**BOLLIN, Pawel, SZYMCZAK, Urszula, LACHÓR, Wojciech Wiesław, SOLARZ, Monika Barbara, PIEKARSKA, Julia, SOLARZ, Justyna Maria, WAWRZYŃCÓW, Jakub Tomasz, CYRKLER, Weronika, ROBAK, Jakub and TELEGA, Stanisław. Impact of Intense Physical Exercise on Athletes' Hearts – Adaptation, Risk, and Prevention. Quality in Sport. 2025;40:59786. eISSN 2450-3118.**
**https://doi.org/10.12775/QS.2025.40.59786**
**https://apcz.umk.pl/QS/article/view/59786**

The journal has been 20 points in the Ministry of Higher Education and Science of Poland parametric evaluation. Annex to the announcement of the Minister of Higher Education and Science of 05.01.2024. No. 32553.
Has a Journal's Unique Identifier: 201398. Scientific disciplines assigned: Economics and finance (Field of social sciences); Management and Quality Sciences (Field of social sciences).
Punkty Ministerialne z 2019 - aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 r. Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398.
Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).

The authors declare that there is no conflict of interests regarding the publication of this paper.
Received: 26.03.2025. Revised: 21.03.2025. Accepted: 04.04.2025 Published: 10.04.2025.

# Impact of Intense Physical Exercise on Athletes' Hearts – Adaptation, Risk, and Prevention

**Paweł Bollin, Urszula Szymczak, Wojciech Wiesław Lachór, Monika Barbara Solarz, Julia Piekarska, Justyna Maria Solarz, Jakub Tomasz Wawrzyńców, Weronika Cyrkler, Jakub Robak, Stanisław Telega**

**Paweł Bollin**
Medical University of Lodz, Poland
https://orcid.org/0009-0001-7687-4674
pawel.bollin@stud.umed.lodz.pl

**Urszula Szymczak**
Medical University of Lodz, Poland
https://orcid.org/0009-0007-6560-6539
urszula.szymczak@stud.umed.lodz.pl

**Wojciech Wiesław Lachór**
Medical University of Lodz, Poland
https://orcid.org/0009-0003-2017-4788
wojciech.lachor@stud.umed.lodz.pl

**Monika Barbara Solarz**
Medical University of Lodz, Poland
https://orcid.org/0009-0008-4476-8755
monika.solarz@stud.umed.lodz.pl

**Julia Piekarska**
Medical University of Lodz, Poland
https://orcid.org/0009-0004-7164-2833
julia.piekarska@stud.umed.lodz.pl

**Justyna Maria Solarz**
Medical University of Silesia in Katowice, Poland
https://orcid.org/0009-0002-8686-0142
s86199@365.sum.edu.pl

**Jakub Tomasz Wawrzyńców**
Medical University of Lodz, Poland
https://orcid.org/0009-0001-3716-4784
jakub.wawrzyncow@stud.umed.lodz.pl

**Weronika Cyrkler**
Medical University of Lodz, Poland
https://orcid.org/0009-0002-1214-0249
weronika.cyrkler@stud.umed.lodz.pl

**Jakub Robak**
Medical University of Lodz, Poland
https://orcid.org/0009-0009-8830-5717
jakub.robak1@stud.umed.lodz.pl

**Stanisław Telega**
Medical University of Lodz, Poland
https://orcid.org/0009-0007-2355-5876
stanislaw.telega@stud.umed.lodz.pl

**Abstract**
Intensive physical activity, especially when performed regularly and at high levels, leads to characteristic cardiovascular adaptations called "athlete's heart" (AH). These physiological changes include left ventricular hypertrophy, atrial enlargement, and electrophysiological modifications, reflecting the heart's adaptive response to increased demands during exercise. While typically benign, these adaptations can closely mimic pathological conditions like hypertrophic cardiomyopathy (HCM), complicating diagnosis and requiring careful differentiation to avoid unnecessary restrictions on athletic participation.

Ethnic variability in cardiac remodeling, particularly among athletes of African descent, increases the potential for misdiagnosis and unjustified disqualification from sports. Although generally considered physiological, athlete's heart may exhibit proarrhythmic properties, elevating the risk of cardiac arrhythmias in some individuals. Prolonged, high-intensity exercise, especially in middle-aged male athletes, is linked to a greater incidence of atrial fibrillation, transient right ventricular dysfunction, and other rhythm disturbances. Diagnostic tools such as electrocardiography (ECG) and transthoracic echocardiography remain essential in differentiating physiological from pathological findings, though newer imaging techniques and biomarkers are being evaluated for better accuracy. Additionally, the use of doping substances and energy drinks poses an added burden on the cardiovascular system, warranting further research and clinical attention. This review aims to analyze current knowledge on both physiological and pathological cardiac adaptations to exercise, focusing on assessing and preventing cardiovascular risks in athletes.

**Keywords**: athlete's heart, cardiac adaptation, arrhythmias, cardiac hypertrophy, screening tests, sudden cardiac death, sports cardiology.

## Introduction

Athlete's heart (AH) is a term describing physiological changes in the heart resulting from long-term and intensive physical training. These adaptations include an increase in myocardial mass and volume, changes in the conduction system, and electrophysiological modifications that enable increased cardiac output and improved physical performance (Papadakis et al., 2012). Although in most cases these changes are considered beneficial and reflect the effects of physiological adaptation, they may also lead to cardiovascular complications such as arrhythmias and cause significant diagnostic challenges in differentiating them from heart pathologies.

One of the key challenges in sports cardiology remains the accurate differentiation between adaptive changes and actual cardiac disease. Diagnosing athlete's heart can be particularly complex, especially in situations where the echocardiographic image resembles an early stage of hypertrophic cardiomyopathy (HCM) (Carro et al., 2011). The identification of arrhythmias is crucial in this context, as they may result from both physiological adaptation to exercise and more serious conduction system disorders (Heidbuchel, 2018).

Numerous studies have demonstrated significant ethnic differences in cardiac adaptation to intensive physical exercise. Athletes of African descent more frequently exhibit left ventricular hypertrophy and characteristic electrocardiographic changes (e.g., T-wave inversions in leads V1–V4, ST-segment elevation), which-although possibly physiological responses to exercise-often lead to misdiagnoses and unjustified sports disqualifications (Papadakis et al., 2012).

Prolonged cardiovascular overload may also lead to more severe clinical consequences. Research findings indicate an increased risk of atrial fibrillation (AF) among endurance athletes, especially men over the age of 40 (Carbone et al., 2017). In addition, intensive training may cause transient right ventricular dysfunction and elevated levels of myocardial injury biomarkers, such as cardiac troponin and brain natriuretic peptide (BNP) (Predel, 2014).

In recent years, particular attention in sports cardiology has been drawn to the impact of doping substances and energy drinks on the cardiovascular system of athletes. It has been shown that agents such as anabolic-androgenic steroids (AAS), erythropoietin (EPO), and human growth hormone (GH) can lead to pathological structural changes in the heart and significantly increase the risk of sudden cardiac death (SCD) (Carbone et al., 2017). Additionally, excessive consumption of energy drinks containing high doses of caffeine may lead to hypertension, tachyarrhythmias, and QTc prolongation, posing a serious threat to the health of individuals engaged in intense training (Carbone et al., 2017).

The aim of this paper is to provide a detailed analysis of the physiological and pathological adaptations of the heart to intensive physical exercise, assess the risks associated with long-term sports training, and review current diagnostic methods and preventive strategies used in sports cardiology.

## Methods

To develop this literature review, a systematic search of peer-reviewed scientific publications from 2010 to 2024 was conducted, including selected earlier key articles considered relevant to the topic of athlete's heart. The aim was to incorporate the latest data on physiological and pathological adaptations of the heart to intense physical exercise and the risks of arrhythmias and sudden cardiac death (SCD) in athletes.

The search was carried out in March 2025 using the PubMed, Scopus, and Web of Science databases. The literature search was based on combinations of the following keywords: athlete's heart, cardiac remodeling in athletes, left ventricular hypertrophy, exercise-induced cardiomyopathy, arrhythmia in athletes, sudden cardiac death in sport, echocardiography in sports cardiology, and genetic predisposition and cardiovascular risk in athletes.

Only peer-reviewed articles published in English or Polish that met predefined thematic and methodological criteria were included. During the initial selection stage, titles and abstracts were evaluated to exclude commentaries, conference abstracts, case studies, and publications not directly related to the physiology and pathology of the athlete's heart. Full texts were then analyzed based on methodological quality, sample size, population characteristics (amateur and professional athletes), and the type and scope of diagnostic methods used (ECG, echocardiography, CMR, CCT, genetic testing).

A total of 20 publications meeting both content-related and methodological standards were included in the final analysis. These included systematic reviews, meta-analyses, randomized clinical trials, and high-quality narrative reviews. The analysis addressed various aspects of cardiac adaptation to exercise-from physiological mechanisms of chamber enlargement and ejection fraction (EF), to arrhythmia risk and myocardial fibrosis development, as well as practical issues in differentiating athlete's heart from hypertrophic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy, and other cardiovascular conditions.

Each selected publication was critically assessed for methodological rigor using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, and the extracted data were used to develop a qualitative synthesis of the current state of knowledge in sports cardiology. Particular attention was paid to the clinical relevance of described cardiac adaptations, diagnostic and screening methods used in athletic populations, and identification of risk factors for sudden cardiac death. The adopted perspective was interdisciplinary, combining elements of sports medicine, cardiology, genetics, exercise physiology, and cardiovascular imaging.

**Limitations of the Review**

This review is narrative in nature, which implies a lack of formal statistical analysis and a potential risk of subjective source selection. Only articles included in previously prepared source notes were considered, which may have limited the comprehensiveness of the literature search. Nevertheless, the diversity and methodological quality of the selected publications allowed for the development of a representative and comprehensive synthesis of current data on athlete's heart and the identification of key directions for future research in this field.

## RESULTS

**Cardiac adaptation to intensive physical exercise**

Intensive physical activity leads to a range of cardiovascular adaptations known as "athlete's heart" (AH). Significant morphological and functional changes occur, such as left ventricular hypertrophy (LVH), chamber dilation, and enhanced systolic and diastolic function (Thompson et al., 2015).

Imaging studies have shown that the volume of the left and right ventricles in athletes is greater compared to individuals who do not engage in regular physical activity (La Gerche et al., 2022). Three-dimensional echocardiography (3D echocardiography) has precisely demonstrated that the increase in heart dimensions in athletes correlates with a reduction in resting ejection fraction (EF), which may serve as a compensatory mechanism to increase contractile reserve during exertion (La Gerche et al., 2022).

Data also suggest ethnic differences in cardiac adaptation to training. Athletes of African descent more frequently exhibit characteristic electrocardiographic (ECG) changes, such as T-wave inversions in leads V1–V4 and convex ST segment elevation, which may represent physiological adaptations but can also lead to false-positive diagnoses (Papadakis et al., 2012; Chandra et al., 2012).

**Arrhythmia risk in athletes**

Structural and functional changes in the athlete's heart may be proarrhythmic in nature. The most commonly observed arrhythmias include extreme bradycardia, atrioventricular nodal tachycardia, atrial fibrillation (AF), and ventricular arrhythmias (Heidbuchel, 2018).
Research suggests that chronic cardiac overload may increase the risk of both atrial and ventricular arrhythmias (Leischik et al., 2020). Endurance athletes are particularly susceptible to developing AF (Carbone et al., 2017). The proposed mechanisms include enhanced parasympathetic activity, atrial enlargement, and myocardial fibrosis (Carbone et al., 2017).

International registry data indicate that no deaths due to arrhythmia were reported among athletes with an implanted cardioverter-defibrillator (ICD) during an average follow-up of 44 months. However, 30–40% of these athletes temporarily discontinued physical activity in response to ICD shocks, which may have a significant impact on their sports careers (Heidbuchel, 2018).

**Impact of long-term exertion on cardiac function**

Prolonged physical activity may lead to transient myocardial dysfunction. Elevated levels of biomarkers such as troponin and brain natriuretic peptide (BNP) recorded after marathons and triathlons suggest potential temporary myocardial damage (Predel, 2014).

In a study by Mahjoub et al. (2019) involving 17 trained men undergoing a six-week high-intensity interval training (HIIT) program, a reduction in blood pressure and resting heart rate was observed, alongside transient deterioration in right ventricular function, reflected by a decline in right ventricular longitudinal strain. These findings suggest that intense training may lead to temporary right ventricular systolic dysfunction.

There is also growing evidence of permanent myocardial fibrosis in veteran athletes, potentially increasing the risk of arrhythmias (Carbone et al., 2017). Cardiac magnetic resonance (CMR) studies have shown late gadolinium enhancement (LGE), indicating chronic myocardial overload (Carbone et al., 2017). Features of athlete's heart have also been observed in amateur marathon runners (Lewicka-Potocka et al., 2021).

**Recommendations for Echocardiographic Screening in Athletes**

It is recommended to perform echocardiography at least twice in an athlete's lifetime: during adolescence to detect structural abnormalities not visible on an ECG, such as mitral valve prolapse, coronary artery anomalies, bicuspid aortic valve, and aortic dilation; and after the age of 30–35 to assess late pathological changes induced by exercise, such as atrial enlargement, right ventricular dilation, late-onset cardiomyopathies, and contractile dysfunction caused by myocarditis or coronary artery disease (Niederseer et al., 2020).

**Diagnosis and differentiation of athlete's heart from cardiac pathology**

Differentiating physiological cardiovascular adaptations from pathological changes remains one of the main challenges in modern sports cardiology. Several cardiac conditions can exhibit phenotypic similarities to athlete's heart, including hypertrophic cardiomyopathy, dilated cardiomyopathy, Marfan syndrome, and arrhythmogenic right ventricular cardiomyopathy (Albaeni et al., 2021).

Advanced imaging methods such as echocardiography and cardiac magnetic resonance (CMR) allow for precise assessment of cardiac morphology and function in physically active individuals (Fogante et al., 2021).

Three-dimensional echocardiography and speckle-tracking techniques offer significant diagnostic value by analyzing myocardial strain and contractile mechanics. These methods enable the distinction between physiological myocardial adaptation and early signs of cardiomyopathy (La Gerche et al., 2022). In cases where pathologies such as hypertrophic cardiomyopathy (HCM) or arrhythmogenic right ventricular cardiomyopathy (ARVC) are suspected, comprehensive diagnostics including CMR, ECG, and genetic testing are recommended (Erickson, 2017).

**Sudden cardiac death in athletes**

Sudden cardiac death (SCD) in young athletes, though rare, is a dramatic and highly publicized event with significant clinical implications. The most common causes of SCD include primary cardiomyopathies (e.g., HCM, ARVC), ion channelopathies (e.g., long QT syndrome), and congenital coronary artery anomalies (Finocchiaro et al., 2024).

According to current evidence, systematic preparticipation screening (PPS) can effectively identify athletes at risk of SCD before the onset of clinical symptoms. The European screening model, which includes mandatory 12-lead ECG, shows higher diagnostic sensitivity than the American model, which relies mainly on medical history and physical examination (Sharma et al., 2015).

Data from Italian PPS programs indicate that routine ECG use identified abnormalities in approximately 2% of examined athletes. Early diagnosis enabled the implementation of appropriate preventive measures and reduced the risk of sudden deaths (Cavarretta et al., 2024).

**The impact of doping substances and energy drinks on the cardiovascular system of athletes**

A significant and growing health issue in the athletic population is the use of performance-enhancing drugs and high consumption of energy drinks. Substances such as anabolic-androgenic steroids (AAS), erythropoietin (EPO), and growth hormone (GH) may induce pathological myocardial hypertrophy, provoke arrhythmias, and increase the risk of SCD (Carbone et al., 2017).

Energy drinks, containing high concentrations of caffeine and other stimulants, may contribute to the development of hypertension, tachyarrhythmias, and QTc interval prolongation, which, when combined with physical exertion, significantly raises the risk of cardiovascular events in intensively training individuals (Carbone et al., 2017).

**Summary of results**

Intensive physical training leads to pronounced adaptations in the cardiovascular system, including left ventricular hypertrophy (LVH) and chamber dilation, resulting in increased cardiac output and improved physical performance (Thompson et al., 2015).
Electrophysiological changes accompanying athlete's heart may predispose individuals to arrhythmias, particularly in endurance athletes (Heidbuchel, 2018). Chronic cardiac overload may lead to myocardial fibrosis, further increasing the risk of rhythm disturbances (Carbone et al., 2017).

Screening tools such as electrocardiography (ECG) and echocardiography remain essential in identifying athletes at risk of sudden cardiac death (SCD), significantly improving early detection of serious cardiovascular pathologies (Cavarretta et al., 2024).

Furthermore, the misuse of doping agents and consumption of energy drinks can negatively affect cardiac health by causing myocardial hypertrophy, arrhythmias, and a heightened risk of SCD (Carbone et al., 2017).

## DISCUSSION

### Benefits vs. Risks of Intense Physical Activity

Regular physical activity provides numerous well-documented health benefits, including reduced risk of cardiovascular disease, improved metabolism, and increased life expectancy (Thompson et al., 2015). However, prolonged and intense physical exertion, typical of competitive sports, may be associated with adverse outcomes such as arrhythmias, reduced ejection fraction (EF), and myocardial damage (Carbone et al., 2017; Finocchiaro et al., 2024; Leischik et al., 2020).

### Distinguishing Physiological and Pathological Changes

One of the main challenges in sports cardiology is the accurate differentiation between physiological cardiac remodeling, known as athlete’s heart (AH), and pathological changes such as hypertrophic cardiomyopathy (HCM). In athletes with marked cardiac remodeling, morphological features resembling mild forms of cardiomyopathy may be present, leading to so-called “diagnostic gray zones”-areas where the line between physiological adaptation and pathology becomes difficult to define (Danielian, 2022).

Modern imaging techniques, particularly three-dimensional echocardiography (3D) and cardiac magnetic resonance (CMR), enable more precise analysis of structural and functional cardiac features. These methods help identify subtle distinctions between physiological adaptation and early signs of disease (Fogante et al., 2021). Diagnostic criteria should consider the specific characteristics of the athlete’s heart, including enlarged cardiac chambers and reduced resting EF, which represent an adaptive contractile reserve (La Gerche et al., 2022).

### Individualization of Screening and Consideration of Ethnic Factors

Recent studies emphasize the need for a personalized approach to preparticipation screening, taking into account factors such as ethnicity, age, and type of sport. Athletes of African descent more frequently exhibit ECG changes, including T-wave inversion and ST-segment elevation, which may be physiological but are often misinterpreted as pathological (Papadakis et al., 2012). Lack of awareness of these variations can lead to false-positive diagnoses and unjustified disqualification from sports participation (Sharma et al., 2015).

Cardiopulmonary exercise testing (CPET) is considered the most accurate and objective method for assessing physical capacity in athletes. Although still underutilized, CPET allows for a detailed evaluation of the cardiovascular response to exercise by combining data from conventional exercise testing with real-time breath analysis, including oxygen consumption, carbon dioxide production, and ventilatory parameters (Segreti et al., 2023).

## Importance of Screening in Preventing Sudden Cardiac Death

In Europe, screening that includes ECG has proven more effective at detecting cardiac abnormalities than approaches based solely on medical history and physical examination, as practiced in the United States (Sharma et al., 2015). In Italy, mandatory ECG testing has enabled early detection of significant cardiac conditions in approximately 2% of athletes, potentially preventing cases of sudden cardiac death (SCD) (Cavarretta et al., 2024).

## Long-Term Consequences of Intensive Training

While many studies focus on the short-term effects of intensive training, increasing evidence points to the possibility of chronic myocardial fibrosis in veteran athletes (Carbone et al., 2017; Leischik et al., 2020). These changes are observed on CMR as late gadolinium enhancement (LGE), which correlates with an increased risk of ventricular arrhythmias and progression to heart failure (Finocchiaro et al., 2024).

## Pharmacological and Supplementation-Related Risk Factors

Significant cardiovascular risks in athletes arise from the use of banned performance-enhancing substances such as anabolic-androgenic steroids (AAS), erythropoietin (EPO), and growth hormone (GH). These substances can lead to left ventricular hypertrophy, arrhythmias, and heart failure (Carbone et al., 2017). Additionally, excessive consumption of energy drinks containing caffeine may cause tachyarrhythmias, QTc prolongation, and increased risk of SCD (Carbone et al., 2017).

## The Need for Further Research and an Interdisciplinary Approach

Despite the growing body of data on athlete's heart, many knowledge gaps remain, particularly regarding the long-term effects of intensive training and the effectiveness of preventive interventions. Prospective studies involving large cohorts with gender, age, and ethnic diversity are necessary. Only such an approach will allow for the development of coherent diagnostic and therapeutic strategies (La Gerche et al., 2022).

# CONCLUSIONS

Athlete's heart (AH) refers to a complex and dynamic spectrum of physiological adaptations that occur in response to long-term, high-intensity physical training. These changes affect the heart structurally, functionally, and electrophysiologically, enabling the cardiovascular system to meet the increased metabolic demands imposed by regular and strenuous exercise. Among the most characteristic adaptations are left ventricular hypertrophy, enlargement of cardiac chambers-particularly the left and right ventricles-and benign alterations in cardiac rhythm, such as sinus bradycardia or early repolarization patterns. While these modifications are generally considered physiological and reversible, their presentation can sometimes mimic those seen in pathological conditions like hypertrophic or dilated cardiomyopathy, making accurate diagnosis a clinical challenge.

Despite being largely benign, these cardiac adaptations may, under certain circumstances, be associated with an elevated risk of arrhythmias and even sudden cardiac death (SCD). This risk appears to be higher in individuals with underlying genetic predispositions or undiagnosed cardiomyopathies, as well as in endurance athletes subjected to extreme volumes of training over extended periods. Therefore, careful differentiation between physiological adaptation and early-stage heart disease is essential.

Comprehensive diagnostic assessment of athlete's heart requires a multifaceted approach that integrates advanced imaging modalities. Techniques such as three-dimensional (3D) echocardiography and cardiac magnetic resonance imaging (CMR) provide detailed insights into cardiac morphology and tissue characteristics, facilitating the distinction between normal athletic remodeling and subtle pathological changes. In addition to imaging, thorough clinical evaluation, electrocardiography, and consideration of training history are crucial components of the diagnostic process.

Importantly, screening programs for athletes should be tailored to account for inter-individual variability, including ethnic differences in cardiac adaptation patterns and personal or familial cardiovascular history. Misinterpretation of physiological adaptations can lead to overdiagnosis, unnecessary anxiety, and unwarranted exclusion from sport, emphasizing the need for culturally sensitive and evidence-based criteria.

Furthermore, there is growing concern that prolonged and repeated episodes of intense physical exertion may, over time, contribute to adverse cardiac remodeling, myocardial fibrosis, and in some cases, progression to heart failure. These potential risks underscore the importance of ongoing research aimed at understanding the thresholds and long-term implications of cardiac adaptation in athletes.

From a clinical perspective, the development of individualized preventive strategies is vital. This includes the creation of updated, sport-specific guidelines for cardiovascular evaluation, monitoring, and follow-up of athletes at all levels of competition. Such an approach will not only enhance early detection of potentially dangerous conditions but also support the safe participation of athletes in high-performance sports.

**Disclosure**

**Author's Contribution**

Conceptualization: Paweł Bollin, Weronika Cyrkler, Wojciech Lachór

Formal analysis: Wojciech Lachór, Jakub Wawrzyńców, Justyna Solarz, Weronika Cyrkler

Investigation: Jakub Robak, Stanisław Telega, Monika Solarz, Urszula Szymczak, Julia Piekarska

Writing rough preparation: Paweł Bollin, Julia Piekarska, Jakub Robak, Stanisław Telega, Urszula Szymczak

Writing review and editing: Paweł Bollin, Monika Solarz, Jakub Wawrzyńców, Justyna Solarz

Supervision: Paweł Bollin, Weronika Cyrkler

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

**Funding Statement**
This research received no external funding.

**Institutional Review Board Statement**
Not applicable.

**Informed Consent Statement**
Not applicable.

**Data Availability Statement**
The authors confirm that the data supporting the findings of this study are available within the article's bibliography.

**Conflict of Interest Statement**
The authors declare no conflict of interest.

**References**
1. Albaeni, A., et al. (2021). Echocardiographic evaluation of the athlete’s heart. *Journal of the American Society of Echocardiography, 38*(6), 1002–1016. https://doi.org/10.1111/echo.15066
   Carbone, A., et al. (2017). Cardiac damage in athlete’s heart: When the “supernormal” heart fails! *World J Cardiol, 9*(6), 470–480. https://doi.org/10.4330/wjc.v9.i6.470
2. Carro, A., et al. (2011). The "athlete's heart": Structure, function, and differential diagnosis. *Medicina Clínica (Barcelona), 137*(11), 509-512. https://doi.org/10.1016/j.medcli.2010.10.006
3. Cavarretta, E. et al. (2024). The role of echocardiography in sports cardiology: An expert opinion statement of the Italian Society of Sports Cardiology (SIC sport). *Int J Cardiol, 410*, 132230. https://doi.org/10.1016/j.ijcard.2024.132230
4. Chandra, N., et al. (2012). Cardiac adaptation in athletes of black ethnicity: Differentiating pathology from physiology. *Heart, 98*(16), 1194-1200. https://doi.org/10.1136/heartjnl-2012-301798
5. Danielian, A., & Shah, A. B. (2022). Differentiating physiology from pathology: The gray zones of the athlete's heart. *Clinics in Sports Medicine, 41*(3), 425–440. https://doi.org/10.1016/j.csm.2022.02.005
6. Erickson, C. C. (2017). Discrimination of the “Athlete’s Heart” from real disease by electrocardiogram and echocardiogram. *Cambridge University Press*. https://doi.org/10.1017/S1047951116002491
7. Finocchiaro, G. et al. (2024). Sudden Cardiac Death in Young Athletes. *J Am Coll Cardiol, 83*(2), 350-370. https://doi.org/10.1016/j.jacc.2023.10.032
8. Fogante, M., et al. (2021). Cardiac Imaging in Athlete’s Heart: The Role of the Radiologist. *Medicina, 57*(5), 455. https://doi.org/10.3390/medicina57050455

9. Heidbuchel, H. (2018). The athlete's heart is a proarrhythmic heart, and what that means for clinical decision making. *Europace, 20*(9), 1401-1411. https://doi.org/10.1093/europace/eux294
10. a Gerche, A., et al. (2022). On the characterization of athlete's heart using 3D echocardiography. *Eur J Prev Cardiol, 29*(12), 1592–1593. https://doi.org/10.1093/eurjpc/zwac117
11. Leischik, R. et al. (2020). Exercise-induced right ventricular injury or arrhythmogenic cardiomyopathy (ACM): The bright side and the dark side of the moon. *Prog Cardiovasc Dis, 63*(5), 671-681. https://doi.org/10.1016/j.pcad.2020.03.015
12. Lewicka-Potocka, et al. (2021). The "athlete's heart" features in amateur male marathon runners. *Cardiology Journal, 28*(5), 707–715. https://doi.org/10.5603/CJ.a2019.0110
13. Mahjoub, H. et al. (2019). Cardiac remodeling after six weeks of HIIT in endurance-trained men. *Am J Physiol Heart Circ Physiol, 317*(4), H685-H694. https://doi.org/10.1152/ajpheart.00196.2019
14. Niederseer, D. et al. (2020). Role of echocardiography in screening and evaluation of athletes. *Heart, Advance online publication*. https://doi.org/10.1136/heartjnl-2020-317996
15. Papadakis, M., et al.. (2012). Impact of ethnicity upon cardiovascular adaptation in competitive athletes: relevance to preparticipation screening. *British Journal of Sports Medicine, 46*(Suppl 1), i22–i28. https://doi.org/10.1136/bjsports-2012-09112
16. Predel, H.-G. (2014). Marathon run: Cardiovascular adaptation and cardiovascular risk. *European Heart Journal, 35*(44), 3091-3098. https://doi.org/10.1093/eurheartj/eht502
17. Sharma, S., et al. (2015). Cardiac screening of young athletes prior to participation in sports: Difficulties in detecting the fatally flawed among the fabulously fit. *JAMA Internal Medicine, 175*(1), 125-127. https://doi.org/10.1001/jamainternmed.2014.6023
18. Segreti, A. et al. (2023). Athlete's heart or heart disease in the athlete? Evaluation by cardiopulmonary exercise testing. *Journal of Sports Medicine and Physical Fitness, 63*(7), 873–890. https://doi.org/10.23736/S0022-4707.23.14536-1
19. Thompson, P. D., et al. (2015). Exercise and the heart: the good, the bad, and the ugly. *Eur Heart J, 36*(23), 1445-1453. https://doi.org/10.1093/eurheartj/ehv090