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Epidemiology, pathogenesis and management of atrial fibrillation in athletes - a comprehensive review

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Abstract
Background: Atrial fibrillation (AF) is the most common cardiac arrhythmia, affecting millions worldwide. While moderate physical activity is known to reduce AF risk, endurance athletes, particularly males, appear to have a higher prevalence of AF. The relationship between physical activity and AF follows a U-shaped curve, where both sedentary lifestyles and extreme-levels of physical activity increase the risk. Understanding the pathophysiology, risk factors, and management of AF in athletes is crucial for optimizing both cardiovascular health and athletic performance.
Aim of the work: This study aims to review current literature on AF in athletes, focusing on its prevalence, pathophysiology, risk factors, gender differences, clinical significance, and management strategies. It also seeks to identify gaps in research and suggest future directions for improving prevention and treatment in this population.
Materials and methods: A thorough literature review was conducted using databases such as PubMed and Google Scholar, covering studies from the last 20 years. Keywords included "atrial fibrillation," "athletes," "endurance sports," and "exercise-induced AF." Studies were selected based on relevance, methodology, and sample size.
Results: Findings suggest that AF prevalence is significantly higher in endurance athletes, particularly in middle-aged men with long-term high-intensity training. Key contributing factors include atrial remodeling, inflammation, fibrosis and autonomic nervous system imbalance. While male athletes appear to be at greater risk, evidence in female athletes remains limited and inconclusive. Management strategies emphasize risk factor modification, individualized treatment plans, careful use of medications and ablation therapy. Exercise reduction as a preventive strategy remains debated.
Conclusions: The relationship between AF and athletic activity is complex, requiring individualized clinical approaches. While endurance training may elevate AF risk, athletes generally have a lower overall cardiovascular mortality rate. More research is needed to refine screening protocols, establish optimal treatment strategies, and determine safe training limits for athletes with AF

Key words: "atrial fibrillation", "athletes", "epidemiology", "pathophysiology", "management" "exercise-induced atrial fibrillation", "athlete's heart"

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1. Introduction

Atrial fibrillation (AF) is a heart disorder characterized by chaotic and irregular atrial contractions which lead to inefficient blood flow (Eijsvogels et al., 2016). Atrial fibrillation is the most common arrhythmia in the world, with an increasing number of patients affected (Joglar et al., 2023). It is estimated that around 50 million people have AF globally (Tsao et al., 2023) . According to 2024 European Society of Cardiology (ESC) Guidelines for the management of atrial fibrillation, we can classify AF as first-diagnosed, paroxysmal, persistent and permanent. This definition of AF has been heavily discussed in recent years with alternative classifications being presented. New classifications tend to include a more pathophysiological approach (Van Gelder et al., 2024). AF can present itself with a variety of symptoms, although a significant amount of patients (12-45%) remain asymptomatic during an episode. Patients usually report palpitation, shortness of breath, fatigue, chest pain, poor exercise capacity and syncope (Heidt et al., 2016). There are a number of risk factors for AF, with the most important being advanced age, smoking, alcohol use, obesity, chronic kidney disease, obstructive sleep apnoea, thyroid disease, diabetes and hypertension. There is also a well established link between AF and other cardiovascular diseases such as heart failure (HF), coronary artery disease (CAD) and valvular heart disease (Joglar et al., 2023) . One of the most interesting risk factors for developing AF is physical activity. It is well known that the lack of physical activity and sedentary lifestyle are correlated to higher AF morbidity rate (Mohanty et al., 2016; Sagris et al., 2021) . It is also universally acknowledged that physical activity at guideline-levels is associated with a significant decrease in risk of AF (Mishima et al., 2021). The recommended physical activity mentioned by different guidelines seems to be around 150-300 minutes of moderate and 75-150 minutes of vigorous activity in a week (Bull et al., 2020a) . However, there have been numerous studies suggesting that high-level athletes, especially men, participating in endurance sports seem to have a significantly higher risk of AF (Abdulla & Nielsen, 2009; Certo Pereira et al., 2024; Eijsvogels et al., 2016; Lampert et al., 2024; Newman et al., 2021; A. Palermi et al., 2025; Sanna et al., 2018a; Turagam et al., 2015). The aforementioned 2024 ESC guidelines state that both decreased and extreme-levels of physical activity are correlated to increased risk of AF. AF in the athletic population presents unique diagnostic and management challenges. While regular physical activity is known to influence AF risk, the exact nature of this relationship remains unclear. Current research suggests a complex interplay between endurance training, autonomic function, and cardiac remodeling. However, key knowledge gaps persist, particularly regarding sex differences, optimal screening strategies, and individualized treatment approaches.

2. Aim of the work

This study aims to perform a thorough review of available literature on AF in athlete population and synthesize current research, presenting an up-to date inquiry into the complex relationship between physical activity and atrial fibrillation. This study will put special emphasis on:
- evaluating AF prevalence in athletes
- analysing sex differences in exercise-induced AF
- examining key pathological mechanisms
- identifying important risk factors for AF in athletes
- assessing the clinical significance of AF in athletes
- reviewing current management strategies

Additionally, this study aims to highlight key evidence gaps in current knowledge regarding Atrial Fibrillation in athletes.

3. Materials and methods

3.1 Study Design

This study is a narrative literature review aimed at analysing existing research on the correlation between atrial fibrillation (AF) and athletic activity, particularly in endurance sports. The review focuses on epidemiology, pathophysiology, risk factors, gender differences, and management strategies for AF in athletes.

3.2 Search Strategy

A comprehensive search was conducted using electronic databases, including: PubMed and Google Scholar. The search covered publications from the last 20 years, prioritizing recent studies (2015–2025). The following search terms, keywords and MeSH terms were used:
- “Atrial fibrillation in athletes”,
- “Athlete’s heart”
- “Exercise-induced atrial fibrillation”
- “Atrial fibrillation in young athletes”
- “Atrial fibrillation in marathon runners”
- “Long-term effects of exercise on atrial fibrillation”
- “AF prevalence in athletes”
- “Arrhythmias in athletes”
- “Atrial fibrillation risk factors in athletes”
- “Pathophysiology of atrial fibrillation in athletes”
- “Treatment of atrial fibrillation in athletes”
- “Atrial fibrillation management in competitive athletes”
- “Anticoagulation drugs in athletes”
- “Atrial Fibrilation” AND (“Athletes” OR “Physical activity” OR “Sports” OR “Endurance sports” OR “ endurance exercise”)

Additionally, secondary data from international guidelines, such as the European Society of Cardiology (ESC) and the American College of Cardiology (ACC), were integrated to provide a comprehensive overview of current recommendations and management strategies.

3.3 Inclusion and Exclusion Criteria

Inclusion Criteria:

- Peer-reviewed articles, meta-analyses, systematic reviews, and clinical guidelines.
- Studies investigating the prevalence, risk factors, pathophysiology, and management of AF in athletes.
- Research focusing on male and/or female athletes, participating in endurance and strength sports.

Exclusion Criteria:

- Case reports or studies with small sample sizes (<50 participants).
- Articles not published in English.

3.4 Data Collection

A literature review was conducted independently by all authors. Abstracts were screened to assess the relevance. Full-text examination was performed for articles that met the inclusion criteria. Following the initial selection, data extraction was performed, capturing key variables such as study design, sample size, population demographics, methods of AF diagnosis, and statistical analyses used. Data were then categorized into relevant themes, such as epidemiology, risk factors, sex differences, and AF management in athletes.

4. Literature review results

4.1 How physical activity affects overall health

Physical activity has overwhelmingly positive impact on overall health. It is necessary throughout all phases of human development (Miko et al., 2020). According to 2020 WHO guidelines on physical activity and sedentary behaviour state that although maintaining necessary levels of physical activity has universally positive influence on human health, it affects various aspects of it in different age groups. In children and adolescents it offers benefits for various health outcomes, including physical fitness (cardiorespiratory and muscular), cardiometabolic health (blood pressure, dyslipidemia, glucose and insulin resistance), bone health, cognitive performance (academic achievement, executive function), mental health (lower depression symptoms), and reduced body fat. In adults between 18 and 65 years of age achieving guideline levels of physical activity we observe significant reduction in both cardiovascular disease and all-cause mortality. This age group also benefits from a reduction in morbidity rates of hypertension, type II diabetes and site-specific cancers. Furthermore, appropriate physical activity in adults positively affects mental health, cognitive abilities and sleep. In elderly people physical activity helps reduce the risk of falls, fall-related injuries, additionally it mitigates the decline in bone health and functional capacity (Bull et al., 2020b). However in recent years it has been increasingly discussed that physical activity especially high intensity endurance training may actually increase the risk for various cardiovascular diseases (Eijsvogels et al., 2016). This may be partially explained by complex adaptation mechanisms of a human heart that ensure maximal athletic performance (S. Palermi et al., 2023). Those aforementioned mechanisms can be jointly described as Athlete's Heart (Prior & La Gerche, 2012). It usually comprises of left ventricle hypertrophy, right ventricle dilatation and atrial enlargement along with various functional and electrical changes (Baggish & Wood, 2011). Extreme levels of physical activity seems to be correlated with a higher prevalence of atrial fibrillation, atrial flutter and various bradyarrhythmias (Eijsvogels et al., 2016; Martinez et al., 2021). Additionally there's a controversial and heavily discussed correlation between high-levels of physical activity and the presence of coronary artery calcification (CAC) as a marker of asymptomatic atherosclerotic cardiovascular disease (ASCVD) (Gulsin & Moss, 2021; Sung et al., 2021) .

4.2 Correlation between physical activity and atrial fibrillation

2023 American College of Cardiology guidelines for the diagnosis and management state that the corelation between atrial fibrillation (AF) and physical activity seems to be U-shaped, with both sedentary lifestyle and extreme levels of physical activity being recognised as risk factors for AF (Joglar et al., 2023) . However , some studies have challenged this model. A meta-analysis by Ofman et al. comparing the least and the most physically active groups of patients found that there is no correlation between regular physical activity and higher risk of AF (Ofman et al., 2013). Similarly, a study by Setor et al., involving nearly 2 million people form 23 cohort studies seems to be in agreement with the aforementioned study [21]. No correlation between physical activity and AF has been found when comparing the most vs least physically active groups in the general population [21]. However, this may be partially explained by the sex-specific difference with regular physical activity being associated with increased risk of AF in men(RR=1.20; 95% Cl) and decreased risk in women(RR=0.91; 95% Cl) (Kunutsor et al., 2021) . On the contrary a study by Andersen et. al that analysed a large group of long distance cross-country skiers showed that elite athletes may have higher risk of AF. Data form this study identified faster finishing times and higher number of races completed as significant risk factors for AF (Andersen et al., 2013). A Norwegian cohort study that followed-up about 20000 patients shows a similar J-shaped correlation between physical activity and AF in men, with only moderate physical activity being associated with lower risk of AF. Higher levels of physical activity as well as lower levels have similarly increased risk of developing AF. During the average 20 year follow-up patients were intermittently surveyed for physical activity levels (Morseth et al., 2016). A recently published meta-analysis seems to support this data as the results show a significant increase in the prevalence of AF in athletes when compared to a non-athlete control group (OR=2.46; 95% CI 1.73-3.5). Furthermore the results of said study reveal that athletes under the age of 55 have significantly increased risk when compared with older athletes (Newman et al., 2021). Despite all that data it is necessary to emphasize the fact that there are various ways of quantifying an athlete's exposure to physical activity like self-reported questionnaire, direct observations and activity monitors (Sallis, 2010). Another key variable in assessing physical activity in said studies is the cut-off points dividing patients into groups with low, moderate and extreme levels of physical activity. Especially the last one seems to be the most controversial. There isn't one universal recognized way of assessing physical activity, therefore there are key differences regarding quantifying physical activity in the aforementioned studies. However one study assessed the corelation between AF and cumulative years of regular endurance training in men, with it being positively correlated with both AF and AFl (Myrstad et al., 2014) . In conclusion the relationship between AF prevalence and physical activity is complex, however with numerous publication being published over the recent years it has become less controversial and more widely acknowledged.

4.3 Sex differences

Multiple studies have established a correlation between physical activity and AF risk in men, but the data for women remains inconclusive. A large cohort study of over 300,000 participants found that increased self-reported physical activity correlated with AF risk in men but not in women (Thelle et al., 2013). However, this study relied on prescription records for flecainide and sotalol to assess AF incidence, which may not accurately reflect true AF prevalence. This limitation raises questions about whether AF risk differs by sex or if the measurement method was insufficient to detect cases in women. A study analysing AF prevalence in Swedish cross-country skiers, that included over 200,000 athletes proved that female skiers have significantly reduced risk of AF (HR=0.55; 95% CI, 0.48–0.64) when compared to a non-skiing control group. The negative correlation between AF and physical activity in women was significant regardless of finishing time or number of races completed. However, male athletes with fastest finishing times and highest number of races had the highest prevalence of AF during follow-up (Svedberg et al., 2019) . A big prospective observational study that followed-up post-menopausal women proved that physical activity can have a protective effect regarding AF prevalence in said population. However reduced AF risk was partially mediated by how physical activity affect obesity and overall body weight (Azarbal et al., 2014) . A study by Myrstad et al. failed to find a statistically significant correlation between physical activity and AF in female cross-country skiers when compared to a non-athlete control group, despite a high prevalence of AF especially in older women, with extensive endurance training history (Myrstad et al., 2024). Results of aforementioned studies seem to be in line with the majority of published articles regarding gender differences for AF in athletes. Some studies have suggested a hypothesis that female athletes may be less susceptible to cardiovascular changes associated with high levels of physical activity. Furthermore, this hypothesis imply that female athletes can engage in physical activity at higher intensities than men without a greater risk of developing atrial fibrillation (Czulada et al., 2024). Conversely, there have been a few articles published in the recent years suggesting that high level female athletes are at greater risk for developing AF. A study by Drca et al. proved that elite female athletes have higher risk for AF (HR=2.56: 95% CI 1.22-5.37). It is necessary to note that said study only included about 200 female athletes (Drca et al., 2023). Nearly all studies that have looked into AF prevalence in female athletes faced similar limitations, which in turn influence the quality of those articles. Gender differences in exercise participation may play a role, as women were historically excluded from many endurance sports. Since AF develops after prolonged exercise over years, limited follow-up and number of cases could explain the lack of a clear link between exercise and AF in women (Myrstad et al., 2015). There's also an argument that lower participation in sport events and decreased levels of cumulative sports exposure may vastly influence the data.

4.4 Epidemiology and risk factors

AF prevalence in athletes varies significantly across published studies ranging from 1 % up to 30 % in some smaller retrospective studies (Grimsmo et al., 2010; Sanna et al., 2018b). AF prevalence in the overall population seems to be around 1-2 % (Kornej et al., 2020) . The prevalence varies depending on race/ethnicity, sex, risk factor profile and age (Linz et al., 2024). AF prevalence in overall population rises significantly with age ranging from <1% in populations aged 40 years or younger and rising to 10-17% in people aged >80 years (Lippi et al., 2020) . However the same corelation between age and AF in athlete population is more complexed and nuanced. The available data suggest that the highest prevalence of AF in athletes is observed in middle-aged men especially those with multiple years of endurance training (Sanna et al., 2018b). It seems that older men, especially those who started training only after the age of 40-50 years do not have increased risk of AF (Guasch & Mont, 2016). There've been a few controversies regarding risk factors for AF in elite athletes, especially regarding the cut-off point for the amount of physical activity which attenuates the beneficial effects regarding AF. Regardless of this 2020 ESC guidelines list male sex, middle age, tall stature and total lifetime exercise dose exceeding 1500 – 2000 hours (Hindricks et al., 2021). Different studies have included obstructive sleep apnoea (Surda et al., 2019) and hypertension (Shapero et al., 2016) as prevalent comorbidities in athletes increasing the risk for AF (Martinez et al., 2021). Endurance sports such as running, cycling, and cross-country skiing seem to have the strongest correlation with AF (Guasch & Mont, 2016) . Although it's necessary to emphasize the fact that there isn't strong enough data to exclude different sports as potential risk factors for exercise-induced AF. Some studies have also mentioned lower heart rate (Thelle et al., 2013) and long PQ time (Grimsmo et al., 2010) as potential risk factors.

4.5 Pathophysiology

4.5.1 Athlete's heart

Athlete's heart or exercise-induced cardiac remodeling (EICR) is a medical term which describes the long-term consequences of intense physical activity on our cardiovascular system. It comprises of structural, functional and electrical remodeling (Prior & La Gerche, 2012) . Structural remodeling can be characterized by left ventricular hypertrophy, right ventricular dilatation and atrial enlargement (Prior & La Gerche, 2012) . Furthermore, it is hypothesized that the type of training determines the type of LV remodeling as eccentric hypertrophy with increased RV dimensions being more commonly found in athletes exposed to endurance training. On the contrary strength training is associated with concentric LV hypertrophy (S. Palermi et al., 2023) . However, the aforementioned hypothesis called the "Morganroth Hypothesis" has been challenged by several studies published recently (Kooreman et al., 2019; Kusy et al., 2021) . Regarding the functional remodeling of an athlete's heart, the data that support said theory have been scarce and less consistent that the one for structural changes. However there have been a few studies that suggest that up to 10-15 % of endurance athletes have reduced LV and RV ejection fractions (Baggish & Wood, 2011; Claessen et al., 2024) . As for electrical remodeling associated with athlete's heart the most common ECG findings are: sinus bradycardia, early repolarization, first degree atrioventricular block (AVB), Mobitz type I (Wenckebach) second degree AVB, incomplete RBBB, ectopic atrial arrhythmia and sinus arrhythmia. All aforementioned findings are considered to be "physiological" in athletes and do not require additional investigation (Martinez et al., 2021). However when evaluating an athlete with ECG changes it is necessary to rule out various cardiac disorders most importantly channelopathies such as long-QT syndrome(LQTS), catecholaminergic polymorphic ventricular tachycardia (CPVT), Brugada syndrome (BrS), early repolarization syndrome and short-QT syndrome (Ackerman et al., 2015). Recent studies have shown that even 3-4 hours of training every week for a duration of 3 months can lead to LV remodeling (Arbab-Zadeh et al., 2014) and higher prevalence of sinus bradycardia (Bessem et al., 2018). Athlete's heart in itself is considered to be benign and physiological, however it is necessary to remain vigilant as there might be various cardiomyopathies overlapping with athlete's heart, such as dilated cardiomyopathy, hypertrophic cardiomyopathy and arrhythmogenic right ventricular cardiomyopathy (Pelliccia et al., 2021; Sharma et al., 2015).

4.5.2 Atrial enlargement

Atrial enlargement is a common finding among athletes, particularly those engaged in high-endurance sports. Multiple studies have shown that elite athletes exhibit significantly larger left atrial (LA) dimensions compared to non-athletes (Herrera et al., 2022; Iskandar et al., 2015; Pelliccia et al., 2005; Trivedi et al., 2020). LA enlargement in athletes is statistically significant when described by either LA diameter (Iskandar et al., 2015; Pelliccia et al., 2005) or LA volume indexed to body surface (Herrera et al., 2022; Iskandar et al., 2015). Interestingly, the degree of LA enlargement appears to correlate with training type: endurance athletes experience greater LA dilatation than those engaged in more static or strength-based activities (McClean et al., 2015). This might indicate that atrial enlargement may play a role in atrial fibrillation (AF) pathophysiology, as sporting disciplines with dynamic components like triathlon, running or cycling seem to have the highest risk of AF (Van Gelder et al., 2024). Moreover, atrial dilatation is a known pathophysiological factor and an independent risk factor for AF (Chen et al., 2021). However, atrial dilatation is considered by many to be a physiological response to increased physical activity in athletes, being recognized as a component of EICR (Flanagan et al., 2023). As of the time of writing this article no study proved that AF enlargement in athletes varies morphologically from a non-athlete population (Guasch & Mont, 2016). Furthermore, it was reported that AF dilatation and electrical remodeling in athletes does not impair atrial mechanical functions (Brugger et al., 2014). Interesting, a study by Trivedi et al. that compared 4 groups of patients: athletes with paroxysmal AF, athletes without AF, non-athletes with AF and a healthy control group hypothesizes that even though athletes have significantly increased LA volumes, it may not be correlated to AF prevalence. There's speculation that different pathophysiological mechanisms such as impaired atrial contractile function, atrial remodeling or atrial myopathy all caused by hemodynamic stress induced by repetitive vigorous exercise may play a more important role (Trivedi et al., 2020). There isn't a sufficient amount of data to unequivocally prove or disprove that AF enlargement plays a significant role in pathophysiology of exercise-induced AF.

4.5.3 Fibrosis and inflammatory response

Inflammation and fibrosis coexist together as key pathophysiological processes and the interplay between them creates a maladaptive cycle leading to pathologic atrial remodeling in atrial fibrillation (Guasch et al., 2018; Guasch & Mont, 2016; Harada & Nattel, 2021). Inflammatory response influence cardiac fibroblasts, accelerating collagen deposition (Harada & Nattel, 2021; Hinderer & Schenke-Layland, 2019). Increased atrial fibrosis has deleterious effect on electrical conduction and promotes re-entry formation (Guasch et al., 2018; Guasch & Mont, 2016). Comprehensive data on atrial fibrosis in exercise-induced AF comes mostly from animal model studies. Two experimental studies that analyzed AF inducibility in rats exposed to 16 weeks of treadmill training (Guasch et al., 2013) or 6 weeks of swimming training (Aschar-Sobbi et al., 2015) showed a significant increase in AF inducibility in association with inflammatory response, fibrosis and vagal tone (Aschar-Sobbi et al., 2015; Guasch et al., 2013). There's no available studies that directly assess fibrosis in humans as invasive procedures like atrial biopsies are not viable for a larger population of patients (Guasch et al., 2018). There's however a plethora of data to suggest that high-level athletes have increased levels of profibrotic markers such as carboxyterminal propeptide of collagen type I (PICP), carboxyterminal telopeptide of collagen type I (CITP), tissue inhibitor of matrix metalloproteinase type I (TIMP1), galectin 3 (Guasch & Mont, 2016; Lindsay & Dunn, 2007). In recent years TNFα has emerged as a potential factor in exercise-induced AF. In the aforementioned animal model study TNFα proved to be a key pathophysiological factor in atrial remodeling, with different forms of TNFα inihibition attenuating the AF inducibility in swimming-trained mice (Aschar-Sobbi et al., 2015). The amount of data regarding TNFα and AF in athletes is scarce, however it has been reported that athletes participating in marathons have significantly elevated levels of TNFα and IL-6 (Wilhelm et al., 2014). Furthermore elevated levels of inflammatory cytokines after strenuous endurance exercise seem to be correlated with exercise-induced cardiac dysfunction (La Gerche et al., 2015). A publication by Hattori et.al prove that markers of oxidative stress, a well-known factor in AF pathophysiology (Karam et al., 2017; Pfenniger et al., 2024), significantly increase following a ultra-marathon race (Hattori et al., 2009). On top of that higher levels of ROS (reactive oxygen species) are correlated with faster finishing times (Hattori et al., 2009). ECG changes commonly associated with fibrosis, such as pathologic Q waves, fragmented QRS and inverted T waves are more commonly observed in athletes (Kramer et al., 2024). A large study that reviewed MR findings showed, that myocardial fibrosis is much more prevalent in endurance athletes than in general population (Allwood et al., 2024a). Younger athletes seem to have the highest prevalence of myocardial fibrosis, however major fibrosis is more commonly observed in veteran athletes. Interestingly there were no sex differences regarding the prevalence of fibrosis in the aforementioned study (Allwood et al., 2024a). Available data support the hypothesis that high volume of endurance training is associated with myocardial fibrosis (Domenech-Ximenos et al., 2020; Tahir et al., 2018; Wilson et al., 2011). The most common fibrosis pattern in athletes, regardless of the age, seems to be " insertion point fibrosis" which refers to a nonischemic fibrosis in intraventricular septum, where muscle fibers form left and right ventricle connect (Allwood et al., 2024a; Małek & Bucciarelli-Ducci, 2020). There's an ongoing debate, which type of myocardial fibrosis is a benign, incidental finding and which is actually correlated to adverse cardiovascular outcomes. As of today there's lack of data to form a compelling argument that certain fibrosis patterns are clinically irrelevant (Allwood et al., 2024a; Małek & Bucciarelli-Ducci, 2020). However, some studies illuminate the fact that major stria-pattern fibrosis occurring in midmyocardial and epicardial locations may be correlated to arrhythmias and sudden cardiac death (Cipriani et al., 2019; Małek & Bucciarelli-Ducci, 2020; Zorzi et al., 2016). The underlying mechanisms of AF in athletes remain underexplored. However, there is speculation that increased systemic blood pressure, excessive activation of renin-angiotensin-aldosterone or continuous microstructural damage of the myocardium may all play a significant role in fibrosis and atrial remodeling (Guasch et al., 2018; Guasch & Mont, 2016).

4.5.4 Autonomic nervous system

Imbalance of the autonomic nervous system plays a key role in atrial fibrillation (AF) pathogenesis, as it was proven both in animal models and in human patients (Brundel et al., 2022; Rebecchi et al., 2021). Parasympathetic stimulation, mostly through its effect on ionic channels lowers the heart rate, reduces conduction speed in atrio-ventricular node, shortens both action potential (AP) duration and atrial effective refractory period (ERP). All those aforementioned mechanisms cumulatively increase AF inducibility by propagating re-entry mechanisms and facilitating conversion of different atrial arrhythmias to AF (Rebecchi et al., 2021; Scherlag et al., 2005; Yeh et al., n.d.). Sympathetic stimulation through it's effect on calcium and potassium cellular currents affects automaticity and repolarization of the heart, significantly affecting AF inducibility (Rebecchi et al., 2021). There's also a recognized distinction of paroxysmal AF to vagal and adrenergic AF. This classification is based on precipitating conditions, patient's history and risk factors. Vagal AF is more commonly triggered in situations with enhanced parasympathetic tone, such as during sleeping hours or during rest following a large meal. Furthermore, vagal AF is more prevalent in younger people, especially men and is rarely associated with any structural heart disease (Rebecchi et al., 2021, 2023). Contrarily adrenergic AF more commonly occurs during the day and is usually associated with physical activity or psychophysical stress. Underlying structural heart disease is also much more prevalent in adrenergic AF (Rebecchi et al., 2021, 2023). We observe a significant enhancement of both parasympathetic and sympathetic tone in athletes (Fu & Levine, 2013). The enhancement in parasympathetic tone is continuous as opposed to a more temporary sympathetic tone enhancement (Wilhelm et al., 2011) . The majority of available data point to the vagal enhancement being more pronounced in AF pathophysiology amongst elite athletes (Eijsvogels et al., 2016; Guasch et al., 2018; Guasch & Mont, 2016; Kourek et al., 2024) . In athletes, especially those participating in elite endurance sports we can observe lower resting heart rate (RHR) (Biswas, 2020; Reimers et al., 2018) , lower intrinsic heart rate (Boyett et al., 2013) and higher heart rate variability(HRV) (Kiss et al., 2016; Mishica et al., 2021) . The changes in RHR and HRV can be partially attributed to an increased parasympathetic tone (Boyett et al., 2013) . Certain indices of HRV are said to positively correlate with AF in certain clinical situations (Khan et al., 2021; Kim et al., 2022; Perkiömäki et al., 2014) . However it's necessary to mention that in recent years different pathophysiological factors in development of bradycardia and AF in athletes were discussed. Some studies have suggested ion channel/Ca^{2+} remodeling (Boyett et al., 2013) or myocardial hypertrophy (Azevedo et al., 2014) as potential drivers of bradycardia and AF. Interestingly, a study by Azevedo et al. have suggested that different sport disciplines like running may have a more pronounced autonomic mechanism of bradycardia, while the mechanism for cycling may be non-autonomic, with cardiac remodeling playing a more significant role (Azevedo et al., 2014) . A previously mentioned by us trial examining AF inducibility in exercise trained mice proved that vagal enhancement is an important factor in AF (Guasch et al., 2013). AF in athletes usually occurs predominantly in situations associated with vagal enhancement like during sleep or postprandial rest (Guasch & Mont, 2016) . There isn't however enough data available to irrefutably confirm that vagal tone enhancement is positively correlated to AF. The lack of data calls for large trials examining the specific pathophysiology of AF in athletes, leading to better diagnostic capabilities, risk stratification and management.

4.6 Management

The most common symptoms of atrial fibrillation (AF) in athletes are heart palpitations, syncope and dyspnea on exertion, although up to 50% of patients may remain asymptomatic during an episode of AF (Heidt et al., 2016; Turagam et al., 2015) . The aforementioned symptoms may occur during exercise or have no correlation with it, so it's necessary to remain vigilant when evaluating a symptomatic athlete with a history of physical activity. AF management is focused on alleviating symptoms and complication prevention, with stroke being the most severe. In general population non-valvular AF is associated with a fivefold increase in stroke risk and a twenty-fold increase for AF related to mitral stenosis (Elsheikh et al., 2024). However, analyzing stroke risk in athlete population yields interesting results. The majority of data supports the hypothesis that AF is a independent risk factor for stroke in endurance athletes (Certo Pereira et al., 2024; Myrstad et al., 2020; Pallikadavath et al., 2023), especially those ≥65 years of age (Myrstad et al., 2020) . Interestingly, available studies suggest that athletes with AF have lower stroke risk when compared to a non-athlete population with AF (Certo Pereira et al., 2024; Proietti et al., 2017) . Furthermore, patients with AF participating in regular physical activity have lower all-cause mortality (Proietti et al., 2017). This paradox may be due to overall cardiovascular fitness, better endothelial function, or lower baseline atherosclerosis levels in athletes. However, further research is needed to clarify the mechanisms behind this discrepancy. Appropriate screening plays a crucial role in athlete population as many of them remain asymptomatic and it should consist of at least a medical history exam, physical examination and a 12-lead ECG (Kourek et al., 2024) . According to the 2024 HRS expert consensus statement on arrhythmias in athletes an initial diagnosis of symptomatic patients or those with personal ECG findings have to be confirmed in a 12-lead ECG examination or if necessary by long-term monitoring such as a Holter monitor, external or implanted loop recorder and patch continuous monitor (Lampert et al., 2024) . Elite endurance athletes present a variety of physiological adaptations of the cardiovascular system which may be observed in a 12-lead ECG (ABELA & SHARMA, 2020). Further evaluation of a newly diagnosed athlete with AF should additionally include a physical examination, echocardiogram, laboratory tests and an extended medical history evaluation, focused on exercise history and modifiable risk factors (Lampert et al., 2024). When interpreting any potentially pathologic ECG findings it's necessary to use international recommendations specific for an athlete population (Sharma et al., 2018). Exercise test are considered to be a useful diagnostic tool for recreating high-adrenergic training scenarios (Lampert et al., 2024). ECG and echocardiogram findings play a role in screening for various underlying heart disease such as cardiac myopathies or channelopathies. However, any clinical signs pointing to a underlying heart disease, especially in younger patients presents a need for further clinical examination like a cardiac MRI or genetic testing (Lampert et al., 2024). Additionally, cardiac MRI is a modern tool for assessing myocardial fibrosis in athletes, allowing for the detection of certain high-risk fibrosis patterns (Allwood et al., 2024b; Tahir et al., 2018). Patients over the age of 25 especially those presenting cardiovascular risk factors for AF may require further examination of ASCVD (Moorman et al., 2021). Modern AF treatment in athletes should be focused on risk factor modification, heart rate control, rhythm control and thromboembolism prevention (Lampert et al., 2024). The use of performance-enhancing drugs should be assessed and addressed as well as different modifiable risk factors known for non-athlete population. One potential strategy for alleviating risk factors in athletes is decreasing the physical activity level, which has been heavily discussed in recent years (A. Palermi et al., 2025; *Prescribed Detraining: Effects on Cardiac Structure, Cardiac Electrophysiology, and the Athlete - American College of Cardiology*, n.d.). The data behind such strategy is slim, however there have been a few studies that showed a reduction in AF episodes following deconditioning in elite athletes (*Prescribed Detraining: Effects on Cardiac Structure, Cardiac Electrophysiology, and the Athlete - American College of Cardiology*, n.d.). A 2024 HRS expert consensus state that exercise detraining and modification to low or moderate intensity may be considered in elite endurance athletes (Lampert et al., 2024). However, such interventions should never prohibit a patient from achieving guideline levels of physical activity (150-300 minutes of moderate activity per week), as sedentary lifestyle is a known risk for AF, even in previously trained athletes (Van Gelder et al., 2024). Due to a lack of large studies regarding AF management in athletes, the pharmacological treatment of AF in said subpopulation is based on the guidelines for general population with a few notable exceptions, caused by this group's specific needs and risk (Pelliccia et al., 2021; Van Gelder et al., 2024). Rate control is usually only necessary in symptomatic patients, especially those with higher HR (Pelliccia et al., 2021). Beta-blockers a first line-therapy in most clinical situations in patients with AF should be considered, however they may not be well tolerated by highly trained athletes as they may impair their physical performance (Pelliccia et al., 2021). Furthermore, beta-blockers may be listed as forbidden by many anti-doping agencies. Non-dihydropyridine calcium blockers may be a viable option, however they aren't usually potent enough in monotherapy. Digitalis may be considered in a limited amount of cases as it mostly affect resting HR by increasing vagal tone (Kourek et al., 2024; Pelliccia et al., 2021). Achieving rate control in athletes using oral medication can be challenging as class III and Ic antiarrhythmic drugs all have important limitations. Class III drugs like amiodarone are usually contraindicated in younger patients because of potential adverse effects (Pelliccia et al., 2021). Sotalol is considered to be a viable option however it is rarely used in monotherapy (Pelliccia et al., 2021). The use of Ic antiarrhythmic drugs is more common in clinical practice, however it is necessary to note that those drugs may promote the conversion to AFl, which may lead to 1:1 AV conduction with serious cardiovascular implications. When prescribing a class Ic drug to an athlete, physicians should always consider performing prophylactic cavo-tricuspid-isthmus ablation or adding a beta-blocker (Pelliccia et al., 2021).

Class Ic antiarrhythmic drugs like propafenone or flecainide in addition to a beta-blocker or non-dihydropyridine calcium blocker may be considered as a “pill in a pocket” strategy, especially in patients with sporadic paroxysmal AF (Pelliccia et al., 2021). Catheter ablation in athlete population may be considered when the therapeutic effect isn’t sufficient or if antiarrhythmic drugs are poorly tolerated and/or contraindicated (Hindricks et al., 2021; Lampert et al., 2024). Alternatively ablation may be a first-line therapy in athletes, prioritizing shared decision-making when choosing a management strategy (Lampert et al., 2024). Athletes should cease intense physical activity for 1 month following an ablation procedure (Pelliccia et al., 2021). Regarding anticoagulation therapy, athletes should be assessed the same way as the general population. A CHADS-VA score of 1 means that the use of anticoagulation drugs should be considered, and recommended for patients with a score of 2 or more regardless of the sex category (Van Gelder et al., 2024). DOAC are superior to VKA in patients who are eligible for a DOAC treatment (Sanna et al., 2018a). DOAC are contraindicated for patients participating in sports with direct bodily contact (Steffel et al., 2018) and shared-decision making regarding anticoagulation therapy and participation in said sports disciplines should be prioritized (Lampert et al., 2024). Left atrial appendage occlusion can be considered in some patients with anticoagulation indication and bleeding risk (Lampert et al., 2024).

5. Conclusions

Atrial fibrillation (AF) in athletes remains a complex and multifaceted issue. While moderate physical activity is known to reduce AF risk, high-intensity endurance training appears to increase its prevalence, particularly in middle-aged male athletes. The mechanisms behind exercise-induced AF likely involves structural and electrical remodeling of the heart, including atrial enlargement, fibrosis, inflammation, and autonomic nervous system imbalances. Despite the increased risk of AF in certain athletic populations, athletes with AF generally have a lower risk of stroke and overall mortality compared to non-athletes. However, appropriate screening, early diagnosis, and tailored management strategies are crucial, especially for those experiencing symptoms or competing at elite levels. The management of AF in athletes should prioritize symptom control, risk factor modification, and individualized treatment plans, balancing the benefits of continued physical activity with the potential AF complications. While reducing exercise intensity has been proposed as a potential strategy, there is currently insufficient evidence to support strict deconditioning recommendations. Instead, a patient-centered approach, incorporating shared decision-making, is essential. Further research is needed to better understand the long-term implications of AF in athletes, identify risk factors, improve available diagnostic options, find optimal prevention strategies and refine treatment guidelines tailored to this unique population.

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Authors do not report any disclosure

7. Authors’ Contributions Statement

All authors have read and agreed with the published version of the manuscript.
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