide phosphate oxidase (NADPH), mitochondrial dysfunction, and calcium overload. Some medications can reduce oxidative stress, such as Vitamins E, Vitamins C, angiotensin-converting enzyme inhibitors (ACEI), angiotensin receptor blockers (ARB), sacubitril/valsartan, and ranolazine. Thirdly, atrial fibrosis is a key factor in the development and maintenance of AF. Notably, atrial enlargement and atrial fibrosis caused by hypertension, valvular disease, and other factors are the structural basis for the development and maintenance of AF. Regional fibrosis of the left atrial appendage (LAA) is a significant predictor of AF recurrence after ablation.

rate. Whether inhibition of the inflammatory response reduces AF recurrence after CA has been a question of interest to researchers. Colchicine is an exceptional and advanced antiinflammatory agent that has been used for many years in the management of acute inflammatory episodes in gout and familial Mediterranean fever [122]. Several previous studies showed that colchicine can reduce AF recurrence after PVI [73,123]. However, recent studies do not support this hypothesis. Iqbal et al. categorized patients with AF into colchicine-treated and no-colchicine-treated groups and found that the prophylactic use of colchicine is not associated with AF recurrence [124]. Consistent with the findings of this study, Benz et al. argued that the administration of colchicine for 10 days after CA does not result in a decrease in AF recurrence or AF-associated clinical events. However, it effectively alleviates post-ablation chest pain and increases the incidence of diarrhea [125]. Therefore, the ability of colchicine to reduce AF recurrence after CA warrants further investigation.

Oxidative stress refers to a state of an imbalance between the production of ROS and the ability of the body's antioxidant defenses

to neutralize them, which can have detrimental effects on the pathophysiology of cardiac remodeling [126]. In a prospective multicenter study including 1439 patients, researchers found that higher oxidative stress is strongly associated with the development of AF [127]. Oxidative stress is potentially involved in the development of AF through various pathways, including xanthine oxidase, nicotinamide adenine dinucleotide phosphate oxidase, mitochondrial dysfunction, and calcium overload [128–131]. Indicators of oxidative stress are elevated after CA in patients with AF and are associated with short-term AF recurrence [132]. Urinary isoxanthopterin is a noninvasive marker that reflects ROS levels and has recently been found to be useful in predicting AF recurrence after CA [133]. Targeting oxidative stress is expected to be an effective approach for treating AF and improving its prognosis. Vitamins E and C are essential antioxidants that function at different locations in the cell to neutralize ROS. Some studies have shown that vitamins C and E improve the prognosis of AF ablation [134,135]. Statins, commonly used as lipid-lowering agents in cardiovascular diseases, have been found to reduce AF recurrence after cardioversion by modulating NADPH oxidase activity [136,137]. Angiotensin-converting enzyme inhibitors and angiotensin receptor blockers can reduce the risk of all-cause and cardiovascular death in patients with AF [138]. In an animal study, sacubitril/valsartan attenuated atrial structural and electrical remodeling [139]. In a clinical study, sacubitril/valsartan reduced AF recurrence [140]. Other medications, such as ranolazine can also inhibit oxidative stress, thus reducing arrhythmias [141]. In conclusion, oxidative stress may be an important target for reducing AF recurrence.

Atrial fibrosis, a key factor in the development and maintenance of AF, is a complex process involving various interactions [142]. It is the primary histopathological finding in patients with AF and a significant predictor of ablation failure [143]. Atrial fibrosis and AF are causally related. Notably, atrial enlargement and atrial fibrosis caused by hypertension, valvular disease, and other factors are the structural basis for the development and maintenance of AF [144,145]. In contrast, AF promotes atrial fibrosis [146]. In summary, a mutually reinforcing relationship exists between AF and atrial fibrosis. Numerous reasons contribute to AF recurrence after CA, with atrial fibrosis being a major cause [147]. Previous studies reported a strong relationship between the degree of atrial fibrosis and AF recurrence. Higher levels of atrial fibrosis are associated with higher AF recurrence rates [148,149]. In addition, the rate of AF recurrence varies among the different sites of atrial fibrosis. Assaf et al. [150] included 734 patients with persistent AF treated for the first time with CA who underwent LGE-magnetic resonance imaging within 1 month before ablation and were followed up for 1 year. They found that regional fibrosis of the LAA is a significant predictor of AF recurrence after ablation in patients undergoing MRI-guided fibrosis ablation [150]. However, targeting atrial fibrosis remains challenging. Marrouche et al. [151] conducted a large multicenter prospective clinical study including 843 patients with symptomatic or asymptomatic persistent AF who underwent AF ablation. The study [151] randomly assigned patients with persistent AF into the following two groups: one receiving PVI combined with MRI-guided atrial fibrosis ablation (n = 421) and the other receiving PVI alone (n = 422). No significant difference in the recurrence of atrial arrhythmia was observed between the patients who underwent MRI-guided fibrosis ablation plus PVI and those who underwent PVI catheter ablation alone [151]. In conclusion, atrial fibrosis plays an important role in the development, maintenance, and recurrence of AF. Currently, no effective treatment is available for atrial fibrosis, thus making it a potential target for future treatment.

8. Conclusion

The prevalence of patients with AF is increasing every year, and CA has become a routine treatment for AF; however, the success rate of CA needs to be further improved. This article reviews the predictors of AF recurrence after CA, including biomarkers of myocardial fibrosis, inflammation indicators, microRNAs and circular RNAs, AF recurrence scores, and imaging indicators. Additionally, we discuss the mechanisms underlying AF recurrence and potential therapeutic targets. With further advancements in science and the accumulation of clinical experience, it is believed that the recurrence rate of AF will decrease.

Funding

This work was supported by the Qingdao Medical and Health Research Project (2023-WJZD169) and 2023 Shandong Province Medical and Health Technology Project (2023BJ000010).

Data availability statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Ethics declarations

The ethical statement is not applicable in this study as this is a review paper, and we are using secondary published information.

CRediT authorship contribution statement

Degang Mo: Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Mengmeng Wang:** Writing – review & editing, Methodology, Conceptualization. **Peng Zhang:** Writing – review & editing, Investigation. **Hongyan Dai:** Writing – review & editing, Project administration, Methodology, Investigation, Conceptualization. **Jun Guan:** Writing – original draft, Project administration, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to thank Editage (www.editage.cn) for English language editing.

References

[1] J.R. Baman, R.S. Passman, Atrial fibrillation, JAMA 325 (2021) 2218, https://doi.org/10.1001/jama.2020.23700.
[2] C.T. January, L.S. Wann, H. Calkins, et al., AHA/ACC/HRS focused update of the 2014 AHA/ACC/HRS guideline for the management of patients with atrial fibrillation: a report of the American college of cardiology/American heart association task force on clinical practice guidelines and the heart rhythm society in collaboration with the society of thoracic surgeons, Circulation 140 (2019) e125–e151, https://doi.org/10.1161/CIR.0000000000000665, 2019.
[3] P. Kirchhof, S. Benussi, D. Kotecha, et al., ESC Guidelines for the management of atrial fibrillation developed in collaboration with EACTS, Eur. Heart J. 37 (2016) 2893–2962, https://doi.org/10.1093/eurheartj/ehw210, 2016.
[4] M.H. Hsieh, C.T. Tai, C.F. Tsai, et al., Clinical outcome of very late recurrence of atrial fibrillation after catheter ablation of paroxysmal atrial fibrillation, J. Cardiovasc. Electrophysiol. 14 (2003) 598–601, https://doi.org/10.1046/j.1540-8167.2003.03047.x.
[5] J.L. Pallisgaard, G.H. Gislason, J. Hansen, et al., Temporal trends in atrial fibrillation recurrence rates after ablation between 2005 and 2014: a nationwide Danish cohort study, Eur. Heart J. 39 (2018) 442–449, https://doi.org/10.1093/eurheartj/ehx466.
[6] Y. Tian, Y. Wang, W. Chen, Y. Yin, M. Qin, Role of serum TGF-beta1 level in atrial fibrosis and outcome after catheter ablation for paroxysmal atrial fibrillation, Medicine (Baltim.) 96 (2017) e9210, https://doi.org/10.1097/MD.0000000000009210.
[7] F. Kizilirmak, T. Gokdeniz, H.M. Gunes, et al., Myocardial injury biomarkers after radiofrequency catheter and cryoballoon ablation for atrial fibrillation and their impact on recurrence, Kardiol. Pol. 75 (2017) 126–134, https://doi.org/10.5603/KP.a2016.0089.
[8] N. Papageorgiou, R. Providencia, D. Falconer, et al., Predictive role of BNP/NT-proBNP in non-heart failure patients undergoing catheter ablation for atrial fibrillation: an updated systematic review, Curr. Med. Chem. 27 (2020) 4469–4478, https://doi.org/10.2174/0929867326666191213095554.
[9] P.B. Meyre, C. Sticherling, F. Spies, et al., C-reactive protein for prediction of atrial fibrillation recurrence after catheter ablation, BMC Cardiovasc. Disord. 20 (2020) 427, https://doi.org/10.1186/s12872-020-01711-x.
[10] N. Wu, B. Xu, Y. Xiang, et al., Association of inflammatory factors with occurrence and recurrence of atrial fibrillation: a meta-analysis, Int. J. Cardiol. 169 (2013) 62–72, https://doi.org/10.1016/j.ijcard.2013.08.078.
[11] Z.H. Lu, N. Liu, R. Bai, et al., HbA1c levels as predictors of ablation outcome in type 2 diabetes mellitus and paroxysmal atrial fibrillation, Herz 40 (Suppl 2) (2015) 130–136, https://doi.org/10.1007/s00059-014-4154-6.
[12] J. Liu, C. Lin, T. Zhou, et al., Plasma myeloperoxidase: association with atrial fibrillation progression and recurrence after catheter ablation, Front Cardiovasc Med 10 (2023) 1150324, https://doi.org/10.3389/fcvm.2023.1150324.
[13] R. Khan, R. Sheppard, Fibrosis in heart disease: understanding the role of transforming growth factor-beta in cardiomyopathy, valvular disease and arrhythmia, Immunology 118 (2006) 10–24, https://doi.org/10.1111/j.1365-2567.2006.02336.x.
[14] T. Kimura, S. Takatsuki, K. Inagawa, et al., Serum inflammation markers predicting successful initial catheter ablation for atrial fibrillation, Heart Lung Circ. 23 (2014) 636–643, https://doi.org/10.1016/j.hlc.2014.02.003.
[15] C.H. Wu, Y.F. Hu, C.Y. Chou, et al., Transforming growth factor-beta1 level and outcome after catheter ablation for nonparoxysmal atrial fibrillation, Heart Rhythm 10 (2013) 10–15, https://doi.org/10.1016/j.hrthm.2012.09.016.
[16] H. Kishima, T. Mine, S. Takahashi, K. Ashida, M. Ishihara, T. Masuyama, The impact of transforming growth factor-beta(1) level on outcome after catheter ablation in patients with atrial fibrillation, J. Cardiovasc. Electrophysiol. 28 (2017) 402–409, https://doi.org/10.1111/jce.13169.
[17] J. Xiao, Y. Zhang, Y. Tang, et al., MiRNA-1202 promotes the TGF-beta1-induced proliferation, differentiation and collagen production of cardiac fibroblasts by targeting nNOS, PLoS One 16 (2021) e0256066, https://doi.org/10.1371/journal.pone.0256066.
[18] H. Wang, Y. Chen, S. Zhao, X. Wang, K. Lu, H. Xiao, Effect of Sox9 on TGF-beta1-mediated atrial fibrosis, Acta Biochim. Biophys. Sin. 53 (2021) 1450–1458, https://doi.org/10.1093/abbs/gmab132.
[19] Y. Liu, Z. Yin, X. Xu, et al., Crosstalk between the activated Slit2-Robo1 pathway and TGF-beta1 signalling promotes cardiac fibrosis, ESC Heart Fail 8 (2021) 447–460, https://doi.org/10.1002/ehf2.13095.
[20] G. Isola, A. Polizzi, A. Alibrandi, R.C. Williams, A. Lo Giudice, Analysis of galectin-3 levels as a source of coronary heart disease risk during periodontitis, J. Periodontal. Res. 56 (2021) 597–605, https://doi.org/10.1111/jre.12860.
[21] H. Shen, J. Wang, J. Min, et al., Activation of TGF-beta1/alpha-SMA/col I profibrotic pathway in fibroblasts by galectin-3 contributes to atrial fibrosis in experimental models and patients, Cell. Physiol. Biochem. 47 (2018) 851–863, https://doi.org/10.1159/000490077.
[22] Z.B. Ruan, R.F. Gao, F. Wang, et al., Circulating galectin-3 and aldosterone for predicting atrial fibrillation recurrence after radiofrequency catheter ablation, Cardiovasc Ther 2022 (2022) 6993904, https://doi.org/10.1155/2022/6993904.
[23] R. Pranata, E. Yonas, V. Chintya, A.E. Tondas, S.B. Raharjo, Serum Galectin-3 level and recurrence of atrial fibrillation post-ablation - systematic review and meta-analysis, Indian Pacing Electrophysiol J. 20 (2020) 64–69, https://doi.org/10.1016/j.ipej.2020.02.002.
[24] G. Lippi, G. Cervellin, F. Sanchis-Gomar, Galectin-3 in atrial fibrillation: simple bystander, player or both? Clin. Biochem. 48 (2015) 818–822, https://doi.org/10.1016/j.clinbiochem.2015.04.021.
[25] J. Kornej, J. Schmidl, L. Ueberham, et al., Galectin-3 in patients with atrial fibrillation undergoing radiofrequency catheter ablation, PLoS One 10 (2015) e0123574, https://doi.org/10.1371/journal.pone.0123574.
[26] G.A. Begg, R. Karim, T. Oesterlein, et al., Left atrial voltage, circulating biomarkers of fibrosis, and atrial fibrillation ablation. A prospective cohort study, PLoS One 13 (2018) e0189936, https://doi.org/10.1371/journal.pone.0189936.
[27] J.S. Mathew, M.C. Sachs, R. Katz, et al., Fibroblast growth factor-23 and incident atrial fibrillation: the multi-ethnic study of atherosclerosis (MESA) and the cardiovascular health study (CHS), Circulation 130 (2014) 298–307, https://doi.org/10.1161/CIRCULATIONAHA.113.005499.
[28] T. Schmitz, B. Wein, M. Heier, A. Peters, C. Meisinger, J. Linseisen, Baseline fibroblast growth factor 23 is associated with long-term mortality in ST-elevation myocardial infarction-results from the augsburg myocardial infarction registry, Front Cardiovasc Med 10 (2023) 1173281, https://doi.org/10.3389/fcvm.2023.1173281.
[29] Z. Tan, T. Song, S. Huang, et al., Relationship between serum growth differentiation factor 15, fibroblast growth factor-23 and risk of atrial fibrillation: a systematic review and meta-analysis, Front Cardiovasc Med 9 (2022) 899667, https://doi.org/10.3389/fcvm.2022.899667.
[30] P. Pandhi, J.M. Ter Maaten, S.D. Anker, et al., Pathophysiologic processes and novel biomarkers associated with congestion in heart failure, JACC Heart Fail 10 (2022) 623–632, https://doi.org/10.1016/j.jchf.2022.05.013.
[31] K. Mizia-Stec, J. Wieczorek, M. Polak, et al., Lower soluble Klotho and higher fibroblast growth factor 23 serum levels are associated with episodes of atrial fibrillation, Cytokine 111 (2018) 106–111, https://doi.org/10.1016/j.cyto.2018.08.005.
[32] G.A. Begg, G.Y. Lip, S. Plein, M.H. Tayebjee, Circulating biomarkers of fibrosis and cardioversion of atrial fibrillation: a prospective, controlled cohort study, Clin. Biochem. 50 (2017) 11–15, https://doi.org/10.1016/j.clinbiochem.2016.09.008.

[33] Q. Dong, S. Li, W. Wang, et al., FGF23 regulates atrial fibrosis in atrial fibrillation by mediating the STAT3 and SMAD3 pathways, J. Cell. Physiol. 234 (2019) 19502–19510, https://doi.org/10.1002/jcp.28548.

[34] D.A. Pascual-Figal, A. Lax, M.T. Perez-Martinez, M. del Carmen Asensio-Lopez, J. Sanchez-Mas, G. Network, Clinical relevance of sST2 in cardiac diseases, Clin. Chem. Lab. Med. 54 (2016) 29–35, https://doi.org/10.1515/cclm-2015-0074.

[35] R. Tan, H. Yu, X. Han, et al., Circulating soluble suppression of tumorigenicity 2 predicts recurrence after radiofrequency ablation of persistent atrial fibrillation, Front Cardiovasc Med 8 (2021) 653312, https://doi.org/10.3389/fcvm.2021.653312.

[36] J. Fan, Y. Li, Q. Yan, et al., Higher serum sST2 is associated with increased left atrial low-voltage areas and atrial fibrillation recurrence in patients undergoing radiofrequency ablation, J Interv Card Electrophysiol 64 (2022) 733–742, https://doi.org/10.1007/s10840-022-01153-9.

[37] M. Badoz, G. Serzian, B. Favoulet, et al., Impact of midregional N-terminal pro-atrial natriuretic peptide and soluble suppression of tumorigenicity 2 levels on heart rhythm in patients treated with catheter ablation for atrial fibrillation: the biorhythm study, J. Am. Heart Assoc. 10 (2021) e020917, https://doi.org/10.1161/JAHA.121.020917.

[38] C. Sohns, N.F. Marrouche, Atrial fibrillation and cardiac fibrosis, Eur. Heart J. 41 (2020) 1123–1131, https://doi.org/10.1093/eurheartj/ehz786.

[39] V.A. Ionin, E.I. Baranova, E.L. Zaslavskaya, E.Y. Petrishcheva, A.N. Morozov, E.V. Shlyakhto, Galectin-3, N-terminal propeptides of type I and III procollagen in patients with atrial fibrillation and metabolic syndrome, Int. J. Mol. Sci. 21 (2020), https://doi.org/10.3390/ijms21165689.

[40] L.F. Buckley, A.M. Agha, P. Dorbala, et al., MMP-2 associates with incident heart failure and atrial fibrillation: the ARIC study, Circ Heart Fail 16 (2023) e010849, https://doi.org/10.1161/CIRCHEARTFAILURE.123.010849.

[41] J. Lewkowicz, M. Knapp, A. Tankiewicz-Kwedlo, et al., MMP-9 in atrial remodeling in patients with atrial fibrillation, Ann. Cardiol. Angeiol 64 (2015) 285–291, https://doi.org/10.1016/j.ancard.2014.12.004.

[42] F. Lombardi, S. Belletti, P.M. Battezzati, R. Pacciolla, M.L. Biondi, MMP-1 and MMP-3 polymorphism and arrhythmia recurrence after electrical cardioversion in patients with persistent atrial fibrillation, J. Cardiovasc. Med. 12 (2011) 37–42, https://doi.org/10.2459/JCM.0b013e3283403366.

[43] R. Hiram, F. Xiong, P. Naud, et al., An inflammation resolution-promoting intervention prevents atrial fibrillation due to left-ventricular dysfunction, Cardiovasc. Res. (2023), https://doi.org/10.1093/cvr/cvad175.

[44] D. Carballo, S. Noble, S. Carballo, et al., Biomarkers and arrhythmia recurrence following radiofrequency ablation of atrial fibrillation, J. Int. Med. Res. 46 (2018) 5183–5194, https://doi.org/10.1177/0300060518793807.

[45] S.C. Marott, B.G. Nordestgaard, J. Zacho, et al., Does elevated C-reactive protein increase atrial fibrillation risk? A Mendelian randomization of 47,000 individuals from the general population, J. Am. Coll. Cardiol. 56 (2010) 789–795, https://doi.org/10.1016/j.jacc.2010.02.066.

[46] X. Li, S. Peng, X. Wu, et al., C-reactive protein and atrial fibrillation: insights from epidemiological and Mendelian randomization studies, Nutr. Metabol. Cardiovasc. Dis. 32 (2022) 1519–1527, https://doi.org/10.1016/j.numecd.2022.03.008.

[47] L. Scott Jr., N. Li, D. Dobrev, Role of inflammatory signaling in atrial fibrillation, Int. J. Cardiol. 287 (2019) 195–200, https://doi.org/10.1016/j.ijcard.2018.10.020.

[48] S.N. Psychari, D. Chatzopoulos, E.K. Iliodromitis, T.S. Apostolou, D.T. Kremastinos, C-reactive protein, interleukin 6, and N-terminal pro-brain natriuretic peptide following cardioversion of atrial fibrillation: is there a role of biomarkers in arrhythmia recurrence? Angiology 62 (2011) 310–316, https://doi.org/10.1177/0003319710382418.

[49] E. Lewicka, J. Dudzinska-Gehrmann, A. Dabrowska-Kugacka, et al., Neopterin and interleukin-6 as predictors of recurrent atrial fibrillation, Anatol. J. Cardiol. 16 (2016) 563–571, https://doi.org/10.5152/AnatolJCardiol.2015.6272.

[50] F. Cabrera-Bueno, C. Medina-Palomo, A. Ruiz-Salas, et al., Serum levels of interleukin-2 predict the recurrence of atrial fibrillation after pulmonary vein ablation, Cytokine 73 (2015) 74–78, https://doi.org/10.1016/j.cyto.2015.01.026.

[51] Y. Liu, D. Luo, E. Liu, et al., MiRNA21 and IL-18 levels in left atrial blood in patients with atrial fibrillation undergoing cryoablation and their predictive value for recurrence of atrial fibrillation, J Interv Card Electrophysiol 64 (2022) 111–120, https://doi.org/10.1007/s10840-022-01125-z.

[52] G. Semenzato, Tumour necrosis factor: a cytokine with multiple biological activities, Br. J. Cancer 61 (1990) 354–361, https://doi.org/10.1038/bjc.1990.78.

[53] A. AlKassas, M. Fouda, G. Fassini, M. Sanhoury, Pre-procedural high serum visfatin and tumor necrosis factor-alpha might predict recurrent atrial fibrillation after catheter ablation, Egypt Heart J 75 (2023) 63, https://doi.org/10.1186/s43044-023-00383-0.

[54] J. Kneller, R. Zou, E.J. Vigmond, Z. Wang, L.J. Leon, S. Nattel, Cholinergic atrial fibrillation in a computer model of a two-dimensional sheet of canine atrial cells with realistic ionic properties, Circ. Res. 90 (2002) E73–E87, https://doi.org/10.1161/01.res.0000019783.88094.ba.

[55] U. Canpolat, K. Aytemir, H. Yorgun, et al., Role of preablation neutrophil/lymphocyte ratio on outcomes of cryoballoon-based atrial fibrillation ablation, Am. J. Cardiol. 112 (2013) 513–519, https://doi.org/10.1016/j.amjcard.2013.04.015.

[56] N.H. Adamstein, J.G. MacFadyen, L.M. Rose, et al., The neutrophil-lymphocyte ratio and incident atherosclerotic events: analyses from five contemporary randomized trials, Eur. Heart J. 42 (2021) 896–903, https://doi.org/10.1093/eurheartj/ehaa1034.

[57] X. Guo, S. Zhang, X. Yan, et al., Postablation neutrophil/lymphocyte ratio correlates with arrhythmia recurrence after catheter ablation of lone atrial fibrillation, Chin Med J (Engl). 127 (2014) 1033–1038.

[58] Q. Shao, K. Chen, S.W. Rha, H.E. Lim, G. Li, T. Liu, Usefulness of neutrophil/lymphocyte ratio as a predictor of atrial fibrillation: a meta-analysis, Arch. Med. Res. 46 (2015) 199–206, https://doi.org/10.1016/j.arcmed.2015.03.011.

[59] B. Ding, P. Liu, F. Zhang, J. Hui, L. He, Predicting values of neutrophil-to-lymphocyte ratio (NLR), high-sensitivity C-reactive protein (hs-CRP), and left atrial diameter (LAD) in patients with nonvalvular atrial fibrillation recurrence after radiofrequency ablation, Med Sci Monit 28 (2022) e934569, https://doi.org/10.12659/MSM.934569.

[60] G. Bazoukis, K.P. Letsas, K. Vlachos, et al., Simple hematological predictors of AF recurrence in patients undergoing atrial fibrillation ablation, J Geriatr Cardiol 16 (2019) 671–675, https://doi.org/10.11909/j.issn.1671-5411.2019.09.008.

[61] M. Yano, Y. Egami, K. Ukita, et al., Atrial fibrillation type modulates the clinical predictive value of neutrophil-to-lymphocyte ratio for atrial fibrillation recurrence after catheter ablation, Int J Cardiol Heart Vasc 31 (2020) 100664, https://doi.org/10.1016/j.ijcha.2020.100664.

[62] O. Altintas, A. Tasal, E. Niftaliyev, O.T. Kucukdagli, T. Asil, Association of platelet-to-lymphocyte ratio with silent brain infarcts in patients with paroxysmal atrial fibrillation, Neurol. Res. 38 (2016) 753–758, https://doi.org/10.1080/01616412.2016.1210357.

[63] W. Huang, H. Sun, Y. Tang, Y. Luo, H. Liu, Platelet-to-Lymphocyte ratio improves the predictive ability of the risk score for atrial fibrillation recurrence after radiofrequency ablation, J. Inflamm. Res. 16 (2023) 6023–6038, https://doi.org/10.2147/JIR.S440722.

[64] B. Hu, X.R. Yang, Y. Xu, et al., Systemic immune-inflammation index predicts prognosis of patients after curative resection for hepatocellular carcinoma, Clin. Cancer Res. 20 (2014) 6212–6222, https://doi.org/10.1158/1078-0432.CCR-14-0442.

[65] Y. Luo, J. Zhang, T. Liu, et al., The systemic-immune-inflammation index predicts the recurrence of atrial fibrillation after cryomaze concomitant with mitral valve surgery, BMC Cardiovasc. Disord. 22 (2022) 45, https://doi.org/10.1186/s12872-022-02494-z.

[66] Z. Zhao, B. Jiang, F. Zhang, et al., Association between the systemic immune-inflammation index and outcomes among atrial fibrillation patients with diabetes undergoing radiofrequency catheter ablation, Clin. Cardiol. 46 (2023) 1426–1433, https://doi.org/10.1002/clc.24116.

[67] E. Kaplan, F.A. Ekizler, H. Saribas, et al., Effectiveness of the systemic immune inflammation index to predict atrial fibrillation recurrence after cryoablation, Biomark Med 17 (2023) 101–109, https://doi.org/10.2217/bmm-2022-0515.

[68] K.V. Swanson, M. Deng, J.P. Ting, The NLRP3 inflammasome: molecular activation and regulation to therapeutics, Nat. Rev. Immunol. 19 (2019) 477–489, https://doi.org/10.1038/s41577-019-0165-0.

[69] B. Butts, R.A. Gary, S.B. Dunbar, J. Butler, The importance of NLRP3 inflammasome in heart failure, J. Card. Fail. 21 (2015) 586–593, https://doi.org/10.1016/j.cardfail.2015.04.014.

[70] M. Takahashi, Cell-specific roles of NLRP3 inflammasome in myocardial infarction, J. Cardiovasc. Pharmacol. 74 (2019) 188–193, https://doi.org/10.1097/FJC.0000000000000709.

[71] C. Yao, T. Veleva, L. Scott Jr., et al., Enhanced cardiomyocyte NLRP3 inflammasome signaling promotes atrial fibrillation, Circulation 138 (2018) 2227–2242, https://doi.org/10.1161/CIRCULATIONAHA.118.035202.

[72] M.J.M. Silvis, A.T.L. Fiolet, T.S.J. Opstal, et al., Colchicine reduces extracellular vesicle NLRP3 inflammasome protein levels in chronic coronary disease: a LoDoCo2 biomarker substudy, Atherosclerosis 334 (2021) 93–100, https://doi.org/10.1016/j.atherosclerosis.2021.08.005.
[73] S. Deftereos, G. Giannopoulos, C. Kossyvakis, et al., Colchicine for prevention of early atrial fibrillation recurrence after pulmonary vein isolation: a randomized controlled study, J. Am. Coll. Cardiol. 60 (2012) 1790–1796, https://doi.org/10.1016/j.jacc.2012.07.031.
[74] D.P. Bartel, MicroRNAs: genomics, biogenesis, mechanism, and function, Cell 116 (2004) 281–297, https://doi.org/10.1016/s0092-8674(04)00045-5.
[75] Q. Zhou, C. Maleck, S.N.I. von Ungern-Sternberg, et al., Circulating MicroRNA-21 correlates with left atrial low-voltage areas and is associated with procedure outcome in patients undergoing atrial fibrillation ablation, Circ Arrhythm Electrophysiol 11 (2018) e006242, https://doi.org/10.1161/CIRCEP.118.006242.
[76] X. Zhang, X.P. Xiao, X.A. Ren, T. Cui, Plasma miRNA-155 levels predict atrial fibrillation recurrence after cardioversion, Heart Surg. Forum 22 (2019) E140–E148, https://doi.org/10.1532/hsf.2281.
[77] W. He, R. Tang, J. Han, et al., The impact of MicroRNA-155 on the effect of cryoablation in paroxysmal atrial fibrillation, Cell Mol Biol (Noisy-le-grand). 69 (2023) 144–149, https://doi.org/10.14715/cmb/2023.69.12.23.
[78] M. Harada, D. Okuzaki, A. Yamauchi, et al., Circulating miR-20b-5p and miR-330-3p are novel biomarkers for progression of atrial fibrillation: intracardiac/extracardiac plasma sample analysis by small RNA sequencing, PLoS One 18 (2023) e0283942, https://doi.org/10.1371/journal.pone.0283942.
[79] R. Lage, M. Cebro-Marquez, M.E. Vilar-Sanchez, et al., Circulating miR-451a expression may predict recurrence in atrial fibrillation patients after catheter pulmonary vein ablation, Cells 12 (2023), https://doi.org/10.3390/cells12040638.
[80] Y. Zhang, H. Shen, P. Wang, et al., Identification and characterization of circular RNAs in atrial appendage of patients with atrial fibrillation, Exp. Cell Res. 389 (2020) 111821, https://doi.org/10.1016/j.yexcr.2020.111821.
[81] X. Zhu, Y. Wang, R. Mo, et al., Left atrial appendage circular RNAs are new predictors of atrial fibrillation recurrence after surgical ablation in valvular atrial fibrillation patients, Heart Surg. Forum 24 (2021) E968–E976, https://doi.org/10.1532/hsf.4125.
[82] S.S. Liu, H.Y. Guo, J. Zhu, et al., Circulating circRNA expression profile and its potential role in late recurrence of paroxysmal atrial fibrillation post catheter ablation, J Geriatr Cardiol 20 (2023) 788–800, https://doi.org/10.26599/1671-5411.2023.11.006.
[83] C. Grouin, L. Deleger, A. Rosier, et al., Automatic computation of CHA2DS2-VASc score: information extraction from clinical texts for thromboembolism risk assessment. AMIA Annu Symp Proc. 2011, 2011, pp. 501–510.
[84] Corrigendum to, ESC Guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the European Association of Cardio-Thoracic Surgery (EACTS), Eur. Heart J. 42 (2020) 546–547, https://doi.org/10.1093/eurheartj/ehaa945, 2021.
[85] A. Kisheva, Y. Yotov, Risk factors for recurrence of atrial fibrillation, Anatol. J. Cardiol. 25 (2021) 338–345, https://doi.org/10.14744/AnatolJCardiol.2020.80914.
[86] R. Rordorf, S. Iacopino, R. Verlato, et al., Role of CHA(2)DS(2)-VASc score in predicting atrial fibrillation recurrence in patients undergoing pulmonary vein isolation with cryoballoon ablation, J Interv Card Electrophysiol 66 (2023) 1193–1200, https://doi.org/10.1007/s10840-022-01430-7.
[87] Y.G. Li, A. Bisson, A. Bodin, et al., C(2) HEST score and prediction of incident atrial fibrillation in poststroke patients: a French nationwide study, J. Am. Heart Assoc. 8 (2019) e012546, https://doi.org/10.1161/JAHA.119.012546.
[88] G.Y.H. Lip, F. Skjoth, P.B. Nielsen, T.B. Larsen, Evaluation of the C(2)HEST risk score as a possible opportunistic screening tool for incident atrial fibrillation in a healthy population (from a nationwide Danish cohort study), Am. J. Cardiol. 125 (2020) 48–54, https://doi.org/10.1016/j.amjcard.2019.09.034.
[89] W. Liang, Y. Wu, R. Xue, et al., C(2)HEST score predicts clinical outcomes in heart failure with preserved ejection fraction: a secondary analysis of the TOPCAT trial, BMC Med. 19 (2021) 44, https://doi.org/10.1186/s12916-021-01921-w.
[90] F. Levent, S. Kanat, A. Tutuncu, Predictive value of C2HEST score for atrial fibrillation recurrence following successful cryoballoon pulmonary vein isolation in paroxysmal atrial fibrillation, Angiology 74 (2023) 273–281, https://doi.org/10.1177/00033197221102230.
[91] G. Ozmen, F. Koca, C(2)HEST and CHA(2)DS(2)-Vasc for predicting recurrence after catheter ablation of paroxysmal atrial fibrillation, Kardiologiia 63 (2023) 52–60, https://doi.org/10.18087/cardio.2023.6.n2426.
[92] N. Shibata, T. Kondo, R. Morimoto, et al., Clinical value of the HATCH score for predicting adverse outcomes in patients with heart failure, Heart Ves. 37 (2022) 1363–1372, https://doi.org/10.1007/s00380-022-02035-w.
[93] M. Selvi, H. Gungor, C. Zencir, et al., A new predictor of atrial fibrillation after coronary artery bypass graft surgery: HATCH score, J Investig Med 66 (2018) 648–652, https://doi.org/10.1136/jim-2017-000525.
[94] D.D. Miao, X.B. Zang, S.L. Zhang, et al., [Predictive value of HATCH score on atrial fibrillation recurrence post radiofrequency catheter ablation], Zhonghua Xinxueguanbing Zazhi 40 (2012) 821–824.
[95] J. Han, G. Li, D. Zhang, X. Wang, X. Guo, Predicting late recurrence of atrial fibrillation after radiofrequency ablation in patients with atrial fibrillation: comparison of C2HEST and HATCH scores, Front Cardiovasc Med 9 (2022) 907817, https://doi.org/10.3389/fcvm.2022.907817.
[96] S.S. Khan, W.S. Post, X. Guo, et al., Coronary artery calcium score and polygenic risk score for the prediction of coronary heart disease events, JAMA 329 (2023) 1768–1777, https://doi.org/10.1001/jama.2023.7575.
[97] N. Malguria, S. Zimmerman, E.K. Fishman, Coronary artery calcium scoring: current status and review of literature, J. Comput. Assist. Tomogr. 42 (2018) 887–897, https://doi.org/10.1097/RCT.0000000000000825.
[98] S. Lopes Fernandes, R. Ladeiras-Lopes, M. Silva, et al., Higher coronary artery calcium score is associated with increased risk of atrial fibrillation recurrence after catheter ablation, J Cardiovasc Comput Tomogr. 17 (2023) 22–27, https://doi.org/10.1016/j.jcct.2022.10.002.
[99] S. Fernandes, I. Cruz, R. Faria, et al., Impact of coronary artery calcium score screening on cardiovascular risk stratification of patients with atrial fibrillation undergoing ablation, Cardiology 148 (2023) 427–433, https://doi.org/10.1159/000532018.
[100] S. Cay, M. Kara, F. Ozcan, et al., A new scoring system: PAT(2)C(2)H score. Its clinical use and comparison with HATCH and CHA(2)DS(2)-VASc scores in predicting arrhythmia recurrence after cryoballoon ablation of paroxysmal atrial fibrillation, J Interv Card Electrophysiol 65 (2022) 701–710, https://doi.org/10.1007/s10840-022-01328-4.
[101] T.S. Potpara, N. Mujovic, B. Sivasambu, et al., Validation of the MB-LATER score for prediction of late recurrence after catheter-ablation of atrial fibrillation, Int. J. Cardiol. 276 (2019) 130–135, https://doi.org/10.1016/j.ijcard.2018.08.018.
[102] J. Kornej, K. Schumacher, B. Dinov, et al., Prediction of electro-anatomical substrate and arrhythmia recurrences using APPLE, DR-FLASH and MB-LATER scores in patients with atrial fibrillation undergoing catheter ablation, Sci. Rep. 8 (2018) 12686, https://doi.org/10.1038/s41598-018-31133-x.
[103] N. Mujovic, M. Marinkovic, N. Markovic, A. Shantsila, G.Y. Lip, T.S. Potpara, Prediction of very late arrhythmia recurrence after radiofrequency catheter ablation of atrial fibrillation: the MB-LATER clinical score, Sci. Rep. 7 (2017) 40828, https://doi.org/10.1038/srep40828.
[104] G. Peigh, R.M. Kaplan, A. Bavishi, et al., A novel risk model for very late return of atrial fibrillation beyond 1 year after cryoballoon ablation: the SCALE-CryoAF score, J Interv Card Electrophysiol 58 (2020) 209–217, https://doi.org/10.1007/s10840-019-00588-x.
[105] T. Nayak, G. Peigh, A.B. Chicos, et al., Validation of the SCALE-CryoAF risk model to predict very late return of atrial fibrillation after cryoballoon ablation, J Interv Card Electrophysiol 66 (2023) 1859–1865, https://doi.org/10.1007/s10840-023-01494-z.
[106] M. Sano, C.H. Heeger, V. Sciacca, et al., Evaluation of predictive scores for late and very late recurrence after cryoballoon-based ablation of atrial fibrillation, J Interv Card Electrophysiol 61 (2021) 321–332, https://doi.org/10.1007/s10840-020-00778-y.
[107] X. Jin, J. Pan, H. Wu, D. Xu, Are left ventricular ejection fraction and left atrial diameter related to atrial fibrillation recurrence after catheter ablation? A meta-analysis, Medicine (Baltimore) 97 (2018) e10822 https://doi.org/10.1097/MD.0000000000010822.
[108] L. Chollet, S.U.R. Iqbal, S. Wittmer, et al., Impact of atrial fibrillation phenotype and left atrial volume on outcome after pulmonary vein isolation, Europace 26 (2024), https://doi.org/10.1093/europace/euae071.
[109] A.B. Nielsen, K.G. Skaarup, K. Djernaes, et al., Left atrial contractile strain predicts recurrence of atrial tachyarrhythmia after catheter ablation, Int. J. Cardiol. 358 (2022) 51–57, https://doi.org/10.1016/j.ijcard.2022.04.056.
[110] R. Hauser, A.B. Nielsen, K.G. Skaarup, et al., Left atrial strain predicts incident atrial fibrillation in the general population: the Copenhagen City Heart Study, Eur Heart J Cardiovasc Imaging 23 (2021) 52–60, https://doi.org/10.1093/ehjci/jeab202.

[111] P. Chen, Y. Shi, J. Ju, et al., Left atrial appendage flow velocity predicts recurrence of atrial fibrillation after catheter ablation: a systematic review and meta-analysis, Front Cardiovasc Med 9 (2022) 971848, https://doi.org/10.3389/fcvm.2022.971848.
[112] M. Masuda, M. Fujita, O. Iida, et al., An E/e' ratio on echocardiography predicts the existence of left atrial low-voltage areas and poor outcomes after catheter ablation for atrial fibrillation, Europace 20 (2018) e60–e68, https://doi.org/10.1093/europace/eux119.
[113] K. Ghafouri, K.B. Franke, F.S. Foo, M.K. Stiles, Clinical utility of cardiac magnetic resonance imaging to assess the left atrium before catheter ablation for atrial fibrillation - a systematic review and meta-analysis, Int. J. Cardiol. 339 (2021) 192–202, https://doi.org/10.1016/j.ijcard.2021.07.030.
[114] P. Suksaranjit, N.F. Marrouche, F.T. Han, et al., Relation of left atrial appendage remodeling by magnetic resonance imaging and outcome of ablation for atrial fibrillation, Am. J. Cardiol. 122 (2018) 83–88, https://doi.org/10.1016/j.amjcard.2018.03.027.
[115] G. Hindricks, T. Potpara, N. Dagres, et al., ESC Guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the European Association for Cardio-Thoracic Surgery (EACTS): the Task Force for the diagnosis and management of atrial fibrillation of the European Society of Cardiology (ESC) Developed with the special contribution of the European Heart Rhythm Association (EHRA) of the ESC, Eur. Heart J. 42 (2020) 373–498, https://doi.org/10.1093/eurheartj/ehaa612, 2021.
[116] M. Rav Acha, O. Tovia-Brodie, Y. Michowitz, et al., Cryoballoon-induced circumferential pulmonary vein fibrosis, assessed by late gadolinium-enhancement cardiac magnetic resonance imaging, and its correlation with clinical atrial fibrillation recurrence, J. Clin. Med. 12 (2023), https://doi.org/10.3390/jcm12062442.
[117] Z.B. Ruan, H.X. Liang, F. Wang, et al., Influencing factors of recurrence of nonvalvular atrial fibrillation after radiofrequency catheter ablation and construction of clinical nomogram prediction model, Int. J. Clin. Pract. 2022 (2022) 8521735, https://doi.org/10.1155/2022/8521735.
[118] X. Zeng, Q. Li, M. Zhang, W. Wang, X. Tan, Green tea may be benefit to the therapy of atrial fibrillation, J. Cell. Biochem. 112 (2011) 1709–1712, https://doi.org/10.1002/jcb.23096.
[119] M. Al-Ani, S. Ambadapadi, J.R. Yaron, et al., Atrial fibrillation ablation increases inflammation-chemokine modulation suppresses activation of leukocytes isolated after ablation, Cardiovasc. Hematol. Disord.: Drug Targets 17 (2017) 195–204, https://doi.org/10.2174/1871529X17666170918140442.
[120] G. Yin, B. Ma, B. Zhou, J. Wu, L. You, R. Xie, Inflammatory response after different ablation strategies for paroxysmal atrial fibrillation, Heart Surg. Forum 23 (2020) E703–E711, https://doi.org/10.1532/hsf.3149.
[121] Y. Wei, Y. Bao, C. Lin, et al., Early recurrence after cryoballoon versus radiofrequency ablation for paroxysmal atrial fibrillation: mechanism and implication in long-term outcome, BMC Cardiovasc. Disord. 22 (2022) 400, https://doi.org/10.1186/s12872-022-02816-1.
[122] M. Imazio, M. Nidorf, Colchicine and the heart, Eur. Heart J. 42 (2021) 2745–2760, https://doi.org/10.1093/eurheartj/ehab221.
[123] S. Deftereos, G. Giannopoulos, M. Efremidis, et al., Colchicine for prevention of atrial fibrillation recurrence after pulmonary vein isolation: mid-term efficacy and effect on quality of life, Heart Rhythm 11 (2014) 620–628, https://doi.org/10.1016/j.hrthm.2014.02.002.
[124] A.M. Iqbal, K.Y. Li, S. Gautam, Colchicine usage for prevention of post atrial fibrillation ablation pericarditis in patients undergoing high-power short-duration ablation, J. Cardiovasc. Electrophysiol. 34 (2023) 1370–1376, https://doi.org/10.1111/jce.15941.
[125] A.P. Benz, G. Amit, S.J. Connolly, et al., Colchicine to prevent atrial fibrillation recurrence after catheter ablation: a randomized, placebo-controlled trial, Circ Arrhythm Electrophysiol 17 (2024) e01238, https://doi.org/10.1161/CIRCEP.123.012387.
[126] S. Huo, W. Shi, H. Ma, et al., Alleviation of inflammation and oxidative stress in pressure overload-induced cardiac remodeling and heart failure via IL-6/STAT3 inhibition by raloxifene, Oxid. Med. Cell. Longev. 2021 (2021) 6699054, https://doi.org/10.1155/2021/6699054.
[127] A. Samman Tahhan, P.B. Sandesara, S.S. Hayek, et al., Association between oxidative stress and atrial fibrillation, Heart Rhythm 14 (2017) 1849–1855, https://doi.org/10.1016/j.hrthm.2017.07.028.
[128] D. Xu, N. Murakoshi, K. Tajiri, et al., Xanthine oxidase inhibitor febuxostat reduces atrial fibrillation susceptibility by inhibition of oxidized CaMKII in Dahl salt-sensitive rats, Clin Sci (Lond). 135 (2021) 2409–2422, https://doi.org/10.1042/CS20210405.
[129] S. Barangi, A.W. Hayes, G. Karimi, The more effective treatment of atrial fibrillation applying the natural compounds; as NADPH oxidase and ion channel inhibitors, Crit. Rev. Food Sci. Nutr. 58 (2018) 1230–1241, https://doi.org/10.1080/10408398.2017.1379000.
[130] S. Fumagalli, G. Ricciardi, C. Di Serio, et al., Inflammation, mitochondrial dysfunction and physical performance: a possible association in older patients with persistent atrial fibrillation-the results of a preliminary study, Aging Clin. Exp. Res. 35 (2023) 2831–2837, https://doi.org/10.1007/s40520-023-02558-w.
[131] B. Lkhagva, Y.K. Lin, Y.C. Chen, et al., ZFHX3 knockdown dysregulates mitochondrial adaptations to tachypacing in atrial myocytes through enhanced oxidative stress and calcium overload, Acta Physiol. 231 (2021) e13604, https://doi.org/10.1111/apha.13604.
[132] B. Richter, M. Gwechenberger, A. Socas, et al., Markers of oxidative stress after ablation of atrial fibrillation are associated with inflammation, delivered radiofrequency energy and early recurrence of atrial fibrillation, Clin. Res. Cardiol. 101 (2012) 217–225, https://doi.org/10.1007/s00392-011-0383-3.
[133] T. Koi, N. Kataoka, K. Uchida, T. Imamura, K. Kinugawa, Urinary isoxanthopterin as a novel predictor following catheter ablation for atrial fibrillation, J Arrhythm 39 (2023) 159–165, https://doi.org/10.1002/joa3.12828.
[134] R. Rodrigo, P. Korantzopoulos, M. Cereceda, et al., A randomized controlled trial to prevent post-operative atrial fibrillation by antioxidant reinforcement, J. Am. Coll. Cardiol. 62 (2013) 1457–1465, https://doi.org/10.1016/j.jacc.2013.07.014.
[135] F. Petersen, R. Rodrigo, M. Richter, S. Kostin, The effects of polyunsaturated fatty acids and antioxidant vitamins on atrial oxidative stress, nitrotyrosine residues, and connexins following extracorporeal circulation in patients undergoing cardiac surgery, Mol. Cell. Biochem. 433 (2017) 27–40, https://doi.org/10.1007/s11010-017-3013-1.
[136] L. Fiedler, L. Hallsson, M. Tscharre, et al., Upstream statin therapy and long-term recurrence of atrial fibrillation after cardioversion: a propensity-matched analysis, J. Clin. Med. 10 (2021), https://doi.org/10.3390/jcm10040807.
[137] A. Oesterle, J.K. Liao, The pleiotropic effects of statins - from coronary artery disease and stroke to atrial fibrillation and ventricular tachyarrhythmia, Curr. Vasc. Pharmacol. 17 (2019) 222–232, https://doi.org/10.2174/1570161116666180817155058.
[138] W. Xu, Y.M. Yang, J. Zhu, et al., Impact of renin-angiotensin-aldosterone-system inhibitor drugs on mortality in patients with atrial fibrillation and hypertension, BMC Cardiovasc. Disord. 22 (2022) 141, https://doi.org/10.1186/s12872-022-02580-2.
[139] L.Y. Li, Q. Lou, G.Z. Liu, et al., Sacubitril/valsartan attenuates atrial electrical and structural remodelling in a rabbit model of atrial fibrillation, Eur. J. Pharmacol. 881 (2020) 173120, https://doi.org/10.1016/j.ejphar.2020.173120.
[140] R. De Vecchis, A. Paccone, M. Di Maio, Upstream therapy for atrial fibrillation prevention: the role of sacubitril/valsartan, Cardiol Res 11 (2020) 213–218, https://doi.org/10.14740/cr1073.
[141] A. Ratte, F. Wiedmann, M. Kraft, H.A. Katus, C. Schmidt, Antiarrhythmic properties of ranolazine: inhibition of atrial fibrillation associated TASK-1 potassium channels, Front. Pharmacol. 10 (2019) 1367, https://doi.org/10.3389/fphar.2019.01367.
[142] C.Y. Li, J.R. Zhang, W.N. Hu, S.N. Li, Atrial fibrosis underlying atrial fibrillation, Int. J. Mol. Med. 47 (9) (2021), https://doi.org/10.3892/ijmm.2020.4842.
[143] H. Kottkamp, D. Schreiber, F. Moser, A. Rieger, Therapeutic approaches to atrial fibrillation ablation targeting atrial fibrosis, JACC Clin Electrophysiol. 3 (2017) 643–653, https://doi.org/10.1016/j.jacep.2017.05.009.
[144] S.R. Lee, C.S. Park, E.K. Choi, et al., Hypertension burden and the risk of new-onset atrial fibrillation: a nationwide population-based study, Hypertension 77 (2021) 919–928, https://doi.org/10.1161/HYPERTENSIONAHA.120.16659.
[145] A. Brandes, Rheumatic mitral valve stenosis and atrial fibrillation - vicious twins, Int. J. Cardiol. 395 (2024) 131566, https://doi.org/10.1016/j.ijcard.2023.131566.
[146] W. Tan, K. Wang, X. Yang, K. Wang, N. Wang, T.B. Jiang, LncRNA HOTAIR promotes myocardial fibrosis in atrial fibrillation through binding with PTBP1 to increase the stability of Wnt5a, Int. J. Cardiol. 369 (2022) 21–28, https://doi.org/10.1016/j.ijcard.2022.06.073.
[147] N.F. Marrouche, D. Wilber, G. Hindricks, et al., Association of atrial tissue fibrosis identified by delayed enhancement MRI and atrial fibrillation catheter ablation: the DECAAF study, JAMA 311 (2014) 498–506, https://doi.org/10.1001/jama.2014.3.
[148] N. Akoum, M. Daccarett, C. McGann, et al., Atrial fibrosis helps select the appropriate patient and strategy in catheter ablation of atrial fibrillation: a DE-MRI guided approach, J. Cardiovasc. Electrophysiol. 22 (2011) 16–22, https://doi.org/10.1111/j.1540-8167.2010.01876.x.

[149] C. McGann, N. Akoum, A. Patel, et al., Atrial fibrillation ablation outcome is predicted by left atrial remodeling on MRI, Circ Arrhythm Electrophysiol 7 (2014) 23–30, https://doi.org/10.1161/CIRCEP.113.000689.
[150] A. Assaf, M. Mekhael, C. Noujaim, et al., Effect of fibrosis regionality on atrial fibrillation recurrence: insights from DECAAF II, Europace 25 (2023), https://doi.org/10.1093/europace/euad199.
[151] N.F. Marrouche, O. Wazni, C. McGann, et al., Effect of MRI-guided fibrosis ablation vs conventional catheter ablation on atrial arrhythmia recurrence in patients with persistent atrial fibrillation: the DECAAF II randomized clinical trial, JAMA 327 (2022) 2296–2305, https://doi.org/10.1001/jama.2022.8831.