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ORIGINAL RESEARCH

Early Repolarization in Pediatric Athletes: A Dynamic Electrocardiographic Pattern With Benign Prognosis

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BACKGROUND: Early repolarization pattern (ERP) is considered a common training-related and benign ECG finding in young adult athletes. Few data exist on ERP in the pediatric athletes population. Therefore, we aimed to evaluate the ERP prevalence, characteristics, and prognosis in pediatric athletes aged ≤16 years.

METHODS AND RESULTS: Eight-hundred eighty-six consecutive pediatric athletes engaged in 17 different sports (mean age, 11.7±2.5 years; 7–16 years) were enrolled and prospectively evaluated with medical history, physical examination, resting and exercise ECGs, and transthoracic echocardiography during their preparticipation screening. Known cardiovascular diseases associated with sudden cardiac death was considered exclusion criteria. Athletes were followed up yearly for 4 years. The prevalence of ERP was 117 (13.2%), equally distributed in both sexes (P=0.072), irrespectively of body mass index and classification of sports. The most common ERP localizations were inferolateral and inferior leads (53.8% and 27.3%, respectively). Notching J-point morphology was the most prevalent (70%), and rapidly ascending ST elevation (96%) was the most common ST-segment morphology. Athletes with ERP were older (P<0.001) had lower rest and recovery heart rates (P<0.001), increased precordial and limb R-wave voltages (P<0.001), increased R/S Sokolow index (P<0.001), and longer PR interval (P=0.006) in comparison with the athletes without ERP. Neither major cardiovascular nor arrhythmic events, nor sudden cardiac death were recorded over a median follow-up of 4.2 years. One hundred seventeen (80.3%) athletes with ERP exhibited a persistent ERP. ERP localization and J-point morphology changed during follow-up in 11 (11.7%) and 17 (18%) of athletes, respectively.

CONCLUSIONS: ERP is common in pediatric athletes. It was mostly located in the inferolateral leads and associated with concave ascending ST segment with other training-related ECG changes. The lack of either sudden cardiac death or cardiomyopathies linked to sudden cardiac death over follow-up suggests that in pediatric athletes, ERP may be considered a benign training-related ECG phenomenon with a potential dynamic pattern.

Key Words: early repolarization pattern ■ pediatric athletes ■ preparticipation screening ■ sudden cardiac death

The early repolarization pattern (ERP) has long been considered a benign phenomenon frequently found in elite athletes.[1,2] However, recent studies have challenged this evidence in both the general population and in athletes showing an increased risk of sudden cardiac death (SCD), particularly in those with either inferior or inferolateral ERP ≥2 mm and in those with ERP associated with a horizontal/descending ST segment.[3,4]

The prevalence of ERP in adult athletes is several folds higher than in the general population, ranging from 14% to 44%, especially in those participating in endurance sports.[5–7]

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CLINICAL PERSPECTIVE

What Is New?

- Early repolarization pattern is a common finding in pediatric athletes, and is mostly located in inferolateral leads.

What Are the Clinical Implications?

- In pediatric athletes, early repolarization pattern may be considered a benign pattern with dynamic characteristics.

Nonstandard Abbreviations and Acronyms

ERP	early repolarization pattern
PPS	preparticipation screening
SCD	sudden cardiac death

Little evidence exists about the clinical features and prognosis of ERP in pediatric athletes, in which the prevalence ranges from 17% to 36%.[8] Furthermore, it is unclear whether ERP in this population represents a dynamic ECG abnormality that potentially varies not only with training but also with growth and pubertal sprout.

In 2016, the Scientific Statement from the American Heart Association on ERP underlined the need for large-scale studies to determine the characteristics and the long-term outcomes of ERP.[5]

The past few years have seen a significant rise in pediatric athletes competing at different levels and therefore undergoing preparticipation screening (PPS). Therefore, this present prospective study aimed to investigate the prevalence, characteristics, and prognosis of ERP in pediatric athletes aged ≤16 years undergoing PPS.

METHODS

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Population

We prospectively enrolled pediatric athletes of both sexes, aged 7 to 16 years, undergoing PPS at the University of L'Aquila (L'Aquila, Italy) and at the Cardiocentro Ticino (Lugano, Switzerland) between January 2014 and December 2018. Known cardiovascular diseases associated with SCD were considered exclusion criteria. Written informed consent was obtained either from the athlete or from a parent or from a guardian when required. The research protocol was approved by the institutional review board at Cardiocentro Ticino.

General Schedule

All athletes underwent PPS comprising family and medical history, physical examination based on the American Heart Association's 14-point protocol, 12-lead resting ECG, exercise stress testing, and transthoracic echocardiography.[9]

The need for a second-level investigation was determined by the screening physician when suggested by clinical examination, ECG, and echocardiography in accordance with national and international guidelines. Sports were classified in 4 groups of training-related cardiovascular adaptation according to the categorization proposed by the Italian Federation of Sports Medicine.[10]

Rest and Exercise 12-Lead ECGs

ECGs were recorded at rest and during exercise stress testing using a standard 12-lead position and a digital caliber for measurements. Two independent, blinded sport medicine physicians (G.H. and B.C.) interpreted the ECG tracings, which were reviewed by a blinded cardiologist in case of disagreement. ERP was defined as an elevation of the QRS-ST junction (J-point) by ≥0.1 mV usually associated with a late QRS slurring, notching (J wave), or discrete QRS complex in at least 2 contiguous leads.

The morphology of the J-point was classified as notched when a sharp and well-defined hump (Jp) was noted immediately after the R wave (Jo), slurred was defined as gradual transition from the R wave of the QRS complex (Jp) into the ST segment with upright concavity toward Jt, and discrete QRS complex was defined as ERP after the ECG signal returns to baseline.[11]

The ST segment following the J-point was coded either as ascending, namely rising gradually toward the peak of the T wave, or descending, downsloping gradually toward the T wave, or horizontal. The predominant J-point and ST-segment morphology were described for each ERP localization. Heart rate, P-wave duration, PR interval, QRS duration, and QT interval (in lead II), R and S amplitude were measured. QT interval was corrected for heart rate by Bazett formula.

ECG findings were classified as normal, borderline, or abnormal according to the international ECG criteria.[2]

Transthoracic Echocardiography

Two-dimensional transthoracic echocardiography was performed in all subjects by experienced sport medicine physicians using a commercially available system

(Vivid-I, General Electric; E Cube 7, Alpinion Medical Systems, Seoul, Korea; or CX 50, Philips). Standard views were obtained, and dimensions of cavities and wall thickness measurements as well as pulsed color and tissue Doppler measurements were made in accordance with established guidelines.[12]

Diagnosis of arrhythmogenic cardiomyopathy was based on the 2010 Modified Task Force criteria.[13]

Hypertrophic cardiomyopathy required echocardiographic demonstration of left ventricular (LV) wall thickness for body-surface area >2 SDs different from the value for a normal population of infants, children, and adolescents with similar body-surface area or the presence of localized LV hypertrophy.

Dilated cardiomyopathy was considered in individuals with a dilated left ventricle (end-diastolic dimension *Z* score >2) and depressed ventricular function (LV fractional shortening *Z* score <–2 or LV ejection fraction >2 SD below normal for age).[14]

Follow-Up by Preparticipation Screening

The Italian Federations of Sports considers yearly PPS mandatory for participation in competitive sports.[15] Therefore, athletes were prospectively followed up yearly from January 2015 until September 2019 with PPS. Seven athletes were lost at follow-up. Data records from the PPS were retrospectively evaluated. Those data included physical examination, new-onset symptoms, rest and stress ECG, and further transthoracic echocardiography second-level examinations when required by the screening physician. The above data and cardiovascular events are recorded in each athlete's file, thus reducing sources of bias and confounders.

Statistical Analysis

We used descriptive statistics to assess the distribution of all variables. Continuous variables were reported as mean±SD, and categorical variables were reported as absolute numbers and percentage. We compared quantitative variables using the Student *t* test and categorical variables using either χ^2 test or Fischer exact test. One-way ANOVA was applied to assess statistical differences between the means of >2 groups with Bonferroni post hoc test correction. A 2-sided rounded *P* value of <0.05 was considered statistically significant for all analyses. SPSS version 21.0 (IBM, Armonk, NY) was used for the statistical analysis.

RESULTS

Study Sample and Baseline PPS Results

We enrolled 886 consecutive pediatric White athletes aged 11.7±2.5 years engaged in 17 different sports. The athletes were mostly men (642, 72.5%), largely asymptomatic (808, 91.2%), and predominantly (191, 21.5%) engaged in sports classified as mixed and endurance for 6.35±2.2 hours per week. The most common abnormality on physical examination was a systolic heart murmur ≥2/6 (n=19, 2.1%).

ERP prevalence was 13.2% (n=117), irrespective of body mass index, classification of sports, and without gender-specific distribution (*P*=0.072) (Table).

At baseline evaluation, 7 athletes (0.79%) were diagnosed with pathologies at risk for SCD in the group without ERP (ERP–): 3 were diagnosed with Wolf-Parkinson-White syndrome, 1 was diagnosed with type-1 long-QT syndrome, 2 were diagnosed with moderate/severe Ebstein anomaly, and 1 patent was diagnosed with Botallo duct with LV dilation. The diagnostic process of these conditions is detailed in Table S1.

None of the athletes with ERP on the 12-lead ECG (ERP+) was diagnosed with cardiovascular disease associated with SCD during baseline evaluation.

ERP Localization and Morphology

Overall, ERP was largely located in inferolateral leads (63, 53.8%) followed by inferior leads (45, 39%) and lateral leads (9.5%). In 93 male athletes with ERP+, the inferior localization (32, 34%) was more prevalent in comparison with 24 female athletes with ERP+ (3, 12%). In the latter, ERP was more common in the lateral leads (5, 21%), whereas only 6 (6%) male athletes exhibited ERP in these leads (Figure 1).

The notching J-point morphology was the most frequent both in male and female athletes (66, 71% and 16, 67%, respectively). The rapidly ascending ST elevation was the most common ST-segment morphology (121, 96%) without gender-specific distribution (Figure 2).

Baseline Comparison of ERP+ and ERP– Athletes

ERP+ athletes were older than ERP– athletes (12.5±2.2 versus 11.6±2.6, *P*<0.001). ERP+ athletes had lower rest and recovery heart rates (75.0±11.3 versus 84.0±15.3, *P*<0.001), increased precordial and limb R-wave voltages (20.8±5.3 versus 17.6±5.2, *P*<0.001), increased R/S Sokolow index (35.4±7.6 versus 30.0±7.8, *P*<0.001), and longer PR interval (141.9±23.4 versus 136.1±20.1, *P*=0.006) in comparison with the athletes without ERP (ERP–) (Table). No exercise-induced arrhythmias were detected during exercise stress testing in ERP+ athletes.

Description of ERP Subgroups

Among athletes with ERP, there were differences in various clinical and ECG variables according to ERP

Table. **Demographic and Clinical Baseline Characteristics**

Parameter	All, n=886	ERP+, n=117	ERP–, n=769	*P* value
Demographic characteristics				
Age, y	11.7	12.5±2.2	11.6±2.6	<0.001
Male sex	642	93 (79.5)	550 (71.5)	0.072
Body mass index, kg/m^2	20	20.1±2.8	20.0±3.7	0.786
Endurance sport	191	32 (27.4)	169 (22)	0.196
Symptoms	7 (0.8)	1 (0.8)	6 (0.7)	0.90
Physical examination abnormalities	22 (2.4)	3 (2.5)	19 (2.47)	0.98
Family history of CVD	24 (2.7)	5 (4.2)	19 (2.4)	0.25
Resting 12-lead ECG				
HR, bpm	76±13	67.8±9.5	77.1±13.2	<0.001
P duration, ms	93.9±14.4	95.4±17	93.7±14	0.267
PR interval, ms	124±16.7	141.9±23.4	136.1±20.1	0.006
QRS duration, ms	92.2±10.4	88.3±9.1	92.9±10.5	<0.001
Sokolow index, mV	30.8±7.9	35.4±7.6	30.0±7.8	<0.001
Maximal precordial R, mV	18.9±3	20.8±5.3	17.6±5.2	<0.001
Limb leads QRS voltage, mV	15.4±7.1	22.1±9.1	14.2±6	<0.001
QTc interval, ms	426.4±19.6	417.2±21	427.8±19	<0.001
Sinus arrhythmia	45 (5.9)	0 (0)	45 (5.9)	0.007
Incomplete RBBB	87 (9.8)	14 (12)	73 (9.5)	0.402
RVH-ESC	10 (1.12)	2 (1.7)	8 (1)	0.629
Juvenile T-wave pattern	195 (22)	18 (15.4)	177 (23)	0.063
Stress ECG				
Peak HR, bpm	155±16	159.3±18	154.0±16	0.003
Recovery HR, bpm	83±15	75.0±11.3	84.0±15.3	<0.001
Recovery QTc, ms	412±26	407.5±23.2	414.0±26.1	0.007

The table reports the comparison between ERP+ and ERP– pediatric athletes. CVD indicates cardiovascular disease; ERP, early repolarization pattern; HR, heart rate; RBBB, right bundle branch block; and RVH-ESC, right ventricular hypertrophy according to ESC ecg criteria.

localization (Table S2). Post hoc tests showed that athletes with anterior ERP had higher mean age (13.8±1.7 years, *P*=0.016), longer PR interval (159.9±10.3, *P*=0.008), and higher peak heart rate during stress ECGs (175.6±14.2, *P*=0.0046). Similarly, inferior ERP was associated with higher body mass index (21.4±2.8, *P*=0.004), whereas inferolateral ERP had higher QTc interval (421.6±19.3, *P*=0.042) (Table S2).

Among athletes with ERP with different J-point morphology, subjects with discrete notch had longer PR interval (152.4 ms versus 145.1 ms versus 128.4 ms, *P*<0.001), higher peak (177 bpm versus 157 bpm versus 158 bpm, *P* 0.007), and higher recovery heart rate (87 bpm versus 77 bpm versus 73 bpm, *P* 0.004) as compared with athletes with slurring and notching J-point, respectively (Table S3).

Follow-Up Data

Over a mean follow-up period of 4.2 years, during which athletes continued to train, none of the ERP+ athletes experienced major cardiovascular events, major arrhythmic events, and SCD. Moreover, none of the ERP+ athletes was diagnosed with a structural heart disease.

Among the 117 ERP+ athletes at baseline, 94 (80.3%) exhibited this pattern over the entire follow-up (persistent ERP) (Figure 3A).

In athletes with persistent ERP, we observed a change in localization in 11 (11.7%) athletes, whereas 17 (18%) athletes presented a different J-point morphology and 2 (2.1%) a distinct ST morphology (Figure 3B).

In this subgroup, the most common localization of ERP was in inferolateral leads (40, 42.5%) and inferior leads (35, 37.2%), the most frequent J-point morphology was QRS notching (60, 63.8%), whereas QRS slurring and discrete notch were both detected in 18% of athletes.

Four athletes with persistent ERP underwent further examination (Holter and cardiac magnetic resonance imaging) for isolated premature ventricular contractions during the stress test at follow-up, and no pathological findings were demonstrated.

Among ERP– athletes at baseline, 18 (2.3%) manifested this pattern over the following PPS visits, mainly

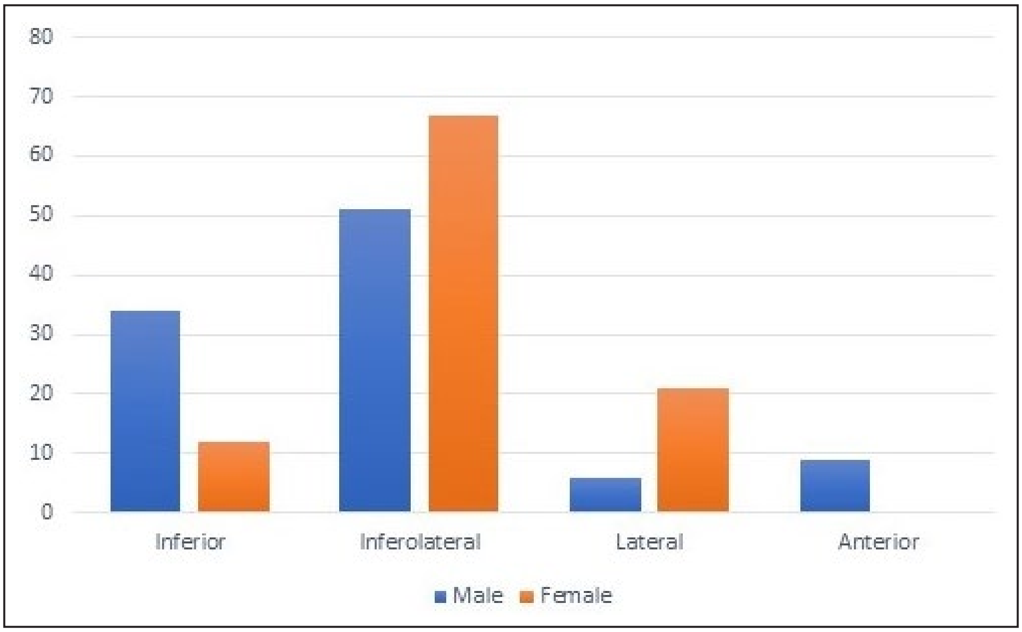

Figure 1. Early repolarization distribution according to lead localization (n=117).

located in inferolateral leads (10, 53%) and inferior leads (6, 37%), with notch morphology in 89% of athletes. In this subgroup without ERP at baseline, 7 (0, 79%) athletes were restricted from competitive sport during the baseline evaluation. No ERP– athletes were restricted from competitive sports during the following PPS visits.

DISCUSSION

To the best of our knowledge, this is the first study that investigated ERP and provided follow-up in a cohort of White pediatric athletes competing at local and national level in various sports disciplines. We found that ERP is a common and potentially dynamic ECG finding in pediatric athletes and is frequently associated with other training-related ECG changes, carrying a benign prognosis over a median 4.2 years follow-up.

The cutoff age of 16 years was chosen to discriminate the pediatric population. Actually, the most recent ECG interpretation recommendations (2017 international recommendations) have been developed in athlete cohorts with the majority of subjects aged ≥16 years (85.5%), although these are addressed for athletes aged 12 to 35 years.[2]

ERP Prevalence in Pediatric Athletes

Although ERP is common in young adult athletes (aged <35 years), particularly in those who practice

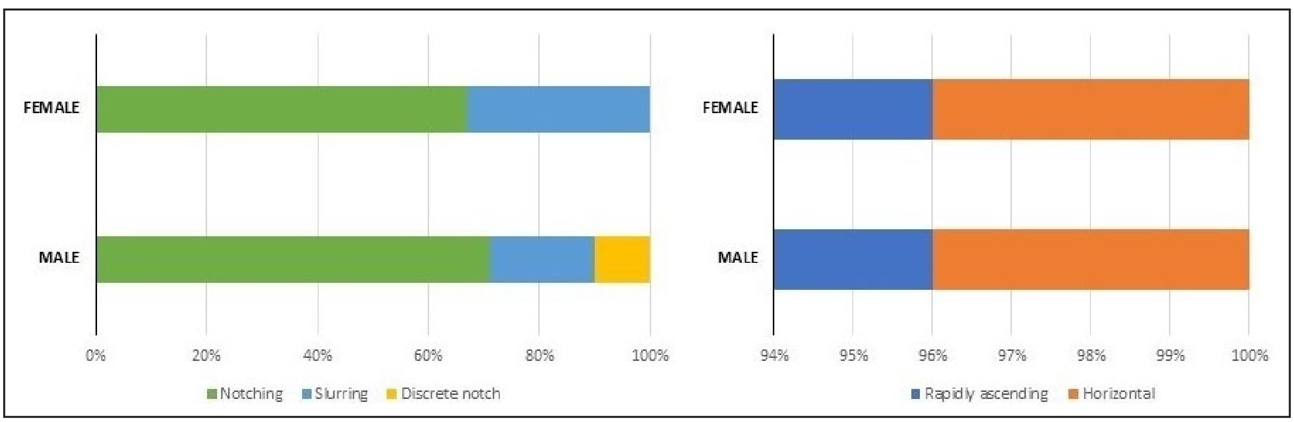

Figure 2. Early repolarization distribution of morphology according to J-point and ST segment (n=117).

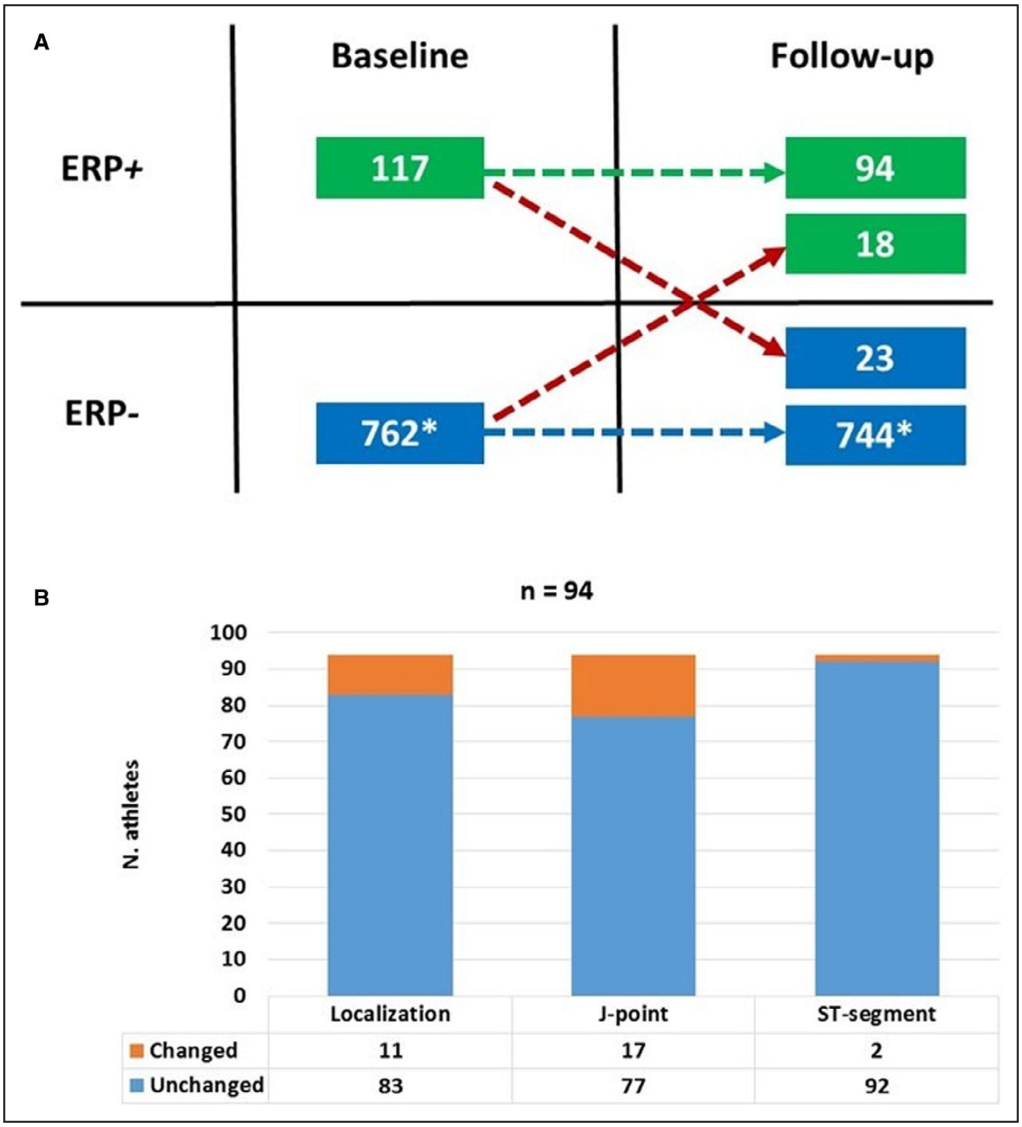

Figure 3. Follow-up data of the prevalence, localization, and morphology of the early repolarization pattern (ERP).
A, Changes in prevalence of ERP+ and ERP− at baseline and at the end of the follow-up. **B**, Changes in localization and morphology of patients with ERP+ at baseline and with persistent ERP.

endurance sports, few data about prevalence of this ECG pattern exist in pediatric athletes. The prevalence of ERP in our study was 13.2%, which was lower than that reported by McClean et al, which showed an ERP prevalence of 25.6% to 49.2% in pediatric athletes aged 13.8±1.3 years.[16] However, ERP prevalence varies across cohorts of athletes aged ≤16 years at between 17% and 49% based on sex, race, and type and level of sports practiced.[17,18]

Similarly, the prevalence of ERP is highly variable in nonathlete children, ranging from 5% to 13% and up to 40%, because of the difference in definitions and referral populations.[19–21] Therefore, in the absence of a control group of nonathlete children, we cannot ascertain whether the prevalence in our cohort is higher than the reported prevalence in the reference general pediatric population.

Furthermore, considering similar training hours per week, we assumed that our cohort differed in prevalence from that previously reported because of a broader variety of practiced sports and absence of Black athletes who exhibit the highest prevalence of ERP.[22]

Previous studies in community-based general populations and young adult athletes showed a significantly higher prevalence of ERP in men than women, suggesting that the presence of ERP is strongly associated with age and sex.[23,24]

Different from young adult athletes, in our study there was a higher prevalence of ERP in male athletes, but this was not statistically significant.

This fact may be attributable to the higher testosterone levels in adult men and supports the androgen hypothesis explaining the gender differences in ventricular repolarization by a strong influence of androgen hormones.[25]

Notably, Surawicz et al found that ERP prevalence was similar in both castrated men and virilized women, strengthening the androgen hypothesis.[26]

Electrocardiographic Features Associated With ERP

Numerous studies have shown that ERP is independently associated with other training-related ECG changes in young adult athletes such as left ventricular hypertrophy, sinus bradycardia, and incomplete right bundle branch block.[6]

Increased vagal discharge was one of the major predictors of ERP in athletes and in the general population.[27] This may result from the parasympathetic modulation of the electrophysiological properties of the myocardium that leads to augmented regional electrophysiological differences and repolarization dispersion resulting in ST-segment elevation, higher amplitude of J waves, and prominent T waves.[11]

In this regard, sinus bradycardia is mainly present in highly trained endurance athletes, which explains the high prevalence of ERP in this population. Pediatric athletes have less-pronounced training-related ECG changes compared with their adult counterparts, most likely because of lower intensity and shorter time of exposure to sports.[28]

Similar to the adult counterparts, ERP in pediatric athletes was associated with other training-related ECG changes such as rest heart rate, PR interval, Sokolow index, and recovery heart rate. However, we did not find a higher prevalence of ERP in those athletes engaged in endurance sports. Taking into account the questionable clinical significance of the PR-interval difference reported in ERP+ as compared with ERP, overall, these data seem to corroborate the hypothesis that in the pediatric athlete population, ERP may be related to a higher vagal tone.

ERP Localization and Morphology

Previous studies have shown that inferolateral and anterior localization are the most common patterns of ERP both in the general population and young adult athletes.

Isolated inferior and lateral localization are less common, and together account for about 25% of ERP in young adult competitive athletes.[23,29]

De Asmundis et al found, inferolateral leads (18.2%) were the most common localization of ERP in a population of 121 young teen athletes (mean age, 13.5±2.7 years).[18]

Further studies in adolescent athletes confirmed the higher prevalence of ERP in inferolateral leads, ranging from 43% to 48%, followed by inferior and lateral localization.[19]

Our findings are in line with the above mentioned studies confirming that ERP in inferolateral leads was by far the most frequent localization in both sexes (51% and 67% in men and women, respectively). In our study, notched J-point was the most common ERP morphology in both sexes, particularly in male athletes. This evidence is consistent with other studies both in adult elite athletes and in the general population. Female athletes exhibited a higher prevalence of slurring J-point (33% versus 19%), confirming the results of study by Rohel et al in female nonathletes with ERP.[30]

We have also confirmed that ERP with ascending ST segment was the most common pattern, whereas either horizontal or descending ST segments were rare patterns as in the adult counterpart.

We found that the majority of athletes with ERP continued to show this pattern during follow-up, so-called persistent ERP, in accordance with other studies in adult athletes.[31]

Interestingly, 28% of the athlete with persistent ERP showed a change in either localization or in J-point morphology during follow-up. This could be explained by either a higher training load associated with growth or growth itself. No previous studies have shown similar results; therefore, these data require prospective validation and pathophysiological confirmation.

ERP Prognosis

In recent years, several studies have demonstrated an association between inferior and inferolateral ERP localization, as well as specific J-point and ST-segment morphology with an increased risk of SCD in nonathletes.[32,33]

A single case-control study showed an association between inferolateral ERP and SCD in athletes; however, both the definition of ERP used and the fact that controls were not matched for age, sex, and training exposure resulted in an unexpectedly low prevalence of ERP in this study.[3]

Nonetheless, ERP is traditionally considered a benign ECG finding in adult athletes carrying a good prognosis. The lack of either major cardiovascular events, major arrhythmic events, SCD, or diagnosis of structural cardiomyopathies associated with SCD over the 4.2-year median follow-up in our study suggests a benign nature of ERP, even in pediatric athletes without a family history of SCD. We cannot confirm whether the presence of ERP as well as the presence of particular localization and/or morphological pattern may have the same benign prognosis in either the general nonathlete population or in special cohorts such as those referred for symptomatic arrhythmias, resuscitated SCD, and family history of SCD.

Limitations

Given the low rates of SCD in young athletes, the major limitation of the present study is the relatively small sample size. However, no study has prospectively evaluated ERP in this cohort of athletes. Furthermore, our results from a population of White athletes is not generalizable to either the general population or subjects of different racial or ethnic origins. Although our follow-up schedule was comprehensive, it was relatively short. Therefore, we cannot exclude the possibility of adverse clinical consequences occurring over longer time periods. Moreover, we cannot provide data on the maturational status of the pediatric group.

CONCLUSIONS

ERP is a common ECG finding in pediatric athletes without gender-specific distribution different from young adult athletes. In this cohort of athletes, ERP is largely localized in inferolateral leads, and it is frequently associated with concave ascending ST segment as well as with other training-related ECG abnormalities. Importantly, we showed that ERP may be considered a benign ECG pattern with potentially dynamic characteristics in White pediatric athletes.

ARTICLE INFORMATION

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Disclosures

None.

Supplementary Material

Tables S1–S3

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SUPPLEMENTAL MATERIAL

Table S1. Patients diagnosed with abnormalities associated to sudden cardiac death.

Age	Sex	Sport	Abnormal findings at PPS	Examinations	Diagnosis	ECG Findings	2017 International	2010 ESC	Seattle criteria
7	M	Karate	ECG	24h-AECG EST EPS	WPW	Short PR-interval Delta wave	Pathological	Pathological	Pathological
8	M	Soccer	ECG	TTE 24h-AECG EST	Ebstein's anomaly	CRBBB	Normal	Pathological	Pathological
12	F	Track and field	ECG	EST 24h-AECG, EPS	WPW	Short PR-interval Delta wave	Pathological	Pathological	Pathological
12	F	Dancing	ECG	TTE 24h-AECG EST	Ebstein's anomaly	CRBBB	Normal	Pathological	Pathological
14	M	Dancesport	ECG	TTE 24h-AECG Cardiology consultation EST	LQTS-1	Resting QTc 495 ms	Pathological	Pathological	Pathological
16	M	Soccer	ECG	EST 24h-AECG EPS	WPW	Short PR-interval Delta wave	Pathological	Pathological	Pathological
10	M	Basketball	TTE	TEE EST Cardiology consultation	Patent Botallo's duct Mild LV dilatation	Normal ECG	Normal	Normal	Normal

ECG = electrocardiography; EPS = Electrophysiology studies; EST = exercise stress test; F = female sex; LV = left ventricular; M = male sex; SAECG = Signal-averaged electrocardiography; TEE = transthoracic echocardiography; 24h-AECG = 24-hour ambulatory ECG monitoring; CRBB=Complete Right Bundle Branch Block

Table S2. Comparison between pediatric athletes with ERP according to lead localization.

Parameter	Inferior (n=35)		Inferolateral (n=63)		Lateral (n=11)		Anterior (n=8)		p-value
	Mean	±sd (%)	Mean	±sd (%)	Mean	±sd (%)	Mean	±sd (%)	
Demographic characteristics									
Age, years	13.2	± 1.9	12	± 2.2	11.9	± 2.4	13.8	± 1.7	0.016
Male gender	32	(91.4)	47	(74.6)	6	(54.5)	8	(100)	0.017
Body mass index, Kg/m²	21.4	± 2.8	19.3	± 2.7	19.5	± 2.5	20.9	± 2.1	0.004
Endurance sport	6	(17.1)	19	(30.2)	4	(36.4)	3	(37.5)	0.399
Rest ECG									
Heart rate, bpm	67.4	± 9.1	67.9	± 10.3	70.4	± 7.8	65.5	± 8.1	0.702
P duration, ms	92.5	± 18.2	97	± 15.5	96.5	± 19.1	92.4	± 21.6	0.872
PR interval, ms	142.7	± 18.3	140.6	± 26.8	134	± 17.3	159.9	± 10.3	0.008
QRS duration, ms	88.8	± 11.1	88.9	± 8.1	87.6	± 9.7	82.8	± 6.6	0.303
Sokolow index, mV	35.8	± 6.5	35.7	± 8.3	34.1	± 6.6	32.4	± 7.1	0.681
Maximal precordial R, mV	19.8	± 5.5	21.3	± 5.3	20.7	± 5.0	20.4	± 5.4	0.556
Limb leads QRS voltage, mV	24.1	± 10.7	20.9	± 8.5	21.1	± 8.2	25.5	± 6.4	0.256
QTc interval, ms	413.3	± 19.3	421.6	± 19.3	417.4	± 19.1	398.5	± 32.4	0.042
Sinus arrhythmia									-
Incomplete RBBB	6	(17.1)	5	(7.9)	1	(9.1)	2	(25.0)	0.356
RVH_ESC	2	(5.7)	0	0	0	0	0	0	0.190
Juvenile T-wave pattern	7	(20.0)	10	(15.9)	1	(9.1)	0	0	0.499
Stress ECG									

Peak HR , bpm	160.9	± 17.1	156.4	± 19.0	158.2	± 16.8	175.6	± 14.2	0.046
Recovery HR, bpm	77.9	± 13.1	73	± 10.7	78.2	± 6.8	77	± 10.0	0.052
Recovery QTc, HR	401.6	± 23.6	406.5	± 23.3	416.6	± 18.4	413.8	± 23.5	0.239
TTE									
IVSd, mm	9.1	± 1.4	8.5	± 1.3	7.8	± 1.3	8.1	± 0.9	0.060
EDD, mm	47.4	± 4.3	44.6	± 5.1	42.9	± 5.4	45.6	± 3.3	0.080
PWd, mm	9	± 1.3	8.3	± 1.3	7.6	± 1.6	8.2	± 0.9	0.030

TTE: Transthoracic Echocardiography; IVSd: Interventricularseptal end diastole; EDD: End-Diastolic-Diameter; PWD: Posterior Wall end diastole.

Table S3. Comparison between pediatric athletes with ERP according to J-point morphology.

Parameter	Slurring (n=26)		Notching J-point (n=82)		Discrete notch (n=9)		p-value
	Mean	±sd (%)	Mean	±sd (%)	Mean	±sd (%)	
Demographic characteristics							
Age, years	12.2	± 2.5	12.5	± 2.1	13.6	± 1.6	0.321
Male gender	18	(23.1)	66	(80.5)	9	(10)	0.132
Body mass index, Kg/m²	20.1	± 2.7	20.0	± 2.9	20.7	± 2.3	0.532
Endurance sport	6	(23.1)	22	(26.8)	4	(44.4)	0.455
Rest ECG							
Heart rate, bpm	69.6	± 10.6	67.1	± 9.4	69.1	± 7.5	0.515
P duration, ms	94.0	± 12.0	95.6	± 18.6	96.9	± 15.3	0.710
PR interval, ms	128.4	± 14.9	145.1	± 24.9	152.4	± 14.0	<0.001
QRS duration, ms	89.5	± 8.2	88.2	± 9.7	86.4	± 7.0	0.562
Sokolow index, mV	33.9	± 7.8	36.2	± 7.6	32.4	± 6.7	0.229
Maximal precordial R, mV	19.9	± 4.9	21.3	± 5.4	18.9	± 5.9	0.163
Limb leads QRS voltage, mV	20.8	± 8.6	22.1	± 9.4	26.2	± 6.9	0.163
QTc interval, ms	416.8	± 20.4	418.6	± 21.1	404.8	± 20.3	0.165
Sinus arrhythmia							-
Incomplete RBBB	3	(11.5)	8	(9.8)	3	(33.3)	0.117
RVH_ESC	0	(0)	2	(2.4)	0	(0)	0.648
Juvenile T-wave pattern	5	(19.2)	13	(15.9)	0	(0)	0.378
Stress ECG							
Peak HR , bpm	157.1	± 15.0	158.0	± 19.2	177.3	± 8.6	0.007
Recovery HR, bpm	77.3	± 8.3	73.3	± 10.6	86.9	± 16.6	0.004
Recovery QTc, HR	410.0	± 20.1	405.9	± 24.0	401.4	± 25.0	0.671
TTE							
IVSd, mm	8.4	± 1.5	8.5	± 1.3	9.4	± 1.3	0.361
EDD, mm	43.3	± 5.0	45.5	± 5.0	48.3	± 1.7	0.089
PWd, mm	8.2	± 1.8	8.4	± 1.2	9.4	± 0.5	0.137

TTE: Transthoracic Echocardiography; IVSd: Interventricularseptal end diastole; EDD: End-Diastolic-Diameter; PWD: Posterior Wall end diastole.