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Abstract

Background—Inferior lead early repolarization pattern (ERP) has recently been associated with sudden cardiac death. Although ERP is common among athletes, prevalence, ECG lead distribution, clinical characteristics, and effects of physical training remain uncertain. We sought to examine the non-anterior early repolarization pattern (ERP) in competitive athletes.

Methods and Results—ERP was assessed in a cross-sectional cohort of collegiate athletes (n=879). The relationship between ERP and cardiac structure were then examined in a longitudinal subgroup (n=146) before and after a 90-day period of exercise training. ERP was defined as J-point elevation $\geq$ 0.1 mV in at least two leads within a non-anterior territory (inferior [II, III, aVF] or lateral [I, aVL, V4-V6]). Non-anterior ERP was present in 25.1% (221/879) of athletes including the inferior subtype in 3.8% (33/879). Exercise training led to significant increases in the prevalence of ERP and the inferior subtype but there were no associations between ERP and echocardiographic measures of left ventricular remodeling. In a multivariable model, ERP was associated with black race (OR 5.84, CI 3.54-9.61, p<0.001), increased QRS voltage (OR 2.08, CI 1.71-2.52, p<0.001), and slower HR (OR 1.54, CI 1.26-1.87, p<0.001).

Conclusions—Non-anterior ERP including the inferior subtype are common and have strong clinical associations among competitive athletes. The finding of increased ERP prevalence following intense physical training establishes a strong association between exercise and the ERP.

Keywords

exercise; electrocardiography; electrophysiology athlete's heart; early repolarization

Introduction

Since its initial description nearly seventy-five years ago,[1] the early repolarization pattern (ERP) has been considered a normal variant.[2-4] However, emerging evidence from case-control[5, 6] and prospective cohort[7] studies suggest that ERP in the inferior leads is associated with an increased risk of sudden cardiac death (SCD).

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Conflict of Interest Disclosures: None

The prevalence, clinical associations, and underlying mechanisms of this potentially malignant ERP subtype remains largely unstudied in young competitive athletes. Although SCD in athletes is relatively rare, it is an important clinical problem with devastating impact on families and communities. Valuable athlete SCD registry data have shown that the majority of athlete SCD is attributable to cardiac causes but that an identifiable cardiac disorder is absent roughly one third of the time.[8] Mechanisms and markers of electrical instability in the absence of identifiable heart disease are lacking in this population.

It is well established that ERP is more common among young athletes (prevalence estimates of 20 to 90%) than in the general population.[6,9] However, the recently identified and potentially malignant inferior ERP pattern has not been thoroughly examined in this population. Further, there are no available longitudinal data documenting the impact of exercise training on ERP. Accordingly, we conducted the current study to examine the prevalence, ECG lead distribution, clinical characteristics, effect of physical training, and structural LV parameters associated with ERP and the inferior subtype in young competitive athletes.

Methods

Study design

We utilized cross-sectional and prospective longitudinal study designs to examine specific aspects of ERP in competitive athletes. A large cross-sectional cohort comprised of competitive collegiate athletes was recruited to examine the demographic and clinical features associated with the presence of ERP. A sub-group of this cohort was studied in a prospective and longitudinal fashion to examine the effects of exercise training and exercise-induced cardiac remodeling on ERP.

Study subjects

Athletes enrolled in the Harvard Athletics Initiative, an on-going effort designed to address numerous aspects of student-athlete cardiovascular health, were studied. For the present study, male and female student athletes 18 years old who were official participants in competitive inter-collegiate athletics were enrolled between 2006 and 2010. Written informed consent was obtained from all participants before involvement. The Harvard University Institutional Review Board and the Partner's Healthcare Human Research Committee approved the protocol before study initiation.

Study protocol

The cross-sectional cohort consisted of newly matriculated student athletes who were recruited for participation in varsity-level (intercollegiate) competitive athletics. Participants were enrolled and studied during pre-participation screening sessions as previously reported.[10] This study excluded individuals with any cardiovascular disease that was detected during screening or previously known. Height, weight, resting vital signs, medication use, and personal/family medical history were obtained. Prior exercise training history was elicited by questionnaires and was confirmed by training logs. Exercise training history spanned the eight weeks prior to enrollment and was quantified as hours per week engaged in either endurance or strength training as previously detailed.[11,12] A resting 12-lead electrocardiogram (ECG) was obtained in each participant.

A sub-group of participants were studied longitudinally to examine the impact of exercise training on ERP prevalence and to assess the relationship between ERP and exercise-induced cardiac remodeling. This subgroup included male rowers and football players. These 2 athlete groups were chosen based on previously published data which documented

sport-specific cardiac remodeling among these forms of endurance- (rowers) and strength- (football players) trained athletes using a similar study design.[12] Each athlete was studied with 12-lead electrocardiography and echocardiography before and after a 90-day session of team-based training and competition. Detailed records of exercise training during this 90-day study period were recorded.

Clinical Follow-up

All athletes in both the cross-sectional and longitudinal cohorts have been followed prospectively from the time of enrollment for the occurrence of adverse cardiac events. This follow-up period captured each individual's participation in organized intercollegiate athletics, the critical time period during which sport-related adverse outcomes would be most likely to occur. Because enrollment occurred over 4 consecutive years, follow-up duration was variable. No participants were lost to clinical follow-up.

Twelve-Lead ECG adjudication

Electrocardiography was performed using standard 12-lead placement and equipment (MAC 5500, GE Healthcare, Milwaukee, Wisconsin). Individuals were studied in the supine position after >5 minutes of quiet rest. ECGs were adjudicated by two independent reviewers who were blinded to all subject characteristics. In ambiguous cases, final adjudication was achieved by consensus with a third reviewer. Early repolarization within a single lead was defined as elevation of the J-point (offset of QRS complex) of at least 0.1 mV. The amplitude of J-point elevation was semi-quantitatively coded as 0.1mV-<0.2mV or ≥0.2mV. Reviewers categorized the presence of ERP in each of the twelve leads separately and then by territory (anterior [V_1-V_3], inferior [II, III, aVF], lateral [V_4-V_6,I, aVL]). In order to be consistent with prior studies,[5-7] anterior lead (V1-V3) early repolarization was recorded, but was not included in the definition of an ECG that was positive for ERP to avoid confusion with the Brugada syndrome. The ECG was considered to exhibit the ERP if early repolarization was present in at least two leads within a non-anterior territory (inferior [II, III, aVF] or lateral [V_4-V_6,I, aVL]).

The morphology of the J-point was coded as notched (positive J deflection), slurred (terminal QRS slurring), discrete notched (notch is observed after signal return to baseline), or discrete (early repolarization after signal return to baseline). The ST segment was coded as ascending (after the J-point, signal ascends gradually until the peak of T-wave), descending (after the J-point, signal descends gradually until the T-wave), or horizontal (before T-wave, signal is horizontal). The predominant J-point and ST segment morphology were classified for each territory. Representative examples of these morphologies are shown in Figure 1.

Other ECG measurements included PR interval, QT interval, heart rate-corrected QT interval (Bazett's correction), mean heart rate, and QRS duration. QRS amplitude was recorded as a continuous variable using the Sokolow-Lyon index (S in V_1 + R in V_5 or V_6 [whichever is greater]).[13] Left ventricular (LV) hypertrophy was recorded as a dichotomous variable as defined by a Sokolow-Lyon index ≥ 3.5mV. Presence of right bundle branch block (RBBB, defined as QRS complex ≥ 0.12 msec in duration with an rSR' morphology in lead V_1 and a qRS in lead V_6), incomplete RBBB (IRBBB, defined as a RBBB morphology with a QRS duration of > 0.1 msec and < 0.12 msec), or left bundle branch block (LBBB, defined QRS complex ≥ 0.12 msec in duration with QS or rS complex in lead V_1 and a monophasic R wave in leads I and V_6) were noted.

Echocardiography

Echocardiography was performed using a commercially available system (Vivid-I, GE Healthcare, Milwaukee, WI) with a 1.9–3.8-mHz phased-array transducer. Participants were imaged at rest >12 h after the most recent training session. Imaging was performed to facilitate structural measurements and assessment for the presence of occult pathology of relevance to sport participation risk.[10] Two-dimensional imaging was performed from standard parasternal and apical transducer positions with frame rates of 25–100 frames/s by trained sonographers. Each sonographer performed both baseline and post-study imaging on the same individuals. Cardiac structural measurements were made according to current guidelines.[14] LV mass was estimated using the area-length formula and LV volumes were estimated using Simpson's biplane technique. Relative wall thickness was calculated using the formula: [(septal thickness + posterior wall thickness) / left ventricular internal diameter at end diastole]. All data were stored digitally and post-hoc analyses were performed by cardiologists blinded to study time point (EchoPac, version 7.0, GE Healthcare).

Statistical analysis

In the cross-sectional cohort, the prevalence with 95% confidence intervals and clinical correlates of ERP and the inferior subtype were examined. A chi square test was performed to examine if the prevalence of ERP and the inferior subtype were distributed differently across sport types. Clinical characteristics were compared by ERP status (ERP positive vs. ERP negative, and inferior subtype ERP positive vs. ERP negative) using Fisher's exact test for dichotomous covariates and T-test for independent samples for continuous variables. Univariable binary logistic regression models were used to test for association of clinical characteristics that differed based on ERP status (ERP positive vs. ERP negative, and inferior subtype ERP positive vs. ERP negative). A multivariable model was then built (forward stepwise selection) to determine the factors associated with ERP and specifically the inferior subtype using the significant covariates identified by univariable regression (threshold for entry and retention in the model $p < 0.05$).

In the longitudinal cohort, clinical and echocardiographic characteristics were compared pre- and post-season to characterize the nature of the training period using a paired-sample T-test. We then assessed changes in the prevalence of ERP and the inferior subtype after exercise training for rowers and football players pooled and by individual sport using McNemar's test. Clinical and echocardiographic characteristics were compared pre- and post-season using a paired-sample T test. Echocardiographic characteristics were then compared (ERP positive vs. ERP negative, and inferior subtype positive ERP vs. ERP negative) in order to determine if ERP was associated with particular echocardiographic parameters using independent sample T test. Two-tailed $p < 0.05$ was defined as statistical significance throughout.

Results

Clinical characteristics of cross-sectional cohort

Characteristics of the athletes included in the cross-sectional cohort are shown in Table 1. This group was comprised of 879 athletes (64% male) and included representation from 20 sport types.

Prevalence and characteristics associated with ERP

ERP was present in 221/879 [25.1 % ($CI_{95} = 21.4\text{-}28.9$)] participants and ERP was significantly more common among male athletes (33%) than among female athletes (11%, $p < 0.001$). The inferior ERP subtype was observed in 33/879 [3.8% ($CI_{95} = 2.1\text{-}5.4$)] which accounted for 14.9% of all ERP (Figure 2). The most common morphology of ERP in the

lateral leads was a discrete J-point (101/199 [51%] discrete, 80/199 [40%] discrete notched, 14/199 [7%] notched, and 4/199 [2%] slurred) with an ascending ST segment (197/199 [99%] ascending and 2/199 [1%] horizontal). The most common morphology of ERP in the inferior leads was a notched J-point (19/33 [56%] notched, 10/33 [30%] slurred, 3/33 [9%] discrete notched, and 2/33 [6%] discrete) with an ascending ST segment (18/33 [55%] ascending and 15/33 [45%] horizontal). Marked J-point elevation (>0.2mV) was observed in two or more leads within an inferior or lateral territory in 18/879 (2%) of athletes. Isolated marked J-point elevation in a single lead, however, was more common. For example, isolated marked J-point elevation was observed in lead V4 in 199/879 (22.6%) of athletes.

The prevalence of ERP varied by sport type ranging from 0% to 63% as shown in Figure 3. In chi-square analysis, the variability in ERP prevalence by sport type was driven by lateral ERP (p < 0.001), as the comparatively uncommon inferior ERP did not differ significantly by sport (p = 0.14).

Compared to ERP negative athletes, those with ERP were more likely to be male, black, taller, have slower heart rates and have performed more previous exercise training (Table 2). In addition, those with ERP had longer QRS-complex duration and higher QRS voltage. Athletes with the inferior ERP subtype were also more likely to be black, to have lower heart rates and to have increased QRS voltage compared with ERP negative athletes.

These variables were each considered separately in univariable logistic regression models (Table 3A) and then collectively in a multivariable logistic regression model for association with ERP or the inferior subtype (Table 3B). Multivariable regression demonstrated that male sex, black race, slower heart rate and increased QRS voltage were significant associated with ERP while black race, slower heart rate and increased QRS voltage were significantly associated with the inferior ERP subtype. The covariate with the largest effect (highest odds ratio) on ERP prevalence was black race with odds ratios for ERP of 5.8 (3.54-9.61, p < 0.001) and for the inferior subtype of 21.1 (95% CI 9.1-49.1, p < 0.001, Table 3B).

Characteristics of the longitudinal training cohort

The longitudinal training cohort was comprised of male football players (n = 78) and male rowers (n = 68) as described in table 4. Training during the 90-day study period (football = 19 ± 2 hours/week, crew = 21 ± 1 hours/week) was significantly higher than that experience by the athletes during the 8 weeks prior to enrollment. The football training regimen consisted predominantly of strength training (17 ± 1 hours/week) while the rowers engaged in mostly endurance training (19 ± 1 hours/week). At completion of the training period, football players demonstrated weight gain (219 ± 35 lbs to 223 ± 35 lbs, p < 0.001) and increased blood pressure (systolic from 116 ± 9 to 125 ± 13, p < 0.001; diastolic from 64 ± 11 to 67 ± 11, p = 0.008). In contrast, crew athletes demonstrated a drop in blood pressure (systolic from 114 ± 9 to 112 ± 8, p<0.001; diastolic from 61 ± 9 to 59 ± 8, p=0.006) and a drop in heart rate (62 ±6 to 56 ±4, p < 0.001, Table 4).

Both football players and rowers experienced significant exercise-induced LV remodeling during the 90-day study period (Table 5). Football players experienced concentric hypertrophy as demonstrated by increases in LV mass, wall thickness, and relative wall thickness. LV mass increased by similar magnitude in rowers but was attributable to eccentric LV hypertrophy as characterized by LV chamber enlargement and unchanged relative wall thickness.

ERP and exercise training

The prevalence of ERP and the inferior subtype before and after exercise training is shown in Table 6. At the conclusion of the training period, the prevalence of ERP increased from 37.2% (55/148) to 52.7% (78/148) (p = 0.003). This included a significant increase in the prevalence of the inferior ERP subtype from 4.1% (6/148) to 8.1% (12/148) (p = 0.031). A representative pre- and post- training ECG is shown in Figure 4. There were no significant associations between LV parameters (baseline, post-training, or change from baseline to post-training) and either ERP subtype.

Clinical follow-up

All participants were followed for significant cardiac events for 21 ± 13 months (range 7 to 50 months) during organized intercollegiate sport participation. During this follow-up period, there were no cases of SCD, unexplained syncope, or hospitalization with a cardiovascular diagnosis.

Discussion

Recent studies suggest that ERP, specifically the inferior lead pattern, is associated with an increased risk of cardiac death.[7] This observation is seemingly at odds with the fact that that ERP is particularly common in young, competitive athletes with prevalence estimates ranging from 20-90%.[15-20] To our knowledge, ERP lead distribution in athletes has been addressed in only two prior studies. Specifically, Rosso *et al* utilized a cross-sectional, case-control approach to show that ERP (both inferior and lateral) was more common in young athletes (n = 132) than among sedentary controls but less common than among idiopathic ventricular fibrillation victims.[6] Most recently, Junttila *et al* presented data documenting a non-anterior ERP prevalence of 30% in a sample of 503 collegiate athletes and demonstrated associations between ERP and both male gender and ECG correlates of LV mass.[21]

The present study provides additive information about ERP in competitive athletes. Our data are in accord with the recent report by Junttila *et al* and confirm that a significant percentage of young competitive athletes (~25% in the present study) show ERP in either the inferior or lateral ECG leads. While our data demonstrate that the inferior ERP subtype is comparatively uncommon, we found that it is associated with the same athlete characteristics (ethnicity, heart rate, etc.) as the more common lateral subtype. Importantly, the current study is the first to demonstrate that exercise training is causal in the development of ERP. Specifically, both ERP and the inferior subtype increased in prevalence after intense physical training. Interestingly and somewhat surprisingly, neither ERP nor the inferior subtype was associated with the structural left ventricular measures, including chamber volume or wall thickness, that are well established components of the "athlete's heart." These data suggest that exercise-related ERP may be an isolated electrical phenomenon that develops in parallel but not as a result of structural myocardial remodeling. In aggregate, our data suggest that ERP (including the inferior subtype) is a common finding in young healthy competitive athletes that is a direct result of exercise training.

Mechanistic explanations for the ERP are an area of active investigation but at present remain incompletely understood. In general, ERP is visible on the surface electrocardiogram when adjacent areas of myocardium repolarize at slightly different rates causing intramyocardial current flow and upward displacement of the ST segment.[22] ERP can be thought of as an electrocardiographic signature of repolarization dispersion and can arise in numerous conditions including myocardial injury,[23] extremes of temperature such as hypothermia, local differences in I_{to} current density,[24] and primary heritable disorders (e.g.

mutations in *KCNJ8*,[25] *CACNA1C, CACNB2B*, and *CACNA2D1* [26]). In athletes, it has been proposed that parasympathetic modulation increases regional electrophysiological differences and repolarization dispersion resulting in ST elevation, J-waves, and prominent T-waves.[27] Although this study was not intended to examine mechanisms of ERP, several issues deserve mention. First, the finding that ERP (and the inferior subtype) were more common in bradycardic athletes supports a causal link between an alteration in the autonomic balance favoring parasympathetic dominance and these ERP subtypes. It should be noted, however, that other investigators have found that ST segment elevation is not attenuated by concomitant atropine and propranolol administration.[28] Second, ERP shared no significant associations with any aspect of structural LV remodeling. As such, it appears that while ERP may develop in parallel with structural features of the athlete's heart, it is not clearly caused by exercise-induced LV hypertrophy or dilation.

Findings from the current study have important implications with respect to the care of the athletic patient. Our data demonstrate that non-anterior ERP, including the inferior subtype, is a common characteristic of the healthy athlete ECG and does not indicate an underlying structural abnormality. Thus, when found on an ECG that is obtained during pre-participation screening, preoperative clearance, or routine health maintenance physical examinations in an asymptomatic athlete, ERP should not necessarily mandate further costly diagnostic testing. In addition, practitioners should recognize that ERP is a dynamic process that is more likely to be observed in healthy athletes at times of peak fitness.

Several limitations of this study are noteworthy. First, this study was not adequately powered to assess the relationship between ERP and sudden cardiac death in athletes and thus we cannot make definitive conclusions about this important topic. However, it is noteworthy that no athlete with ERP, including those with the inferior subtype, experienced an adverse cardiovascular event during an average follow-up period of roughly 2 years. This follow-up period is short but included the critical period of safety concern during which athletes were participating in intercollegiate athletics. Second, although we detected no association between ERP and underlying cardiac structure, we acknowledge that the echocardiographic assessment was limited to basic LV parameters. It is possible that ERP may be a reflection of structural features not included in this protocol such as those that define the right ventricle. Finally, we chose to study collegiate athletes, a fairly homogeneous population with respect to age, heart rate, blood pressure, and co-morbid medical conditions thereby limiting power to detect associations between clinical variables and ERP. However, we chose this group as it represents a large percentage of the real world competitive athletic population.

In conclusion, non-anterior ERP including the inferior subtype is common among young competitive athletes. Importantly, the inferior and more common lateral ERP subtypes are associated with similar athlete characteristics and both increase in prevalence with intense exercise training. These data establish a causal link between exercise training and ERP. Further investigation is warranted to fully characterize the prognostic implications of ERP in competitive athletes.

Acknowledgments

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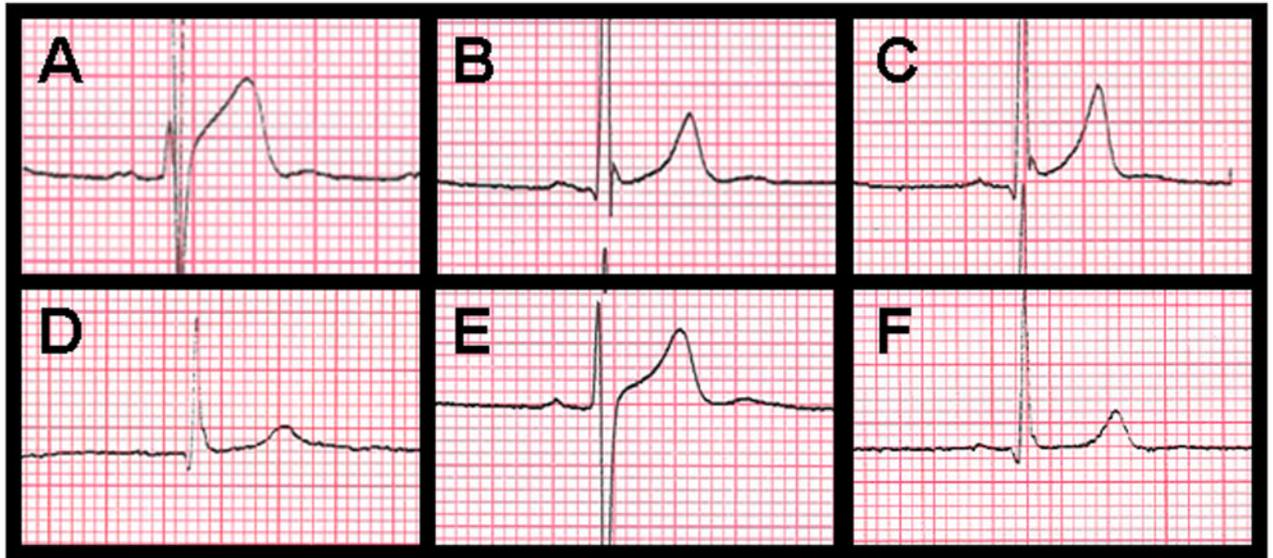
Figure 1.
ERP morphologic classifications: (a) marked ERP (>0.2mV) with discrete J-point and ascending ST segment, (b) discrete notched J-point and ascending ST segment, (c) notched J-point and ascending ST segment, (d) slurred J-point and ascending ST segment, (e) discrete J-point and ascending ST segment (f) slurred J-point and horizontal ST segment.
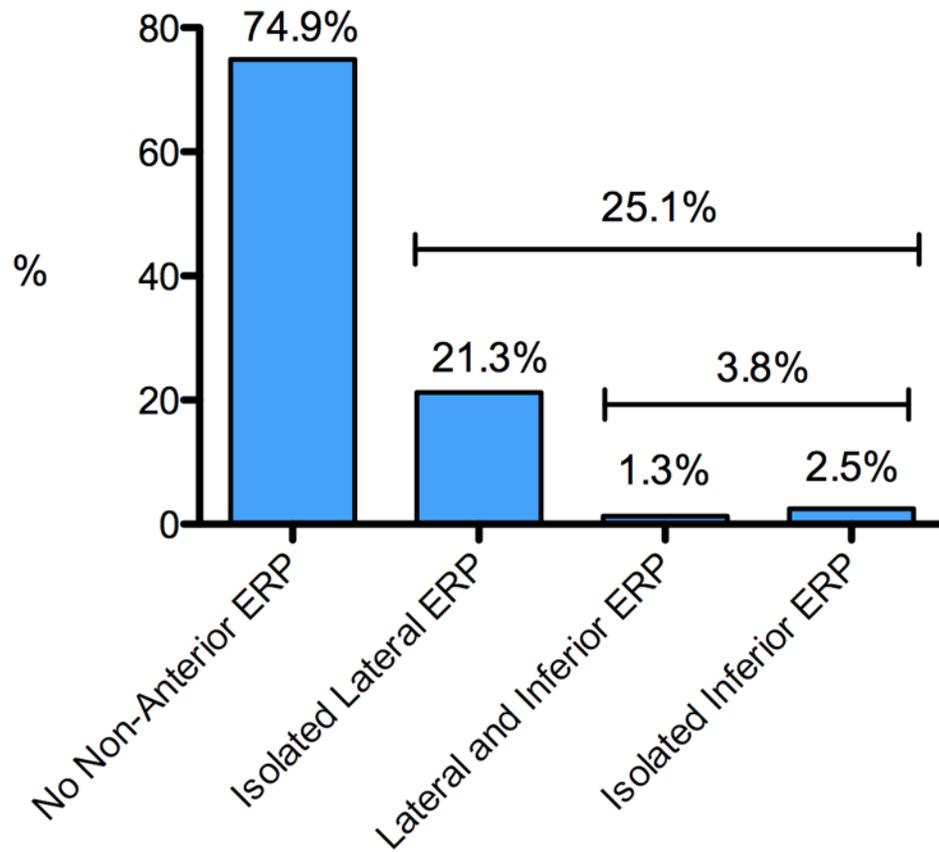
Figure 2.
Prevalence and ECG lead distribution of non-anterior ERP among competitive intercollegiate athletes (n=879).
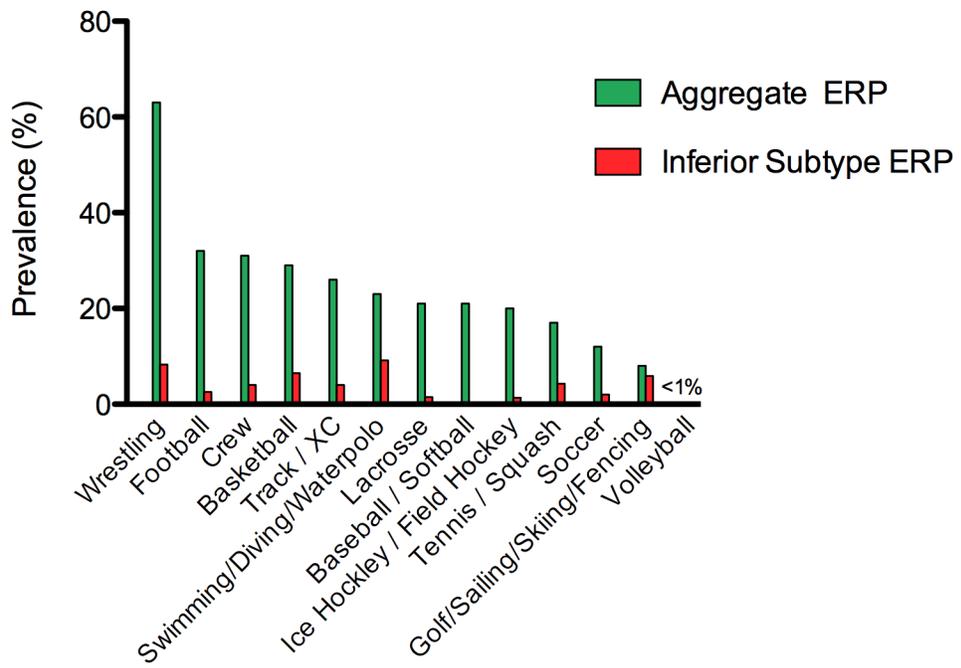
Figure 3.
Prevalence of ERP and the inferior ERP subtype as function of sport type among competitive intercollegiate athletes (n=879).
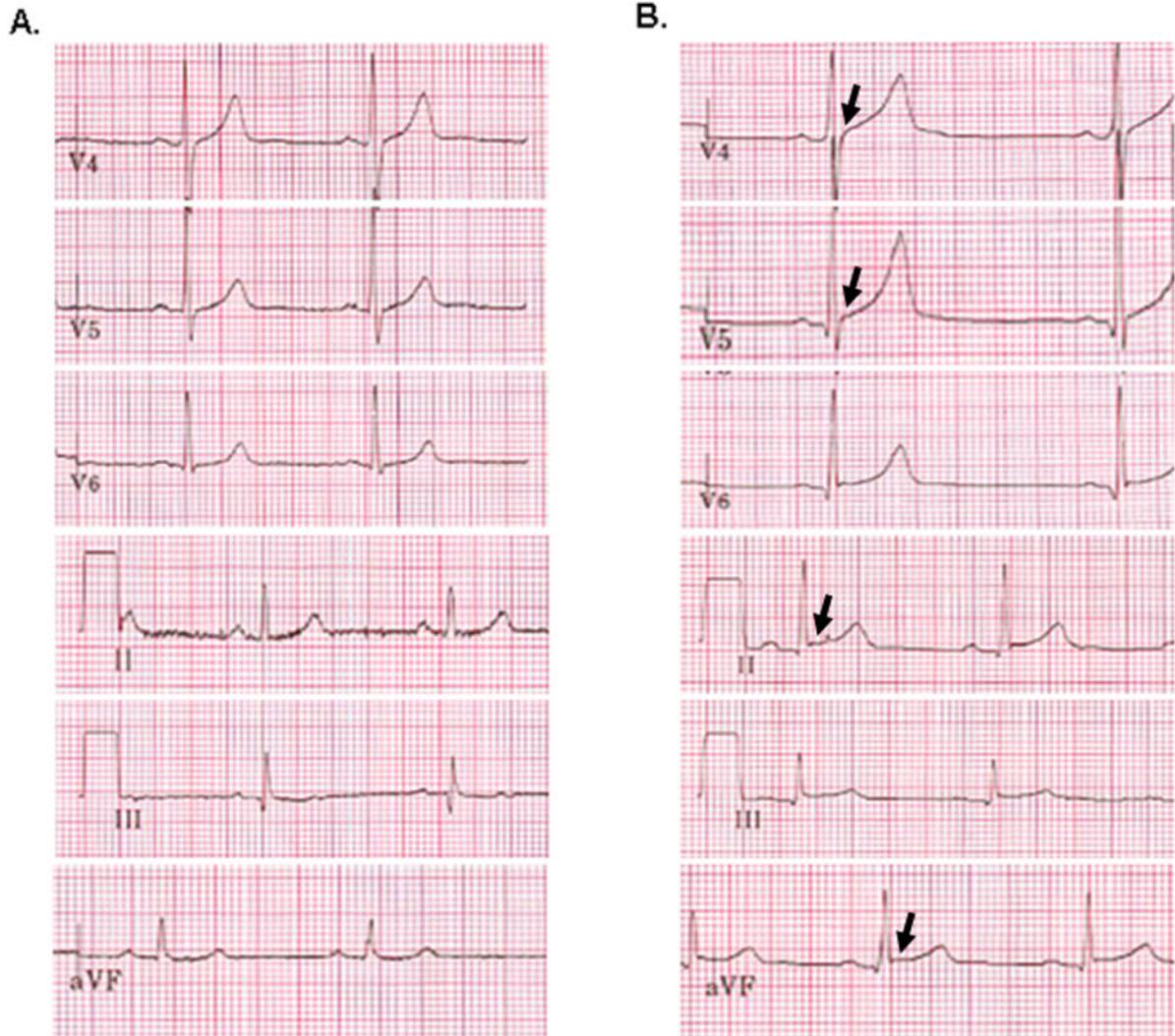
Figure 4.
Lateral (V4-6) and inferior (II, III, aVF) 12-lead ECG leads in a collegiate rower before (A.) and after (B.) 90-days of team-based exercise training demonstrating the development of non-anterior early repolarization pattern (arrows).

Table 1

Characteristics of cross-sectional athlete cohort

	All sports pooled (n = 879)
Demographics	
Age, years	18.4 ± 0.8
Sex, % male	545/879 (62%)
Race	
Caucasian	742 (84.3%)
Black	92 (10.5%)
Asian	36 (4.1%)
Latino	6 (0.7%)
Anthropometrics	
Height, inches	70.2 ± 3.0
Weight, pounds	167 ± 30
BSA, m^2	1.93 ± 0.21
BMI, kg/m^2	23.6 ± 2.7
Clinical data	
HTN	3 (0.3%)
Family history of HTN	42 (7.4%)
Medication use	149 (17%)
Resting HR	60.3 ± 9.7
Systolic BP, mmHg	116.6 ± 8.6
Diastolic BP, mmHg	56.9 ± 11.5
Training volume	
Total, hrs/w	6.7 ± 3.8
Strength, hrs/w	2.9 ± 2.7
Endurance, hrs/w	3.9 ± 2.5
Follow up	18 ± 14

BSA: body surface area, BMI: body mass index, HTN: hypertension, HR: heart rate, BP: blood pressure, hrs/w: hours/week, continuous variables are shown as mean ± standard deviation.

Table 2

Means and SD of covariates by ERP status among pre-season athletes (cross-sectional cohort)

	All sports pooled, preseason (n=879)							
	ERP neg (n = 658)		ERP positive (n = 221)			Inferior ERP pos (n = 33)		
	Mean or N	SD or %	Mean or N	SD or %	p*	Mean or N	SD or %	p*
Demographics								
Age, years	18.4	0.8	18.5	0.9	0.02	18.4	0.8	0.99
Sex, % male	358	54.4%	187	84.2%	<0.001	10	30.3%	0.23
Black, %	36	5.5%	56	25.2%	<0.001	17	51.5%	<0.001
Anthropometrics								
Height, inches	70.0	2.9	71.0	3.0	<0.001	71.0	2.3	0.05
Weight, pounds	165.3	30.6	171.2	29.9	0.12	166.9	23.9	0.75
BMI, kg/m^2	23.5	2.7	23.7	2.6	0.37	23.2	2.0	0.47
Clinical data								
Diastolic BP, mmHg	116.0	8.7	115.7	8.2	0.60	115.3	8.3	0.61
Systolic BP, mmHg	56.4	11.4	58.7	11.4	0.11	60.1	12.5	0.07
ECG data (on post season ECG)								
HR bpm	61.2	9.9	57.5	8.7	<0.001	54.4	8.8	<0.001
PR interval, msec	147.7	19.8	150.8	25.9	0.07	152.6	20.0	0.17
QRS, msec	92.4	11.5	95.1	9.1	0.001	93.6	8.5	0.54
QTc, msec	408.4	24.7	405.8	32.6	0.22	407.8	34.5	0.91
Sokolow-Lyon index, mV	2.81	0.95	3.65	0.98	<0.001	3.51	1.18	<0.001
Sokolow-Lyon index, >3.5mV	142	21.6%	114	51.4%	<0.001	16	48.5%	<0.001
LBBB	0	0.0%	0	0.0%	N/A	0	0.0%	N/A
RBBB	8	1.2%	3	1.4%	0.56	0	0.0%	0.66
IRBBB	60	9.1%	33	14.9%	0.014	0	0.0%	0.023
Training characteristics								
Strength training, hrs	2.8	2.7	3.1	2.8	0.082	2.9	2.7	0.67
Endurance training, hrs	3.8	2.3	4.2	3.0	0.033	3.8	2.4	0.99
Total training, hrs	6.5	3.8	7.3	4.0	0.009	6.3	2.8	0.75
Medical history								

All sports pooled, preseason (n=879)

	ERP neg (n = 658)		ERP positive (n = 221)			Inferior ERP pos (n = 33)		
	Mean or N	SD or %	Mean or N	SD or %	p*	Mean or N	SD or %	p*
HTN	3	0.5%	0	0.0%	0.42	0	0.0%	0.89
FH or HTN	51	7.8%	15	6.8%	0.37	1	3.0%	0.28
Med use	121	18.4%	28	12.6%	0.026	6	18.2%	0.50

ERP includes both lateral and inferior subtypes. BMI: body mass index, BP: blood pressure, HTN: hypertension, FH: family history,

*
compared to ERP negative

Table 3

Covariate relationships to ERP

A. Univariate relationships between subject characteristics and ERP status

| | All sports pooled (univariable model) | | | |
| | ERP | | Inferior ERP subtype | |
	OR	p*	OR	p*
Demographics				
Young age, per year increase	0.80 (0.67-0.96)	0.019	---	---
Sex, male vs. female	4.47 (3.03-6.61)	<0.001	---	---
Black race, vs. non-black	5.83 (3.72-9.15)	<0.001	18.32 (8.60-39.04)	<0.001
Anthropometrics				
Height, per inches	1.12 (1.06-1.18)	<0.001	---	---
ECG data (on post season ECG)				
Heart rate, per 10bpm decrease	1.52 (1.28-1.81)	<0.001	2.32 (1.51-3.56)	<0.001
QRS, per 10 msec	1.26 (1.10-1.44)	0.001	---	---
Sokolow-Lyon index, per mV	2.36 (1.98-2.82)	<0.001	1.92 (1.38-2.67)	<0.001
Sokolow-Lyon index, >3.5mV	3.82 (2.77-5.26)	<0.001	3.45 (1.70-6.97)	0.001
Training characteristics				
Endurance training, per hour	1.07 (1.00-1.13)	0.034	---	---
Total training, per hour	1.05 (1.01-1.09)	0.01	---	---
Medical history				
Medication use	0.64 (0.41-1.00)	0.049	---	---

B. Multivariable model describing associations with ERP status.

| | All sports pooled (multi-variable model) | | | |
| | ERP | | Inferior ERP subtype | |
	OR	p*	OR	p*
Demographics				
Sex, male vs. female	2.21 (1.40-3.47)	0.001	---	---
Black race, vs. non-black	5.84 (3.54-9.61)	<0.001	21.09 (9.07-49.08)	<0.001
ECG data (on post season ECG)				
Heart rate, per 10bpm decrease	1.54 (1.26-1.87)	<0.001	2.41 (1.48-3.93)	<0.001
Sokolow-Lyon index, per mV	2.08 (1.71-2.52)	<0.001	2.44 (1.33-4.46)	0.004

*compared to ERP negative subjects

Table 4

Clinical characteristics of the longitudinal training cohort

	Football (n = 78)		P*	Crew (n = 68)		P*
	Pre-season	**Post-season**		**Pre-season**	**Post-season**	
Age, years	18.7 ± 0.6	---		18.7 ± 0.6	---	
Race		---			---	
Caucasian	56 (71.8%)	---		60 (88.2%)	---	
Black	19 (24.4%)	---		2 (2.9%)	---	
Asian	0	---		6 (8.8%)	---	
Latino	3 (3.8%)	---		0	---	
Height, inches	73.6 ± 2.7	---		73.6 ± 2.7	---	
Weight, pounds	219.1 ± 35.4	223.2 ± 35.2	<0.001	182.7 ± 22.8	183.1 ± 22.7	0.31
BMI	28.3 ± 3.7	28.9 ± 3.7	<0.001	23.6 ± 2.6	23.7 ± 2.5	0.35
HTN	0	---		0	---	
Family history of HTN	21 (26.9%)	---		6 (8.8%)	---	
Medication use	9 (11.5%)	---		9 (13.2%)	---	
Resting HR, bpm	66.6 ± 6.6	66.5 ± 9.7	0.895	61.3 ± 6.3	55.7 ± 4.5	<0.001
Systolic BP, mmHg	116.3 ± 9.0	125.3 ± 13.3	<0.001	114.4 ± 8.7	111.5 ± 8.2	0.002
Diastolic BP, mmHg	64.7 ± 10.8	67.3 ± 10.8	0.008	60.8 ± 9.3	58.7 ± 7.8	0.006
Prior training volume						
Total, hrs/w	9.8 ± 2.4	---		10.9 ± 3.8		
Strength, hrs/w	7.3 ± 2.6	---		2.8 ± 3.0	---	
Endurance, hrs/w	2.6 ± 2.1	---		7.8 ± 4.6	---	

BMI: body mass index, HTN: hypertension, FH: family history, HR: heart rate, BP: blood pressure, hrs/w: hours/week

*
compared to pre-season within a sport

Table 5

Echocardiographic left ventricular measures before and after training

	Football (n = 78)		p[*]	Crew (n = 68)		p[*]
	Pre-season	Post-season		Pre-season	Post-season	
LV function						
LVEF	64.9% ± 6.7%	65% ± 6.6%	0.757	60.2 5.5	59.8 5.4%	0.42
LV mass measurements						
LV mass	222.5 ± 28.6	248.1 ± 35.3	<0.001	217.5 ± 33.1	242.2 ± 34.7	<0.001
LV mass index	98.8 ± 13.6	109.0 ± 15.0	<0.001	104.9 ± 12.4	116.9 ± 13.3	<0.001
IVS	9.4 ± 0.8	10.7 ± 1.0	<0.001	9.9 ± 1.1	10.6 ± 1.2	<0.001
IVS index	4.2 ± 0.5	4.7 ± 0.6	<0.001	4.8 ± 0.6	5.1 ± 0.7	<0.001
PWT	9.9 ± 0.9	11.1 ± 1.0	<0.001	10.1 ± 1.0	10.7 ± 1.1	<0.001
PWT index	4.4 ± 0.6	4.9 ± 0.7	<0.001	4.9 ± 0.6	5.2 ± 0.6	<0.001
LV size/volume measurements						
LVIDd	51.4 ± 3.7	51.9 ± 3.7	0.26	53.8 ± 4.5	55.7 ± 4.4	<0.001
LVIDd index	22.9 ± 2.2	22.9 ± 2.3	0.954	26.1 ± 2.3	27.0 ± 2.2	<0.001
LVEDV	147.3 ± 21.0	145.6 ± 24.2	0.277	166.8 ± 27.6	183.7 ± 26.5	<0.001
LVEDV index	65.5 ± 10.2	64.0 ± 10.2	0.042	80.5 ± 11.3	88.7 ± 11.1	<0.001
Composite measurements						
Relative wall thickness	0.37 ± 0.042	0.42 ± 0.050	<0.001	0.37 ± 0.039	0.38 ± 0.046	0.006

LV: left ventricle, IVS: interventricular septal thickness, PWT: posterior wall thickness, IDd: internal dimension in diastole, IDs: internal dimension in systole, EDV: end diastolic volume,

[*]
compared to preseason within a sport using a paired-sample T test.

Table 6

Changes in ERP prevalence with training

	All sports (n = 148)					
	Pre-season		**Post-season**		**p**
	N	%	N	%	
ERP	55	37.2%	78	52.7%	0.003
Inferior ERP subtype	6	4.1%	12	8.1%	0.031
	Football (n = 78)				
	Pre-season		Post-season		
	N	%	N	%	
ERP	28	35.9%	35	44.9%	0.25
Inferior ERP subtype	3	3.8%	6	7.7%	0.25
	Crew (n = 68)				
	Pre-season		Post-season		
	N	%	N	%	
ERP	27	39.7%	43	63.2%	0.03
Inferior ERP subtype	3	4.4%	6	8.8%	0.21

*
p compares pre-season to post-season