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Journal article

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**Early repolarization patterns associated with increased arrhythmic risk are common in young non-Caucasian Australian males and not influenced by athletic status.**

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**Abstract**

**Background:** Early repolarization (ER) with a horizontal ST-segment (ST-h) and high amplitude J-waves in the inferior leads is associated with an increased risk of cardiac arrhythmic death. The effect of ethnicity and athletic status on this increased-risk ER pattern has not been established. Aboriginal Australian/Torres Strait Islander and Pacific Islander/Maori (non-Caucasian) subjects are well represented in Australian sport, however the patterns and prevalence of ER in these populations are unknown.

**Objectives:** The aim of our study was to assess the prevalence and the effect of athletic activity on ER patterns in young non-Caucasian and Caucasian (C) subjects.

**Methods:** The ECGs of 726 male athletes (23.8% non-C) and 170 male controls (45.9% non-C) aged 16-40 were analyzed for the presence of ER, defined as J-point elevation (J-wave, QRS-slur or discrete ST-elevation) of  $\geq 0.1$  mV in  $\geq 2$  inferior (II,III,aVF) or lateral (I,aVL,V4-V6) leads. ST-morphology was coded as horizontal or ascending. 'Increased-risk ER' was defined as inferior ER with ST-h and J-waves  $> 2$  mV.

**Results:** Regardless of athletic status, ER and increased-risk ER were more prevalent in non-C than C (53.8% vs 32% and 7.6% vs 1.2%, respectively,  $p < 0.0001$ ). Whilst lower heart rate, larger QRS voltages and shorter QRS-duration were predictors of ER, non-C ethnicity was the only independent predictor of increased-risk ER (OR 17.621, 95% CI 4.98-62.346,  $p < 0.0001$ ).

**Conclusions:** ER patterns associated with increased arrhythmic risk are more common in young non-C than C subjects and not influenced by athletic status. The long-term clinical significance of ER in these populations is yet to be determined.

**Key words:** early repolarization, athlete, indigenous Australian, ethnicity, VF

**Abbreviations**

A=athletic

AMI=acute myocardial infarction

BSA=body surface area

C=Caucasian

CV=cardiovascular

ECG=12-lead electrocardiogram

ER=early repolarization

IPVF=idiopathic ventricular fibrillation

LVH=left ventricular hypertrophy

NA=non-athletic

Non-C=subjects of Aboriginal Australian/Torres Strait Islander and Pacific Islander/Maori heritage

QTc=corrected QT interval

SCD=sudden cardiac death

ST-a=ascending ST-segment

ST-h=horizontal ST-segment

## Introduction

Early repolarization (ER) is generally considered a normal finding in young, athletic individuals. The most common description of ER in athletes is J-point elevation with an associated ascending ST-segment (ST-a) in the anterolateral ECG leads, and the benign nature of this pattern has been confirmed in several studies (1-3). However, in more recent years it has become clear that not all patterns of ER are the same. Since 2008 when Haissaguerre described a high prevalence of prominent J-waves or QRS-slurs in the inferolateral ECG leads in survivors of sudden cardiac arrest due to idiopathic ventricular fibrillation (IPVF), a series of studies have confirmed an association with IPVF, as well as an increased risk of atrial and ventricular tachyarrhythmias and death in the context of acute myocardial ischaemia (4-10). The highest arrhythmic risk has been associated with inferior ER with a horizontal ST-segment (ST-h) and high amplitude (>2mV) J-waves (11-13). The prevalence of this pattern in young, athletic populations and the effect of athletic training is unclear, as most studies focusing on athletes have not considered the ST-segment morphology, and have lacked age-matched, non-athletic controls (with most control groups consisting of middle-aged subjects) (3, 7, 12). Furthermore, descriptions of the patterns and prevalence of ER in young athletic populations of ethnic backgrounds other than African American or Caucasian are lacking.

Approximately 11% of the professional male players in the Australian Football League are of Aboriginal Australian/Torres Strait Islander heritage and up to 30% of professional male players in Rugby football codes are of Pacific Islander or Maori heritage, yet we have no data on the patterns and prevalence of ECG patterns in these populations, in whom cardiac mortality related to premature coronary disease far exceeds that of their non-indigenous counterparts (14, 15). Thus, the aim of this study was to determine if the patterns and prevalence of ER in young subjects of Aboriginal Australian/Torres Strait Islander and Pacific Islander or Maori heritage (hence-forth collectively referred to as non-Caucasian, or non-C) may differ from Caucasians, and whether athletic training may affect these patterns.

## Methods

### Study Population

De-identified ECGs of 1,306 consecutive elite athletes aged 16-35 who underwent pre-participation cardiac screening inclusive of an ECG between June 2011 and December 2013 were analysed. Our study methods have been described in detail elsewhere (16, 17). All subjects provided written, informed consent and ethics approval was obtained from the Human Research and Ethics Committee at St Vincent's Hospital, Melbourne and the Australian Institute of Sport, Canberra. As gender differences in ER have been well described, only male athletes were selected for this analysis as the non-Caucasian group contained a much smaller proportion of females than the Caucasian athlete (C-A) group. All of the non-C-A were participating in football codes, thus only C-A footballers (who could be expected to be performing very similar training volume and intensity) were selected as a comparative group. There were 553 C and 173 non-C elite male athletes included.

### Non-athletic control population

Non-athletic (NA) subjects were recruited prospectively, predominantly through advertisement for voluntary cardiac screening at a local University. Subjects were excluded if they were participating in 3 or more hours per week of intense exercise, if they were known to have cardiac disease or if they were aged over 40 years. Only males were included in this analysis. As for athletes, ethnicity was determined by a self-reported questionnaire, which contained options including Caucasian, Asian, African, Aboriginal Australian, Torres Strait Islander, Pacific Islander, Maori and "other". A proportion of non-C non-athletic control subjects' ECGs were obtained retrospectively, having been collected as part of the Heart of the Heart Study between May 2008 and November 2009 (18). A total of 78 non-C-NA and 92 C-NA males met inclusion criteria and were included in this analysis.

### ECG analysis

All ECGs were recorded at rest at 25mm/s and 10mm/mV. To blind the interpreting cardiologists as to subject grouping, all ECGs were scanned electronically and coded. Analysis was performed with ECGs in electronic format, magnified to 200%. Reviewers categorized the presence of ER in each lead (except

aVR) separately and then by territory (inferior, II, III, aVF or lateral V4-V6, I, aVL). Although the anterior leads were analysed, they were not included in the definition of an ER positive ECG. Measures of ER, described as follows, are outlined in Figure 1. Morphology of the J-point was categorized either as a J-wave (sharp, well defined hump or notch immediately following a positive QRS complex at the onset of the ST-segment), a QRS slur (when the R-wave gradually becomes the ST-segment with an upright concavity) or as discrete STE without a notch or slur. Amplitude of the J-wave, QRS slur or discrete STE and the subsequent ST-segment (measured at the end of the QRS complex, following the notch or slur, when present) were measured using digital calipers, using the preceding TP segment as baseline. ST-segment elevation (STE) 100ms after merging of the J-point and ST-segment was measured and coded as ascending ( $>0.1\text{mV}$  STE, ascending gradually until the T wave) or horizontal/descending ( $\leq 0.1\text{mV}$  STE, continuing as a flat/descending segment until the onset of the T wave). The ECG was considered to show ER if there was elevation of the J-point (as either a J-wave, QRS slur or discrete ST-elevation) of at least  $0.1\text{mV}$  in at least 2 leads within the inferior (II, III, aVF) or lateral (V4-V6, I, aVL) territories. To be consistent with previous studies (3, 12), if a J-wave was present in one lead and a slur in the other, the territory was coded as J-wave, and if the ST-segment was ascending in some leads and horizontal in others, the territory was categorised ST-h. 'Increased-risk ER' was defined as inferior ER with ST-h and J-waves  $>2\text{mV}$ .

Other measurements included heart rate, PR interval, QRS duration, QTc with Bazett's correction and Sokolow Lyon score for left ventricular hypertrophy (LVH;  $\text{SV1}+\text{RV5}$ , mm).

### ***Inter and intra observer variability***

In order to assess interobserver reliability, a randomly selected subset of 100 ECGs were analysed independently by a 2nd cardiologist. The presence and characteristics of ER described above were analysed in each lead separately and then categorised by territory. To assess intraobserver variability, the primary interpreter also re-analysed each lead and each territory from 350 randomly selected ECGs.

**Statistical analysis**

Values are displayed as mean±standard deviation (SD) or as a number and percentage in each group, as appropriate. Continuous variables were compared between groups using one way ANOVA with Sidak's post hoc test, and categorical variables using the  $\chi^2$  test or Fisher's exact test, when appropriate.

Multivariable logistic regression analyses with a stepwise approach were used to identify characteristics associated with the presence of ER amongst all subjects. Overall ER, and "increased risk ER" (inferior J-wave >2mm and ST-h) were chosen as dependant variables. Independent variables were selected on the basis of associations with ER in previous studies (ethnicity, athletic status, age, HR, QRSd, QTc and LVH score). A p-value of <0.05 was considered significant throughout. Intraobserver and interobserver reliability analyses using the Kappa ( $\kappa$ ) statistic were performed to determine consistency for interpretation of ER patterns, with a  $\kappa$  value >0.61 indicating substantial agreement and >0.81 excellent agreement. All analyses were performed using SPSS version 21 software (SPSS Inc, Chicago, Illinois).



## Results

### *Subject characteristics*

Table 1 summarises the demographic and baseline ECG characteristics of all subjects. Compared to C-A, non-C-A had a slightly larger body surface area (BSA), higher resting heart rate, but similar age, QRSd, QRS axis, QTcB and LVH scores. Both athlete groups were, on average, younger, with lower resting heart rates than NA. Similar to the differences seen in the athlete groups, non-C-NA had a larger BSA, and a higher resting heart rate than C-NA.

### *Patterns and prevalence of ER in non-Caucasian versus Caucasian athletes*

Table 2 details the prevalence, pattern and lead distribution of ER in all groups. ER was more prevalent in non-C-A than C-A. The prevalence of ER isolated to the inferior or lateral leads was similar between athlete groups, but ER involving the inferior *and* lateral leads was almost twice as prevalent in non-C-A than C-A. In the inferior leads, large ( $>2\text{mV}$ ) amplitude J-waves and QRS slurs, and ER with ST-h were more than twice as prevalent, and “increased-risk” ER was 5 times as prevalent in non-C-A as compared to C-A (representative ECGs in Figures 2 and 3). In the lateral leads, ER with J-point elevation of  $\geq 2\text{mV}$  or marked ( $\geq 2\text{mv}$ ) ST-elevation was more prevalent in non-C-A than C-A. Lateral ER with ST-h was rare in both athlete groups.

### *Patterns and prevalence of ER in non-Caucasian versus Caucasian non-athletes*

ER was more prevalent in non-C-NA than C-NA. ER isolated to the inferior or lateral leads occurred with a similar prevalence, but ER involving the inferior *and* lateral leads was more than 6 times as prevalent in non-C-NA than C-NA. When ER was present in the lateral leads, it was more frequently associated with ST-h in non-C-NA than in C-NA.

***Patterns and prevalence of ER in athletes versus non-athletes***

Although athletic status did not influence the overall prevalence of ER or increased-risk ER, differences in lead distribution and ER characteristics between A and NA were observed (Table 2). In the Caucasian cohort, the combination of inferior *and* lateral ER was 3 times more prevalent and J-point amplitude in the lateral leads significantly higher in athletes as compared to non-athletes. In the non-Caucasian cohort, STE in the lateral leads was more marked in athletes. In both the Caucasian and non-Caucasian cohort, inferior ER patterns were very similar in athletes and non-athletes (Table 2).

***Determinants of ER patterns and the effect of ethnicity and athletic status***

Multivariate logistic regression identified non-Caucasian ethnicity, lower heart rate, shorter QRSd and bigger LVH scores, but not athletic activity, as independent predictors of ER (Table 3). However, non-Caucasian ethnicity was the only independent predictor of “increased-risk” ER (OR 17.621, CI 4.98-62.346),  $p < 0.0001$ ) (Table 3).

***Reproducibility of assessment of early repolarisation and territory***

Intraobserver reliability for presence of ER and territory was excellent ( $\kappa = 0.914$ ,  $P < 0.001$ ). Interobserver reliability for presence of ER and territory was also excellent ( $\kappa = 0.871$ ,  $P < 0.001$ ), with substantial reliability between investigators for both ER morphology ( $\kappa = 0.692$ ,  $P < 0.001$ ) and ST-morphology ( $\kappa = 0.647$ ,  $P < 0.001$ ).

## Discussion

This is the first study to describe the ECG findings and patterns of ER in subjects of Aboriginal Australian/Torres Strait Islander and Pacific Islander/Maori heritage. We found that these populations demonstrated a greater prevalence of ER as compared to Caucasians, including patterns which have been associated with increased arrhythmic risk, namely inferior ER with a horizontal ST-segment and high amplitude J-waves. In contrast to prior studies, we found no association between ER prevalence and athletic activity, perhaps as a result of the lesser age discrepancy between athletes and control subjects.

### *Ethnicity and increased-risk ER*

ER is known to be more prevalent in black African American than Caucasian persons, however the prevalence of “increased-risk” ER is reportedly similar in both populations (3, 19). Tikannen et al reported a prevalence of inferior ER with ST-h and J-waves  $\geq 0.1\text{mV}$  of 1.3% in 10,288 middle-aged Finns (19), and a similar prevalence of inferior ER with ST-h (0.6%) was reported by Muramoto et al in a large cohort of middle aged multi-ethnic subjects, with no difference in the prevalence of inferior ER observed between African American and non-African American subjects (3).

Descriptions of ER patterns in other ethnic groups are scarce. In the only comprehensive description of ER patterns in a South-East Asian population, Naruse et al reported a prevalence of inferior J waves  $\geq 2\text{mV}$  (6.4%) and inferior ER with ST-h (9.5%) in middle-aged Japanese subjects presenting with acute myocardial infarction (10). However, as this study lacked a healthy control group for comparison, whether the prevalence of increased-risk ER in the general Japanese population may be similar is unknown.

Increased risk ER was observed in 1.2% of our young male Caucasian cohort, similar to that reported in the aforementioned studies. However, the same pattern was observed with more than 6-fold higher prevalence in non-Caucasian subjects (7.5%). On multivariate analysis, only non-Caucasian ethnicity predicted increased-risk ER, suggesting there may be an ethnic and/or genetic basis underlying this ECG pattern. This concept is supported by reports of familial clustering of ER patterns and the emerging understanding of genetic associations of ER associated with an arrhythmic phenotype (20-22).

***ER prevalence and athletic status***

This the first study to our knowledge, to report a similar prevalence of ER in non-athletic versus athletic males of similar age. Previous investigators have compared the prevalence of ER in young athletes to non-athletic control subjects who were two to three times older (3, 7). This is a significant confounder given that the prevalence of the classic “benign” ER pattern in males peaks late in the 2<sup>nd</sup> decade of life and declines thereafter (13, 24-26), an observation which is not entirely understood but generally attributed to age related changes in sex hormones (27). Thus, a causative effect between athletic activity and increased ER prevalence cannot be based on comparisons of age disparate populations.

Noseworthy et al investigated the effect of intense physical training on the prevalence of ER in young athletes, and reported an increase from 37 to 53% (23). However, this was predominantly due to an increase in ER in their subset of rowers, in whom resting heart rate was also significantly reduced after 13 weeks of training (28). They found no correlation between markers of structural cardiac adaptation and the development of ER. Similarly, Biasco et al showed an association between lower heart rate and the appearance of ER in young soccer players, but no correlation between level of fitness and ER (29). Although the overall prevalence of ER was similar in athletes and non-athletes in our cohort, the magnitude of ST-elevation was greater in the athlete group. Together, these observations suggest that ER with ST-a is a common ECG appearance in young males and that ST-segment elevation is accentuated by lower heart rates, which are likely reflective of high resting parasympathetic tone, independent of the structural adaptations associated with “athlete’s heart”.

***Increased-risk ER, associated ECG features and possible mechanisms***

Previously reported associations between ER, lower heart rate, bigger LVH scores, and shorter QRSd were confirmed in our study (5, 29), but these factors were not associated with increased-risk ER. Tikannen et al has also reported that as compared to ER negative subjects, those with ER and ST-h demonstrated similar heart rates and LVH scores, whereas subjects with ER and ST-a had lower heart rates and larger LVH scores (11). This observation is not direct evidence that the electrophysiological mechanism of “increased-risk” ER differs from that of ER with an ascending ST-segment, but it is an interesting observation in light of the ongoing debate surrounding the pathogenesis of ER.

Whilst there is convincing evidence that ER with ST-a is benign, and most likely due to vagal mediation of outward potassium (Ito) currents in the ventricular epicardium (30, 31), the pathogenesis of J-waves and a ST-h is still uncertain (32). Antzelevitch has proposed that the 2 ECG findings may represent a continuum of the same electrophysiological mechanism, with ER, or J-waves, indicating altered myocardial repolarisation and predisposition to ventricular arrhythmias depending on the location of the epicardial tissue and ion channels involved (12, 33). Thus, in the presence of pro-arrhythmic conditions such as ischaemia, inferior J-waves may represent an additional risk factor for fatal arrhythmia (34).

### ***Clinical implications***

The association between increased-risk ER and ventricular tachyarrhythmias in the context of myocardial ischaemia is of most immediate relevance to populations with a pre-existing risk for cardiac disease and SCD. In Australia, the incidence of AMI in indigenous males aged 25-54 is estimated to be 6-fold higher, and 48-hour mortality following AMI around 10-fold higher than that of non-indigenous males (35). Ischaemic heart disease as a cause of sudden cardiac death (SCD) in young non-indigenous Australians is rare (36), however the incidence of sports related SCD attributable to ischaemic heart disease in young indigenous Australian footballers is estimated to be more than 40-fold higher than that of a comparable non-indigenous population (37). Some, but not all of the disparity in CV outcomes can be explained by a greater prevalence of atherosclerotic risk factors, such as higher rates of smoking, diabetes and obesity in indigenous persons (18). Although speculative, it is possible that increased risk ER patterns add another high-risk marker to what is an already poor population CV risk profile.

However, until a clear association between increased-risk ER and cardiac mortality in Aboriginal Australian/Torres Strait Islander and Pacific Islander or Maori populations is confirmed in prospective studies, there is no evidence to suggest that further diagnostic testing in asymptomatic subjects with this ECG finding is warranted. As with any subject in whom cardiovascular risk is high, immediately modifiable risk factors for AMI such as smoking and sedentary lifestyle should be addressed. Smoking cessation advice and perhaps most importantly *encouraging* regular exercise to those with this ER pattern seems a sensible approach.

**Limitations**

This study was not designed to longitudinally assess the relationship between patterns of ER and risk of SCD or cardiovascular mortality, thus we cannot draw conclusions about the prognostic impact of ER. We did not have echocardiographic information on all subjects, thus we were not able to assess the relationship between structural cardiac abnormalities and ER patterns. We grouped Aboriginal Australian, Torres Strait Islander, Pacific Islander and Maori subjects together, however it is quite possible that ethnic variations in ECG patterns amongst this culturally diverse group of subjects exist. However, this is the only study to assess ECG changes in any of these populations.

**Conclusion**

We have demonstrated that patterns of ER associated with increased arrhythmic risk were very common in subjects of Aboriginal Australian/Torres Strait Islander and Pacific Islander or Maori heritage, and not influenced by athletic training or ECG parameters typically associated with so called benign ER patterns. Given growing evidence that increased risk ER patterns may have a heritable basis, the ethnic variations in the patterns and prevalence of ER we have described are of interest, although further research is needed to determine whether there may be a causative link between the observed patterns of ER and poor cardiovascular outcomes in these populations.

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### **Clinical Perspectives**

ER patterns associated with increased cardiac arrhythmic risk do not appear to be influenced by athletic status and are very common in young indigenous Australian males, a population with an already poor cardiovascular risk profile. Prospective research is required to assess whether there may be a causative link between the increased risk ER pattern and cardiovascular mortality in this population.

**Table 1. Comparison of demographics and ECG characteristics between non-Caucasian athletes, Caucasian athletes, non-Caucasian non-athletic controls and Caucasian non-athletic controls.**

	Non-Caucasian athletes (n=173)	Caucasian athletes (n=553)	Non-Caucasian non-athletes (n=78)	Caucasian non-athletes (n=92)	<i>P</i>
Age, years	20.3±3.6 (16-33)	19.9±3.9 (16-35)	30.5±6.8 (17-40)	26.0±5.9 (20-40)	<0.0001 †‡§
Male, %	100	100	100	100	1.00
BSA, m <sup>2</sup>	2.13±0.2	2.10±0.2	2.10±0.2	1.92±0.2	<0.0001 *†‡§
Heart rate, bpm	62.5±11.2	58.7±10.0	71.5±13.9	66.8±11.7	<0.0001 *†‡§
PR interval, ms	162.2±31.2	162.2±30.1	161.2±18	155.8±19.6	0.254
QRSd, ms	95.9±10.0	96.6±9.6	89.44±8.6	97.15±9.3	<0.0001 †‡
QRS axis, °	66.7±26.2	68.4±26.6	37.7±29.4	67.1±27.0	<0.0001 †‡
QTcB, ms	397.3±23.3	395.7±24.5	401.4±27.7	400.5±21.4	0.118
LVH score, mV	28.1±8.3	29.7±8.2	25.3±8.5	27.7±8.4	<0.0001 ††

Data are expressed as means ± SD or percentages as appropriate.

Age range is also presented in parentheses.

Non-Caucasian indicates subjects of Aboriginal Australian/Torres Strait Islander and Pacific Islander/Maori heritage; BSA, body surface area; bpm, beats per minute; QRSd, QRS duration; °, degrees; QTc B, QTc with Bazett's correction; LVH score, Sokolow Lyon score for left ventricular hypertrophy (SV1+RV5, mV)

\* Statistically significant between non-Caucasian and Caucasian athletes

† Statistically significant between non-Caucasian and Caucasian non-athletes

‡ Statistically significant between non-Caucasian athletes and non-athletes,

§ Statistically significant between Caucasian athletes and non-athletes

†† Statistically significant between Caucasian athletes and non-Caucasian non-athletes

**Table 2. Early repolarization patterns according to lead distribution, J-point and ST morphology in non-Caucasian athletes, Caucasian athletes, non-Caucasian non-athletic controls and Caucasian non-athletic controls.**

	Non-Caucasian athletes (n=173)	Caucasian athletes (n=553)	Non-Caucasian non-athletes (n=78)	Caucasian non-athletes (n=92)	<i>P</i>
<b>Overall ER</b>	90 (52)	177 (32.0)	45 (57.7)	30 (32.6)	<0.0001* <sup>†</sup>
<b>Inferior ER</b>	71 (41.0)	133 (24.1)	35 (44.9)	19 (20.7)	<0.0001* <sup>†</sup>
J-wave	42 (24.3)	64 (11.6)	20 (25.6)	11 (12.0)	<0.001* <sup>†</sup>
QRS slur	28 (16.2)	67 (12.1)	15 (19.2)	7 (7.6)	<0.0001* <sup>†</sup>
Discrete STE	1 (0.6)	2 (0.4)	0	1 (1.1)	0.7159
J-point >2mV	20 (11.6)	29 (5.2)	9 (11.5)	2 (2.2)	0.0025* <sup>†</sup>
ST-a	14 (8.1)	43 (7.8)	8 (10.3)	8 (8.7)	0.8957
STE ≥1mm	17 (9.8)	40 (7.2)	7 (9.0)	7 (7.6)	0.789
ST-h ≥ 1 lead	57 (32.9)	90 (16.3)	27 (34.6)	11 (12.0)	<0.0001* <sup>†</sup>
ST-h ≥ 2 leads	43 (24.9)	67 (12.1)	24 (30.8)	9 (9.8)	<0.0001* <sup>†</sup>
ST-h all 3 leads	16 (9.2)	23 (4.2)	14 (17.9)	3 (3.3)	<0.0001* <sup>†</sup>
Isolated inferior ER	27 (15.6)	50 (9)	11 (14.1)	9 (9.8)	0.075
<b>Increased-risk ER</b>	13 (7.5)	8 (1.4)	6 (7.7)	0	<0.0001* <sup>†</sup>
<b>Lateral ER</b>	64 (37)	127 (23)	34 (43.6)	21 (22.8)	<0.0001* <sup>†</sup>
J-wave	28 (16.2)	80 (14.5)	27 (34.6)	11 (12)	<0.0001 <sup>†</sup>
QRS slur	17 (9.8)	26 (4.7)	6 (7.7)	3 (3.3)	0.0494* <sup>‡</sup>
Discrete STE	19 (11)	21 (3.8)	2 (2.6)	3 (3.3)	<0.0001* <sup>‡</sup>
J-point ≥2mV	48 (27.7)	98 (17.7)	17 (21.8)	8 (8.7)	0.001* <sup>†§</sup>
STE ≥2mV	26 (15)	43 (7.8)	2 (2.6)	4 (4.3)	0.0011* <sup>‡</sup>
ST a	58 (33.5)	115 (20.8)	24 (30.8)	18 (19.6)	0.0043* <sup>†</sup>
ST h	6 (3.5)	12 (2.2)	11 (14.1)	3 (3.3)	<0.0001 <sup>†‡</sup>
ERP I, aVL	9 (5.2)	12 (2.2)	14 (17.9)	3 (3.3)	<0.0001* <sup>†‡</sup>
Isolated lateral ER	19 (11)	45 (8.1)	10 (12.8)	11 (12.0)	0.350
<b>Inferior and lateral ER</b>	44 (25.4)	82 (14.8)	25 (32.1)	4 (4.8)	<0.0001* <sup>†§</sup>
<b>ST-h any lead</b>	59 (34.1)	95 (17.2)	31 (39.7)	12 (13)	<0.0001* <sup>†</sup>

Data are expressed as n (%).

Non-Caucasian indicates subjects of Aboriginal Australian/Torres Strait Islander and Pacific Islander/Maori heritage; ER, early repolarization; Discrete STE, ST-segment elevation in the absence of a J-wave or QRS slur; STE, ST-segment elevation (measured at the end of the QRS complex, following the notch or slur when present); ST-a, ascending ST-segment; ST-h, horizontal or descending ST-segment; Increased risk ER, inferior J-wave >2mV and ST-h

\* Statistically significant between non-Caucasian and Caucasian athletes

<sup>†</sup> Statistically significant between non-Caucasian and Caucasian non-athletes

<sup>‡</sup> Statistically significant between non-Caucasian athletes and non-athletes,

<sup>§</sup> Statistically significant between Caucasian athletes and non-athletes

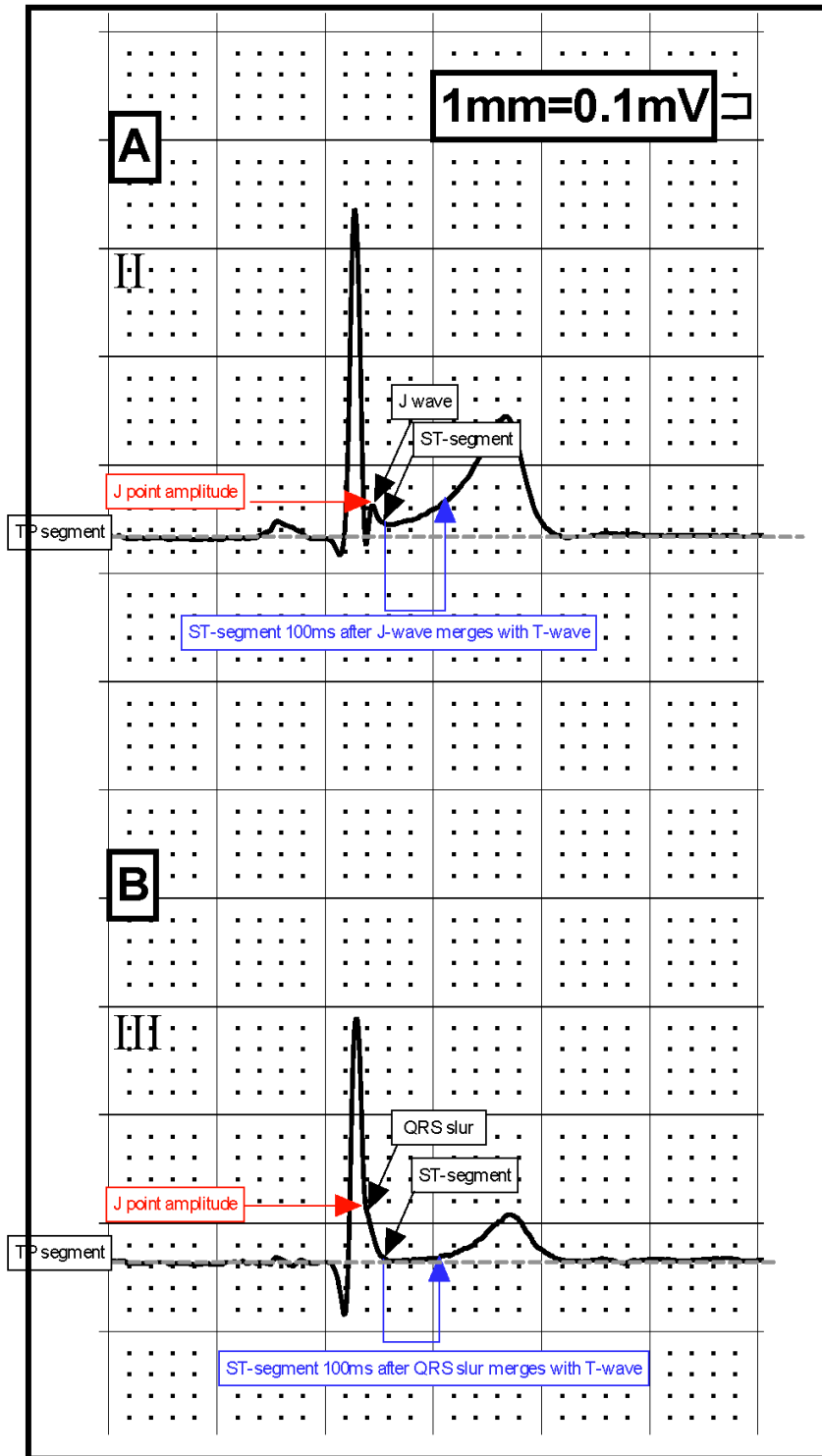
**Table 3. Covariate relationships to early repolarization.**

	Early repolarization (n=342)		Increased-risk ER (n=27)	
	OR (95% CI)	P value*	OR (95% CI)	P value*
<b><i>Univariate relationship between subject characteristics and ER status</i></b>				
Non-Caucasian vs Caucasian	2.463 (1.828-3.318)	<0.0001	17.621 (4.98-62.346)	<0.0001
Heart rate, per bpm	0.985 (0.973-0.997)	0.015	...	...
QRSd (per ms)	0.971 (0.955-0.989)	<0.0001	...	...
LVH score (per mV)	1.062 (1.044-1.081)	<0.0001	...	...
<b><i>Multivariate model describing associations with ER status</i></b>				
Non-Caucasian vs Caucasian	2.922 (2.076-4.113)	<0.0001	17.621 (4.98-62.346)	<0.0001
Heart rate (per bpm)	0.976 (0.963-0.990)	0.001	...	...
QRSd (per ms)	0.977 (0.961-0.993)	0.004	...	...
LVH score (per mV)	1.069 (1.049-1.089)	<0.0001	...	...

ER indicates early repolarization; Increased-risk ER, inferior J-wave >2mV and ST-h; Non-Caucasian indicates subjects of Aboriginal Australian/Torres Strait Islander and Pacific Islander/Maori heritage; bpm, beats per minute; QRSd, QRS duration; LVH score, Sokolow Lyon score for left ventricular hypertrophy (SV1+RV5, mV)

\* compared to ER negative subjects

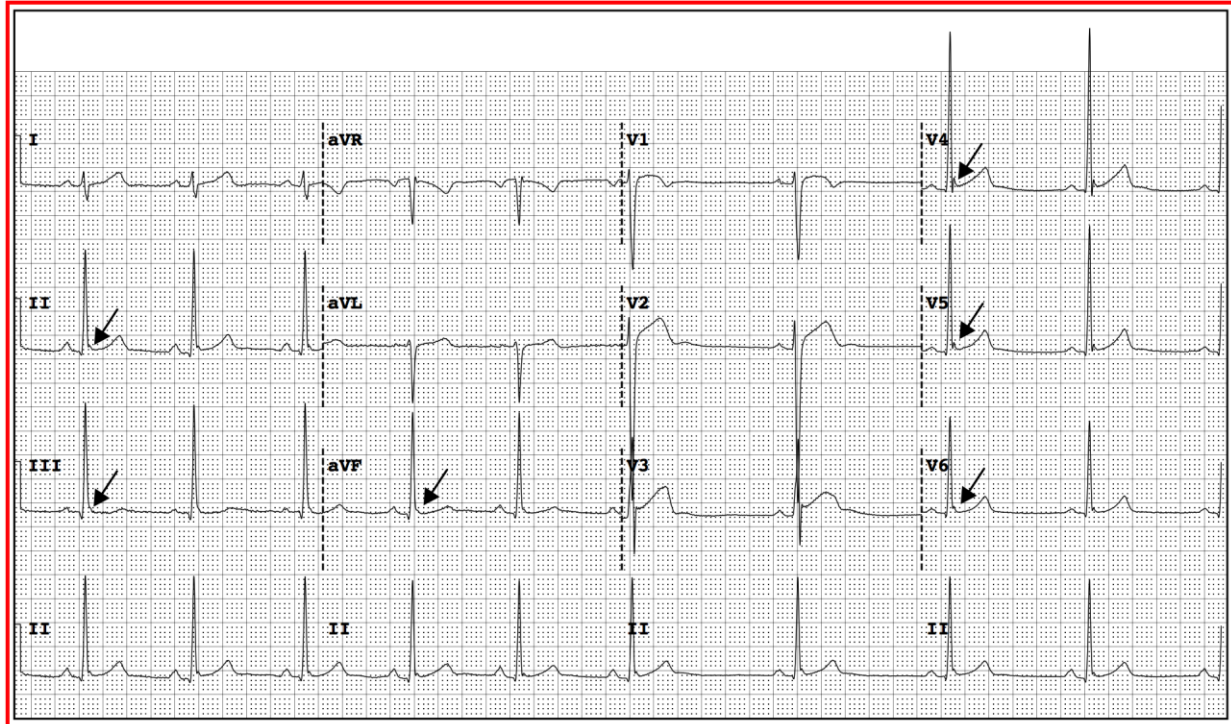
Figure 1. Example measurements and definitions of early repolarization patterns as described in Methods.



**A.** J-wave of  $\geq 1\text{mV}$  amplitude with  $< 1\text{mV}$  of associated ST-segment elevation (measured after the J-wave, as indicated) and an ascending ST-segment (defined as  $\geq 1\text{mV}$  of ST-segment elevation 100ms after J-wave merges with T-wave) in lead II.

**B.** QRS slur of  $> 2\text{mV}$  amplitude with no ST-segment elevation and a horizontal ST-segment in lead III.

**Figure 2.** ECG demonstrating inferior and lateral early repolarization in an 18-year old Caucasian male athlete. In the inferior leads there is a distinct J-wave in lead II, and QRS slurs in leads III and aVF (arrows). The ST-segment is ascending in leads II and aVF, and horizontal in lead III. In the lateral leads there are J-waves in leads V4, V5 and V6 with an ascending ST-segment and associated ST-segment elevation in leads V4 and V5.





**Figure 3.** Increased-risk ER pattern in an 18-year old male athlete of non-Caucasian (Pacific Islander) heritage. Note large amplitude J-waves in the inferior leads (II, III and aVF) with a horizontal/descending ST-segment. There is also discrete ST-segment elevation in the lateral leads (arrows).

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