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Electrocardiographic Abnormalities in Athletic Individuals

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ABSTRACT

Background: Electrocardiographic (ECG) abnormalities are common among athletes due to cardiac adaptations induced by regular physical training. These changes, often benign, can mimic pathological findings, creating challenges in differentiating physiological adaptations from underlying cardiovascular disease. Understanding the prevalence and patterns of ECG changes in athletes can aid in refining cardiovascular screening strategies.
Objective: This study aimed to assess the prevalence of ECG abnormalities in athletic individuals and correlate these abnormalities with the type of exercise performed.
Patients and Methods: This cross-sectional study included 164 athletes aged 18–40 years, divided equally into aerobic (n=82) and anaerobic (n=82) exercise groups. Participants underwent detailed clinical assessments and 12-lead ECG evaluations at rest, immediately post-exercise, and 30 minutes post-exercise. ECG parameters were analyzed for training-related and unrelated changes.
Results: All participants exhibited ECG changes (100%), with 97.6% training-related and 22.6% training-unrelated. Bradycardia was the most common abnormality (78.7%), followed by early repolarization (66.5%) and incomplete right bundle branch block (51.8%). Anaerobic athletes exhibited significantly higher first-degree AV block (35.4% vs. 11.0%, $p < 0.001$) and early repolarization (78.0% vs. 54.9%, $p = 0.002$). Anterior T-wave inversion occurred exclusively in the anaerobic group (11.0% vs. 0%, $p = 0.003$). ECG changes correlated with type of exercise, reflecting distinct physiological adaptations.
Conclusion: ECG abnormalities are prevalent among athletes, with most being benign and training-related. Anaerobic exercise is associated with a higher prevalence of specific ECG changes, highlighting the need for tailored cardiovascular evaluations in athletic populations.
Keywords: Electrocardiography, Athletes, Bradycardia, Early Repolarization, Exercise Physiology.

INTRODUCTION

Engaging in professional or competitive sports can lead to reversible physiological adaptations in the heart, often manifesting as electrocardiographic (ECG) changes that might mimic structural heart disease [1].

In the general population, the prevalence of significant ECG abnormalities ranges from 4% to 9.6%. However, a study involving 32,652 Italian athletes reported a higher prevalence of 12% [2]. An observational study of 73 Polish Olympic athletes revealed ECG alterations in 89% of participants, with only 11% demonstrating normal ECG patterns. Among these athletes, 65% showed benign findings typical of an athlete’s heart, such as sinus bradycardia and first-degree atrioventricular (AV) block, while 23% exhibited atypical features, including ventricular arrhythmias and T-wave inversions. A comparative study in Iran found ECG abnormalities in 34% of athletes compared to 20% of non-athletes, although this difference was not statistically significant [3].

Sinus bradycardia and first- or second-degree AV block (type 1-2) were more frequently observed in runners, who also had significantly longer PR intervals compared to weightlifters, though still below the threshold for diagnosing first-degree AV block. These findings are linked to heightened vagal tone in athletes. Isolated T-wave inversion, observed in 14% of athletes (particularly runners), is significantly higher than the 2-3% prevalence in the general population. While this finding may suggest asymptomatic cardiomyopathy or its potential development, it is commonly seen in athletes of African descent without underlying structural heart disease [4].

Runners and weightlifters demonstrated notable differences in heart rate, rhythm, early repolarization patterns, and isolated left ventricular hypertrophy. These variations are attributed to the enhanced resting vagal tone in endurance-trained athletes, driven by the activation of high-pressure C-fibers in response to an increased left ventricular end-diastolic diameter [4]. Overall, studies highlight a high prevalence of abnormal ECG findings in trained athletes, primarily reflecting benign physiological adaptations to extreme physical exertion. Right ventricular strain is notably more common in endurance activities than in strength training [1].

This study aimed to assess the prevalence of abnormal electrocardiograms in athletic individuals and to correlate these abnormalities with the nature of the sports they engage in.

PATIENTS AND METHODS

Study Design and Participants:

This cross-sectional was conducted in the Cardiology Department of Mansoura University Hospitals, involving 164 athletes. Participants were evenly divided into two groups based on their exercise type. Group 1 comprised individuals performing aerobic activities, such as walking, jogging, running, cycling, or swimming, which are designed to enhance cardiovascular fitness by increasing heart rate. Group 2

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included those engaged in anaerobic exercises, characterized by high-intensity efforts focused on building strength, power, and muscle mass through activities such as weightlifting, sprints, plyometric exercises, fast-paced rope jumping, and bodyweight workouts like push-ups, pull-ups, and squats.

Eligibility Criteria:

Athletes aged 18 to 40 years, actively participating in either aerobic or anaerobic exercise for at least one year, were eligible for inclusion. Exclusion criteria included individuals with diagnosed cardiovascular or significant medical conditions, those taking medications that could influence heart rate or rhythm, recent acute illness or injuries affecting exercise capacity, non-athletic individuals, and those with inconsistent exercise habits.

Assessments

All participants underwent a thorough medical history review, clinical examination, and evaluation for any underlying organic disease. Standard 12-lead ECG recordings were performed in the supine position following 3 minutes of rest, immediately after exercise, and 30 minutes post-exercise. The ECGs were analyzed for various parameters, including heart rate, rhythm, conduction abnormalities, hypertrophy, axis deviations, and evidence of ischemia or infarction. Specific attention was given to metrics such as PR interval, QRS duration, QT interval, P-wave morphology, Q-waves, R amplitude in precordial leads, and T-wave inversion.

Ethical considerations:

Scientific approval was obtained from the Cardiology Department's scientific committee, and ethical and administrative approval was granted by the Mansoura Faculty of Medicine Institutional Research Board (MFM-IRB). Informed consent was obtained from each participant or 1ST degree relative, ensuring confidentiality and explaining the procedure in simple language. Participants had the right to withdraw from the study at any time, and their data were used solely for research purposes, preserving their privacy. The Helsinki Declaration was followed throughout the study's conduct.

Data Management:

Data analysis was conducted using IBM SPSS Statistics (version 25, 2017). The Shapiro-Wilk test assessed data normality. Statistical significance was set at a 95% confidence interval with a p-value threshold of <0.05. Descriptive statistics included mean and standard deviation for quantitative variables. Categorical variables were expressed as frequency and percentage. Parametric and non-parametric data comparisons were performed using independent t-tests and Mann-Whitney U tests, respectively. Fisher's exact test and Chi-square tests were utilized for categorical data comparisons between groups.

RESULTS

Demographics and ECG Findings

The mean age of the participants was 26.01 ± 5.38 years. At rest, the mean heart rate was 53.27 ± 8.92 bpm. After exercise, heart rate increased significantly, with corresponding decreases in the PR interval, QRS duration, and QT interval. Additionally, the mean number of ECG changes was 2.49 ± 1.01, with 2.26 ± 0.86 changes related to training and 1.08 ± 0.28 changes unrelated to training, indicating a moderate occurrence of exercise-induced and non-exercise-related ECG alterations **(Table 1)**.

Table 1: Demographic characteristics, ECG findings at rest and post-exercise, and frequency of ECG changes in the studied sample

All Patients (n=164)	Mean ± SD
Age (years)	26.01 ± 5.383
Height (cm)	173.57 ± 7.586
Weight (kg)	85.24 ± 9.883
Heart Rate (Resting) (bpm)	53.27 ± 8.924
PR Interval (Resting) (ms)	175.71 ± 32.205
QRS Duration (Resting) (ms)	87.32 ± 8.748
QT Interval (Resting) (ms)	397.70 ± 28.408
Heart Rate (Post-Exercise) (bpm)	80.08 ± 12.835
PR Interval (Post-Exercise) (ms)	156.51 ± 29.517
QRS Duration (Post-Exercise) (ms)	77.88 ± 8.017
QT Interval (Post-Exercise) (ms)	352.99 ± 26.672
Number of All ECG Changes	2.49 ± 1.013
Number of Training-Related ECG Changes	2.26 ± 0.863
Number of Training-Unrelated ECG Changes	1.08 ± 0.277

n: number, ECG: Electrocardiogram, SD: Standard deviation, bpm: Beats per minute, ms: Milliseconds.

Prevalence and Types of ECG Changes in Athletes

In the studied sample, all cases (100%) exhibited ECG changes, with 97.6% (n=160) related to training and 22.6% (n=37) unrelated to training. The most common ECG changes were bradycardia (78.7%), early repolarization (66.5%), and incomplete right bundle branch block (IRBBB) (51.8%) **(Table 2)**.

Table 2: Prevalence and types of ECG changes observed in the studied sample

	Condition	Frequency (Percentage)
All patients (n=164)	All changes	164 (100.0%)
	Training related	160 (97.6%)
	Training unrelated	37 (22.6%)
	Bradycardia	129 (78.7%)
Training related	First-degree AV block	38 (23.2%)
	Early repolarization	109 (66.5%)
	IRBBB	85 (51.8%)
Training unrelated	CRBBB	3 (1.8%)
	ILBBB	3 (1.8%)
	RA enlargement	2 (1.2%)
	LA enlargement	2 (1.2%)
	RVH	1 (0.6%)
	RAD	6 (3.7%)
	LAD	7 (4.3%)
	ST segment depression	2 (1.2%)
	Q waves	0 (0.0%)
	Anterior T-wave inversion	9 (5.5%)
	Lateral T-wave inversion	5 (3.0%)

n: Number, AV: Atrioventricular, IRBBB: Incomplete Right Bundle Branch Block, CRBBB: Complete Right Bundle Branch Block, ILBBB: Incomplete Left Bundle Branch Block, RA: Right Atrial, LA: Left Atrial, RVH: Right Ventricular Hypertrophy, RAD: Right Axis Deviation, LAD: Left Axis Deviation.

Comparison between anaerobic and aerobic exercises

- ***Demographics and ECG Findings***

Regarding weight, the anaerobic exercise group exhibited a significantly higher value than the aerobic group. Additionally, significant differences were observed in heart rate and PR interval before and after exercise, with anaerobic exercise leading to a lower heart rate and a longer PR interval. The number of ECG changes also showed a significant difference, with the anaerobic group showing more changes in total ECG alterations and training-related changes. Other variables like heart rate, QRS interval, and QT interval showed no significant differences across both exercise types, although the QRS interval approached statistical significance **(Table 3)**.

Table 3: Demographic characteristics, ECG findings at rest and post-exercise, and frequency of ECG changes in the aerobic and anaerobic exercise groups

Parameter	Anaerobic Exercise (n=82) Mean ± SD	Aerobic Exercise (n=82) Mean ± SD	95% CI	p-value
Age	26.67 ± 4.433	25.35 ± 6.147	-0.34 - 2.97	0.118
Height (cm)	174.32 ± 6.425	172.83 ± 8.568	-0.85 - 3.82	0.210
Weight (kg)	87.79 ± 9.738	82.70 ± 9.411	2.14 - 8.05	0.001*
Heart Rate (At rest) (bpm)	54.32 ± 9.150	52.22 ± 8.620	-0.64 - 4.84	0.133
PR Interval (At rest) (ms)	184.32 ± 29.474	167.11 ± 32.689	7.61 - 26.81	0.001*
QRS Interval (At rest) (ms)	86.01 ± 7.095	88.62 ± 10.011	-5.29 - 0.07	0.056
QT Interval (At rest) (ms)	393.38 ± 26.362	402.01 ± 29.853	-17.32 - 0.05	0.051
Heart Rate (Post-Exercise) (bpm)	74.46 ± 9.852	85.70 ± 13.061	-14.80 - 7.66	< 0.001*
PR Interval (Post-Exercise) (ms)	163.65 ± 26.882	149.38 ± 30.457	5.41 - 23.13	0.002*
QRS Interval (Post-Exercise) (ms)	76.73 ± 6.274	79.04 ± 9.343	-4.76 - 0.15	0.065
QT Interval (Post-Exercise) (ms)	349.38 ± 25.518	356.61 ± 27.459	-15.41- 0.94	0.083
Number of All ECG Changes	2.68 ± 1.070	2.30 ± 0.920	0.07 - 0.69	0.017*
Number of Training-Related ECG Changes	2.40 ± 0.861	2.11 ± 0.847	0.01 - 0.55	0.039*
Number of Training-Unrelated ECG Changes	1.15 ± 0.366	1.00 ± 0.000	-0.03 - 0.33	0.101

n: Number, SD: Standard deviation, bpm: Beats per minute, ms: Milliseconds, ECG: Electrocardiogram, CI: Confidence Interval, *: Statistically significant p-value as <0.05.

Prevalence and Types of ECG Changes

Training-related changes were observed in 98.8% of the anaerobic group and 96.3% of the aerobic group, while training-unrelated changes were seen in 24.4% and 20.7%, respectively. Bradycardia was present in 79.3% of the anaerobic group and 78.0% of the aerobic group, but first-degree AV block was significantly more common in the anaerobic group. Early repolarization was more frequent in the anaerobic group, and IRBBB occurred more often in the aerobic group. Among training-unrelated changes, lateral T-wave inversion was more common in the anaerobic group, and anterior T-wave inversion occurred in 11.0% of the anaerobic group compared to 0% in the aerobic group. Other ECG abnormalities, such as CRBBB, ILBBB, RA and LA enlargement, RVH, RAD, LAD, and ST segment depression, showed no significant differences **(Table 4)**.

Table 4: Prevalence, and types of ECG changes in aerobic and anaerobic exercise groups

Parameter	Anaerobic Exercise (n=82)	Aerobic Exercise (n=82)	p-value
All Changes	82 (100.0%)	82 (100.0%)	1
Training Related	81 (98.8%)	79 (96.3%)	0.620
Training Unrelated	20 (24.4%)	17 (20.7%)	0.575
Training Related Changes			
Bradycardia	65 (79.3%)	64 (78.0%)	0.849
First-degree AV block	29 (35.4%)	9 (11.0%)	< 0.001*
Early repolarization	64 (78.0%)	45 (54.9%)	0.002*
IRBBB	36 (43.9%)	49 (59.8%)	0.042*
Training Unrelated Changes			
CRBBB	1 (1.2%)	2 (2.4%)	0.560
ILBBB	1 (1.2%)	2 (2.4%)	0.560
RA enlargement	1 (1.2%)	1 (1.2%)	1
LA enlargement	1 (1.2%)	1 (1.2%)	1
RVH	1 (1.2%)	0 (0.0%)	1
RAD	3 (3.7%)	3 (3.7%)	1
LAD	1 (1.2%)	6 (7.3%)	0.117
ST segment depression	0 (0.0%)	2 (2.4%)	0.497
Q waves	0 (0.0%)	0 (0.0%)	1
Anterior T-wave inversion	9 (11.0%)	0 (0.0%)	0.003*
Lateral T-wave inversion	5 (6.1%)	0 (0.0%)	0.059

n: number, AV: Atrioventricular, IRBBB: Incomplete Right Bundle Branch Block, CRBBB: Complete Right Bundle Branch Block, ILBBB: Incomplete Left Bundle Branch Block, RA: Right Atrial, LA: Left Atrial, RVH: Right Ventricular Hypertrophy, RAD: Right Axis Deviation, LAD: Left Axis Deviation, *: Statistically significant p-value as <0.05.

DISCUSSION

Over the past 30 years, various ECG alterations in trained athletes have been linked to cardiac adaptations from systematic athletic conditioning. These changes, influenced by gender, race, fitness level, and sport type, can vary significantly. Notably, ECG changes may precede clinical cardiomyopathy, with some asymptomatic athletes developing signs of disease years later [5]. This study aimed to assess the prevalence of abnormal ECGs in athletes and correlate these abnormalities with the nature of the sports.

Our results align with previous study by and **Elbadry *et al.*** [6], which report that the mean age of Egyptian athletes involved in medical research typically falls in the 20s.

Our findings demonstrated an increase in heart rate following exercise, consistent with the compensatory mechanisms described by **Schenk *et al.*** [7] to meet the demands of physical activity. Additionally, we observed a reduction in the duration of PR, QRS, and QT intervals post-exercise, which aligns with typical cardiovascular adaptations to exercise.

Our research indicate that ECG changes were detected in all included cases, which contrasts with the findings of **Dores *et al.*** [8], who reported alterations in approximately 80% of athletes based on the Seattle criteria. The higher incidence in our study may be due to the application of less restrictive diagnostic criteria. Additionally, **Pelliccia *et al.*** [9] observed a much lower prevalence of abnormal ECG findings, with the majority of athletes showing normal or only minor ECG alterations.

Our investigation shows that most ECG abnormalities were training-related, with a smaller proportion of training-unrelated changes. This finding aligns with **Dores *et al.*** [8], who reported a higher prevalence of exercise-related ECG changes, although their study found a lower incidence of training-unrelated changes. Unlike athlete's heart-related ECG changes, training-unrelated abnormalities are rare, and further diagnostic workup is crucial for athletes exhibiting such changes to rule out underlying cardiovascular conditions, as emphasized by **Corrado *et al.*** [10].

Our results revealed that sinus bradycardia was the most frequent ECG abnormality, with a low resting heart rate commonly observed in athletes. This finding is consistent with studies by **Doyen *et al.*** [11], who highlighted that resting sinus bradycardia, characterized by a heart rate under 60 bpm, is common among athletes, influenced by the type of sport and training level.

Our research showed a notable presence of first-degree AV block in the studied population, aligning with findings from multiple studies, which report that first-degree AV block is common among trained athletes, affecting approximately 35% of their ECGs [10]. This prevalence supports the notion that AV conduction slowing and block, similar to sinus bradycardia, are likely mediated by an increased parasympathetic tone and/or reduced resting sympathetic tone [10].

Our results revealed a significant presence of early repolarization, which is consistent with previous studies suggesting that this pattern in athletes is linked to training-related hypervagotonia [12]. Similar findings have been reported, with early repolarization observed in 50–80% of resting ECGs [13]. Additionally, studies indicate that benign early repolarization is more common in athletes, with prevalence estimates ranging from 10% to 90%, much higher than in the general population [14].

Our results are consistent with previous literature, which reports a higher prevalence of IRBBB in athletes compared to healthy controls [15]. The variation in reported prevalence is likely due to differences in the criteria used for defining IRBBB, such as varying QRS duration thresholds [16]. The etiology of IRBBB is often attributed to right ventricular dilation resulting from prolonged intense physical training, leading to delayed electrical conduction through the right [17].

Our investigations align with the literature, as ST segment depression was infrequently observed in our study. Previous research has noted that ST segment depression is often grouped with T-wave inversion, making its isolated incidence difficult to determine. While ST segment elevation due to early repolarization is common in athletes' baseline ECGs, resting ST segment depression is rarely seen, supporting the low prevalence found in our study [18].

Our results are consistent with the literature, as RVH and RA enlargement were rare findings in our study. Previous research has reported that ECG evidence of these conditions is uncommon in athletes [19]. Moreover, data suggest that the right ventricle in athletes undergoes structural and functional adaptations, which may mimic conditions like arrhythmogenic right ventricular cardiomyopathy (ARVC) [19].

Our findings align with previous studies showing that the prevalence of RV hypertrophy based on the Sokolow–Lyon voltage criteria is generally low in athletes. A study by **Somauroo *et al.*** [20] reported a prevalence of 0.6% among professional soccer players. In contrast, **Sharma *et al.*** [21] observed a higher prevalence among junior elite athletes (12%), though no significant difference was found compared to controls. This higher prevalence reported by them contrasts with our findings.

Our results are consistent with existing literature, as atrial enlargement in athletes is typically linked to volume overload resulting from sustained increases in cardiac output during athletic training [22]. **Pelliccia *et al.*** [9] also reported a low prevalence of RA enlargement in a large cohort of highly conditioned athletes, further supporting our findings.

Our findings are in contrast to previous studies, such as the one by **Pelliccia *et al.*** [23], which reported a much higher prevalence of LA enlargement in competitive athletes. Their study, involving 1,777 athletes, found a significant portion with mild to marked LA enlargement, much higher than what we observed. Additionally, a meta-analysis by **Iskandar *et al.*** [24] found that athletes tend to have larger LA size compared to control subjects, with significant increases in both LA diameter and volume. The differences in prevalence observed between studies could be attributed to variations in sample size and the characteristics of the athletic populations involved.

Our results are consistent with prior literature suggesting that T-wave inversion in athletes may be a marker of underlying cardiac conditions. In this study, T-wave inversion was observed in a subset of athletes, with anterior and lateral inversions being the most common patterns. This aligns with findings from **Corrado *et al.*** [10], who indicated that T-wave inversion could be an early sign of cardiomyopathy before morphological changes are detectable. Previous studies, such as those by **Brosnan *et al.*** [25] and **Wilson *et al.*** [26], have reported varying prevalence rates of T-wave inversion in athletes, with some studies showing higher occurrences, particularly in endurance athletes. Conversely, **Pelliccia *et al.*** [9] found lower prevalence rates, suggesting differences in population characteristics or diagnostic criteria across studies.

Our investigations show that bundle branch blocks, including complete RBBB and incomplete LBBB, were observed in a small subset of athletes, consistent with previous studies suggesting that such abnormalities are uncommon in athletes' ECGs. This finding aligns with the observations of **Elizari *et al.*** [27] and **Agarwal and Venugopalan** [28], who noted that bundle branch blocks may arise due to various cardiac pathologies, such as ischemic and hypertensive heart disease, cardiomyopathies, and channelopathies. Although complete RBBB is rare in athletes, with an incidence ranging from 0.2% to 3%, its presence may indicate underlying cardiovascular disease, a trend also observed in our study. The prevalence of RBBB in athletes is notably higher than in the general population, further supporting its potential clinical significance [29].

Our results show a higher prevalence of RBBB and LBBB compared to what is commonly reported in the literature. **Bussink *et al.*** [30] found that RBBB was present in approximately 1% of a large cohort of the general population without cardiovascular disease, which is much lower than the prevalence observed in our study. Similarly, LBBB, which is rare in asymptomatic adults, including athletes, has an estimated prevalence ranging from 0.1% to 0.8% [9, 31], but we observed a higher prevalence of LBBB (1.8%) in our cohort. In contrast, a study by **Kim and Baggish** [32] focused on athletes have reported no cases of LBBB.

Our results are consistent with findings from **Pelliccia *et al.*** [9] and **Corrado *et al.*** [10], who noted that the type of exercise, particularly endurance training, is associated with distinct ECG changes. In our study, while there were no significant differences between the anaerobic and aerobic groups in terms of training-related and unrelated findings, further analysis revealed that anaerobic exercise was linked to a higher prevalence of first-degree AV block and early repolarization, while incomplete RBBB was more common in the aerobic group. These differences may be attributed to the distinct physiological adaptations resulting from the types of exercises performed, with endurance training contributing to larger cardiac output and more pronounced cardiac remodelling, as described by **Maron and Pelliccia** [33].

Our results align with previous studies, such as **Björnstad *et al.*** [34], which noted a relationship between athletic training intensity and ECG changes, particularly in voltage indices for RVH. However, as noted by **Corrado *et al.*** [10], earlier studies often analyzed sports individually without considering the intensity of dynamic and static components. **Pelliccia *et al.*.** [9] demonstrated that athletes engaged in endurance sports, such as cycling and cross-country skiing, exhibited more pronounced ECG changes, likely due to greater physiological and structural remodeling. Furthermore, **Dores *et al.*** [8] reported that athletes involved in high dynamic intensity sports had a higher rate of abnormal ECG changes, supporting the notion that the intensity of exercise plays a key role in ECG alterations.

Our findings underscore the significance of the 12-lead ECG as an essential tool for preparticipation cardiovascular screening in large athlete populations. As highlighted in previous studies, the ECG is a simple and cost-effective method that complements the limited diagnostic capabilities of medical history and physical examination. This approach has been implemented as routine practice in Egypt for the last two decades, reinforcing its value in identifying potential cardiovascular abnormalities and ensuring athlete safety.

This study has several limitations. First, it is a single-center study; therefore, future research should involve multiple centers to enhance the generalizability of the findings. Additionally, echocardiographic assessment of the participants was not performed, and it would be beneficial to correlate ECG data with echocardiographic findings in future studies. Addressing these limitations will provide a more comprehensive understanding of the cardiovascular health of athletes.

CONCLUSION

Athletes are highly susceptible to ECG changes, with bradycardia being the most common abnormality. Furthermore, anaerobic exercise was associated with a higher likelihood of both ECG changes and training-related ECG alterations compared to the aerobic exercise group.

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