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# Prevalence and significance of anterior T-wave inversion in elite football players in the United Kingdom

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## ABSTRACT

**Objective** The "athlete anterior repolarisation pattern", characterised by J-point elevation with ascending convex ST-segments and anterior T-wave inversion (ATWI) confined to leads $V_1$-$V_4$, has been considered a normal finding in athletes of Black ethnicity (African-Caribbean descent). This repolarisation pattern was considered to potentially represent an underlying cardiomyopathy in non-Black athletes although recent studies have challenged this. We assessed the prevalence and significance of ATWI among professional Black and non-Black football players in the UK.

**Methods** Athletes underwent pre-participation screening (2017–2024), including a health questionnaire, a 12-lead ECG and an echocardiogram. ATWI was defined as TWI confined to leads $V_1$ to $V_3$ or $V_4$. Ethnicity was categorised as Black or non-Black.

**Results** 10 955 athletes were studied, comprising 9009 (82.2%) males and 1946 (17.8%) females. 2372 (21.7%) athletes were of Black ethnicity and 8583 (78.3%) were non-Black. Black athletes were marginally younger (18.3±3.8 vs 19.2±4.7 years; p<0.001). ATWI was observed in 255 (10.8%) Black athletes versus 115 (1.3%) non-Black athletes (p<0.001). ATWI was more common in Black males compared with females (251 (11.0%) vs 4 (4.3%); p=0.04). Among non-Black athletes, ATWI was less common in males (81 (1.2%) males vs 34 (1.8%) females; p=0.04). The "athlete anterior repolarisation pattern" was present in 245 (10.3%) Black athletes and 42 (0.5%) non-Black athletes (p<0.001). None of the Black athletes with ATWI exhibited major cardiac pathology, whereas one (0.9%) non-Black athlete with ATWI and isoelectric ST-segments was diagnosed with arrhythmogenic cardiomyopathy.

**Conclusion** The "athlete anterior repolarisation pattern" was 20 times more common in Black athletes than in non-Black athletes. However, this repolarisation pattern was not associated with major pathology in either Black or non-Black athletes in this UK screening cohort. By contrast, the only cardiomyopathy identified in an athlete with any ATWI occurred in a non-Black athlete with isoelectric ST-segments extending to $V_4$.

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The 2017 International Criteria recommend an ethnicity-specific approach to the interpretation of anterior T-wave inversion (ATWI) in athletes.

### WHAT THIS STUDY ADDS

⇒ In a large UK cohort of professional football players, the "athlete anterior repolarisation pattern", defined by convex ST-segment elevation preceding ATWI was present in 10.3% of Black athletes and 0.5% of non-Black athletes. None of the athletes with this pattern had cardiomyopathy after comprehensive evaluation, suggesting that it is a low-risk ECG phenotype more commonly observed in Black than non-Black athletes. The only cardiomyopathy identified in an athlete with any ATWI occurred in a non-Black athlete with isoelectric ST-segments, not the anterior repolarisation pattern.

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ ATWI extending to lead $V_4$, with J-point elevation and ascending convex ST segments, is likely benign in all athletes. In contrast, extensive ATWI with preceding isoelectric ST segments may warrant further investigation for underlying cardiomyopathy, regardless of sex or ethnicity.

## INTRODUCTION

Despite its relatively common presentation among athletes, anterior T-wave inversion (ATWI) on the resting 12-lead ECG may represent an initial electrical expression of cardiomyopathy associated with sudden cardiac death (SCD).[1] The interpretation of TWI relies on several factors, including age, sex, ethnicity, lead distribution, preceding J-point and ST-segment patterns and other concomitant electrical anomalies.[2–6] Prior athlete cohorts report sex-dependent variation in ATWI prevalence,[7 8] with an increased prevalence of ATWI in females.

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When ATWI in leads $V_1$–$V_4$ is preceded by convex ST-segment morphology, often with J-point elevation, in an asymptomatic Black athlete (of African-Caribbean descent) without a relevant family history, this pattern is currently classified as a normal variant according to the 2017 International Criteria for ECG interpretation in athletes.[2 9] Historically, this phenotype was referred to as the "Black anterior repolarisation pattern". In contrast, among non-Black athletes, ATWI extending beyond lead $V_2$ was historically considered abnormal and an indicator for further evaluation for underlying cardiomyopathy. Recent large datasets, however, have challenged this interpretation and suggest that the so-called "Black anterior repolarisation pattern", while less common in non-Black athletes, should be considered a normal variant in athletes irrespective of ethnicity.[10–12] These studies, however, are limited by cohort size or the absence of imaging data.

Clarifying the significance of this specific anterior repolarisation ECG pattern is central to avoiding over-investigation of physiological variants and under-investigation of findings suggestive of cardiomyopathy. This study aimed to evaluate the prevalence and significance of ATWI and ST-segment morphology in a large cohort of Black and non-Black football players in the UK. Secondary objectives were to characterise sex-specific echocardiographic correlates of ATWI and to report baseline clinical diagnoses reached during screening in those with ATWI.

## METHODS

### Study design and population

This was an observational cross-sectional study of elite football players who underwent mandatory pre-participation screening (PPS) as part of the English Football Association (FA) programme between April 2017 and October 2024. The assessment comprised a health questionnaire, 12-lead ECG and transthoracic echocardiogram. All subjects were aged 16 years or above. Ethnicity was self-reported at the time of screening and categorised as Black or non-Black. For the purposes of this analysis, athletes were categorised as Black or non-Black; athletes younger than 16 years and athletes of mixed-race ethnicity were not included in the study.

ECGs were interpreted at the time of screening by expert sports cardiologists within the FA screening programme. Echocardiograms were performed by British Society of Echocardiography (BSE)-accredited cardiac physiologists using a standard athlete screening protocol[13–15] and were subsequently reviewed within the screening pathway by expert cardiologists. Clinical outcomes and the need for downstream investigations were determined at the time of screening by expert sports cardiologists. Downstream investigations including exercise stress test, prolonged cardiac rhythm monitoring and cross-sectional cardiac imaging such as cardiac CT and cardiac magnetic resonance (CMR) imaging were conducted as indicated.

For the purposes of this study, all ECGs and echocardiographic data from the entire cohort were re-evaluated independently by the first author (KY), who was blinded to the original screening outcomes and any diagnoses established following PPS, with retrospective application of the 2017 International Criteria for ECG interpretation in athletes and the BSE guidance.[2 13 15] Any discrepant or equivocal ECG or echocardiographic findings were discussed with the principal investigators (AM and SS), who made the final adjudication.

### Electrocardiogram

A standard 12-lead ECG was performed with the participant in a supine position during quiet respiration using a GE Marquette Hellige recorder (Milwaukee, Wisconsin, USA) or Philips Pagewriter Trim III (Bothell, Washington, USA) at a paper speed of 25 mm/s and calibration of 10 mm/mV. Wave voltages were electronically calculated by the ECG software. Standard ECG measurements included heart rate, rhythm, PR interval, QRS duration, QRS voltage, QRS axis and QT interval. QT interval was corrected using Bazett's formula.

TWI was defined as a negative T wave with an amplitude ≥1 mm (0.1 mV). ATWI was defined as TWI confined to leads $V_1$ to $V_3$ or $V_1$ to $V_4$, and sub-categorised according to the preceding ST-segment patterns. The amplitude of the J-point in the anterior precordial leads ($V_1$–$V_4$) was measured at the end of the QRS complex with reference to the isoelectric baseline defined as the T-P segment. For each ECG with ATWI, the ST-segment morphology was evaluated in the leads showing TWI and categorised as: (1) Elevation if the ST-segment lay above the isoelectric line at the J-point, (2) Depression if below or (3) Isoelectric if in line with the baseline. In the presence of ST elevation, the ST-segment shape between the J-point and the peak of the T wave was classified visually as convex (upsloping/convex upwards) or concave (upwards concavity). When morphology differed between leads, the pattern in the lead with the deepest TWI was used for classification. "Athlete anterior repolarisation pattern" was defined as ATWI confined to leads $V_1$ to $V_3$ or $V_1$ to $V_4$, preceded by J-point/ST-segment elevation with convex ST-segment morphology. In ECGs demonstrating ATWI, assessment of preceding ST-segment morphology, including convex versus concave classification, was reviewed by the first author and the principal investigators (AM and SS).

### Echocardiogram

Two-dimensional transthoracic echocardiography was performed by cardiac physiologists accredited by the BSE using a standard protocol for athletes.[14 15] Standard views were obtained, and wall thickness, cavity dimension measurements and identification of the origins of the left and right coronary arteries were made in accordance with established guidelines.[15 16]

### Definition and classification of clinical outcomes

The result of PPS for each football player was categorised into: (1) 'normal'- no findings requiring action, (2) 'indeterminate' – findings that require further evaluation to distinguish physiological changes from potential pathology and (3) 'abnormal'- findings consistent with cardiac pathology. Indeterminate findings could then be reclassified as normal or abnormal following further evaluation. Once a cardiac disorder was detected, it was further classified as either a major condition associated with SCD or a minor condition. Major cardiac conditions included any form of cardiomyopathy, myocarditis, an anomalous origin of a coronary artery, Wolff-Parkinson-White pattern, long QT syndrome, Brugada syndrome, any ventricular arrhythmia, channelopathy, severe degree of valvular pathology or significant aortopathy.

Minor cardiac conditions include congenital heart disease such as atrial septal defect, small ventricular septal defect, patent ductus arteriosus, valvular heart disease such as bicuspid aortic valve, valvular pathology or aortopathy with mild or moderate severity and supraventricular arrhythmia.



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## Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics V.31.0.1.0 (IBM, Armonk, New York, USA). Normal distribution of all continuous variables was examined using the Shapiro-Wilk test. Values are expressed as either mean±SD or percentages, as appropriate. Differences in prevalence between two independent populations were analysed using the $\chi^2$ test of independence or Fisher's exact test as appropriate and continuous variables were analysed using the two-sample t-test. Statistical significance was defined as a two-tailed p value of $<0.05$ throughout.

## Patient and public involvement

Patients or the public were not involved in the design, conduct, reporting or dissemination plans of our research.

## Equity, diversity and inclusion

The author group consists of junior, mid-career and senior researchers. Authors practise across four countries and represent diverse ethnic backgrounds. Our study population included an ancestrally diverse cohort of elite football players from a standardised screening programme and comprised both male and female athletes from a range of socioeconomic backgrounds. However, socioeconomic backgrounds in terms of cardiovascular impact were not assessed.

# RESULTS

## Demographics

A total of 10955 consecutive football players who underwent cardiovascular PPS were included in the study, of whom 2372 (21.7%) athletes were of Black ethnicity and 8583 (78.3%) athletes were of non-Black ethnicity. Of the total cohort, 9009 (82.2%) were male and 1946 (17.8%) were female. The non-Black group were predominantly White (98%), with the remainder being Asian (2%). The Black athletes were slightly younger than non-Black athletes (18.3±3.8 years vs 19.2±4.7 years; $p<0.001$).

## Prevalence of anterior T-wave inversion

ATWI was identified on the ECG in 370 athletes (3.4% (95% CI 3.0 to 3.7)). Among Black athletes, ATWI was present in 255 athletes (10.8% (95% CI 9.5 to 12.0)), while ATWI was present in 115 (1.3% (95% CI 1.1 to 1.6)) non-Black athletes ($p<0.001$). When considering sex differences, among Black athletes, ATWI was demonstrated in 251 (11.0%) male athletes and in 4 (4.3%) female athletes ($p=0.04$). Among non-Black athletes, ATWI was observed in 81 (1.2%) male athletes in contrast to 34 (1.8%) female athletes ($p=0.04$).

## ST-segment morphology preceding anterior T-wave inversion

Among 370 athletes with ATWI, the J-point and ST-segment in the anterior leads most frequently demonstrated elevation (301/370, 81.4%), with the remainder showing an isoelectric ST-segment (69/370, 18.6%). None of the athletes with ATWI revealed ST-segment depression.

ST-segment elevation preceding ATWI was markedly more common among Black than non-Black athletes (246 (96.5%) vs 55 (47.8%); $p<0.001$). Among athletes with ST elevation, convex morphology predominated in both groups (Black: 245 (99.6%); non-Black: 42 (76.4%)). Thus, almost all Black athletes with ATWI demonstrated the guideline-concordant pattern of ST elevation with convex morphology, whereas more than half of non-Black athletes with ATWI showed either isoelectric ST segments or concave ST-segment elevation. Accordingly, the "athlete anterior repolarisation pattern" was present in 245 (10.3%) Black athletes and 42 (0.5%) non-Black athletes ($p<0.001$) (figure 1).

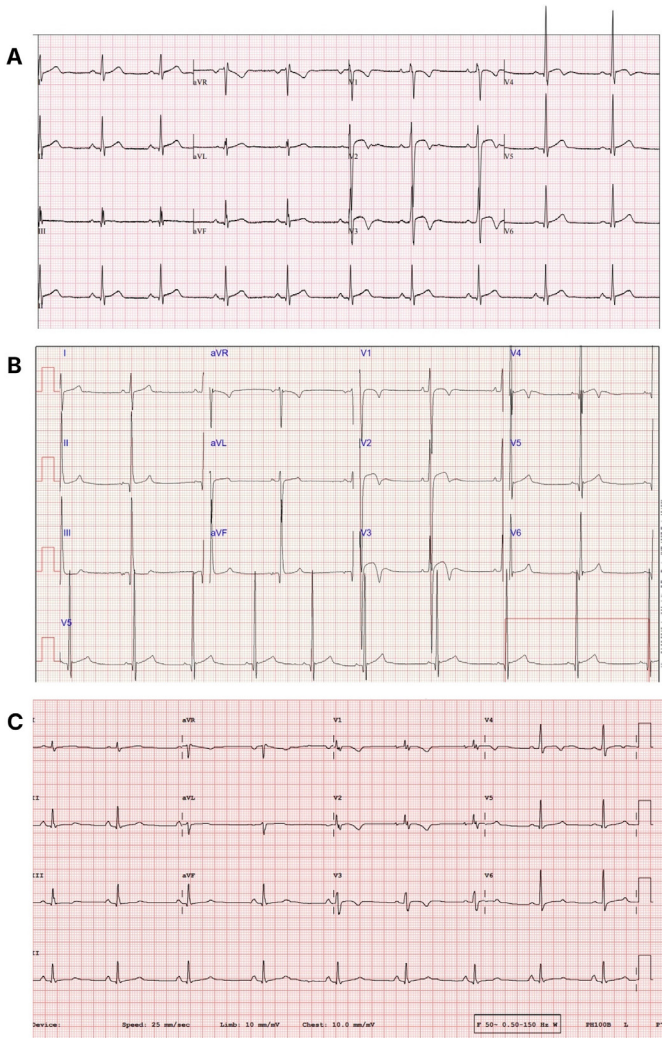



**Figure 1** 12-lead ECG of an athlete demonstrating the athlete anterior repolarisation pattern and arrhythmogenic cardiomyopathy. (A) Athlete anterior repolarisation pattern in a Black athlete, (B) Athlete anterior repolarisation pattern in a non-Black athlete and (C) ECG from the non-Black athlete diagnosed with arrhythmogenic cardiomyopathy, demonstrating isoelectric ST segments preceding T-wave inversion in $V_1$ to $V_4$.

In males, ST morphology was predominantly convex (n=280, 84.3%), followed by isoelectric (n=38, 11.4%) and concave (n=14, 4.2%). In females, isoelectric morphology predominated (n=31, 81.6%), with convex morphology present in a minority (n=7, 18.4%).

## Cardiac structure in both male and female athletes with anterior T-wave inversion

Male athletes with ATWI demonstrated larger right ventricular dimensions compared with male athletes without ATWI (table 1). There was no significant difference in left ventricular diameters and LV mass in male athletes with and without ATWI.

In contrast, there were no differences in left and right ventricular dimensions between female athletes with and without ATWI (table 2).



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**Table 1** Echocardiographic characteristics of male football players with anterior T-wave inversion

| | Male football players with anterior T-wave inversion (n=332) | Male football players without anterior T-wave inversion (n=8677) | P value |
|---|---|---|---|
| LV end-diastolic diameter (mm) | 50.7±3.8 | 51.0±4.2 | 0.16 |
| Indexed LV end-diastolic diameter (mm/m$^2$) | 26.5±2.1 | 26.7±2.3 | 0.09 |
| Maximal LV myocardial wall thickness (mm) | 9.2±1.2 | 9.2±1.3 | 1.0 |
| LV mass (g) | 167±36 | 167±35 | 1.0 |
| LV EF | 62.6±5.7 | 61.5±5.5 | <0.001 |
| RVD1 (mm) | 38.5±4.9 | 37.9±4.7 | 0.03 |
| Indexed RVD1 (mm/m$^2$) | 20.2±2.5 | 19.8±2.5 | 0.004 |
| RVD2 (mm) | 29.9±4.6 | 30.0±4.4 | 0.70 |
| RVD3 (mm) | 79.6±8.1 | 78.0±8.6 | <0.001 |
| RVOT (proximal) (mm) | 28.9±3.8 | 29.0±4.4 | 0.64 |

EF, ejection fraction; LV, left ventricle; RV, right ventricle; RVD, right ventricular diameter; RVOT, right ventricular outflow tract.

## Cardiac pathology in athletes with anterior T-wave inversion

Among 115 non-Black athletes who demonstrated ATWI, 49 (42.6%) athletes underwent one or more additional investigations at the request of the interpreting sports cardiologist due to further suspicion of cardiomyopathy. These included 42 (36.5%) with CMR, 37 (32.2%) with exercise stress test and 20 (17.4%) with prolonged cardiac rhythm monitoring.

Among 255 Black athletes who demonstrated ATWI, 26 (10.2%) athletes underwent one or more additional investigations at the request of the interpreting sports cardiologist. These included 17 (6.7%) with CMR, 15 (5.9%) with exercise stress testing and 8 (3.1%) with prolonged cardiac rhythm monitoring.

One (0.9%) non-Black male athlete was diagnosed with arrhythmogenic cardiomyopathy, while none of the Black athletes with ATWI demonstrated cardiac pathology associated with SCD (p=0.34). The single case of arrhythmogenic cardiomyopathy in the non-Black athlete demonstrated ATWI

**Table 2** Echocardiographic characteristics of female football players with anterior T-wave inversion

| | Female football players with anterior T-wave inversion (n=38) | Female football players without anterior T-wave inversion (n=1908) | P value |
|---|---|---|---|
| LV end-diastolic diameter (mm) | 47.8±4.4 | 47.9±3.6 | 0.27 |
| Indexed LV end-diastolic diameter (mm/m$^2$) | 27.7±2.8 | 27.8±2.3 | 0.83 |
| Maximal LV myocardial wall thickness (mm) | 8.1±1.2 | 8.0±1.0 | 0.61 |
| LV mass (g) | 124±27 | 125±24 | 0.82 |
| LV EF | 62.8±5.1 | 62.8±5.4 | 1.0 |
| RVD1 (mm) | 34.6±4.9 | 34.4±5.1 | 0.80 |
| Indexed RVD1 (mm/m$^2$) | 20.1±3.0 | 19.9±3.0 | 0.69 |
| RVD2 (mm) | 26.9±4.0 | 26.9±4.3 | 1.0 |
| RVD3 (mm) | 72.5±6.7 | 72.5±9.9 | 1.0 |
| RVOT (proximal) (mm) | 26.9±3.7 | 26.9±4.5 | 1.0 |

EF, ejection fraction; LV, left ventricle; RV, right ventricle; RVD, right ventricular diameter; RVOT, right ventricular outflow tract.

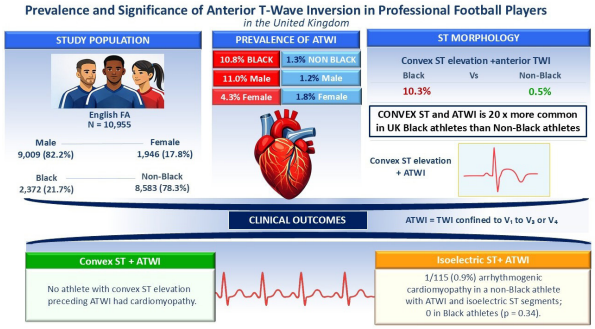



**Figure 2** Central graphic. ATWI, anterior T-wave inversion; FA, Football Association.

extending to lead V$_4$ with isoelectric ST-segments (figure 1). The diagnosis of arrhythmogenic cardiomyopathy was supported by right ventricular dilatation, ventricular tachycardia of right ventricular origin and a pathogenic desmoplakin gene variant. None of the Black or non-Black athletes with convex ST-segment elevation preceding ATWI was diagnosed with cardiomyopathy.

Minor cardiac pathology was diagnosed in two (1.7%) non-Black athletes with ATWI (one case of patent ductus arteriosus and one case with a moderate degree of valvular regurgitation) and four (1.6%) Black athletes with ATWI (one case of patent ductus arteriosus, one case with a moderate degree of valvular regurgitation and two cases of aortic root dilatation; p=1.0). Both Black and non-Black athletes with minor cardiac pathology did not demonstrate other concomitant ECG abnormalities apart from ATWI.

A central graphic summarises our key findings (figure 2).

## DISCUSSION

This study provides a contemporary description of ATWI in a large group of elite football players undergoing uniform ECG- and echocardiography-based screening in the UK. The principal finding is that the "athlete anterior repolarisation pattern" characterised by convex ST-segment elevation preceding ATWI was not associated with cardiomyopathy in either Black or non-Black athletes within this screening cohort. In the UK setting, this pattern was observed in 10.3% of Black athletes and 0.5% of non-Black athletes. By contrast, the only cardiomyopathy identified in an athlete with any ATWI occurred in a non-Black athlete with TWI extending to V$_4$ and isoelectric ST-segments. Male athletes with ATWI demonstrated modestly larger right ventricular dimensions on echocardiography, whereas no structural differences were observed between female athletes with and without ATWI.

The prevalence of ATWI in Black athletes in our study is broadly consistent with prior work in Black athletes,[9] where anterior repolarisation variants preceded by convex ST elevation are usually considered physiological. More recently, Rim *et al*[11] examined a multi-centre US cohort of competitive athletes and observed a 1.9% prevalence of the anterior repolarisation pattern, which was defined by J-point elevation with convex ST-segment elevation and associated ATWI extending to V$_3$ or V$_4$, among 1203 Black athletes. Taken together, these findings suggest that the prevalence of this repolarisation phenotype among Black athletes may vary across study populations and geographic settings, potentially reflecting differences in ancestral background, athlete mix and screening methodology.

Our data also provide insight into the ST-segment morphology preceding ATWI. More than 95% of Black athletes with ATWI



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demonstrated ST-segment elevation with convex morphology, mirroring the 'typical' repolarisation variant described in the 2017 International Criteria.[2] In contrast, only around half of non-Black athletes with ATWI showed ST-segment elevation and a substantial proportion had isoelectric ST-segments preceding the TWI.

We also observed important sex differences in the prevalence and potential structural significance of ATWI. Among Black footballers, ATWI was more prevalent in males, whereas in non-Black athletes ATWI was more frequently observed among females. Our findings among non-Black footballers align closely with a UK-based study which showed that females are more likely to demonstrate ATWI than males.[7] Similarly, a study of 4423 elite athletes from Australia and New Zealand also found that isolated ATWI to $V_2$ or $V_3$ was 4.2 times more common in females compared with males.[8]

In addition, this study demonstrated sex differences in the cardiac structural correlates of ATWI. While male footballers with ATWI demonstrated modestly increased right ventricular dimensions, there were no differences in either left ventricular or right ventricular size between female athletes with and without ATWI. These data support a nuanced, sex- and ethnicity-dependent interpretation of ATWI rather than a uniform threshold applied across all athletes.

## Clinical implications

Current recommendations treat ATWI (regardless of ST-segment morphology) beyond lead $V_2$ in non-Black athletes as an abnormal finding warranting further assessment, while emphasising that the absolute risk of cardiomyopathy remains low.[2] Our data suggest that risk is not uniform across ATWI phenotypes and support the use of preceding ST-segment morphology as an adjunct to contextualise ATWI during PPS. In particular, convex ST-segment elevation preceding ATWI (athlete anterior repolarisation pattern) appears to represent a low-risk phenotype, whereas isoelectric ST-segments, particularly when associated with TWI extending to lead $V_4$, may warrant further evaluation.

## Limitations

There are some limitations in this study, including its cross-sectional design. Long-term follow-up data on clinical events and possible later emergence of cardiomyopathy will not have been captured, so a small residual risk cannot be excluded. Our study cohort was from a single sporting discipline, which may limit generalisability to other sports or other competition levels. In addition, ethnicity was categorised as Black and non-Black. Although this approach was pragmatic and aligned with the ethnicity-based framework of the 2017 International Criteria, it oversimplifies ethnic diversity and limits the generalisability of our findings to Black and non-Black athletes only, with other ethnic groups under-represented in the study. In addition, downstream investigations in athletes with ATWI were directed by expert sports cardiologists within the screening pathway. Although all athletes underwent baseline PPS including a health questionnaire, ECG and echocardiography, this approach introduces the possibility of verification bias, and occult pathology in athletes not referred for further advanced testing cannot be completely excluded. Finally, these findings reflect a UK-based experience, which may well differ from other geographical regions globally.

## CONCLUSION

In a large cohort of elite football players undergoing uniform screening with ECG and echocardiography in the UK, the "athlete anterior repolarisation pattern" characterised by convex ST-segment elevation preceding ATWI was not associated with cardiomyopathy after comprehensive downstream investigation regardless of ethnicity. This pattern was observed in 10.3% of Black athletes and 0.5% of non-Black athletes. The only cardiomyopathy identified in an athlete with any ATWI occurred in a non-Black athlete with isoelectric ST-segment morphology extending to $V_4$. These findings support the view that convex ST-segment elevation preceding ATWI is a low-risk repolarisation phenotype, whereas ATWI with isoelectric ST-segments, particularly when extending to $V_4$, may warrant further evaluation.

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**Contributors** All authors meet the requirements for authorship. CMC, SS and AM were responsible for study conception design. DA, MB, PC, RMC, AK, DO, KP, DhR, DaR, TR, AMV, JW, ZY, SS and AM were responsible for data acquisition. KY and AM were responsible for data analysis. All authors contributed to the critical discussion and interpretation of results. KY drafted the initial manuscript. All authors critically reviewed and revised the manuscript. All authors approved the final version of the manuscript prior to submission. AM, as the corresponding author, is responsible for the overall content as the guarantor.

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**Patient and public involvement** Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

**Patient consent for publication** Consent obtained directly from patient(s).

**Ethics approval** The protocol underwent internal governance review by the FA in accordance with its research governance procedures. The study utilised data collected through the Football Association's established cardiovascular screening programme, with athlete consent, data governance and data use overseen in accordance with Football Association legal and governance requirements. The age of informed consent in the United Kingdom (UK) is 16 years, with parental or guardian consent sought for those under this age.

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**Data availability statement** No data are available.

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