Laszlo R[1], *Steinacker JM*[1]

Competitive Sports and Atrial Fibrillation

Leistungssport und Vorhofflimmern

REVIEW

ACCEPTED: June 2016

PUBLISHED ONLINE: October 2016

DOI: 10.5960/dzsm.2016.243

Laszlo R, Steinacker JM. Competitive Sports and Atrial Fibrillation. Dtsch Z Sportmed. 2016; 67: 237-243.

1. UNIVERSITY HOSPITAL ULM, *Division of Sports and Rehabilitation Medicine, Ulm, Germany*

Summary

› **Recently,** there is evidence that atrial fibrillation (AF) is associated with endurance sports. Training-induced left atrial enlargement, vagotonic increase and left atrial volume strain during exercise may act proarrhythmogenic in terms of a facilitated induction and maintenance of AF in endurance athletes.

› **Nevertheless,** there is currently no evidence of an increased AF prevalence in young endurance athletes. However, longstanding endurance exercise increases AF risk. An exercise-induced atrial remodeling as a potential pathophysiological mechanism is being discussed. However, respective definitive evidence of the latter in human beings is still missing.

› **Two equivalent recommendations** concerning sports participation (European Society of Cardiology/ American Heart Association and American College of Cardiology) are available for evaluation of competitive athletes with AF. Both exhibit blurs and points of criticism which lower practicability in clinical practice. However, they can act as a decision support for evaluation and guidance of most of the competitive athletes with AF. In competitive athletes, a rather individualized or sports-specific approach is necessary also under consideration of pathophysiological aspects and current knowledge concerning the association of AF and endurance sports. The rather brief American recommendations are moving in this direction.

› **At least in cases** concerning professional athletes, interdisciplinary collaboration between experts in cardiology, rhythmology and sports medicine if needed should be considered, not only as public pressure (including social environment of the athlete) on decision-making physicians may sometimes be high.

KEY WORDS:
Atrial Fibrillation, Competitive Sports, Sports Participation, Endurance Exercise

Zusammenfassung

› **Es gibt Hinweise,** dass Ausdauersport mit dem Auftreten von Vorhofflimmern (VHF) assoziiert ist. Eine trainingsinduzierte Vergrößerung des linken Vorhofs, ein erhöhter Vagotonus sowie die linksatriale Volumenbelastung während der Sportausübung können zumindest theoretisch die Induktion und Aufrechterhaltung von VHF fördern.

› **Nichtsdestotrotz** gibt es bis dato keinen sicheren Hinweis auf eine erhöhte VHF-Prävalenz beim jungen Ausdauerathleten. Dahingegen ist das VHF-Risiko bei langjährigen Ausdauerathleten erhöht. Ein trainingsinduziertes atriales Remodeling als möglicher pathophysiologischer Mechanismus wird diskutiert, der definitive Nachweis des Remodelings beim Menschen ist derzeit noch ausstehend.

› **Aktuell stehen zwei Empfehlungen** (European Society of Cardiology/American Heart Association und American College of Cardiology) zur Beurteilung der Sporttauglichkeit von Leistungssportlern mit VHF zur Verfügung. Beide weisen gewisse Unschärfen und Kritikpunkte auf, die die Anwendbarkeit im klinischen Alltag schmälern. Sie können jedoch als Entscheidungshilfe für die Beurteilung der Leistungssportler mit VHF dienen. Im Sinne eines verantwortungsvollen Patientenumgangs ist bei Leistungssportlern eher ein individualisiertes oder auch Sportart-spezifisches Konzept notwendig, bei dem auch pathophysiologische Aspekte und das gegenwärtige Wissen bezüglich der Assoziation von VHF mit Ausdauersport berücksichtigt werden. Die neueren amerikanischen Empfehlungen gehen in diese Richtung.

› **Bei professionellen Athleten** sollte nicht zuletzt aufgrund des unter Umständen großen öffentlichen Drucks (inklusive dem sozialen Umfeld des Athleten) auf den beurteilenden Sportmediziner gegebenenfalls eine interdisziplinäre Entscheidungsfindung unter Miteinbeziehung von Experten der Bereiche Kardiologie, Rhythmologie und Sportmedizin stattfinden.

SCHLÜSSELWÖRTER:
Vorhofflimmern, Leistungssport, Sporttauglichkeit, Ausdauersport

Introduction

Atrial fibrillation (AF) is the most common arrhythmia in man and its prevalence increases with age (9, 10). Recently, there is evidence that AF is associated with endurance sports and therefore it is not unlikely, that practicing sports physicians might get into the situation where eligibility of sports participation of a competitive (professional or ambitious amateur) athlete with AF has to be evaluated (8).

Aim of this review was first to summarize current knowledge concerning the association of AF and endurance sports. In addition, a closer look on potential pathophysiological mechanisms for this association is also made. Finally, currently valid European and, respectively, American recommendations are presented and critically evaluated from a practical point of view. ›

QR-Code scannen und Artikel online lesen.

CORRESPONDING ADDRESS:
Priv.-Doz. Dr. med. Roman Laszlo
University Hospital Ulm, Division of Sports and Rehabilitation Medicine
Leimgrubenweg 14, 89075 Ulm, Germany
✉: roman.laszlo@uniklinik-ulm.de

Atrial Fibrillation – General Aspects

Electrophysiologically, AF is characterized by an uncoordinated atrial excitation propagation resulting in an atrial heart rate between 400 and 600 beats per minute. In this situation, the atrioventricular node acts as a frequency filter with irregular atrioventricular conduction and consecutive absolute arrhythmia of the ventricle (23). Clinically, AF can be classified into various types (Table 1, Figure 1). Correct classification of AF is important, as many therapeutic decisions (e.g. rate vs. rhythm control, valvular/non-valvular concerning applicability of CHA2DS2-VASc score for verification of the indication for oral anticoagulation) depend on AF type (9, 10). Male sex, age, diabetes mellitus, hypertension, congestive heart failure and valvular heart disease were identified as "classical" risk factors (6). In case of the absence of these typical risk factors, AF is classified as so-called "lone atrial fibrillation" (9, 10).

Atrial Fibrillation and Endurance Sports

Ambitious endurance sports may result in an increase of the atria in terms of an athlete's heart, a vagotonic increase and is finally accompanied by an atrial volume strain during exercise (5, 12, 33). Paroxysmal AF is focally triggered by atrial extrasystoles originating from the pulmonary veins (16). On the one hand, focal triggering of AF is influenced negatively by a vagotonic increase and, on the other hand, positively by atrial volume strain (19, 40).

Besides focal triggering, the anatomic substrate that is the left atrium plays an important role for AF maintenance. According to Moe and Allessie, multiple wavelets with a circumference defined by the so-called wavelength (product of atrial effective refractory period [AERP] and conduction velocity [CV]) are circulating simultaneously within the atria in terms of so called micro-reentry (2, 23). The more coincident reentry circuits are circulating, the more stable is AF (2). Simplified, these reentry circuits need certain "atrial space" which is increasingly available in case of an enlarged left atrium. Therefore, left atrial dilatation as a consequence of endurance sports may favour AF at least theoretically.

Reduction of AERP and/or CV may act as another theoretical possibility for an increase of coincident reentry circuits despite unchanged atrial size. In a dog model of AF, vagal stimulation reduced AERP and increased CV. Taken together, this constellation resulted in a pro-arrhythmogenic reduction of the atrial wavelength particularly at higher atrial rates (28). In another animal model, an increase of left atrial pressure also led to a reduction of atrial wavelength and increased atrial vulnerability during programmed atrial stimulation (35).

To summarize, from an electrophysiological point of view, left atrial dilatation, volume strain and vagotonic increase potentially associated with endurance sports may influence both focal triggering of AF and AF substrate in a pro-arrhythmogenic manner at least theoretically.

Left atrial enlargement and volume strain as well as vagotonic increase can be observed already in younger and middle age endurance athletes (37). Therefore, one could assume that in comparison to coeval normal population, prevalence of AF might be also increased in younger endurance athletes. Up to date, there are only little studies concerning this age group (7, 33). These studies may be criticized due to methodical deficiencies: small group size, symptom-driven induction of AF diagnostics despite the bad correlation of symptoms and actually present arrhythmia in AF and too short Holter ECG duration for a reliable registration of paroxysmal AF (4, 7, 13, 33). Taken together, at the moment there is no clear evidence for an increased prevalence of AF in young or middle-aged endurance athletes but a final evaluation is currently not possible as a consequence of the above-mentioned points.

Table 1

Types of atrial fibrillation (9, 10).

TYPE	DEFINITION
First diagnosed AF	Every patient who presents with AF for the first time irrespective of the duration of the arrhythmia or the presence and severity of AF-related symptoms.
Paroxysmal AF	Self-terminating, usually within 48 hours. The 48 h time point is clinically important as after this, the likelihood of spontaneous conversion to sinus rhythm is low and anticoagulation must be considered according to the CHA2DS2-VASc-Score.
Persistent AF	AF episode either lasts longer than seven days or requires termination by cardioversion, either with drugs or by direct current cardioversion.
Long-standing persistent AF	Lasted for ≥1 year when it is decided to adopt a rhythm control strategy.
Permanent AF	Presence of the arrhythmia is accepted by the patient (and the physician). Hence, rhythm control interventions are, by definition, not pursued in patients with permanent AF. Should a rhythm control strategy be adopted, the arrhythmia is re-designated as "long-standing persistent AF".
Lone AF	Atrial fibrillation without "classical" risk factors: age, smoking, diabetes, left ventricular hypertrophy, hypertension, previous myocardial infarction, congestive heart failure, valvular heart disease (6).
Silent (asymptomatic) AF	Manifestation as an AF-related complication (e.g. ischaemic stroke or tachycardiomyopathy) or diagnosed by an opportunistic ECG. Silent AF may present as any of the temporal forms of AF.
Valvular AF	AF as a consequences of valvular heart diseases (e.g. mitral valve insufficiency).

Concerning the association of AF and endurance sports in veteran athletes, several studies have been published. Calvo et al. summarized these data and, depending on the respective study, a relative risk of AF in veteran endurance athletes in comparison to a control group between 2.87 (1.20; 6.91) and 8.80 (1.2; 61.2) was reported (8). In a 2009 meta-analysis, Abdulla et al. determined an increased AF risk of veteran endurance athletes (calculated odds ratio 5.29 (3.57; 7.85)) (1). However, again, it can be criticized that many or even most of the included studies have methodical deficiencies as for instance small cohort size, lacking control group, quantification of physical activity or selection bias (14).

In the meantime, a very large study including 52.755 long-distant cross-country skiers (Vasaloppet, 90km) has been published by Andersen et al. (3). AF risk of the athletes was calculated depending on the target time (as a measure of endurance capacity) and, respectively, on the number of past completed races (as a measure of life-time training time). AF risk was 1.20 (0.93; 1.55) fold increased in the fastest participants in comparison to the slowest and 1.29 (1.04; 16.1) fold increased in participants which completed more than five competitions in comparison to first-time attendees. Another study including a methodically positive multivariate adjustment (i.a. "classical" AF risk factors) of 509 male competitors (age 65-90 years) of the Birkebeiner cross-country ski race also reported of a moderately increased relative AF risk (1.9 [1.14; 3.19]) of veteran endurance athletes in comparison to age-matched normal population (6, 32).

In almost all studies concerning the potential association of AF and competitive endurance sports, AF in athletes with diagnosed arrhythmia was classified as "lone AF" (Table 1). However,

several new AF risk factors have been identified in the last few years which makes it necessary to critically re-evaluate the term "lone AF" (38). In the meantime, for example chronic inflammation, obesity, sleep apnoea syndrome, above average alcohol consumption, steroid abuse or a genetic predisposition are known to be factors which favour occurrence of AF (18, 21, 22, 29). These "new" AF risk factors as potential confounders were disregarded in most of the previous accomplished studies (14). However, these factors are highly relevant as, for example, many studies gave evidence that in athletically active people, alcohol consumption is higher than in normal population by tendency (11, 27, 41). Athletes of the above mentioned Birkebeiner-study also drank more alcohol than people of the comparison group (32).

Summarized, the majority of studies point to an increased AF risk ("lone atrial fibrillation") of longtime endurance athletes whereby the relative risk was possibly overestimated in early studies, due to methodical problems and non-consideration of "new" AF risk factors showing also the need for a critical questioning of the definition of "lone AF" (1, 8, 14, 31, 38).

Sports-Induced Atrial Remodeling as a Potential Mechanism for AF in Longtime Endurance Athletes

Atrial fibrillation promotion by endurance exercise was mechanistically explored in a rat model by Guasch et al. (15). In this study, 16 weeks of daily treadmill training for 1 h had remarkably effects on the left atrium like dilatation, fibrosis and also proarrhytmogenic electrical alterations on ion-channel level. As a consequence, AF inducibility during programmed stimulation was increased (and rapidly returned to baseline with detraining) in the exercise rats. These observed processes are called "atrial remodeling". Generally spoken, atrial remodeling includes electrical, structural and mechanical alterations of the atrium which favour initiation and maintenance of AF (23). Atrial remodeling can be induced by a variety of diseases including AF itself ("AF begets AF"), classical and also new AF risk factors (e.g. alcohol) (22, 39, 42).

Regarding atrial remodeling due to longtime endurance training in humans, first indications are reported in some studies (26, 43, 44, 45). However, most of these studies point to endurance sports-induced cardiac alteration of the whole heart but to not atrial specific findings. Wilhelm et al. reported of an association of left atrial size and the extent of lifetime training in hobby endurance athletes whereas, simultaneously, left ventricular dimension was comparable in all athletes so that this finding is not explainable by a classic athlete's heart with a harmonic enlargement of all cardiac caves (37, 43). To summarize, further studies are needed to substantiate the evidence of exercise-induced atrial remodeling in human beings.

Eligibility of Sports Participation of Competitive Athletes with Atrial Fibrillation

Two equivalent recommendations (European Society of Cardiology/American Heart Association and American College of Cardiology) concerning sports participation are available for evaluation of competitive athletes with AF. In the following section, these guidelines are presented (17, 46). In addition, the author's personal comments and interpretations of the somewhat blurry points are given. Table 2 summarizes both guidelines and the author's personal comments.

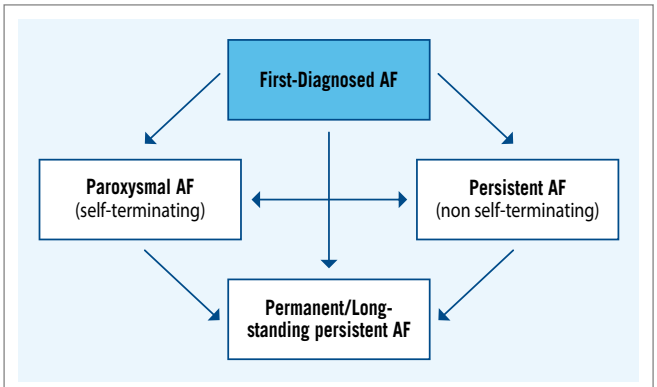

Figure 1

Types of atrial fibrillation (9, 10).

Guidelines from the European Society of Cardiology

European recommendations concerning sports participation of patients with AF have been published in 2006 (17). According to this publication, all patients should undergo anamnesis, echo, resting- and Holter-ECG and cardiac stress testing. Particular attention should be also paid to potential illegal drug use, as for example anabolic steroid abuse might cause atrial fibrillation (24).

Thereafter, further strategy depends on the respective clinical situation. If AF in athletes is caused by a treatable condition (e.g. hyperthyroidism, pericarditis), participation both in competitive and leisure-time sports is eligible after two months of "stable sinus rhythm" and a follow-up after 12 months is recommended. In addition, diagnostics should also focus on other risk factors (especially arterial hypertension, structural heart disease) and, if necessary, sports capability should be adapted to these factors.

If no treatable causes for AF can be identified, in case of a primary event or rare paroxysms, competitive sports participation is possible after three months of "stable sinus rhythm". The principle of "pill-in-the-pocket" under consideration of a sports break in case of arrhythmias and/or drug intake (2 half-life periods) may be also an option for some of these athletes. Annual follow-ups are recommended in this patient group (9, 10).

In case of absence of a structural heart disease especially including pre-excitation syndromes, AF is not a potential life-threatening arrhythmia (17). Therefore, atrioventricular conduction during sports participation is decisive for respective recommendations in the by far greatest group of competitive athletes with more frequent paroxysmal, persistent or permanent AF. Focus of anamnesis should be laid on symptoms of haemodynamical impairment during sports participation and in case of persistent or permanent AF, frequency behavior should be evaluated during cardiac stress testing. In case of positive symptoms and/or rapid atrioventricular conduction, specific rate-controlling drugs are indicated. Unfortunately, betablockers are often not well-tolerated by the athletes and, in some cases of professional athletes, they might be also doping-relevant. Often, alternatives (calcium channel antagonists, digitalis glycosides) are often not sufficient concerning ventricular rate control. In any case, a slow increase of dosing is necessary. If adequate rate-control is secured and there are no symptoms of haemodynamic impairment, competitive sports participation is possible. If, alternatively, rhythm control is considered to be an adequate therapy strategy for the athlete, either an antiarrhythmic drug treatment and/or invasive treatment of AF ›

Table 2

Comparison of the European and American Guidelines (17, 46).

	EUROPEAN GUIDELINES	AMERICAN GUIDELINES	AUTHOR'S PERSONAL COMMENT
Clinical diagnostics	- Anamnesis	- Anamnesis	- Cardiac stress testing reasonable for evaluation of atrioventricular conduction in case of non self-terminating AF
	- Resting ECG	- Thyroid function test	- Cardiac stress testing reasonable for evaluation of cardiac risk in certain athletes
	- Holter ECG	- Queries for drug use	- Basal TSH/queries for drug use reasonable
	- Cardiac stress testing	- Resting ECG	- Focus of diagnostics also on other risk factors, if necessary, adapt competitive sports capability
	- Echocardiography	- Echocardiography	
	- Focus of diagnostics also on other risk factors, if necessary, adapt sports capability		
Therapy	- Secondary or to reversible cause: no specific recommendations	- No specific recommendations apart from mention of catheter ablation to obviate the need for rate control or antiarrhythmic drugs	- Individualized therapy according to the AF guidelines (9, 10)
	- First onset or very sporadic paroxysms: "Pill-in-the-pocket" approach for some athletes		
	- Paroxysmal or permanent, without major cardiac disease: Individualized therapy		
Antithrombotic therapy/oral anticoagulation	- "Classical indications for anticoagulation", CHA2DS2-VASc-Score not explicitly mentioned (not yet published in 2006)	- Use of CHA2DS2-VASc-Score	- Use of Use of CHA_2DS_2-VASc-Score for decision-making in non-valvular AF
	- Anticoagulation therapy excludes athletes from sports with a risk of bodily collision or trauma	- Consider bleeding risk in the context of the specific sports before clearance	- Consider bleeding risk in the context of the specific sport for decision-making concerning competitive sports capability
Return to play	- Secondary or to reversible cause: all sports when stable sinus rhythm for > 2 months	- No specific return to play recommendations: "Athletes with low-risk AF that is well-tolerated and self-terminating may participate in all competitive sports without therapy"	- European Guidelines: no clinical or pathophysiological rationale for the proposed intervals
	-First onset or very sporadic paroxysms: all sports when stable sinus rhythm > 3 months		- European Guidelines: definition of "stable sinus rhythm" not specified → 7d Holter – ECG, sometimes (implantable) event recorder depending on clinical situation
	- Paroxysmal or permanent, without major cardiac disease: all sports when proven rate control with absence of haemodynamic impairment		- American Guidelines: "low risk" not specified → AF without any underlying cardiac disease
			- Individual Return to play recommendation
Follow-up	- Secondary or to reversible cause: yearly	- No specific recommendations	- Individualized Follow-up
	- First onset or very sporadic paroxysms: yearly		
	- Paroxysmal or permanent, without major cardiac disease: every 6 months		
Specific recommendations for specific sports	- No specific recommendations	- No specific recommendations	- Association of AF and endurance sports
			- No evidence for association of AF in otherwise classified sports
			→ **Specific recommendations for specific sports useful**

might be an option. Class I antiarrhythmics should be always combined with betablockers to prevent 1:1 conduction of atrial flutter in particular during situations with high sympathetic tone. Success rates of pulmonary vein isolation in athletes as a catheter-ablative strategy are comparable to normal population (20). In both rate- or rhythm-control strategies, a shortened follow-up interval of 6 months is recommended.

Guidelines from the American Heart Association and American College of Cardiology

By the end of 2015, new scientific statements concerning eligibility and disqualification recommendations for competitive athletes with cardiovascular abnormalities including one statement concerning arrhythmias and conduction defects (Task Force 9) with rather brief recommendations concerning AF have been published by the American Heart Association and American College of Cardiology (46). Hereby, athletes with AF should undergo a workup that includes thyroid function test, queries for drug use, ECG and echocardiography. In the case that low-risk AF is well-tolerated and self-terminating, the athlete may participate in all competitive sports without therapy. If antithrombotic therapy, other than aspirin, is indicated, the bleeding risk in the context of the specific sport has to be considered before clearance. Indication for anticoagulation in athletes is verified in the same way as in normal population by using CHA2DS2-VASc-Score (9, 10). If needed, athletes should be restricted from participation in high-impact contact sports (30, 34) because of the bleeding risk (46). Finally, the recommendations mention that catheter ablation of AF could potentially obviate the need for rate control or antiarrhythmic drugs and should therefore be considered in athletes.

Critical Evaluation of the Recommendations of the European and American Societies

Several points remain unclear concerning the implementation of both the European and American recommendations in everyday clinical practice. On the one hand, the association between AF and endurance sports like for example long-distance running, cross-county skiing or rowing is well known as delineated (25). One the other hand, there is lack of evidence of an association of AF and otherwise classified sports. Thus, it is incomprehensible why only general and no sports-specific recommendations are given in both guidelines.

Concerning the recommendations of the European Society of Cardiology, no clinical or pathophysiological rationale for the proposed intervals until the return to play in subjects with AF and treatable cause or rare paroxysms/first-time arrhythmia is evident. In addition, the recommendations speak of "stable sinus rhythm" as prerequisite of return to play in these two patient groups. Unfortunately, no clear definition of "stable sinus rhythm" is given. In the author's opinion, at least a 7d Holter ECG should be used in order to secure "stable sinus rhythm", as a 24 hour Holter ECG registration is not suitable for a reliable exclusion of paroxysmal AF and in some clinical situations,

also an (implantable) event recorder implantation has to be discussed (9, 10, 36).

In a positive way, no (not evidence-based) specific time intervals for the return to play are given in the recommendations of the American Heart Association and American College of Cardiology. As another difference to the European recommendations, cardiac stress testing (and also Holter ECG) during clinical work-up of the athlete is not obligatory whereas thyroid function test is specifically mentioned. In the author's opinion, the rationale for cardiac stress testing as described in the European recommendations (i.a. evaluation of frequency behavior) is comprehensible from a rhythmological point of view and should be obligatory at least in subjects with persistent or permanent AF. Ergometry seems to be also useful for evaluation of other cardiovascular risk factors, hence it should be used according to the respective German cardiological/sports medicinal recommendations. Thyroid function test (basal TSH) seems to be useful to the author. As another point of criticism, the definition of "low risk AF" is not exactly specified. In the author's opinion, "low risk AF" may be understood as AF without any underlying cardiac disease.

Summarized, in direct comparison, the American recommendations are more liberal concerning eligibility of sports participation in comparison to the older European recommendations where certain conditions (i.a. rate control, see above) are required.

Summary

At least theoretically, a training-induced left atrial enlargement, vagotonic increase and left atrial volume strain during exercise may act proarrhythmogenic in terms of a facilitated induction and maintenance of atrial fibrillation in endurance athletes. Nevertheless, currently there is no evidence of an increased AF prevalence in young endurance athletes. However, longstanding endurance exercise increases AF risk in veteran athletes whereas the relative risk was probably overestimated in early studies due to methodical problems and insufficient consideration of "new" AF risk factors. As a consequence of findings in an animal model, an exercise-induced atrial remodeling as a potential pathophysiological mechanism is being discussed, a respective definitive evidence of the latter in human beings is still missing.

To the author's opinion, both in scientific and popular media, the association between AF and endurance sports has been somewhat exaggerated within the last years. Despite the slightly increased AF risk in veteran athletes, the clinical situation in which solely endurance exercise and no other risk factors can be identified as a potential cause for AF may occur rather occasionally. In any case, the slightly increased AF risk as a consequence of long-standing endurance exercise does not reduce the doubtless positive effects of training concerning for example cardiovascular risk reduction or physical and mental well-being in general. Therefore, AF risk should also not be used as an unreflected standalone argument for modification of training intensity or even a sedentary lifestyle.

Two equivalent recommendations concerning sports participation are available for everyday clinical evaluation of competitive athletes with AF. Both exhibit certain blurs and points of criticism which lower practicability in everyday clinical practice. However, they can act as a decision support for evaluation and guidance of most of the competitive (both professional and ambitious amateur) athletes with AF. In terms of a responsible patient care, a rather individualized or sports-specific approach might be necessary also under consideration of pathophysiological aspects and the current knowledge concerning the association of AF and endurance sports. The rather brief or in a way more liberal American recommendations published recently are moving in this direction. At least in cases concerning professional athletes, interdisciplinary collaboration between experts in cardiology, rhythmology and sports medicine if needed, should be considered, not only as public pressure (including social environment of the athlete) on decision-making physicians may be sometimes high.

Conflict of Interest

The authors have no conflict of interest.

References

(1) **ABDULLA J, NIELSEN JR.** Is the risk of atrial fibrillation higher in athletes than in the general population? A systematic review and meta-analysis. Europace. 2009; 11: 1156-1159. doi:10.1093/europace/eup197

(2) **ALLESSIE MA, BONKE FI, SCHOPMAN FJ.** Circus movement in rabbit atrial muscle as a mechanism of tachycardia. III. The „leading circle" concept: a new model of circus movement in cardiac tissue without the involvement of an anatomical obstacle. Circ Res. 1977; 41: 9-18. doi:10.1161/01.RES.41.1.9

(3) **ANDERSEN K, FARAHMAND B, AHLBOM A, HELD C, LJUNGHALL S, MICHAELSSON K, SUNDSTROM J.** Risk of arrhythmias in 52 755 long-distance cross-country skiers: a cohort study. Eur Heart J. 2013; 34: 3624-3631. doi:10.1093/eurheartj/eht188

(4) **ARYA A, PIORKOWSKI C, SOMMER P, KOTTKAMP H, HINDRICKS G.** Clinical implications of various follow up strategies after catheter ablation of atrial fibrillation. Pacing Clin Electrophysiol. 2007; 30: 458-462. doi:10.1111/j.1540-8159.2007.00693.x

(5) **BAGGISH AL, WOOD MJ.** Athlete's heart and cardiovascular care of the athlete: scientific and clinical update. Circulation. 2011; 123: 2723-2735. doi:10.1161/CIRCULATIONAHA.110.981571

(6) **BENJAMIN EJ, LEVY D, VAZIRI SM, D'AGOSTINO RB, BELANGER AJ, WOLF PA.** Independent risk factors for atrial fibrillation in a population-based cohort: the Framingham Heart Study. JAMA. 1994; 271: 840-844.

(7) **BJØRNSTAD HH, BJORNSTAD TH, URHEIM S, HOFF PI, SMITH G, MARON BJ.** Long-term assessment of electrocardiographic and echocardiographic findings in Norwegian elite endurance athletes. Cardiology. 2009; 112: 234-241. doi:10.1159/000151435

(8) **CALVO N, BRUGADA J, SITGES M, MONT L.** Atrial fibrillation and atrial flutter in athletes. Br J Sports Med. 2012; 46: i37-i43. doi:10.1136/bjsports-2012-091171

(9) **CAMM AJ, KIRCHHOF P, LIP GY, SCHOTTEN U, SAVELIEVA I, ERNST S, VAN GELDER IC, AL-ATTAR N, HINDRICKS G, PRENDERGAST B, HEIDBUCHEL H, ALFIERI O, ANGELINI A, ATAR D, COLONNA P, DE CATERINA R, DE SUTTER J, GOETTE A, GORENEK B, HELDAL M, HOHLOSER SH, KOLH P, LE HEUZEY JY, PONIKOWSKI P, RUTTEN FH.** Guidelines for the management of atrial fibrillation: the Task Force for the Management of Atrial Fibrillation of the European Society of Cardiology (ESC). Europace. 2010; 12: 1360-1420. doi:10.1093/europace/euq350

(10) **CAMM AJ, LIP GY, DE CATERINA R, SAVELIEVA I, ATAR D, HOHNLOSER SH, HINDRICKS G, KIRCHHOF P.** 2012 focused update of the ESC Guidelines for the management of atrial fibrillation: an update of the 2010 ESC Guidelines for the management of atrial fibrillation--developed with the special contribution of the European Heart Rhythm Association. Europace. 2012; 14: 1385-1413. doi:10.1093/europace/eus305

(11) **DIEHL K, THIEL A, ZIPFEL S, MAYER J, LITAKER DG, SCHNEIDER S.** How Healthy is the Behavior of Young Athletes? A Systematic Literature Review and Meta-Analyses. J Sports Sci Med. 2012; 11: 201-220.

(12) **ESTES NA, 3RD, LINK MS, CANNOM D, NACCARELLI GV, PRYSTOWSKY EN, MARON BJ, OLSHANSKY B.** Report of the NASPE policy conference on arrhythmias and the athlete. J Cardiovasc Electrophysiol. 2001; 12: 1208-1219. doi:10.1046/j.1540-8167.2001.01208.x

(13) FETSCH T, BAUER P, ENGBERDING R, KOCH HP, LUKL J, MEINERTZ T, OEFF M, SEIPEL L, TRAPPE HJ, TREESE N, BREITHARDT G. Prevention of atrial fibrillation after cardioversion: results of the PAFAC trial 2. Eur Heart J. 2004; 25: 1385-1394. doi:10.1016/j.ehj.2004.04.015

(14) GRAFF-IVERSEN S, GJESDAL K, JUGESSUR A, MYRSTAD M, NYSTAD W, SELMER R, THELLE DS. Atrial fibrillation, physical activity and endurance training. Tidsskr Nor Laegeforen. 2012; 132: 295-299. doi:10.4045/tidsskr.11.0567

(15) GUASCH E, BENITO B, QI X, CIFELLI C, NAUD P, SHI Y, MIGHIU A, TARDIF JC, TADEVOSYAN A, CHEN Y, GILLIS MA, IWASAKI YK, DOBREV D, MONT L, HEXIMER S, NATTEL S. Atrial fibrillation promotion by endurance exercise: demonstration and mechanistic exploration in an animal model. J Am Coll Cardiol. 2013; 62: 68-77. doi:10.1016/j.jacc.2013.01.091

(16) HAISSAGUERRE M, JAIS P, SHAH DC, TAKAHASHI A, HOCINI M, QUINIOU G, GARRIGUE S, LE-MOUROUX A, LE-METAYER P, CLEMENTY J. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. N Engl J Med. 1998; 339: 659-666. doi:10.1056/NEJM199809033391003

(17) HEIDBUCHEL H, PANHUYZEN-GOEDKOOP N, CORRADO D, HOFFMANN E, BIFFI A, DELISE P, BLOMSTROM-LUNDQVIST C, VANHEES L, IVARHOFF P, DORWARTH U, PELLICCIA A. Recommendations for participation in leisure-time physical activity and competitive sports in patients with arrhythmias and potentially arrhythmogenic conditions Part I: Supraventricular arrhythmias and pacemakers. Eur J Cardiovasc Prev Rehabil. 2006; 13: 475-484. doi:10.1097/01.hjr.0000216543.54066.72

(18) IQBAL FM, BEEHARILAL PS, SADAT K, MOHAJER R, LEWIS BE. Steroid induced atrial fibrillation. Compr Ther. 2008; 34: 111-114.

(19) KALIFA J, JALIFE J, ZAITSEV AV, BAGWE S, WARREN M, MORENO J, BERENFELD O, NATTEL S. Intra-atrial pressure increases rate and organization of waves emanating from the superior pulmonary veins during atrial fibrillation. Circulation. 2003; 108: 668-671. doi:10.1161/01.CIR.0000086979.39843.7B

(20) KOOPMAN P, NUYENS D, GARWEG C, LA GERCHE A, DE BUCK S, VAN CASTEREN L, ALZAND B, WILLEMS R, HEIDBUCHEL H. Efficacy of radiofrequency catheter ablation in athletes with atrial fibrillation. Europace. 2011; 13: 1386-1393. doi:10.1093/europace/eur142

(21) KUMAR S, TEH AW, MEDI C, KISTLER PM, MORTON JB, KALMAN JM. Atrial remodeling in varying clinical substrates within beating human hearts: relevance to atrial fibrillation. Prog Biophys Mol Biol. 2012; 110: 278-294. doi:10.1016/j.pbiomolbio.2012.07.011

(22) LASZLO R, EICK C, SCHWIEBERT M, SCHREINER B, WEIG HJ, WERETKA S, BOSCH RF, SCHREIECK JL. Alcohol-induced electrical remodeling: effects of sustained short-term ethanol infusion on ion currents in rabbit atrium. Alcohol Clin Exp Res. 2009; 33: 1697-1703. doi:10.1111/j.1530-0277.2009.01006.x

(23) LASZLO R, GRAZE H, LASZLO S, SCHREIECK J. Atrial fibrillation - Links between principles of pathophysiology and treatment. Dtsch Med Wochenschr. 2010; 135: 862-867. doi:10.1055/s-0030-1253670

(24) LAU DH, STILES MK, JOHN B. Shashidhar, Young GD, Sanders P. Atrial fibrillation and anabolic steroid abuse. Int J Cardiol. 2007; 117: e86-e87. doi:10.1016/j.ijcard.2006.11.199

(25) LEVINE BD, BAGGISH AL, KOVACS RJ, LINK MS, MARON MS, MITCHELL JH. Eligibility and Disqualification Recommendations for Competitive Athletes With Cardiovascular Abnormalities: Task Force 1: Classification of Sports: Dynamic, Static, and Impact: A Scientific Statement From the American Heart Association and American College of Cardiology. J Am Coll Cardiol. 2015; 66: 2350-2355. doi:10.1016/j.jacc.2015.09.033

(26) LINDSAY MM, DUNN FG. Biochemical evidence of myocardial fibrosis in veteran endurance athletes. Br J Sports Med. 2007; 41: 447-452. doi:10.1136/bjsm.2006.031534

(27) LISHA NE, SUSSMAN S, FAPA F, LEVENTHAL AM. Physical activity and alcohol use disorders. Am J Drug Alcohol Abuse. 2013; 39: 115-120. doi:10.3109/00952990.2012.713060

(28) LIU L, NATTEL S. Differing sympathetic and vagal effects on atrial fibrillation in dogs: role of refractoriness heterogeneity. Am J Physiol. 1997; 273: H805-H816.

(29) MENZ V, GRIMM W, HOFFMANN J, MAISCH B. Alcohol and rhythm disturbance: the holiday heart syndrome. Herz. 1996; 21: 227-231.

(30) MITCHELL JH, HASKELL W, SNELL P, VAN CAMP SP. Task Force 8: classification of sports. J Am Coll Cardiol. 2005; 45: 1364-1367. doi:10.1016/j.jacc.2005.02.015

(31) MÜSSIGBRODT A, RICHTER S, HINDRICKS G, BOLLMANN A. Vorhofflimmern bei Ausdauersportlern. Dtsch Z Sportmed. 2010; 61: 190-200.

(32) MYRSTAD M, LOCHEN ML, GRAFF-IVERSEN S, GULSVIK AK, THELLE DS, STIGUM H, RANHOFF AH. Increased risk of atrial fibrillation among elderly Norwegian men with a history of long-term endurance sport practice. Scand J Med Sci Sports. 2014; 24: e238-e244. doi:10.1111/sms.12150

(33) PELLICCIA A, MARON BJ, DI PAOLO FM, BIFFI A, QUATTRINI FM, PISICCHIO C, ROSELLI A, CASELLI S, CULASSO F. Prevalence and clinical significance of left atrial remodeling in competitive athletes. J Am Coll Cardiol. 2005; 46: 690-696. doi:10.1016/j.jacc.2005.04.052

(34) PELLICCIA A, FAGARD R, BJORNSTAD HH, ANASTASSAKIS A, ARBUSTINI E, ASSANELLI D, BIFFI A, BORJESSON M, CARRE F, CORRADO D, DELISE P, DORWARTH U, HIRTH A, HEIDBUCHEL H, HOFFMANN E, MELLWIG KP, PANHUYZEN-GOEDKOOP N, PISANI A, SOLBERG EE, VAN-BUUREN F, VANHEES L, BLOMSTROM-LUNDQVIST C, DELIGIANNIS A, DUGMORE D, GLIKSON M, HOFF PI, HOFFMANN A, HORSTKOTTE D, NORDREHAUG JE, OUDHOF J, MCKENNA WJ, PENCO M, PRIORI S, REYBROUCK T, SENDEN J, SPATARO A, THIENE G. Recommendations for competitive sports participation in athletes with cardiovascular disease: a consensus document from the Study Group of Sports Cardiology of the Working Group of Cardiac Rehabilitation and Exercise Physiology and the Working Group of Myocardial and Pericardial Diseases of the European Society of Cardiology. Eur Heart J. 2005; 26: 1422-1445. doi:10.1093/eurheartj/ehi325

(35) RAVELLI F, ALLESSIE M. Effects of atrial dilatation on refractory period and vulnerability to atrial fibrillation in the isolated Langendorff-perfused rabbit heart. Circulation. 1997; 96: 1686-1695. doi:10.1161/01.CIR.96.5.1686

(36) ROSERO SZ, KUTYIFA V, OLSHANSKY B, ZAREBA W. Ambulatory ECG monitoring in atrial fibrillation management. Prog Cardiovasc Dis. 2013; 56: 143-152. doi:10.1016/j.pcad.2013.10.001

(37) SCHARHAG J, LÖLLGEN H, KINDERMANN W. Herz und Leistungssport: Nutzen oder Schaden? Dtsch Arztebl Int. 2013; 110: 14-24.

(38) SCHOONDERWOERD BA, SMIT MD, PEN L, VAN GELDER IC. New risk factors for atrial fibrillation: causes of ‚not-so-lone atrial fibrillation'. Europace. 2008; 10: 668-673. doi:10.1093/europace/eun124

(39) SCHOTTEN U, VERHEULE S, KIRCHHOF P, GOETTE A. Pathophysiological mechanisms of atrial fibrillation: a translational appraisal. Physiol Rev. 2011; 91: 265-325. doi:10.1152/physrev.00031.2009

(40) TAI CT, CHIOU CW, WEN ZC, HSIEH MH, TSAI CF, LIN WS, CHEN CC, LIN YK, YU WC, DING YA, CHANG MS, CHEN SA. Effect of phenylephrine on focal atrial fibrillation originating in the pulmonary veins and superior vena cava. J Am Coll Cardiol. 2000; 36: 788-793. doi:10.1016/S0735-1097(00)00792-0

(41) TAMMINEN KA, HOLT NL, CROCKER PR. Adolescent athletes: psychosocial challenges and clinical concerns. Curr Opin Psychiatry. 2012; 25: 293-300. doi:10.1097/YCO.0b013e3283541248

(42) WIJFFELS MC, KIRCHHOF CJ, DORLAND R, ALLESSIE MA. Atrial fibrillation begets atrial fibrillation. A study in awake chronically instrumented goats. Circulation. 1995; 92: 1954-1968. doi:10.1161/01.CIR.92.7.1954

(43) WILHELM M, ROTEN L, TANNER H, WILHELM I, SCHMID JP, SANER H. Atrial remodeling, autonomic tone, and lifetime training hours in nonelite athletes. Am J Cardiol. 2011; 108: 580-585. doi:10.1016/j.amjcard.2011.03.086

(44) WILHELM M, ZUEGER T, DE MARCHI S, RIMOLDI SF, BRUGGER N, STEINER R, STETTLER C, NUOFFER JM, SEILER C, ITH M. Inflammation and atrial remodeling after a mountain marathon. Scand J Med Sci Sports. 2014; 24: 519-525. doi:10.1111/sms.12030

(45) WILSON M, O'HANLON R, PRASAD S, DEIGHAN A, MACMILLAN P, OXBOROUGH D, GODFREY R, SMITH G, MACEIRA A, SHARMA S, GEORGE K, WHYTE G. Diverse patterns of myocardial fibrosis in lifelong, veteran endurance athletes. J Appl Physiol. 2011; 110: 1622-1626. doi:10.1152/japplphysiol.01280.2010

(46) ZIPES DP, LINK MS, ACKERMAN MJ, KOVACS RJ, MYERBURG RJ, ESTES NA III. Eligibility and Disqualification Recommendations for Competitive Athletes With Cardiovascular Abnormalities: Task Force 9: Arrhythmias and Conduction Defects: A Scientific Statement From the American Heart Association and American College of Cardiology. J Am Coll Cardiol. 2015; 66: 2412-2423.