NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

Quality in Sport. eISSN 2450-3118.

Journal Home Page
https://apcz.umk.pl/QS/index

HOBOT, Mikołaj Piotr, DOBOSZ, Gabriela Patrycja, PRZYBYLSKA, Zuzanna, PURPURA, Aleksandra Anna, ROLSKI, Wiktor, MICHALSKA, Paulina, PRZYSTAŚ, Bartłomiej, GRZECHOWIAK, Magdalena, and PODESZWA, Sebastian. The Impact of Recreational Long-Distance Running on the Cardiovascular System of Amateurs – Health Benefits and the Risk of the Overload: A Review. Quality in Sport. 2026;54:70088. eISSN 2450-3118. https://doi.org/10.12775/QS.2026.54.70088

The journal has been awarded 20 points in the parametric evaluation by the Ministry of Higher Education and Science of Poland. This is according to the Annex to the announcement of the Minister of Higher Education and Science dated 05.01.2024, No. 32553. The journal has a 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 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 interest regarding the publication of this paper.
Received: 22.03.2026. Revised: 01.04.2026. Accepted: 05.04.2026. Published: 07.04.2026.

The Impact of Recreational Long-Distance Running on the Cardiovascular System of Amateurs – Health Benefits and the Risk of Overload: A Review

Mikołaj Piotr Hobot[1]

ORCID: https://orcid.org/0009-0001-2829-6005

e-mail mhobot00@gmail.com

Gabriela Patrycja Dobosz[1]
ORCID: https://orcid.org/0009-0009-4012-9101
E-mail: gabrieladoboszz@gmail.com

Zuzanna Przybylska [1]
nr ORCID: https://orcid.org/0009-0001-3329-4602
e-mail: s86122@365.sum.edu.pl

Aleksandra Anna Purpura[1]
ORCID https://orcid.org/0009-0006-3893-7730
e-mail: aleksandrapurpura@gmail.com

Wiktor Rolski [1]
nr ORCID: https://orcid.org/0009-0005-1439-4842
e-mail: rolskiwiktor@gmail.com

Paulina Michalska[1]
nr ORCID: https://orcid.org/0009-0007-4141-5906
e-mail: pmichalska000@gmail.com

Bartłomiej Przystaś[1]
nr ORCID: https://orcid.org/0009-0009-6121-3839
e-mail: kbartek2002@gmail.com

Magdalena Grzechowiak[1]
nr ORCID: https://orcid.org/0009-0001-8486-0352
e-mail: magdagrzechowiak24@gmail.com

Sebastian Podeszwa[1]
nr ORCID: https://orcid.org/0009-0000-2973-5324
e-mail s86106@365.sum.edu.pl

[1] Medical University of Silesia in Katowice, 15 Poniatowskiego Street, 40-055 Katowice, Poland

Corresponding Author

Mikołaj Hobot, E-mail mhobot00@gmail.com

ABSTRACT

Background. Long-distance running has surged in popularity among recreational athletes. While moderate exercise prevents cardiovascular disease, extreme endurance events by amateurs—often lacking professional medical monitoring—raise clinical concerns regarding myocardial overload.

Aim. To systematize current knowledge on the physiological benefits and potential cardiovascular risks of recreational long-distance running in amateur athletes.

Material and methods. A narrative review was conducted using PubMed, Web of Science, and Scopus. We analyzed 35 peer-reviewed English articles from the last two decades focusing on amateur runners. Data extraction targeted echocardiography, cardiac magnetic resonance, and biochemical markers of myocardial injury.

Results. Regular running induces favorable cardiovascular adaptations ("athlete's heart"), improving metabolic profiles and reducing all-cause mortality. Conversely, acute extreme exertion (e.g., marathons) consistently triggers transient exercise-induced cardiac fatigue (EICF) and the release of cardiac biomarkers (troponins, BNP). The right ventricle is disproportionately affected by this acute strain, whereas half-marathons induce significantly less impairment. Long-term veteran amateurs exhibit a higher prevalence of atrial fibrillation and elevated coronary artery calcification (CAC) scores; however, these plaques are predominantly calcified and stable.

Conclusions. Recreational running provides substantial, dose-dependent cardiovascular benefits, but extreme distances expose amateurs to acute cardiac fatigue and chronic structural remodeling. To safely maximize outcomes, amateurs should prioritize structured recovery, distance moderation, and routine cardiovascular screening before severe events.

Keywords: recreational running, amateur marathon, athlete's heart, cardiac fatigue, cardiovascular risk

1. Introduction

In recent years, there has been an unprecedented surge in the popularity of mass-participation endurance events, such as half-marathons, marathons, and ultramarathons. Long-distance running is no longer the exclusive domain of elite, professional athletes. Today, the vast majority of participants in these events are recreational runners—amateurs who engage in rigorous training regimens alongside their daily occupational and social responsibilities. While it is universally acknowledged that regular moderate physical activity is a cornerstone in the prevention and management of cardiovascular diseases [1], the physiological impact of extreme endurance exercise on the amateur cardiovascular system remains a subject of intense scientific debate, constantly raising the question of whether extreme running acts as a panacea or a poison for the heart [2].

Unlike professional athletes, who are subject to strict medical monitoring, optimized recovery protocols, and personalized training loads, amateur runners often push their physiological limits without adequate professional supervision. This raises critical questions regarding the "dose-response" relationship of exercise. While moderate running promotes favorable cardiovascular adaptations, extreme volumes and intensities may trigger transient myocardial fatigue [3], elevated cardiac damage markers [4], and potentially chronic structural changes such as myocardial fibrosis or an increased susceptibility to arrhythmias like atrial fibrillation.

Research objective:

To systematize the current state of knowledge regarding both the physiological health benefits and the potential cardiovascular risks associated with long-distance running in amateur athletes, based on an analysis of 35 selected scientific studies.

Research problems:

1. What are the primary cardiovascular benefits and physiological adaptations resulting from long-distance running in amateur populations?
2. Does long-term recreational distance running increase the risk of acute cardiac fatigue and chronic structural myocardial damage?

Research hypotheses:

1: The synthesized literature is expected to confirm that recreational long-distance running induces positive cardiovascular adaptations (the so-called "athlete's heart"), while simultaneously exposing amateurs to transient cardiac fatigue following acute bouts of extreme exertion.

2: The analysis anticipates finding evidence that prolonged endurance exercise in amateurs, especially without professional training control, correlates with elevated markers of cardiac damage and an increased risk of long-term adverse outcomes, such as myocardial fibrosis or arrhythmias.

2. Research materials and methods

2.1. Participants

The population analyzed in this review consists of participants derived from the 35 selected source studies. The target group comprises healthy adult individuals classified as recreational or amateur long-distance runners (e.g., half-marathoners, marathoners, and ultramarathoners). Elite, professional athletes, individuals with pre-existing congenital heart defects, and non-human (animal) models were strictly excluded from the scope of this analysis to ensure the findings are highly applicable to the general population engaging in amateur endurance sports.

2.2. Procedure

This study was designed as a comprehensive narrative review based on a systematic literature search strategy. The research procedure involved screening major electronic medical and sports science databases, primarily PubMed, Web of Science, and Scopus. The search strategy utilized a combination of the following Medical Subject Headings (MeSH) and keywords: ("recreational runner" OR "amateur marathon" OR "amateur athletes") AND ("cardiovascular risk" OR "athlete's heart" OR "cardiac fatigue" OR "myocardial fibrosis"). The inclusion criteria were restricted to peer-reviewed articles published in English over the last two decades. Following the initial database search, duplicate records were removed. The remaining articles underwent a rigorous screening of titles and abstracts to ensure compliance with the predefined inclusion criteria. Ultimately, a precise set of 35 articles directly addressing the cardiovascular parameters in amateur runners was selected for full-text analysis, in-depth data extraction, and synthesis.

2.3. Data collection and analysis

Data extraction focused on both qualitative and quantitative cardiovascular outcomes reported in the literature. The analyzed variables included blood biomarkers (e.g., cardiac troponins, BNP), echocardiographic parameters (e.g., right and left ventricular structure and function), and cardiac magnetic resonance imaging (CMR) findings. The collected data were synthesized to contrast physiological adaptations with pathological risks.

2.3.1. Statistical software

Due to the review design of this study, no specific statistical software was used for original data computation. However, reference management software was utilized to organize the extracted data and format the bibliography in accordance with the journal's requirements.

2.3.2. AI statement

Artificial intelligence tools were used solely as assistive instruments in the preparation of this manuscript. AI support was applied to improve academic language clarity, coherence, and stylistic consistency, as well as to assist in the organization of the narrative structure. All scientific content, interpretation of the literature, and final conclusions were determined by the authors. The use of AI did not replace human judgment at any stage of the research process.

3. Physiological adaptation and health benefits in amateurs

Regular endurance running is robustly associated with widespread cardiovascular and metabolic benefits. The primary physiological goal of these adaptations is to increase the efficiency of oxygen delivery, optimize thermoregulation, and improve energy substrate utilization during prolonged exertion [1]. When physically inactive adults transition into a routine of habitual endurance running, the systemic changes are profound. A comprehensive meta-analysis evaluating the effects of running on indices of health demonstrated significant reductions in resting heart rate and arterial blood pressure, accompanied by marked improvements in body composition, lipid profiles, and fasting insulin sensitivity [5]. Over time, these structural and functional modifications culminate in what is clinically recognized as the "athlete's heart". As highlighted in recent reviews detailing molecular and echocardiographic findings, the hallmark of this adaptation is eccentric remodeling of the left ventricle, which dilates to accommodate a larger stroke volume while maintaining normal or enhanced diastolic function [6]. This specific pattern of physiological hypertrophy is well-documented in amateur male marathon runners [7]. Importantly, the adaptive response to endurance exercise is not entirely uniform and may be influenced by sex, as recent investigations have revealed subtle morphological, functional, and biochemical differences in cardiac adaptation between male and female amateur runners [8].

Beyond steady-state running, the incorporation of varied training protocols yields additional benefits. For instance, integrating weekly high-intensity interval training (HIIT) significantly improves maximal oxygen uptake and submaximal running economy without overburdening the cardiovascular system [9]. Similarly, performance in recreational runners is heavily influenced by a combination of biomechanical, physiological, and anthropometrical predictors,

underscoring the need for a holistic approach to amateur training [10]. Consequently, experts strongly advocate for individualized endurance training programs that are carefully calibrated based on the runner's ongoing recovery and training status [11]. Furthermore, emerging nutritional interventions are showing promise; recent randomized double-blind trials indicate that novel supplements, such as nicotinamide mononucleotide, can safely enhance aerobic capacity in amateur runners by optimizing cellular energy metabolism [12].

4. Cardiac fatigue and markers of myocardial damage

Despite the undisputed systemic benefits of moderate training, acute bouts of extreme endurance exercise expose amateurs to severe physiological and mechanical stress. Over the last decade, cardiological research has increasingly focused on a phenomenon known as exercise-induced cardiac fatigue (EICF). This condition is characterized by a transient, reversible reduction in both left and right ventricular systolic and diastolic function immediately following prolonged exertion [3]. The complex physiology and pathophysiology of marathon running reveal a massive upregulation of oxidative stress and altered calcium handling during the event [13]. A critical objective measure of this stress is the release of cardiac biomarkers. Robust systematic reviews and meta-analyses confirm a highly significant post-exercise elevation of cardiac damage markers, specifically cardiac troponins (cTn) and B-type natriuretic peptides (BNP), following medium- and long-distance events [4]. It is widely accepted that marathon running is a primary physiological cause of acute troponin elevation [14]. However, the prevailing consensus suggests that in healthy amateurs, this reflects a transient increase in myocyte membrane permeability rather than irreversible myocardial necrosis.

Extreme endurance running does not only stress the heart but also heavily impacts the kidneys. Large cohort studies evaluating combined cardiac and renal function in amateur marathoners corroborate this systemic strain, noting temporary declines in the glomerular filtration rate [15]. Notably, significant elevations in both cardiac and renal biomarkers can be observed even after moderately long events, such as a 21 km treadmill run, proving that the physiological toll begins well before the marathon distance is reached [16]. Because acute physiological stress affects multiple organ systems simultaneously, developing and adhering to optimal renal and cardiac function recovery strategies is essential for amateur runners post-marathon [17]. While these biomarkers typically return to baseline within 48 hours, the recurrent mechanical stress raises valid concerns regarding the long-term effects of endurance exercise on cardiac morphology and the potential for chronic injury indicators [18].

5. Structural changes, right ventricular remodeling, and fibrosis risk

While the left ventricle adapts remarkably well to increased training volumes, the right ventricle (RV) appears disproportionately vulnerable during extreme endurance events. Because cardiac output increases up to fivefold during a marathon, pulmonary artery pressure rises significantly, placing a tremendous hemodynamic load on the thin-walled RV. This acute wall stress can lead to exercise-induced right ventricular dysfunction and structural remodeling [19]. Advanced cardiological imaging, such as three-dimensional speckle tracking echocardiography, confirms the presence of early structural alterations and reduced systolic RV function in amateur marathon runners immediately post-race [20]. Crucially, the magnitude of these right-sided changes is heavily distance-dependent. Studies comparing different events show that recreational half-marathon runners exhibit significantly less RV strain and functional impairment compared to amateurs completing full marathons or ultramarathons [21].

In a subset of inadequately prepared amateurs, recurrent micro-trauma, inflammation, and RV overload can lead to the accumulation of collagen in the extracellular matrix. The presence of focal myocardial fibrosis, often detected via late gadolinium enhancement at the right ventricular insertion points, remains a topic of intense debate regarding whether it serves as a pathological risk marker for future arrhythmias or merely a benign physiological adaptation to chronic stretching [22]. Alongside structural changes, the electrical stability of the amateur heart is also altered. The high prevalence of early repolarization patterns on the electrocardiograms of athletes requires careful clinical evaluation to distinguish normal high vagal tone from potentially arrhythmogenic substrates [23]. To effectively monitor this physiological strain, assessing the athlete's training history and monitoring cardiac autonomic recovery—such as heart rate variability following submaximal exercise—are highly recommended strategies to prevent overtraining and structural overload [24].

6. Cardiovascular risk profile and arrhythmias in long-term amateur runners

The cardiovascular risk profile of experienced, long-term amateur runners presents a fascinating and complex clinical paradox. On one hand, regular recreational running effectively mitigates classic modifiable cardiovascular disease risk factors such as hypertension, obesity, and dyslipidemia [25]. However, the intersection of decades of endurance training with the natural aging process creates unique challenges for cardiac physiology [26]. In middle-aged recreational runners, maintaining optimal performance becomes physiologically taxing; research demonstrates that cardiac output often drops during the latter stages of a marathon due to dehydration and a decline in stroke volume [27]. Furthermore, standard heart rate monitoring

becomes highly unreliable late in the race. Due to a phenomenon known as cardiovascular drift, the heart rate does not accurately reflect the true percentage of maximal oxygen uptake (%VO2max) during the final kilometers, masking the severe physiological cost experienced by the runner [28]. Another acute manifestation of severe exertion is the alteration of vascular compliance, demonstrating an acute, transient spike in aortic stiffness immediately post-half-marathon [29].

Most notably, long-term endurance running is strongly and independently associated with an increased prevalence of atrial fibrillation (AFib) [30]. The pathophysiology of AFib in endurance athletes is multifactorial, involving progressive left atrial dilation, heightened parasympathetic tone, and potential micro-fibrosis [31]. This well-documented association continuously fuels the clinical debate regarding "how much is too much" when prescribing endurance physical activity [32]. While acute events like myocardial infarction remain a rare but catastrophic concern—even in younger athletic cohorts—due to factors like anomalous coronary arteries or premature atherosclerosis [33], the spectrum of coronary artery disease in older, experienced endurance athletes is highly unique [34]. The widely discussed "athlete's paradox" reveals that highly active individuals often possess significantly elevated coronary artery calcification (CAC) scores compared to sedentary peers. However, advanced imaging shows that these exercise-induced plaques are predominantly calcified, dense, and stable. Consequently, despite the high calcium score, these plaques do not inherently increase the risk of acute rupture or all-cause mortality, highlighting the extraordinary resilience of the long-term amateur runner's cardiovascular system [35].

7. Discussion

The primary objective of this review was to systematize the physiological benefits and potential cardiovascular risks associated with long-distance running in amateur athletes. The synthesized literature highlights a distinct "dose-response" paradox. On one end of the spectrum, the evidence overwhelmingly supports the cardiovascular benefits of moderate running, driving positive left ventricular remodeling, improved metabolic efficiency, and reduced all-cause mortality [1, 5, 11]. Conversely, pushing the body through extreme distances consistently triggers transient exercise-induced cardiac fatigue (EICF) and the leakage of myocardial damage markers, such as troponins [3, 4, 14]. The right ventricle is particularly vulnerable to this acute hemodynamic overload, establishing the full marathon distance as a critical threshold where physiological strain significantly increases compared to the half-marathon [19, 21].

Chronic exposure to such extreme stress in long-term amateurs raises critical questions concerning the development of myocardial fibrosis [22] and the well-documented elevated prevalence of atrial fibrillation [30, 31, 32]. A significant limitation of the current literature is the heterogeneous definition of "amateur" or "recreational" runners, with studies frequently pooling individuals with vastly different training histories, baseline fitness levels, and age profiles [7, 8, 25, 26]. Unlike elite professionals who undergo rigorous, continuous cardiological screening and monitoring [33, 34], amateurs frequently navigate extreme challenges relying on subjective feelings. This lack of professional oversight exacerbates the risk of cumulative myocardial micro-trauma, making baseline cardiovascular screening essential—especially in light of complex phenomena like elevated but stable coronary calcification in veteran runners [35].

7.1. Limitations of the study

This review has several limitations that should be acknowledged. First, the methodological design as a narrative review implies that the literature search and selection process may be subject to inherent selection bias compared to a strictly formal systematic review. Second, the inclusion criteria were restricted to peer-reviewed articles published in English over the last two decades, which might exclude relevant findings published in other languages or older foundational studies. Finally, as noted previously, the heterogeneous definition of "amateur" or "recreational" runners across the included studies limits the ability to draw universally standardized conclusions, as the source participants varied significantly in their baseline fitness levels, age profiles, and training histories.

8. Conclusions

Based on the systematic review of the literature regarding the cardiovascular impact of recreational long-distance running, the following conclusions can be drawn:

1. **Dose-dependent benefits:** Regular, moderate-intensity endurance running induces highly favorable cardiovascular adaptations in amateurs. The development of physiological eccentric hypertrophy, combined with an improved metabolic profile and enhanced vascular compliance, significantly reduces all-cause cardiovascular mortality.
2. **Acute cardiac fatigue:** Extreme endurance events, particularly full marathons, subject the amateur myocardium to severe acute stress. This is evidenced by transient exercise-induced cardiac fatigue (EICF) and the temporary leakage of cardiac biomarkers (cardiac troponins and BNP).

3. **Right ventricular vulnerability:** The right ventricle (RV) is disproportionately susceptible to acute dilation and hemodynamic strain during prolonged exertion. For amateur runners, distances such as the half-marathon appear to offer a safer physiological threshold.
4. **Long-term risks in experienced amateurs:** Decades of high-volume endurance running without professional medical supervision can lead to chronic structural alterations, including an elevated prevalence of atrial fibrillation (AFib) and higher coronary artery calcification (CAC) scores.
5. **Clinical recommendations:** To maximize the health benefits and minimize the risk of cumulative myocardial micro-trauma, recreational runners should prioritize structured recovery protocols and undergo routine baseline cardiovascular screening before engaging in extreme endurance events.

Disclosure

Supplementary materials: None

Author contributions: Conceptualization, M.H., W.R. and Z.P.; Methodology, B.P., W.R. and G.D.; Software, M.G.; Validation, All authors; Formal Analysis, G.D., P.M., S.P. and A.P.; Investigation, All authors; Resources, All authors; Data Curation, M.H., Z.P. and P.M.; Writing – Original Draft Preparation, M.H., G.D. and M.G.; Writing – Review & Editing, A.P., S.P. and W.R.; Visualization, B.P. and M.H.; Supervision, M.H.; Project Administration, M.H. All authors have read and agreed with the published version of the manuscript.

Funding: This research was conducted without any specific funding from public, commercial, or nonprofit organizations.

Institutional review board statement: Not applicable.

Informed consent statement: Not applicable.

Data availability statement: All data analyzed during this study are included in this published article and are available from the cited literature.

Acknowledgements: None

Conflict of interest: The authors declare there are no conflicts of interest.

Declaration of the use of generative AI and AI-assisted technologies in the writing process.

In preparing this work, the authors used ChatGPT (OpenAI) for the purpose of improving language and readability as well as translating specific terms. After using this tool,the authors

have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

References

1. Nystoriak MA, Bhatnagar A. Cardiovascular Effects and Benefits of Exercise. Front Cardiovasc Med. 2018 Sep 28;5:135. doi: 10.3389/fcvm.2018.00135.

2. Parry-Williams G, Sharma S. The effects of endurance exercise on the heart: panacea or poison? Nat Rev Cardiol. 2020 Jul;17(7):402-412 doi: 10.1038/s41569-020-0354-3.

3. Vitiello D, Palacin F, Poinsard L, Kirsch M, Jouini S, Billat V. Marathon-Induced Cardiac Fatigue: A Review over the Last Decade for the Preservation of the Athletes' Health. Int J Environ Res Public Health. 2021 Aug 17;18(16):8676. doi: 10.3390/ijerph18168676.

4. Rubio-Arias JÁ, Andreu L, Martínez-Aranda LM, Martínez-Rodríguez A, Manonelles P, Ramos-Campo DJ. Effects of medium- and long-distance running on cardiac damage markers in amateur runners: a systematic review, meta-analysis, and metaregression. J Sport Health Sci. 2021 Mar;10(2):192-200. doi: 10.1016/j.jshs.2019.10.003.

5. Hespanhol Junior LC, Pillay JD, van Mechelen W, Verhagen E. Meta-Analyses of the Effects of Habitual Running on Indices of Health in Physically Inactive Adults. Sports Med. 2015 Oct;45(10):1455-68. doi: 10.1007/s40279-015-0359-y.

6. Janik M, Blachut D, Czogalik Ł, Tomasik AR, Wojciechowska C, Kukulski T. Adaptive Changes in Endurance Athletes: A Review of Molecular, Echocardiographic and Electrocardiographic Findings. Int J Mol Sci. 2025 Aug 28;26(17):8329. doi: 10.3390/ijms26178329.

7. Lewicka-Potocka Z, Dąbrowska-Kugacka A, Lewicka E, Kaleta AM, Dorniak K, Daniłowicz-Szymanowicz L, Fijałkowski M, Nabiałek-Trojanowska I, Ratkowski W, Potocki W, Raczak G. The "athlete's heart" features in amateur male marathon runners. Cardiol J. 2021;28(5):707-715. doi: 10.5603/CJ.a2019.0110.

8. Lasocka-Koriat Z, Lewicka-Potocka Z, Kaleta-Duss A, Bulman N, Marciniak E, Kalinowski L, Lewicka E, Dąbrowska-Kugacka A. Morphological, functional and biochemical differences in cardiac adaptation to endurance exercise among male and female amateur marathon runners. Front Physiol. 2025 Mar 4;16:1547894. doi: 10.3389/fphys.2025.1547894.

9. Lenk M, Matzka M, Lauber L, Kunz P, Sperlich B. Impact of weekly frequency of high-intensity interval training on cardiorespiratory, metabolic, and performance measures in recreational runners - An exploratory study. Physiol Rep. 2025 Sep;13(18):e70573. doi: 10.14814/phy2.70573.

10. Peyré-Tartaruga LA, Machado E, Guimarães P, Borba E, Tartaruga MP, Buzzachera CF, Correale L, Lanferdini FJ, da Silva ES. Biomechanical, physiological and anthropometrical predictors of performance in recreational runners. PeerJ. 2024 Feb 26;12:e16940. doi: 10.7717/peerj.16940.

11. Nuuttila OP, Nummela A, Korhonen E, Häkkinen K, Kyröläinen H. Individualized Endurance Training Based on Recovery and Training Status in Recreational Runners. Med Sci Sports Exerc. 2022 Oct 1;54(10):1690-1701. doi: 10.1249/MSS.0000000000002968.

12. Liao B, Zhao Y, Wang D, Zhang X, Hao X, Hu M. Nicotinamide mononucleotide supplementation enhances aerobic capacity in amateur runners: a randomized, double-blind study. J Int Soc Sports Nutr. 2021 Jul 8;18(1):54. doi: 10.1186/s12970-021-00442-4.

13. Braschler L, Nikolaidis PT, Thuany M, Chlíbková D, Rosemann T, Weiss K, Wilhelm M, Knechtle B. Physiology and Pathophysiology of Marathon Running: A narrative Review. Sports Med Open. 2025 Jan 27;11(1):10. doi: 10.1186/s40798-025-00810-3.

14. Regwan S, Hulten EA, Martinho S, Slim J, Villines TC, Mitchell J, Slim AM. Marathon running as a cause of troponin elevation: a systematic review and meta-analysis. J Interv Cardiol. 2010 Oct;23(5):443-50. doi: 10.1111/j.1540-8183.2010.00575.x.

15. Hewing B, Schattke S, Spethmann S, Sanad W, Schroeckh S, Schimke I, Halleck F, Peters H, Brechtel L, Lock J, Baumann G, Dreger H, Borges AC, Knebel F. Cardiac and renal function in a large cohort of amateur marathon runners. Cardiovasc Ultrasound. 2015 Mar 21;13:13. doi: 10.1186/s12947-015-0007-6.

16. Yeo TJ, Ling LH, Lam CSP, Chong JPC, Liew OW, Teo ZL, Gong L, Richards AM, Chan MY. Cardiac and renal biomarkers in recreational runners following a 21 km treadmill run. Clin Cardiol. 2020 Dec;43(12):1443-1449. doi: 10.1002/clc.23459.

17. Hernando C, Hernando C, Panizo N, Collado-Boira E, Folch-Ayora A, Martínez-Navarro I, Hernando B. Renal Function Recovery Strategies Following Marathon in Amateur Runners. Front Physiol. 2022 Feb 28;13:812237. doi: 10.3389/fphys.2022.812237.

18. Hu J, Zhou S, Ryu S, Adams K, Gao Z. Effects of Long-Term Endurance Exercise on Cardiac Morphology, Function, and Injury Indicators among Amateur Marathon Runners. Int J Environ Res Public Health. 2023 Jan 31;20(3):2600. doi: 10.3390/ijerph20032600.

19. La Gerche A, Burns AT, Mooney DJ, Inder WJ, Taylor AJ, Bogaert J, Macisaac AI, Heidbüchel H, Prior DL. Exercise-induced right ventricular dysfunction and structural remodelling in endurance athletes. Eur Heart J. 2012 Apr;33(8):998-1006. doi: 10.1093/eurheartj/ehr397.

20. Hu S, Zhang H, Ma H, Yang C, Hu P, Gao F. Assessment of right ventricular structure and systolic function in amateur marathon runners using three-dimensional speckle tracking echocardiography. Int J Cardiovasc Imaging. 2023 Aug;39(8):1473-1482. doi: 10.1007/s10554-023-02869-z.

21. Dominika B, Michał J, Michalina M, Julia C, Paweł W, Michał K, Marcin S, Dominik K, Michał K, Celina W, Andrzej T, Tomasz K. Exercise-induced ventricular changes in recreational half-marathon runners compared with marathon/ultramarathon runners. Int J Cardiol Heart Vasc. 2026 Feb 14;63:101886. doi: 10.1016/j.ijcha.2026.101886.

22. Katsi V, Triantafyllou E, Fragoulis C, Vazaios C, Maragkoudakis S, Kasiakogias A, Vlachopoulos C, Tsioufis KP. Myocardial Fibrosis in Athletes: Risk Marker or Physiological Adaptation? Biomedicines. 2025 Nov 10;13(11):2747. doi: 10.3390/biomedicines13112747.

23. Elenizi K. Prevalence and Clinical Significance of Early Repolarization in Athletes: A Systematic Review. Ann Noninvasive Electrocardiol. 2025 Jan;30(1):e70032. doi: 10.1111/anec.70032.

24. Špenko M, Potočnik I, Edwards I, Potočnik N. Training History, Cardiac Autonomic Recovery from Submaximal Exercise and Associated Performance in Recreational Runners. Int J Environ Res Public Health. 2022 Aug 9;19(16):9797. doi: 10.3390/ijerph19169797.

25. O'Riordan C, Savage E, Newell M, Flaherty G, Hartigan MSc I. Cardiovascular Disease Risk Factor Profile of Experienced Male Amateur Marathon Runners: A Systematic Review. Sports Health. 2023 Sep-Oct;15(5):661-672. doi: 10.1177/19417381231176534.

26. Kim JH, Ko YA, Hedley J, MacNamara J, Awad M, Taylor W, Healy S, Aida H, Le NA, Wilson PW, White M, Sperling LS, Wilson JS Jr, Baggish AL. The impact of moderate distance recreational running and ageing on cardiac physiology. Heart. 2017 Feb;103(3):219-226. doi: 10.1136/heartjnl-2016-310059.

27. Billat VL, Petot H, Landrain M, Meilland R, Koralsztein JP, Mille-Hamard L. Cardiac output and performance during a marathon race in middle-aged recreational runners. ScientificWorldJournal. 2012;2012:810859. doi: 10.1100/2012/810859.

28. Billat V, Palacin F, Poinsard L, Edwards J, Maron M. Heart Rate Does Not Reflect the %VO2max in Recreational Runners during the Marathon. Int J Environ Res Public Health. 2022 Sep 29;19(19):12451. doi: 10.3390/ijerph191912451.

29. Staniszewska M, Pudło A, Pawlik A. Influence of half marathon race on aortic stiffness in amateur runners. Arch Med Sci. 2017 Jun;13(4):962-964. doi: 10.5114/aoms.2016.59580.

30. Lobo HM, Naves ÍG, Marçal SB, Canzi CC, Rodrigues ABS, Menezes AS Jr. Atrial Fibrillation in Endurance Training Athletes: Scoping Review. Rev Cardiovasc Med. 2023 May 26;24(6):155. doi: 10.31083/j.rcm2406155.

31. Sanchis-Gomar F, Lucia A. Pathophysiology of atrial fibrillation in endurance athletes: an overview of recent findings. CMAJ. 2016 Dec 6;188(17-18):E433-E435. doi: 10.1503/cmaj.160416

32. Centurión OA, Candia JC, Scavenius KE, García LB, Torales JM, Miño LM. The Association Between Atrial Fibrillation and Endurance Physical Activity: How Much is too Much? J Atr Fibrillation. 2019 Oct 31;12(3):2167. doi: 10.4022/jafib.2167.

33. Dotka M, Małek ŁA. Myocardial Infarction in Young Athletes. Diagnostics (Basel). 2023 Jul 25;13(15):2473. doi: 10.3390/diagnostics13152473.

34. Celeski M, Di Gioia G, Nusca A, Segreti A, Squeo MR, Lemme E, Mango F, Ferrera A, Ussia GP, Grigioni F. The Spectrum of Coronary Artery Disease in Elite Endurance Athletes-A Long-Standing Debate: State-of-the-Art Review. J Clin Med. 2024 Aug 30;13(17):5144. doi: 10.3390/jcm13175144.

35. DeFina LF, Radford NB, Barlow CE, Willis BL, Leonard D, Haskell WL, Farrell SW, Pavlovic A, Abel K, Berry JD, Khera A, Levine BD. Association of All-Cause and Cardiovascular Mortality With High Levels of Physical Activity and Concurrent Coronary Artery Calcification. JAMA Cardiol. 2019 Feb 1;4(2):174-181. doi: 10.1001/jamacardio.2018.4628.