UNIVERSITY OF MEDICINE AND PHARMACY

"CAROL DAVILA", BUCHAREST

DOCTORAL SCHOOL

FIELD: MEDICINE

The Impact of Growth and Training on ECG Changes in Elite Athletes

SUMMARY OF THE DOCTORAL THESIS

PhD Supervisor

PROF. UNIV. DR. BĂDĂRĂU IOANA ANCA

PhD Candidate

SMARANDA ALINA MARIA

2025

Table of Contents

List of Published Scientific Works

1. Ionescu AM, Pitsiladis YP, Rozenstoka S, Bigard X, Löllgen H, Bachl N, Debruyne A, Pigozzi F, Casasco M, Jegier A, **Smaranda AM***, Caramoci A, Papadopoulou T. *Preparticipation medical evaluation for elite athletes: EFSMA recommendations on standardised preparticipation evaluation form in European countries*. **BMJ Open Sport Exerc Med.** 2021;7(4):e001178. PMID: 34745648; **ESCI; Q1; original article**, *Corresponding Author*, (Cap. 1),

   https://doi.org/10.1136/bmjsem-2021-001178;
   https://bmjopensem.bmj.com/content/7/4/e001178.

2. **Smaranda AM***, Dragoiu TS, Caramoci A, Afetelor AA, Ionescu AM, Badarau IA. *Artificial Intelligence in Sports Medicine: Reshaping Electrocardiogram Analysis for Athlete Safety – A Narrative Review*. **Sports.** 2024;12(6):144. PMID: 38921838; **ESCI; IF (2024): 2.2**; **Q2; review**, *First Author and Corresponding Author* (Cap.2)

   https://doi.org/10.3390/sports12060144;

   https://www.mdpi.com/2075-4663/12/6/144.

3. **Smaranda AM***, Caramoci A, Dragoiu TS, Badarau IA. *ECG Evolution in Elite Gymnasts: A Retrospective Analysis of Training Adaptations, Risk Prediction, and PPE Optimization*. **Diagnostics.** 2025;15(8):1007. PMID: 40310365; **SCIE**; **IF (2024): 3; Q1**; **original article**, *First Author and Corresponding Author*, https://doi.org/10.3390/diagnostics15081007, (Cap. 6), https://www.mdpi.com/2075-4418/15/8/1007.

4. Caramoci A, **Smaranda AM***, Drăgoiu TS, Bădărău IA. *ECG Screening in Athletes: A Systematic Review of Sport, Age, and Gender Variations*. **Reviews in Cardiovascular Medicine.** 2025;26(5):38209; PMID: 40475715; **SCIE; IF (2024): 1.9; Q3; review sistematic,** *Corresponding Author, (Cap. 5)* https://doi.org/10.31083/RCM38209; https://www.imrpress.com/journal/RCM/26/5/10.31083/RCM38209;

SUMMARY OF THE DOCTORAL THESIS

The Impact of Growth and Training on ECG Changes in Elite Athletes

In sports medicine, the decision to withdraw an elite athlete from competition is never purely algorithmic. It involves more than the interpretation of objective parameters—it is a decision with profound emotional weight, where an ECG tracing may at times become the dividing line between a successful sporting career and a lost medal. Within this context, the electrocardiogram plays a pivotal role in the medical clearance process, providing valuable insights into cardiac adaptations to exercise as well as potential early signs of subclinical disease. Nevertheless, the interpretation of athletes' ECGs remains a genuine challenge in clinical practice.

The present thesis aims to analyse the combined impact of biological growth and systematic training on electrocardiographic changes in elite athletes, through an approach that integrates clinical experience with scientific analysis. Starting from real-world settings, where medical decisions must be taken swiftly yet soundly, this research seeks to contribute to clarifying the distinction between adaptation and pathology, thereby supporting the development of a balanced, rational medical practice aligned with the actual needs of athletes.

The thesis is structured into two main parts: a general section, which provides the theoretical foundation for the scientific endeavour, and a section of personal contributions, which reflects the original research activity. The general section comprises two chapters. The first chapter outlines the essential elements of sports medicine and sports cardiology, with emphasis on exercise physiology and the factors influencing cardiac adaptations in athletes. The second chapter is devoted to cardiovascular screening in sports medicine, including an analysis of electrocardiographic changes and the current challenges in clinical practice.

The second part consists of five chapters. Following the formulation of the hypotheses and general objectives, the research methodology is presented in detail, followed by three

original studies: a retrospective observational study on the prevalence of ECG changes and the validity of the medical clearance certificate, a retrospective longitudinal study focusing on the evolution of ECG patterns in elite gymnasts, and a qualitative study exploring the perceptions and needs of sports medicine physicians regarding ECG interpretation. The thesis concludes with the presentation of the general conclusions and the author's original contributions.

The scientific endeavour presented in this thesis is supported by an extensive bibliography comprising 188 sources, rigorously selected from both national and international specialised literature. Of these, 153 were published within the last 10 years, and more than half—101—within the past 5 years, thereby reflecting a sustained effort to align with the most recent research and recommendations in the field. This updated foundation provides the work not only with theoretical consistency but also with practical relevance, reinforcing the role of the thesis as a starting point for the development of modern guidelines, adapted to the national context, for the cardiovascular evaluation of elite athletes.

I. General Part

1. Foundations of Sports Medicine and Sports Cardiology

The first chapter of the thesis provides a comprehensive overview of the foundations of sports medicine and sports cardiology, highlighting the evolution of this complex field. It also presents and explains the medical clearance certificate as a tool for prevention and performance optimisation, as well as the importance of integrating the ECG into the health assessment of athletes, in line with recent literature [1–3]. A section of the chapter is dedicated to exercise physiology, with a focus on the interaction between the type of physical activity and the specific cardiovascular response [4,5]. Both the characteristic adaptations of the athlete's heart [3] and the factors that may modulate these responses—such as sex, age, genetic background, and ethnic particularities—are discussed [6–8]. The distinctive aspects of cardiovascular adaptations in children and adolescents are also addressed, where differentiating between physiological and potentially pathological changes requires careful and contextualised interpretation [9].

2. Cardiovascular Screening in Sports Medicine: From Clinical Practice to Innovation

The second chapter explores in depth the current strategies of cardiovascular screening in sports medicine, ranging from medical history and clinical examination to resting ECG, advanced investigations, and interpretation algorithms. It presents the evolution of international guidelines, the role of artificial intelligence, and the importance of a multidisciplinary approach in evaluating athlete safety [10–12]. In this context, the standard 12-lead resting electrocardiogram becomes an indispensable component of cardiovascular screening, complementing clinical information with objective data on the heart's electrical activity. The development of ECG interpretation criteria for athletes has had a major impact on diagnostic accuracy. From the initial classifications to the 2017 International Criteria, which introduced a three-tier system—normal, borderline, and abnormal—there has been a significant reduction in false positives and a more tailored approach according to age, sex, and ethnic background [2,13,14,1]. Furthermore, the application of automated algorithms and artificial intelligence in ECG analysis amplifies these benefits, optimising cardiac screening in terms of efficiency, cost, and safety [15]. Cardiovascular screening based on standardised criteria and modern technologies represents an essential component in safeguarding athletes' health and in underpinning balanced, well-informed medical decisions.

II. Personal Contributions

3. Working Hypotheses and General Objectives

The medical clearance certificate, regulated by Law no. 69/2000 and Order of the Ministry of Youth and Sport (MTS) no. 1058/2003, constitutes an essential medico-legal instrument enabling registered athletes to participate safely in training and competition. This thesis investigates the relevance and applicability of the electrocardiogram within this process, as well as the identification of concrete directions for institutional and educational development.

The general objectives of the thesis are as follows:

- O1: To evaluate the prevalence of ECG changes in elite athletes, in correlation with physiological and anthropometric parameters, as well as the specific characteristics of the sporting discipline practiced;

- O2: To analyse the longitudinal evolution of ECG adaptations in a representative cohort of elite gymnasts, in relation to biological age, years of training, and other cardiometabolic and functional performance markers;

- O3: To develop and test predictive models for ECG changes using statistical simulation methods, with the aim of underpinning personalised and cost-efficient strategies for periodic screening;

- O4: To investigate the perceptions and practices of sports medicine physicians in Romania regarding ECG interpretation, issuance of the medical clearance certificate, and the need for a framework of continuing professional education;

- O5: To formulate applicable recommendations for public policies and professional best practices.

4. General Research Methodology

This doctoral thesis integrates three complementary studies aimed at the scientific validation of ECG use in cardiovascular screening of athletes in Romania. Study 1 is an observational, retrospective study conducted on 577 athletes. Study 2, a retrospective longitudinal study, followed a representative cohort of 12 elite gymnasts over a period of more than seven years. Study 3 is qualitative, based on a questionnaire administered to a nationally relevant sample of 52 specialist physicians. The entire scientific endeavour was approved by the Subcommittee for Research Ethics of the "Carol Davila" University of Medicine and Pharmacy, Bucharest, through Approval no. 7603/25.

The statistical analysis was rigorously tailored to the methodological specifics of each study, with the aim of validating the formulated hypotheses and supporting the research objectives. In the observational studies (Studies 1 and 2), both descriptive and inferential methods were applied, including the Chi-square test, ANOVA, Cramer's V coefficient, the independent samples t-test, linear regressions, ARIMA models, and Monte Carlo simulations. Study 3, of qualitative type, was analysed through thematic coding and narrative interpretation, with the integration of closed-response frequencies into the comprehensive

analysis of data. Statistical processing was carried out using SPSS v29, Oracle Crystal Ball, Python 3.11, and Microsoft Excel.

5. Prevalence of ECG Changes in Athletes and the Validity of Screening through the Medical Clearance Certificate: Retrospective Cross-Sectional Observational Study

Study 1 employs a retrospective, observational, cross-sectional design, focused on the analysis of archived medical clearance records at INMS for the year 2023, with the aim of assessing the distribution of ECG changes and the validity of cardiovascular screening under real-world practice conditions. The study population included 577 elite athletes registered in Romania's national teams, aged between 16 and 35 years, drawn from disciplines representative of the three types of energy metabolism (anaerobic, mixed, aerobic): football, rugby, rowing, marathon, triathlon, weightlifting, and athletics. Selection followed strict inclusion and exclusion criteria, and sampling was based on stratified convenience according to the predominant type of physical effort. Data collection was conducted retrospectively, exclusively from official institutional sources, ensuring a high degree of standardisation and internal validity. The main limitation of the study lies in the retrospective nature of the data, the sampling method, and the low representation of female athletes, which reduces the generalisability of the findings and calls for caution in extrapolating the conclusions.

Within this study, the primary objective was to determine the prevalence of ECG changes in elite athletes, according to the International Criteria for ECG Interpretation. The study included a homogeneous sample of 577 athletes registered in Romania's national teams, aged between 16 and 35 years, representing various sporting disciplines.

The results showed that 83.5% of ECGs were classified as physiological, while 16.5% were pathological, with no cases falling into the "borderline" category. The complete absence of this intermediate category—rarely reported in the literature—confirms the effectiveness of the criteria in reducing interpretative ambiguity and unnecessary additional investigations [16,17]. By comparison, a similar study conducted on Italian national team athletes (n=772) reported a prevalence of 17.9% of pathological ECGs, confirming the consistency of the present findings [18].

Among the most frequent physiological changes identified were: sinus bradycardia (56.8%), electrical criteria for left ventricular hypertrophy (11.3%), respiratory arrhythmia (9.7%), and the juvenile pattern (4%). These values fall within the ranges reported in the literature. QRS axis deviations were observed in 3.3% and 5.4% of cases, exceeding the prevalences reported in other studies. T-wave changes included negative T waves (3.6%), bifid T waves (6.6%), and biphasic T waves (1%), with a cumulative prevalence comparable to data from other international studies [19]. QRS fragmentation was observed in 1.9% of athletes, a lower value compared to some studies reporting prevalences of 7% [20], suggesting that in this cohort such changes are rare and may reflect benign remodelling. Additionally, an ECG pattern suggestive of Wolff–Parkinson–White (WPW) syndrome was identified in 0.5% of athletes, consistent with international prevalences (0.1–0.7%) [21,22].

As part of objective O2, the study aimed to validate cardiac screening by correlating the resting electrocardiogram with additional investigations, particularly echocardiography. The results demonstrated that the ECG had excellent specificity (100%), an overall accuracy of 98.61%, and a sensitivity of 92.23%, with only 8 false negative cases. These performance metrics validate the ECG as a first-line tool in cardiological screening of elite athletes. The specialised literature supports these conclusions [21].

In the present study, 94 athletes initially considered not eligible based on ECG changes were re-evaluated by echocardiography and subsequently declared medically eligible. The difference was statistically significant ($p < 0.0001$; Cramer's V = 0.25). In this context, the use of modern decision-making algorithms can ensure an optimal balance between safety and cost-efficiency [169]. However, according to the 2025 Guideline of the British Society of Echocardiography, echocardiography is not recommended as a routine test, being indicated only in the presence of pathological ECG changes, cardiac symptoms, or a suggestive family history [23].

Objective O3 focused on the differentiated analysis of ECG changes according to the predominant type of effort (aerobic, anaerobic, mixed) and demographic factors such as sex and age. The results highlight specific electrophysiological cardiac adaptations reflecting the body's response to different training demands and physiological profiles. Sinus bradycardia was significantly more frequent among athletes involved in aerobic disciplines (68.5%),

compared with mixed (53.1%) and anaerobic (47.6%) sports (p < 0.001; V = 0.177), supporting the deep vagal adaptation associated with sustained dynamic effort.

With regard to electrical criteria for left ventricular hypertrophy, this was more prevalent in endurance sports (21%) compared with mixed (6.2%) and anaerobic (6%) disciplines (p < 0.001; V = 0.224), underscoring the impact of high training volume on cardiac structure. Atrioventricular blocks were more frequently observed in mixed sports (8.1%), while respiratory arrhythmia was particularly associated with aerobic effort (14.5%) (p < 0.001). Additionally, the early repolarisation pattern appeared only in athletes from mixed (2.9%) and aerobic (8%) disciplines.

From a sex-based perspective, notable differences were observed in the prevalence of certain changes. Sinus bradycardia and electrical criteria for left ventricular hypertrophy were more frequent in men, while the juvenile pattern and bifid T waves were more common in women. Negative T waves occurred more frequently in male athletes, whereas bifid T waves (10% in aerobic sports) and biphasic T waves (2.9% in mixed sports) showed a significant correlation with the type of effort, supporting the hypothesis of a distinct repolarisation mechanism depending on training profile and sex.

With regard to age, the juvenile pattern was more frequently observed in athletes under 16 years (8.5%), but was also present at older ages (3.6%), particularly in female athletes. Its persistence beyond puberty, as confirmed by other studies, suggests that it should not be automatically interpreted as pathological but rather correlated with other clinical and paraclinical findings.

In conclusion, this first retrospective study highlights that correct interpretation of the resting ECG, using the current International Criteria, enables an effective distinction between physiological adaptations to exercise and potential cardiological warning signs, thereby contributing significantly to validating the medical clearance certificate as both a functional and cost-effective screening tool. The distribution of ECG changes varies significantly according to type of effort, sex, and age, underscoring the importance of a differentiated and personalised approach in the evaluation of athletes.

6. Evolution of ECG in Elite Gymnasts: Retrospective Analysis of Training Adaptations, Risk Prediction, and Optimisation of Sports Medicine Pre-particapation medical evaluations

Study 2 aimed to conduct a longitudinal analysis of electrocardiographic changes in a homogeneous cohort of elite gymnasts, monitored across up to 14 successive evaluations, within the context of early selection and the intensive training typical of this discipline. The need for this research stems from the scarcity of data regarding ECG evolution in young athletes, particularly females, and from the risk of misinterpreting physiological adaptations as pathologies. The study focused not only on the descriptive analysis of changes but also on predictive modelling of the risk of developing abnormal ECG patterns, using advanced statistical simulation tools (Oracle Crystal Ball), as well as evaluating the cost-effectiveness of semi-annual versus annual sports medicine pathways through Monte Carlo simulations.

The specific objectives were: (O1) to analyse the evolution of ECG and cardiovascular parameters in elite gymnasts during consecutive pre-participation medical evaluations; (O2) to develop a predictive model of ECG risk using Oracle Crystal Ball; and (O3) to compare the cost-effectiveness of evaluations conducted every 6 months versus every 12 months through economic simulations. The study also presents important limitations, such as the small sample size (n = 12), the absence of a control group, and the specific nature of artistic gymnastics, which limits the generalisability of the results. Nevertheless, the accuracy of ECG recordings and the continuity of evaluations remain strong points of the study.

The study assessed the relationships between electrocardiographic changes and three key variables—age, years of training, and aerobic capacity—among elite female athletes. The distribution of ECG changes revealed nonlinear trajectories with respect to age, with two peaks: the first associated with incomplete right bundle branch block during puberty, and the second with the juvenile pattern after the age of 16. Statistically significant associations were identified between age and bradycardia ($p < 0.001$), as well as junctional escape rhythm ($p < 0.001$), both of which were more frequent after the age of 16.

Training age was associated with a progressive decrease in resting heart rate and respiratory arrhythmia, as well as an increase in junctional rhythm after 10 years of training. A negative correlation was observed between seniority and heart rate, but a positive one with first-degree atrioventricular block. Logistic regression identified significant predictors: creatine kinase for arrhythmias ($p = 0.007$) and training volume for incomplete right bundle branch block ($p = 0.022$). Aerobic capacity was correlated with lower heart rate during both exercise and rest, as well as with a reduced prevalence of T-wave inversions. Thus, ECG adaptations reflect cumulative influences of age, training exposure, and functional performance.

Objective O2 explored the use of predictive modelling to anticipate ECG risks with the Oracle Crystal Ball platform. For the longitudinal analysis of resting heart rate, double exponential smoothing time-series modelling was applied in Oracle Crystal Ball. The model, calibrated on the T1–T13 interval, forecasted a progressive decline in resting heart rate during T14–T23, from 61.16 to 54.95 bpm, suggesting the onset of adaptive bradycardia. Model accuracy was high (RMSE = 2.07; Theil U = 0.9461; Durbin–Watson = 1.96), indicating adequate predictive performance. To assess individual variations in ECG scores, an ARIMA(0,0,1) model was applied to the data of one athlete, highlighting a moderate recurrence trend of abnormal changes. The model estimated an intermediate probability (~50%) of reappearance of such changes at T16–T20, with acceptable predictive performance (RMSE = 0.33; Theil U < 1). The model's ability to anticipate the decline in resting heart rate and to signal abnormal changes supports the feasibility of personalised risk assessment. These findings confirm the usefulness of combining historical data with advanced forecasting methods to inform clinical decision-making and early interventions tailored to each physiological profile.

Objective O3 aimed to evaluate the economic efficiency of pre-participation medical evaluation, using Monte Carlo simulations to compare annual versus semi-annual assessment scenarios. The results indicated that annual screening is more cost-efficient, reaching the break-even point after the identification of a single case with cardiac changes, whereas the semi-annual scenario requires three cases to justify the investment. These findings support a rational approach to determining screening frequency, in line with the 2025 UEFA recommendations, which suggest reassessments at 2–4 year intervals between the ages of 12 and 18 [24].

However, the conclusions are not intended to encourage annual screening, particularly in elite athletes or those with symptoms, where semi-annual or even quarterly monitoring remains justified. The study underscores the need to personalise strategies through predictive models and the expansion of databases, while promoting the integration of artificial intelligence algorithms for efficient triage and the reduction of unnecessary testing.

7. Evaluation of the Use of the Pre-Participation Medical Evaluation and ECG Screening in Sports Medicine: Perceptions and Educational Needs

Chapter 7 of the thesis investigates the use of the pre-participation medical evaluation and ECG screening in Romanian practice, through a qualitative study based on a structured questionnaire addressed to sports medicine physicians. This qualitative research conducted among Romanian sports medicine specialists provides deep insights into current practices, challenges, and professional aspirations regarding pre-participation assessment and ECG interpretation. With a representative response rate (over 40% of active specialists), the study reveals widespread use of the ECG as a preventive tool, but also a lack of uniformity in its application. Challenges such as unequal access to equipment, insufficient training, and the absence of a standardised protocol affect the coherence of screening. Despite these barriers, most physicians express support for the development of a National Guideline, the digitalisation of the certification process, and the implementation of continuing education programmes. The results reflect not only the need for structural reform but also the openness of the professional community to modernisation. The author's contribution to the European Federation of Sports Medicine Associations (EFSMA) recommendations lends strategic legitimacy to the study, and its conclusions lay clear foundations for public policy directions and educational initiatives in the field. In essence, the study proposes a coherent model for the evolution of Romanian sports medicine, centred on safety, equity, and standardisation.

General Conclusions and Original Contributions

All objectives formulated across the three studies were fully achieved. Study 1 provided a detailed characterisation of ECG changes according to type of effort, sex, and

physiological parameters, confirming the validity of ECG screening. Study 2 demonstrated significant electrophysiological adaptations in elite gymnasts, with longitudinal stability of ECG tracings and support for the hypothesis of physiological cardiac remodelling. Study 3 revealed the widespread use of ECG in current practice, persistent systemic difficulties, and majority support for standardisation, professional education, and digitalisation. The technical–economic contributions include demonstrating the efficiency of ECG as an accessible, predictive method complementary to echocardiography. Modelling with Oracle Crystal Ball proposes an innovative tool for optimising personalised screening. In addition, the author contributed to the development of EFSMA recommendations, consolidating the European impact of the research.

Future directions include the integration of artificial intelligence in ECG interpretation, validation of risk scores, expansion of the sample to other sporting populations, correlation with biomarkers, and the development of a national digital model for certification. Furthermore, the implementation of a training programme for ECG interpretation in athletes and a national guideline of best practices for pre-participation medical evaluation is proposed.

This thesis represents the first comprehensive national initiative addressing the electrocardiographic evaluation of elite athletes, in accordance with the 2017 International Criteria. It includes the first longitudinal analysis conducted exclusively on elite gymnasts from national teams and introduces the use of Oracle Crystal Ball in Romanian sports medicine for predictive modelling.

The contributions include the identification and characterisation of the juvenile ECG pattern beyond the age of 16, the validation of oxygen pulse as an integrated functional marker, and an innovative correlation between ECG, VO_2max, heart rate, and muscle biomarkers. A differentiated classification of ECG patterns according to the physiological training profile was proposed, as well as a conceptual framework for the personalisation of cardiac screening in female athletes.

Study 3 delivers the first national qualitative investigation into the perceptions of sports medicine physicians, highlighting gaps between current practice and professional training levels. The research documented near-unanimous support for the establishment of a National Guideline, the digitalisation of the certification process, and reform of the relevant legislation.

The central contribution of this thesis lies in the formulation of an integrated model—predictive, clinical, and educational—for the optimisation of ECG screening in athletes, with direct implications for safety in elite sport. Based on the findings, the author proposes clear strategic directions for modernising the current system: standardising evaluation, advancing continuous professional development, integrating digital solutions, and strengthening inter-institutional cooperation.

Selective Bibliography

1.   Ionescu, A.M.; Pitsiladis, Y.P.; Rozenstoka, S.; Bigard, X.; Löllgen, H.; Bachl, N.; Debruyne, A.; Pigozzi, F.; Casasco, M.; Jegier, A.; et al. Preparticipation Medical Evaluation for Elite Athletes: EFSMA Recommendations on Standardised Preparticipation Evaluation Form in European Countries. *BMJ Open Sport Exerc Med* **2021**, *7*, doi:10.1136/bmjsem-2021-001178.

2.   Drezner, J.A.; Sharma, S.; Baggish, A.; Papadakis, M.; Wilson, M.G.; Prutkin, J.M.; Gerche, A.L.; Ackerman, M.J.; Borjesson, M.; Salerno, J.C.; et al. International Criteria for Electrocardiographic Interpretation in Athletes: Consensus Statement. **2017**, doi:10.1136/bjsports-2016-097331.

3.   Maxwell, J.D.; Oxborough, D. The Athletes Heart—from Acute Stimulus to Chronic Adaptation. *British Medical Bulletin* **2025**, *153*, ldae021, doi:10.1093/bmb/ldae021.

4.   Mitchell, J.H.; Haskell, W.; Snell, P.; Van, C.S.P. Task Force 8: Classification of Sports. *JACC* **2005**, *45*, 1364–1367, doi:10.1016/j.jacc.2005.02.015.

5.   McArdle, W.D.; Katch, F.I.; Katch, V.L. *Exercise Physiology: Nutrition, Energy, and Human Performance*; 8th ed.; Wolters Kluwer Health/Lippincott Williams & Wilkins: Baltimore, 2015; ISBN 978-1-4511-9155-4.

6.   *The ESC Textbook of Sports Cardiology*; Oxford University Press, 2019;

7.   Maxwell, J.D.; Oxborough, D. The Athletes Heart—from Acute Stimulus to Chronic Adaptation. *British Medical Bulletin* **2025**, *153*, ldae021, doi:10.1093/bmb/ldae021.

8.   D'Andrea, Antonello.; Bossone, Eduardo. Athlete's Heart : A Multimodal Approach -- from Physiological to Pathological Cardiac Adaptations. In; Academic Press, 2023 ISBN 978-0-323-95222-4.

9.   Ragazzoni, G.L.; Cavigli, L.; Cavarretta, E.; Maffei, S.; Mandoli, G.E.; Pastore, M.C.; Valente, S.; Focardi, M.; Cameli, M.; Di Salvo, G.; et al. How to Evaluate Resting ECG and Imaging in Children Practising Sport: A Critical Review and Proposal of an Algorithm for ECG Interpretation. *European Journal of Preventive Cardiology* **2023**, *30*, 375–383, doi:10.1093/eurjpc/zwac218.

10.   D'Andrea, A.; Sperlongano, S.; Russo, V.; D'Ascenzi, F.; Benfari, G.; Renon, F.; Palermi, S.; Ilardi, F.; Giallauria, F.; Limongelli, G.; et al. The Role of Multimodality Imaging in Athlete's Heart Diagnosis: Current Status and Future Directions. *Journal of Clinical Medicine* **2021**, *10*, 5126, doi:10.3390/jcm10215126.

11.   Baba Ali, N.; Attaripour Esfahani, S.; Scalia, I.G.; Farina, J.M.; Pereyra, M.; Barry, T.; Lester, S.J.; Alsidawi, S.; Steidley, D.E.; Ayoub, C.; et al. The Role of Cardiovascular

Imaging in the Diagnosis of Athlete's Heart: Navigating the Shades of Grey. *Journal of Imaging 2024, Vol. 10, Page 230* **2024**, *10*, 230–230, doi:10.3390/JIMAGING10090230.

12.   Flanagan, H.; Cooper, R.; George, K.P.; Augustine, D.X.; Malhotra, A.; Paton, M.F.; Robinson, S.; Oxborough, D. The Athlete's Heart: Insights from Echocardiography. *Echo Research & Practice* **2023**, *10*, 15–15, doi:10.1186/s44156-023-00027-8.

13.   Weise, A.; Könsgen, N.; Joisten, C.; Schlumberger, F.; Hirschmüller, A.; Breuing, J.; Gooßen, K. Pre-Participation Evaluation of Recreational and Competitive Athletes – A Systematic Review of Guidelines and Consensus Statements. *Sports Medicine - Open* **2025**, *11*, 33, doi:10.1186/s40798-025-00837-6.

14.   Dores, H.; Dinis, P.; Viegas, J.M.; Freitas, A. Preparticipation Cardiovascular Screening of Athletes: Current Controversies and Challenges for the Future. *Diagnostics* **2024**, *14*, 2445, doi:10.3390/diagnostics14212445.

15.   Smaranda, A.M.; Drăgoiu, T.S.; Caramoci, A.; Afetelor, A.A.; Ionescu, A.M.; Bădărău, I.A. Artificial Intelligence in Sports Medicine: Reshaping Electrocardiogram Analysis for Athlete Safety—A Narrative Review. *Sports* **2024**, *12*, 144, doi:10.3390/sports12060144.

16.   Drezner, J.A. 18 Highlights from the International Criteria for ECG Interpretation in Athletes. **2020**, doi:10.1136/bjsports-2019-101537.

17.   Cosio-Lima, L.; Kumar Brooke, N.; Adlof, L.; Simpson, J.; Crawley, A.; Lee, Y. Comparison of the 'Seattle' and 'International' Criteria Electrocardiogram Interpretation in Division II Female Collegiate Athletes: A Preliminary Study. *J. of SCI. IN SPORT AND EXERCISE* **2023**, *5*, 274–279, doi:10.1007/s42978-022-00180-2.

18.   Squeo, M.R.; Ferrera, A.; Mango, F.; Maestrini, V.; Monosilio, S.; Lemme, E.; Crotta, S.; Spinelli, A.; Serdoz, A.; Fiore, R.; et al. Pre-Participation Cardiovascular Screening for Paris 2024 Olympic Games in Elite Athletes: The Italian Pathway. *European Journal of Preventive Cardiology* **2025**, *32*, zwaf236.429, doi:10.1093/eurjpc/zwaf236.429.

19.   Abela, M.; Sharma, S. Abnormal ECG Findings in Athletes: Clinical Evaluation and Considerations. *Current Treatment Options in Cardiovascular Medicine* **2019**, *21*, doi:10.1007/s11936-019-0794-4.

20.   Orlandi, G.; Casatori, L.; Corsi, M.; Toncelli, L.; Boddi, M.; Modesti, P.A.; Stefani, L. 153   Fragmented QRS in Athletes. *European Heart Journal Supplements* **2021**, *23*, suab127.045, doi:10.1093/eurheartj/suab127.045.

21.   Orchard, J.J.; Orchard, J.W.; Davis, A.J.; Puranik, R.; Isbister, J.C.; Gerche, A.L.; Driscoll, T.; Doughty, R.N.; Hamilton, B. Clinical Outcomes of 10 Years of Cardiac Screening in Elite New Zealand Athletes. *Journal of Science and Medicine in Sport* **2023**, *26*, 659–666, doi:10.1016/j.jsams.2023.10.012.

22.   Sim, H.S.S.; Imran, S.S.; Teoh, C.S. Progression of Wolff–Parkinson–White Pattern 12-Lead Electrocardiogram Changes in an Asymptomatic Athlete. *Singapore Med J* **2023**, *64*, 449–453, doi:10.4103/singaporemedj.SMJ-2021-151.

23.   Oxborough, D.; George, K.; Cooper, R.; Bhatia, R.; Ramcharan, T.; Zaidi, A.; Gati, S.; Prakash, K.; Rakhit, D.; Robinson, S.; et al. Echocardiography in the Cardiac Assessment of Young Athletes: A 2025 Guideline from the British Society of Echocardiography (Endorsed by Cardiac Risk in the Young). *Echo Research & Practice* **2025**, *12*, 7, doi:10.1186/s44156-025-00069-0.

24.   Baggish, A.L.; Borjesson, M.; Pieles, G.E.; Schmied, C.; Colombo, C.S.S. de S.; Corcia, C.G.; Drezner, J.A.; Grimm, K.; Mak, G.; Gerche, A.L.; et al. Recommendations for Cardiac Screening and Emergency Action Planning in Youth Football: A FIFA Consensus Statement. *Br J Sports Med* **2025**, *59*, 751–760, doi:10.1136/bjsports-2025-109751.