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Evaluation of Early Repolarization Pattern in Male Teenage Competitive Athletes and Association With Left Ventricular Remodeling

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What is already known on this topic?

- *Early repolarization pattern (ERP) on electrocardiogram is more common among young athletes than in the general population. It has been considered a benign finding. However, ERP has been associated with increased risk of sudden cardiac death. The prevalence of ERP is believed to be 5- to 10-fold greater in the pediatric population than in the adult population. However, though there are a lot of relevant data for the adult population, there is a paucity of evidence regarding children and adolescents.*

What this study adds on this topic?

- *ERP is more commonly seen in those training with combined exercise. It is not associated with structural echocardiographic alterations such as left ventricular remodeling and geometric pattern. Our data support the principle that ERP seems to be primarily an electrophysiological alteration.*

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ABSTRACT

Objective: Early repolarization pattern (ERP) on electrocardiogram is more common among young athletes than in the general population, and has been considered a benign finding. However, ERP has been associated with increased risk of sudden cardiac death. The objectives of this study were to evaluate ERP in teenage athletes; investigate associations between ERP and echocardiographic findings of the left ventricle (LV); and to describe the impact of different sports disciplines on ERP.

Methods: ERP was assessed in male teenage athletes from sports institutions for 5 different types of sport––basketball, swimming, football, wrestling, and tennis. All had been training for at least 3 hours per week for over at least 2 years. ERP was defined as J-point elevation ≥ 1 mV in 2 contiguous and/or lateral leads. A conventional echocardiography was performed in all athletes.

Results: ERP was evaluated in 159 athletes with a mean age of 14 (range 10-18 years). It was more common in those training with combined exercise. There was no association between ERP and echocardiographic findings of left ventricular remodeling and geometric pattern.

Conclusion: ERP is a frequent finding among teenage athletes. However, frequency varies by sports type, being more common in those training with combined exercise. It is not associated with structural echocardiographic alterations and is primarily seen as an electrophysiological change.

Keywords: Adolescent, athlete, early repolarization, sport

INTRODUCTION

Early repolarization pattern (ERP) on electrocardiography (ECG) is characterized by J-point elevation in conjunction with slurring or notching of the terminal portion of the QRS complex and present in at least 2 contiguous inferior and/or lateral ECG leads.[1,2] This ECG pattern was previously considered a benign variant in the general population.[3] However, many studies now suggest that ERP in the inferior leads is a predictor of potentially fatal cardiac arrhythmias.[4] Despite substantial literature concerning the characteristics of ERP in the adult population, there is a paucity of data for the pediatric population.[5,6] Even less is known about clinical significance of ERP in teenage competitive athletes.[7] Although sudden cardiac death is rare in young athletes, it is significantly more common than the incidence in the general population.[8,9]

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The present study evaluated ERP in young teenage athletes. In addition, associations of ERP with sports discipline and exercise type were analyzed. There is a hypothesis that malignant arrhythmias arise in subjects with ERP, in association with structural alterations of the left ventricle (LV).[10,11] Therefore, a further objective of this study was to investigate the association between ERP and any structural echocardiographic changes and geometrical patterns found in the LVs of subjects.

METHODS

Study Population

This was a retrospective single center study. Competitive adolescent and young adult athletes who came to our institution for the health examination required by the sports institution were evaluated retrospectively. They were competing in a range of sports including wrestling, football, tennis, basketball, and swimming. The subjects chosen were involved in regular training programs lasting at least 3 hours per week, over a period of at least 2 years. Athletes whose training had been interrupted for more than 15 days were excluded from the study. All participants had a physical examination, and a detailed medical history was obtained from each. A comprehensive transthoracic echocardiographic examination was performed on the day of the ECG recording. According to the sports discipline, they were grouped into static (wrestling), dynamic (football, tennis), and a combination of both (swimming, basketball) exercise types.[12] Written informed consent was obtained from all participants before involvement. The study had been approved by the Ethics Committee of Kocaeli University (February 12, 2020/ KOGOEKO1.5). The investigation conformed to the principles outlined in the Declaration of Helsinki.

ECG Measurement and Analysis

ECG recordings of athletes who underwent a 12-lead electrocardiogram (Nihon Kohden Electrocardiogram-2350, Shanghai, China) after 10 minutes of resting in a supine position were evaluated retrospectively. The paper speed was 25 mm/s. The filtering range was 0.05 Hz for low-frequency cut-off and 150 Hz for high-frequency cut-off. A pair of calipers and a magnifying glass were used for visual assessment of the ECG traces. The ECG parameters were evaluated by 2 independent cardiologists blinded to the characteristics of the participants. In cases of disagreement, final adjudication was made by an electrophysiologist.

For the definition of early repolarization, the MacFarlane criteria were used.[13] These are: J-point elevation $\geq$ 0.1 mV in $\geq$ 2 contiguous leads, with a notched or slurred morphology. To eliminate the possibility of Brugada syndrome, V1-V3 derivations were excluded. The QRS duration was < 120 ms.

Further, the heart rate, PR, and QRS duration were measured; the corrected QT (QTc) interval was obtained using the Bazett formula. Sinus bradycardia was defined as < 60 beats per minute. The Sokolow–Lyon Index for LV hypertrophy was defined as: S wave in lead V1+R wave in lead V5 or V6 > 35 mm; R wave in lead V5 or V6 > 26 mm. If either of these 2 criteria were present in the trace, this was accepted as LV hypertrophy.

The ECG-specific exclusion criteria were as follows: Participants with the Brugada pattern, Wolff–Parkinson–White pattern, or different types of block morphology (complete or incomplete bundle branch block, left anterior or posterior fascicular block, second or third degree atrioventricular block), prolonged QTc, QRS duration > 120 ms; subjects with a rhythm other than sinus; and participants with frequent premature ventricular or supraventricular beats. Further exclusion criteria were: subjects with a metabolic condition or medication which could affect the ECG; subjects with repaired or non-repaired structural congenital heart disease; any cardiomyopathy; or implantable cardioverter–defibrillator/pace maker implantation.

Echocardiographic Measurements

Two-dimensional and Doppler echocardiography were performed by experienced cardiologists. A commercially available ultrasound system was used with a 3.5 MHz transducer (Vivid 7, General Electric, Vingmed Ultasound AS, Horten, Norway). Participants were positioned in a left lateral decubitus position. Parasternal long- and short- axis views and apical 4-, 3-, and 2-chamber views of the LV were obtained.

The following echocardiographic parameters were assessed according to the established criteria of the American Society of Echocardiography[14]: LV end-diastolic dimension; interventricular septum thickness at end-diastole; LV end-systolic dimension; LV posterior wall thickness at end-diastole. Measurements of the LV dimensions were indexed by body surface area. Ejection fraction of the LV was calculated using the modified Simpson's method.

Diastolic function was measured using pulsed-wave Doppler across the mitral valve leaflets and tissue Doppler velocities of the mitral valve annulus. Left ventricular mass was derived using the Devereux formula. Left ventricular mass index was calculated by dividing LV mass in grams by the height in meters raised to the power of 2.7 (g/height$^{2.7}$). Left ventricular mass index was defined as < or $\geq$ the male-based 95th percentile: 39.36 g/height$^{2.7}$. The definition of relative wall thickness (RWT) was the ratio of LV wall thickness to LV internal dimensions [(interventricular septum+posterior wall thickness)/left ventricular internal dimension] and was classified as < or $\geq$ 0.41. Left ventricular geometry was considered to be normal when both LV mass index was < 95th percentile and RWT < 0.41. LV concentric remodeling was defined as LV mass index < 95th percentile and RWT $\geq$ 0.41. Left ventricular concentric hypertrophy was defined as $\geq$ 95th percentile and RWT $\geq$ 0.41. The definition of eccentric hypertrophy was LV mass index $\geq$ 95thpercentile and RWT < 0.41.[15] Finally, the myocardial performance index (Tei index) was defined as the isovolumetric times (isovolumetric contraction time+isovolumetric relaxation time) divided by ejection time.

Statistical Analysis

Normal distribution of all continuous variables was examined using the Kolmogorov–Smirnov test, and data are presented as mean ± standard deviation or median and range. The unpaired *t*-test or the Mann–Whitney *U*-test were used to assess the intergroup significance, according to data distribution.

Chi-square or Fisher's exact test and Monte Carlo simulations within the chi-square test were used to compare intergroup frequencies for categorical variables. A value of $P < .05$ was

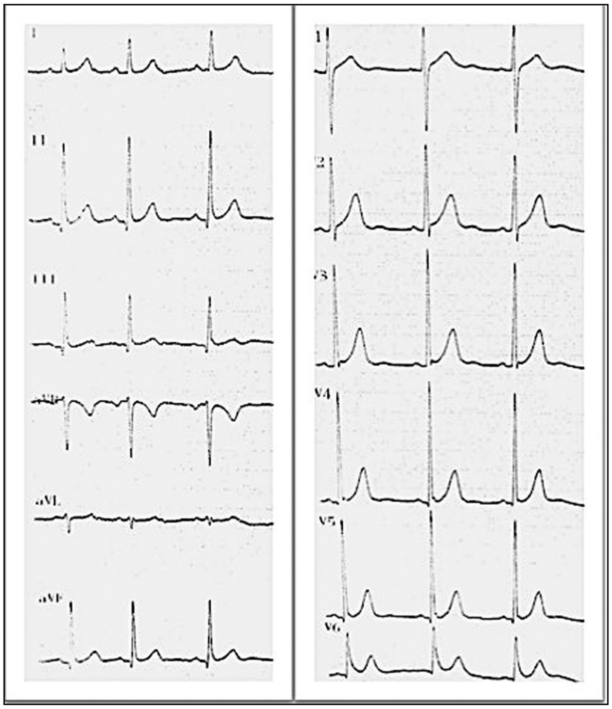

Figure 1. ECG of a teenage athlete with ERP manifest as inferior and lateral J-point elevation and slurring (≥ 0.1 mV) in at least 2 contiguous leads.

considered significant. Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) version 21.0 (IBM SPSS Corp.; Armonk, NY, USA).

RESULTS

One hundred fifty-nine athletes were enrolled. All participants were male and had a mean age of 14 years (range 10-18). Twenty-three (14.5%) had ERP in their resting baseline 12-lead-ECG (Figure 1). The basic characteristics of the study population, divided into 2 groups based on the presence or absence of ERP, are illustrated in Table 1. There were no significant differences

Table 1. Basic Demographic and Clinical Characteristics of the Study Population Stratified by the Presence or Absence of ERP

Variables	ERP absent (*n* = 136) (Mean ± SD)	ERP present (*n* = 23) (Mean ± SD)	*P*[*]
Age (years)	14.66 ± 2.03	14.43 ± 2.15	.615
Heart rate (bpm)	75.1 ± 14.8	74.9 ± 11.3	.948
BP syst. (mmHg)	112.6 ± 10.1	116.7 ± 10.1	.072
BP diast. (mmHg)	64.4 ± 8.1	67.8 ± 9.6	.065
Competition duration (years)	5.43 ± 2.16	4.84 ± 1.97	.224
Exercise load (h/week)	10.92 ± 5.79	9.50 ± 4.01	.259
BSA (m^2)	1.61 ± 0.24	1.60 ± 0.28	.934
BMI (kg/m^2)	20.69±2.77	21.06±3.09	.558

*Student's *t*-test.
ERP, early repolarization pattern; bpm, beats per minute; BP syst., systolic blood pressure; BP diast., diastolic blood pressure; BSA, body surface area; BMI, body mass index.

Table 2. Electrocardiographic Findings Stratified by the Presence or Absence of ERP

Variables	ERP Absent (*n* = 136)	ERP Present (*n* = 23)	*P*
Heart rate (bpm)[a]	75.1 ± 14.8	74.9 ± 11.3	.948[*]
Sinus bradycardia *n* (%)	20 (14.7)	2 (8.7)	.490[*]
PR duration (ms)[a]	133 ± 21	132 ± 18	.781[*]
QRS duration (ms)[a]	70 ± 18	68 ± 17	.747[*]
QTc (ms)[a]	390 ± 26	392 ± 24	.456[*]
V1S (mm)[b]	9.0 (5.0-31.0)	12.0 (5.0-20.0)	.005[&]
V5R (mm)[b]	16.0 (5.0-34.0)	19.0 (5.0-38.0)	.004[&]
V6R (mm)[b]	14.0 (7.0-24.0)	17.0 (10.0-28.0)	.033[&]
V1S+V5R (mm)[b]	26 (8.0-52.0)	32.0 (20.0-52.0)	<.001[&]
Only inferior ERP, *n* (%)		10 (43.6)	
Only lateral ERP, *n* (%)		4 (17.3)	
Inferolateral ERP, *n* (%)		9 (39.1)	

[a]Mean ± SD; [b]Median (min-max); *Student's *t*-test; [&]Mann–Whitney *U*-test.
ERP, early repolarization pattern; bpm, beats per minute.

between the 2 groups. Table 2 depicts the ECG characteristics. ERP was most commonly detected only in the inferior leads (43.6%). The Sokolow–Lyon Index was significantly higher in the group with ERP, although the criteria for electrocardiographic LV hypertrophy were not fulfilled.

Sports Type and ERP

Among the athletes included in the study, football players were the most prevalent (31.4%). Athletes in swimming (28.3%), basketball (15.7%), wrestling (14.4%), and tennis (10.0%) were listed in descending order, respectively. The distribution of ERP in different sport types is shown in Table 3. ERP was more common in swimmers (17.8%) and basketball players (24%) compared to other disciplines (Figure 2) (Table 3). Although the type of training exercise was not significantly associated with ERP pattern, it was more common in combined exercise with both dynamic and static components (Figure 3) (Table 4). Mean competition duration in years and exercise load in hours per week were similar in both the populations with and without ERP [4.84 ± 1.97 vs. 5.43 ± 2.16 (*P* = .224), and 9.50 ± 4.01 vs. 10.92 ± 5.79 (*P* = .259), respectively].

Table 3. Distribution of ERP in Different Types of Sport Using Chi-Square Test

Variables	ERP Absent (*n* = 136, 85.5%)	ERP Present (*n* = 23, 14.5%)	*P*[*]
Basketball, *n* (%)	19 (76.0)	6 (24.0)	.421
Football, *n* (%)	44 (88.0)	6 (12.0)	
Swimming, *n* (%)	37 (82.2)	8 (17.8)	
Wrestling, *n* (%)	21 (91.3)	2 (8.7)	
Tennis, *n* (%)	15 (93.8)	1 (6.2)	

*Monte Carlo simulations within chi-square test (χ^2 = 3.973, $P > .05$).
ERP, early repolarization pattern.

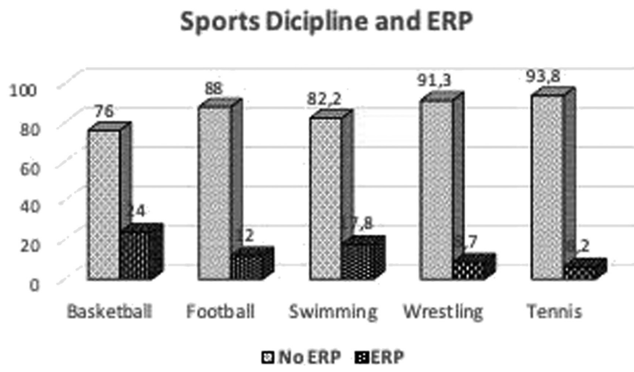

Figure 2. Comparison of sports disciplines undertaken by the athletes with and without ERP.

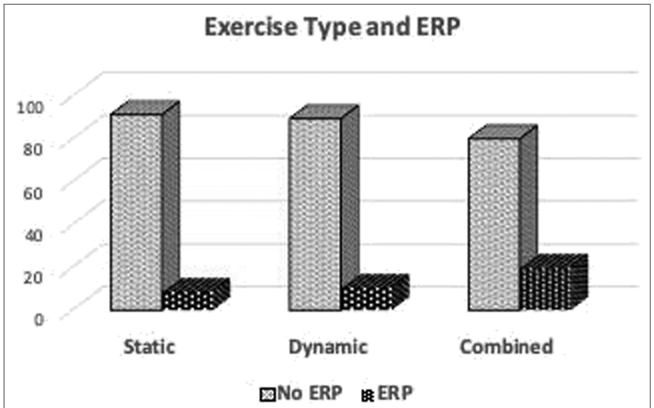

Figure 3. Comparison of exercise types of athletes with and without ERP.

Left Ventricular Geometric Pattern and ERP

ERP was found to be present in 6.7% of the remodeling group, 14.8% of the group with concentric hypertrophy, 15.6% of the group with eccentric hypertrophy, and 17.5% of the group with normal findings. However, there was no statistically significant association between ERP and echocardiographic measurements of left ventricular remodeling and geometric pattern (P = .649) (Figure 4) (Tables 5 and 6).

DISCUSSION

The main findings of this study are a varying incidence of ERP dependent on the sports type, being more common in those training with combined exercise. Further, ERP was not associated with echocardiographic remodeling, suggesting that ERP is primarily an electrophysiological alteration. Additionally, the highest occurrence of ERP in our study was detected in the

Table 4. Distribution of ERP in Different Sports Disciplines Classified According to Type of Training Exercise Undertaken

Variables	ERP Absent (n = 136, 85.5%)	ERP Present (n = 23, 14.5%)	P*
Static, n (%)	21 (91.3)	2 (8.7)	.207
Dynamic, n (%)	59 (89.4)	7 (10.6)	
Combined, n (%)	56 (80.0)	14 (20.0)	

*Chi-square test (χ^2 = 3.146, P > .05).
ERP, early repolarization pattern.

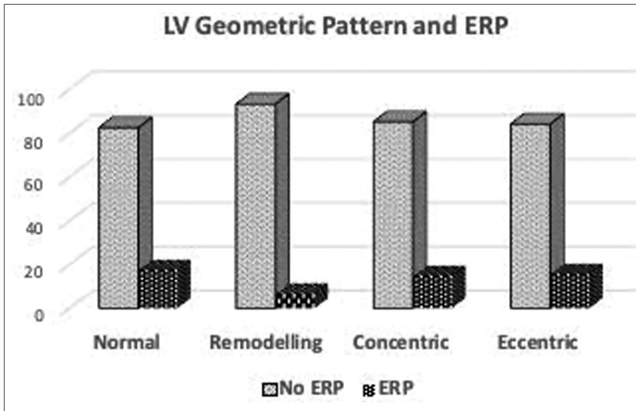

Figure 4. Comparison of LV geometric pattern variables of athletes with and without ERP.

inferior leads. There are conflicting data in the literature. With our study, we tried to bring new and different aspects to this debatable matter.

There is evidence of the association between ERP and sudden cardiac death.[16,17] Although there are data for the adult population,[18] there is a paucity of evidence in children and adolescents. The prevalence of ERP varies between 2% and 13% in the general population.[19] Further, it has been shown that in athletes, the prevalence of ERP is even higher and is associated with a 2.8-fold increased risk for sudden cardiac death.[20] In the pediatric population, the prevalence of ERP is believed to be 5-10 times that of the adult population.[5,6] Maury et al.[21] reported a prevalence of ERP in children

Table 5. Comparison of Echocardiographic Measurements Between the Groups

Variables	ERP absent (n = 136) (Mean ± SD)	ERP present, (n = 23) (Mean ± SD)	P*
LVEDDI (mm/m^2)	29.67 ± 4.55	29.85 ± 6.22	.867
LVEDSI (mm/m^2)	18.75 ± 2.93	18.72 ± 2.54	.954
IVSDI (mm/m^2)	5.73 ± 1.05	6.15 ± 1.45	.100
LVPWDI (mm/m^2)	7.75 ± 1.10	5.97 ± 1.17	.384
EF (%)	65.74 ± 5.27	64.78 ± 4.71	.413
FS	36.01 ± 4.29	35.26 ± 3.94	.437
LVMI (g/ht$^{2.7}$)	37.52 ± 7.89	39.28 ± 6.98	.316
RWT	0.39 ± 0.06	0.39 ± 0.07	.953
E (m/s)	0.94 ± 0.14	0.92 ± 0.15	.583
A (m/s)	0.52 ± 0.10	0.50 ± 0.10	.411
E/A	1.85 ± 0.39	1.87 ± 0.43	.788
DT (m/s)	109.5 ± 22.2	103.2 ± 15.0	.191
E′ (m/s)	0.19 ± 0.03	0.19 ± 0.02	.594
A′ (m/s)	0.07 ± 0.04	0.07 ± 0.01	.956
E′/A′	2.92 ± 0.78	2.84 ± 0.76	.664
Tei Index	0.42 ± 0.08	0.41 ± 0.07	.483

*Student's t-test.
ERP, early repolarization pattern; LVEDD, left ventricular end-diastolic dimension; LVEDS, left ventricular end-systolic dimension; IVSD, interventricular septum thickness at end-diastole; LVPWD, left ventricular posterior wall thickness at end-diastole; I, indexed; EF, ejection fraction; FS, fractional shortening; LVMI, left ventricular mass index; ht, height RWT, relative wall thickness; DT, deceleration time.

Table 6. Association of ERP with Geometric Pattern of LV

Variables	ERP Absent (n = 136, 85.5%)	ERP Present (n = 23, 14.5%)	P^*
Normal, n (%)	47 (82.5)	10 (17.5)	.603
Remodeling, n (%)	28 (93.3)	2 (6.7)	
Concentric hypertrophy, n (%)	23 (85.2)	4 (14.8)	
Eccentric hypertrophy, n (%)	38 (84.4)	7 (15.6)	

*Monte Carlo simulations within chi-square test (χ^2 = 1.957, P > .05).
ERP, early repolarization pattern.

at 23.6%. The prevalence of ERP in young athletes is estimated to range from 20% to 90%.[6]

There are several factors such as gender, age, and ethnicity influencing the prevalence of ERP in general.[21-23] ERP is also reported to be influenced by physical activity.[7] This may be explained by the lower heart rate and higher vagal tone found in athletes accustomed to vigorous sporting activity.[24] Additionally, many studies have highlighted that athletes in endurance sports had a higher prevalence of ERP than their counterparts in other disciplines.[25,26] Finally, in 1 study, the prevalence of ERP was also related to heart rate, and was found to decrease during tachycardia.[21]

In the present study, the overall ratio of ERP was 14.5%. In a similar investigation in adolescent athletes, Miragoli et al.[27] evaluated 414 ECGs and reported the prevalence of ERP to be 22%. One of the reasons for the higher prevalence among athletes may be due to ethnicity. Consistent with other data, ERP is significantly more common in black male athletes.[26] In the study by Miragoli et al.,[27] the prevalence of ERP in black male athletes was 50%, while it was only 17% in male Caucasian athletes. De Asmundis et al.[7] investigated 122 football players below the age of 15 years and showed an even higher prevalence of ERP, at 36%. However, de Asmundis et al. did not take into account the exercise load per week nor the competition duration in years. These parameters may also influence the occurrence.[28] Although scarce data are available for teenage athletes, these and our findings show a remarkable frequency of ERP in this group.

The spatial distribution of ERP also has an effect on the arrhythmogenic risk.[29] An inferior or inferolateral location of ERP has been described as a factor associated with increased arrhythmogenic risk in both the general population and in patients with idiopathic ventricular fibrillation.[30] In our study, the highest occurrence of ERP was detected in the inferior leads (43.6%), followed by the inferolateral and lateral leads. In 2 similar studies, the most common subtype was at the inferior sites, in accordance with our findings.[31,32] In another study, this was found to be in the inferolateral leads.[27] Thus, there is no clear consensus in the existing literature; an issue which remains to be resolved.

A further finding in the present study was a significantly higher Sokolow–Lyon Index in the ERP group, without fulfilling the criteria for electrocardiographic LV hypertrophy. Noseworthy et al.[28] demonstrated an increased QRS voltage in a subset of elite athletes with ECG, but there were no detectable echocardiographic indices of LV hypertrophy. The interpretation of this finding was a physiological adaptation to exercise, suggesting that ERP has to be seen as an electrical remodeling of the heart. This electrical remodeling occurs independent of the structural remodeling.[26] Our echocardiographic findings are in accordance with these results.

In a few studies, an association between exercise type and prevalence of ERP has also been discussed.[18] Our study population was divided into static, dynamic, and combined exercise types, according to Mitchell et al.[12] It was found that ERP was more common in combined exercise types compared to dynamic and static exercise types, although this tendency did not show a statistical significance. In contrast, Reinhard et al.[25] demonstrated a trend toward a higher prevalence of ERP relative to increasingly dynamic exercise in elite athletes, although again, this was not significant. Ahmed et al.[31] reported a higher percentage of subjects with ERP who played football, a dynamic sport, compared to those without ERP, but it should be noted that this cohort included a higher percentage of black participants. In contrast, Noseworthy et al.[28] showed that athletes in rowing, a discipline with a mixed component, had a higher prevalence of ERP compared to football players. This latter finding is in agreement with the results of our study.

As a final result, no association was found in the present study between ERP and echocardiographic measurements of LV remodeling and geometric pattern. In contrast, Miragoli et al.[27] showed a correlation between ERP and concentric LV remodeling. In their investigation, echocardiographic examination was performed and the authors suggested a typical athlete's heart had significant LV structural changes. In contrast, there are many other studies with findings comparable to those in our investigation. Ahmed et al.[31] performed a limited transthoracic echocardiography, and all subjects had a structurally normal heart. Noseworthy et al.[28] also investigated competitive athletes and reported no association between ERP and echocardiographic parameters of LV remodeling. Finally, Reinhard et al.[25] found no difference in left atrial diameter, LV mass, and systolic or diastolic function between early repolarization-positive and -negative athletes.

The reason why we and some other authors could not find any association between early repolarization and echocardiographic parameters of LV structural remodeling has indeed been a matter of discussion.[25,28] In 2 studies, it has been shown that ERP disappears during and immediately after extensive training (a state of increased sympathetic tone and vagal withdrawal). The same phenomenon could also be demonstrated with sympathomimetic agents.[33,34] This suggests that structural changes may not be the only reason for the appearance of ERP. Noseworthy et al.[28] concluded that occurrence of ERP in athletes may be an isolated electrical remodeling which may develop independently without being a consequence of structural remodeling. Our data support the principle that ERP seems to be a primary electrophysiological alteration.

Limitations

There were some limitations to this study, the first of which was a small sample size. A further limitation was that only male athletes were investigated. In addition, the study population was of Turkish ancestry, and therefore the findings of this investigation cannot be generalized to other populations. Further prospective studies should include a larger sample size of mixed gender and ethnicity. Finally, only conventional echocardiography was performed. Subtler imaging techniques such as speckle tracking echocardiography and cardiac magnetic resonance imaging may help to resolve some of the outstanding questions in this field of research.

CONCLUSION

It was demonstrated that ERP is a frequent finding among teenage athletes. In this cohort, inferior ERP was found to be more common than ERP in the lateral or inferolateral leads. Additionally, the presence of ERP in our subjects is not associated with structural echocardiographic alterations, and thus appears to be an electrophysiological adaptation. Finally, ERP seemed to be more common in combined exercise types compared to dynamic and static types. Further, large cohort studies are required to understand the underlying mechanisms of our findings, especially in teenage athletes who are most at risk for sudden cardiac death.

Ethical Committee Approval: Ethics committee approval was received from the Ethics Committee of Kocaeli University (12.02.2020/ KOGOEKO1.5).

Informed Consent: Written informed consent was obtained from all participants before involvement.

Peer Review: Externally peer-reviewed.

Author Contributions: Concept – K.B.; Design - K.B.; Supervision - K.B.; Materials - E.Z.A.; Data Collection and/or Processing - E.Z.A.; Analysis and/or Interpretation - S.Ç.; Literature Search - S.Ç.

Conflict of Interest: The authors have no conflicts of interest to declare.

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