Imaging associations enhance the understanding of ECG abnormalities in male Brazilian football players: findings from the B-Pro Foot ECG study

Filipe Ferrari ,[1,2] Anderson D da Silveira ,[1,2,3] Patrícia K Ziegelmann ,[1,4] Haroldo Aleixo ,[5] Guilherme D Dilda,[6] Luiz G M Emed,[7] Flávia C O Magalhães ,[5] Fernando B Cardoso,[8] Henrique C da Silva,[9] Felipe E F Guerra,[10] Luciano G Soares,[11] Fernando Bassan ,[12] Fabrício Braga ,[13] Artur H Herdy ,[14] Victor Froelicher ,[15] Ricardo Stein ,[1,2,16] for the B-Pro Foot ECG Collaborators

► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/bjsports-2023-108053).

For numbered affiliations see end of article.

Correspondence to
Ricardo Stein, Universidade Federal do Rio Grande do Sul, Porto Alegre 90035-903, Brazil; rstein@cardiol.br

Accepted 29 March 2024
Published Online First
15 April 2024

ABSTRACT

Objectives To evaluate the prevalence of abnormal ECG findings and their association with imaging results in male Brazilian football players.

Methods The 'B-Pro Foot ECG' is a multicentre observational study conducted in 82 Brazilian professional clubs. It analysed 6125 players aged 15–35 years (2496 white, 2004 mixed-race and 1625 black individuals) who underwent cardiovascular screening from 2002 to 2023. All ECGs were reviewed by two experienced cardiologists in the athlete's care. Those with abnormal findings underwent further investigations, including a transthoracic echocardiogram (TTE). Cardiac magnetic resonance (CMR) was subsequently performed based on TTE findings or clinical suspicion.

Results In total, 180 (3%) players had abnormal ECGs and 176 (98%) showed normal TTE results. Athletes aged 26–35 years had a higher prevalence of abnormal ECGs than younger athletes (15–25 years). Black players had a higher prevalence of T-wave inversion (TWI) in the inferior leads than white players (2.6% vs 1.4%; p=0.005), as well as in V5 (2.9%) and V6 (2.1%) compared with white (1.2% and 1.0%; p<0.001) and mixed-race (1.5% and 1.2%; p<0.05) players, respectively. TTE parameters were similar across ethnicities. However, four out of 75 players with inferolateral TWI showed abnormal TTEs and CMR findings consistent with cardiomyopathies. CMR also showed cardiomyopathies or myocarditis in four players with inferolateral TWI and normal TTEs. In total, nine (0.1%) athletes were diagnosed with cardiac diseases and were followed for 40±30 months, with no cardiac events documented.

Conclusion This study found a 3% prevalence of abnormal ECGs in male Brazilian football players. Inferolateral TWI was associated with cardiac pathologies confirmed by CMR, even in athletes with a normal TTE.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Black athletes are more likely to have abnormal ECG findings, such as T-wave inversion, than white athletes.
⇒ Athletes of African/Afro-Caribbean descent show a higher prevalence of echocardiographic left ventricular hypertrophy than white athletes.
⇒ ECG research has focused on individuals of European or African descent and with limited data in other ethnicities.

WHAT THIS STUDY ADDS

⇒ This multicentre observational study is the first extensive investigation of abnormal ECG results and their association with advanced cardiac imaging in male Brazilian football players of different ethnicities.
⇒ In male Brazilian football players with inferolateral T-wave inversion on their ECG, a normal transthoracic echocardiogram does not exclude cardiac pathology that can be identified by cardiac magnetic resonance.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This study demonstrated the ECG profile of an ethnically diverse male Brazilian athletic population, demonstrating a low (3%) overall rate of ECG abnormalities.
⇒ Cardiac magnetic resonance is needed to adequately evaluate athletes with inferolateral T-wave inversion in their ECG.

INTRODUCTION

The role of preparticipation cardiovascular screening in identifying underlying cardiovascular diseases and preventing sudden cardiac death in athletes is pivotal. Typically, this screening involves a 12-lead resting ECG and may require additional testing, such as transthoracic echocardiogram (TTE) or, in some cases, cardiac magnetic resonance (CMR).[1] An 'athlete's heart' may display structural and electrical cardiac adaptations considered physiologic and related to regular exercise.[2] Athletes may also have underlying cardiac conditions associated with sudden cardiac death, including cardiomyopathies and channelopathies.[2]

For over four decades, Italy has pioneered the implementation of a national preparticipation exam (PPE), including an ECG. The evidence collected underscores the key role of the ECG in identifying cardiac diseases at risk of potentially life-threatening arrhythmias. This initiative has contributed to a remarkable 89% reduction in mortality among

To cite: Ferrari F, da Silveira AD, Ziegelmann PK, *et al*. *Br J Sports Med* 2024;**58**:598–605.

young competitive athletes under 35 years.[3 4] However, it is essential to acknowledge that factors such as ethnicity can influence the interpretation of an athletes' ECG.[5]

The study of the ECG in male Brazilian football players holds paramount importance for several reasons. First, football is the most widely practised and popular sport in Brazil, with the Brazilian Football Confederation consisting of 1276 clubs in 2022.[6] Furthermore, as the International Centre for Sports Studies highlighted, Brazil became the leading exporter of football players in the world during the 2022–2023 season.[7] This position underscores the importance of understanding the distinct characteristics of Brazilian players' ECGs. Second, Brazil represents a highly diverse country,[8] encompassing a population with numerous races and ethnicities. This diversity implies that Brazilian athletes may show unique peculiarities that could potentially influence and impact their ECG results. Third, existing guidelines for interpreting athlete ECGs disregard individuals of mixed-race ethnicity.[1] The absence of dedicated considerations for this ethnic group means that the evaluation of these players often relies on extrapolating information from studies done in other regions and in athletes of other ethnic and racial backgrounds. Therefore, conducting a comprehensive study on the ECGs of male Brazilian football players will inform more inclusive and accurate guidelines for the PPE.

METHODS

Study design and data sources

The B-Pro Foot ECG is a multicentre observational study conducted across all five geographical regions of Brazil (18 states and 56 cities as per online supplemental table S1). This study involved collecting PPE data from players who underwent cardiovascular screening across 82 professional football clubs from 18 February 2002 to 18 September 2023 (figure 1). The sample came from all 20 first-division football teams and 18 out of 20 second-division football teams participating in the 2023 Brazilian football championship. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines.

The International Federation of Football Association and the Brazilian Football Confederation adhere to policies endorsing an annual PPE for every athlete from federated clubs. This screening encompasses a cardiovascular-focused history, physical examination and an ECG. Athletes with abnormal ECG findings suggesting pathologies underwent further investigation at the discretion of the club's physician. This included TTE to rule out cardiomyopathies and other structural abnormalities. CMR imaging was reserved for athletes with abnormal TTE results, and a few clubs routinely performed CMR, regardless of TTE findings, when inferolateral T-wave inversion (TWI) was identified. Notably, some well-funded Brazilian clubs perform TTE on all athletes, irrespective of initial screening results. For athletes with multiple PPE assessments across years, only the most recent data were used. To ensure a comprehensive evaluation and avoid underestimating cardiac disease prevalence, for athletes with a cardiac diagnosis, we restricted our analysis to PPE data closest to the diagnosis date. Additionally, only TTE data from athletes with abnormal ECG findings were included. Athletes diagnosed with cardiac disease were followed until 31 December 2023, starting from their diagnosis date.

Participants

All subjects were males aged from 15 to 35 years who engaged in professional football. Additional recorded information included

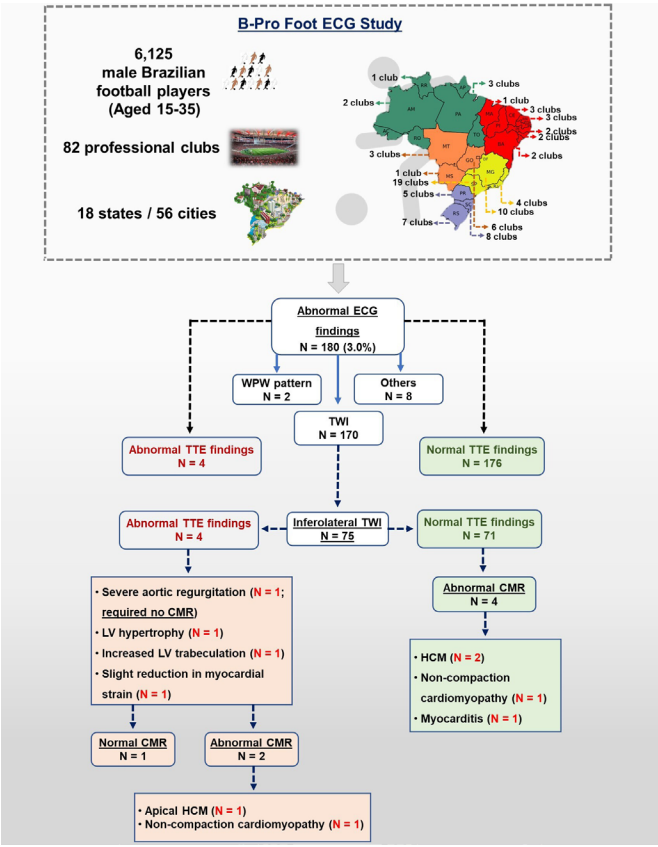

Figure 1 The B-Pro Foot ECG study. CMR, cardiac magnetic resonance; HCM, hypertrophic cardiomyopathy; LV, left ventricular; TTE, transthoracic echocardiogram; TWI, T-wave inversion; WPW, Wolff-Parkinson-White.

ethnicity, height, body weight, body mass index (BMI) and field position. Key exclusion criteria comprised foreign nationalities or players lacking important demographic information, such as age or ethnicity. Ethnicity was determined by examination of skin colour and phenotypic characteristics, such as nose shape and hair texture, gathering data on individuals' racial identities. Athletes displaying a blend of skin colours between white or yellow and black or indigenous were categorised as 'mixed-race'.[9]

12-lead resting ECG

Standard ECGs were conducted using either a Wincardio System (Micromed, DF, Brazil), EP 12 digital apparatus (Dixtal, SP, Brazil) or a digital ECG PC (TEB, V.5.0, MG, Brazil). The ECG analysis was performed with a paper speed of 25 mm/s and a voltage of 10 mm/mV, using the latest international expert's consensus for interpreting athlete ECGs.[1] The prevalence of specific abnormal ECG patterns in players from various ethnicities was compared, and their associations with TTE and CMR findings explored. The prevalence of abnormal ECGs was further examined by age group and field position. The initial interpretation of the ECGs was conducted by a researcher (FF) with extensive training and experience in athlete ECG interpretation. Subsequently, two cardiologists with expertise in sports cardiology (ADS and RS) independently assessed the ECGs, blinded to athlete characteristics. Any discrepancies in interpretation (below 2%) were resolved by consensus. To ensure the precise analysis of parameters such as wave durations, amplitudes, axes, segments, J-point and intervals, the ECGs were scanned

and magnified on a computer. All variables were recorded on a Microsoft Excel spreadsheet.

ECGs were considered abnormal based on the International Criteria for ECG interpretation in athletes, including the presence of two or more borderline ECG criteria.[1] For detailed information regarding the criteria used to classify any ECG changes as 'abnormal' refer to online supplemental table S2.

Transthoracic echocardiogram

TTE was conducted using ultrasound machines, including Affiniti 30 (Philips, USA), Affiniti 70 (Philips, USA), Philips CX 50 (Philips, USA), EnVisor C HD (Philips, USA) or ATL Ultramark 8 or 9 equipment (Bothell, USA). The examination was performed by cardiologists with experience in athlete TTE. First, the athletes are positioned in lateral decubitus and the standard measurements were obtained using the two-dimensional mode parasternal view. The ejection fraction was calculated using the Teicholz method, determined by the ratio of the difference between the left ventricular end-diastolic dimension and the left ventricular end-systolic dimension to the left ventricular end-diastolic dimension. To calculate left ventricular mass, the Devereux formula was used as indexed to body surface area.[10] All TTE were analysed by two independent cardiologists (ADS and RS).

Cardiac magnetic resonance

CMR imaging was used to evaluate potential hypertrophic cardiomyopathy (HCM) and myocarditis. Scans were conducted using cine-magnetic resonance imaging and delayed-enhancement gadolinium-enhanced imaging. The segmental analysis followed the conventional American Heart Association (AHA) 17-segment model,[11] and cavity measurements were based on Kawel-Boehm *et al*.[12] All CMR examinations were carried out in specialised centres.

Statistical analyses

Continuous variables were described as means±SD or medians and quartiles when appropriate, whereas categorical variables were presented as frequencies and percentages. The Shapiro-Wilk test and visual analysis (histograms) were used to assess distribution normality. Poisson's regression model with robust variance was used to assess potential associations between abnormal ECG patterns and demographic factors (age, ethnicity and BMI). Association results were expressed as prevalence ratios (PR) with a 95% CI. Factors with an association<0.20 in univariable models were included in the multivariable model, and a p value<0.05 was considered significant in the multivariable model (and thus maintained in it). Statistical analyses were performed using R, V.4.3.2. The statistical analysis and presentation are consistent with the Checklist for statistical Assessment of Medical Papers.[13]

Equity, diversity and inclusion statement

Our research team comprises researchers from the five demographic regions of Brazil. The population encompassed in our study was diverse, with age range from 15 to 35 years with three ethnicities (white, mixed-race and black) from any socioeconomic background. Study findings may not be generalisable to female athletes or athletes from different geographic regions.

Table 1 Demographic characteristics of male Brazilian football players

	Total (n=6125)	Normal ECG patterns (n=5945)	Abnormal ECG patterns (n=180)
Age (y)	18 (16–23)	18 (16–23)	20 (17–26)
15–17	2498 (40.8)	2441 (41.1)	57 (31.7)
18–25	2526 (41.2)	2452 (41.2)	74 (41.1)
26–35	1101 (18.0)	1052 (17.7)	49 (27.2)
Ethnicity			
White	2496 (40.8)	2426 (40.8)	70 (38.9)
Mixed-race	2004 (32.7)	1946 (32.7)	58 (32.2)
Black	1625 (26.5)	1573 (26.5)	52 (28.9)
Height (cm)	178±9	178±8	177±7
Weight (kg)	72±9	72±9	72±9
BMI			
≤18.5 kg/m²	62 (1.0)	60 (1.0)	2 (1.1)
18.4–24.9 kg/m²	5445 (89.0)	5293 (89.0)	152 (84.5)
≥25.0 kg/m²	618 (10.0)	592 (10.0)	26 (14.4)
Field position			
Goalkeeper	588 (9.6)	582 (9.8)	6 (3.3)
Centre-back	1131 (18.5)	1105 (18.6)	26 (14.4)
Wing-back	852 (13.9)	827 (13.9)	25 (13.9)
Midfielder	1992 (32.5)	1926 (32.4)	66 (36.7)
Forward	1562 (25.5)	1505 (25.3)	57 (31.7)

Age: data expressed as median (IQR). Height and weight: data expressed as mean±SD.

RESULTS

Of 6125 players, 2496 (40.8%) were white, 2004 (32.7%) were mixed-race, 1625 (26.5%) were black, and the median (IQR) age was 18 (16–23) years. There were 588 goalkeepers, 1131 defenders (or centre-backs), 852 wing-backs (right or left), 1992 midfielders and 1562 forwards. Table 1 shows the demographic characteristics of the players. In the entire sample, 180 (3%) athletes showed abnormal ECGs, leading to imaging examinations. The most prevalent ECG abnormality was TWI, accounting for 94% of abnormal cases (170/180).

Abnormal ECG changes

Associated factors with an abnormal ECG pattern

Individuals in the higher age group (26–35 years) had a significantly higher prevalence of abnormal ECG patterns than adolescents aged 15–17 years (adjusted PR: 2.01; 95% CI: 1.37 to 2.96; p<0.001) and those aged 18–25 years (adjusted PR: 1.56; 95% CI: 1.09 to 2.24; p=0.02). Midfielders and forwards showed a higher prevalence of abnormal ECG than goalkeepers (adjusted PR: 2.99; 95% CI, 1.39 to 6.40; p=0.005) and centre-backs or wing-backs (adjusted PR: 1.41; 95% CI, 1.01 to 1.96; p=0.04). This association also remained significant after adjusting for age. However, this study found no significant associations between ethnicity, BMI and an abnormal ECG, as indicated in online supplemental table S3.

Abnormal training-unrelated ECG changes

Black athletes exhibited a higher prevalence of inferior TWI (leads II and aVF) than white athletes (2.6% vs 1.4%, respectively; adjusted PR: 1.9; 95% CI, 1.2 to 3.0; p=0.005). There was no difference in the prevalence of anterior TWI (leads V2–V4) between white and mixed-race players (0.4% vs 0.3%,

Table 2 T-wave inversion in male Brazilian football players

ECG territory	Total (n=6125)	White players (n=2496)	Mixed-race players (n=2004)	Black players (n=1625)	P value
Leads II and aVF (%)	119 (1.9)	35 (1.4)	41 (2.0)	43 (2.6)	Black vs white: **p=0.005** Mixed-race vs white: p=0.10 Black vs mixed-race: p=0.24
Leads V2–V4 (%)	44 (0.7)	9 (0.4)	6 (0.3)	29 (1.8)*	Black vs white: **p<0.001** White vs mixed-race: p=0.73 Black vs mixed-race: **p<0.001**
Lead V5 (%)	108 (1.8)	31 (1.2)	30 (1.5)	47 (2.9)	Black vs white: **p<0.001** Mixed-race vs white: p=0.46 Black vs mixed-race: p=**0.005**
Lead V6 (%)	84 (1.4)	26 (1.0)	24 (1.2)	34 (2.1)	Black vs white: p=**0.008** Mixed-race vs white: p=0.62 Black vs mixed-race: **p=0.04**
Leads II and aVF+V5 and/or V6 (%)	75 (1.2)	23 (0.9)	24 (1.2)	28 (1.7)	Black vs white: **p=0.02** Mixed-race vs white: p=0.37 Black vs mixed-race: p=0.17

*All 29 black athletes presented J-point elevation and convex ST-segment elevation, a pattern considered as a normal repolarisation variant. Values shown in bold are statistically significant.

respectively; p=0.73). No black athlete presented TWI of V1–V4 without J-point elevation and convex ST-segment elevation, a pattern considered a normal repolarisation variant in athletes of Afro-Caribbean descent.[1]

In our study, both white and mixed-race athletes identified as having abnormal anterior TWI, exhibited a repolarisation pattern similar to black athletes ('Afro-Caribbean pattern'). In the entire sample, black players also exhibited a higher prevalence of TWI in leads V5 (2.9%) and V6 (2.1%) than their white counterparts (1.2% and 1.0%), respectively. The adjusted PR was 2.3 (95% CI, 1.5 to 3.7; p<0.001) for lead V5 and 2.0 (95% CI, 1.2 to 3.3; p=0.008) for lead V6. Black athletes also had a higher prevalence of TWI in leads V5 and V6 than mixed-race athletes (2.9% and 2.1% vs 1.5% and 1.2%, respectively), with an adjusted PR of 1.9 (95% CI, 1.2 to 3.0; p=0.005) for lead V5 and 1.7 (95% CI, 1.0 to 3.0; p=0.04) for lead V6. Finally, black athletes exhibited a higher prevalence of inferolateral TWI (leads II and aVF+V5 and/or V6) compared with white athletes (adjusted PR: 1.89; 95% CI, 1.09 to 3.28; p=0.02) (table 2 and figure 2).

Only one athlete (0.02%) exhibited a QRS duration exceeding 140 ms (online supplemental figure S1) and another athlete (0.02%) had a PR interval≥400 ms (online supplemental figure S2). In total, two athletes (0.03%) showed Wolff-Parkinson-White pattern (online supplemental figure S3) and three other

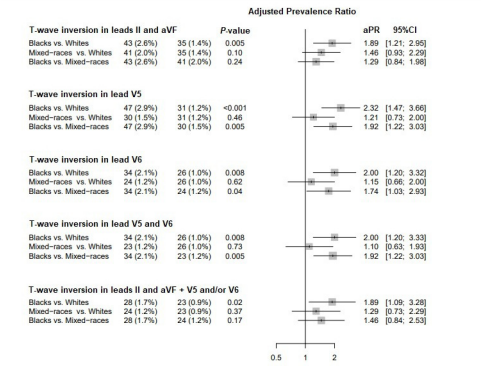

Figure 2 Prevalence of inferior, lateral and inferolateral T-wave inversion in male Brazilian football players. aPR, adjusted prevalence ratio.

athletes (0.05%) had ≥2 premature ventricular contractions (online supplemental figure S4). Out of the entire study population, only one athlete (0.02%) exhibited two borderline findings: complete right bundle branch block with right axis deviation (online supplemental figure S5). No athletes had profound bradycardia (<30 bpm), prolonged corrected QT interval, pathological Q waves, epsilon wave, Brugada type 1 pattern, left bundle branch block, Mobitz type II second-degree atrioventricular block or third-degree atrioventricular block. Table 3 describes the prevalence of abnormal ECG results for each group.

Further cardiovascular evaluation with imaging examinations

Transthoracic echocardiogram

Of the 180 players with abnormal ECG changes, all underwent TTE. However, only four (2.2%) had abnormal TTE findings, all of which showed inferolateral TWI. The first player (black, aged 26) showed left ventricular hypertrophy, characterised by an interventricular septum measuring 13 mm. The second player (white, aged 18) showed increased left ventricular trabeculation in the apical segments. The third player (mixed-race, aged 20) showed a slight reduction in myocardial strain with hypertrophy in the basal portion of the interventricular septum (measuring 12 mm). Finally, the fourth player (white, aged 17) had a bicuspid aortic valve with severe aortic regurgitation. Overall, TTE parameters were similar across all groups (online supplemental table S4).

Cardiac magnetic resonance

A total of 18 athletes (all with inferolateral TWI) underwent CMR evaluation. Of the four players with inferolateral TWI and abnormal TTE findings (described above), one had severe aortic regurgitation and required no CMR. The remaining three underwent CMR. The first player with a 13 mm interventricular septum on TTE demonstrated apical HCM (16 mm) on CMR imaging (figure 3A). The second player exhibited definitive left ventricular non-compaction cardiomyopathy on CMR (figure 3B). This diagnosis was based on several findings: prominent trabeculations in the apical and midventricular segments, a non-compacted to compacted myocardium thickness ratio exceeding 2.3 during end-diastole, non-compacted myocardial mass greater than 25% and a non-compacted myocardial mass

Table 3 Abnormal ECG parameters of male Brazilian football players

Variable	Total (n=6125)	White players (n=2496)	Mixed-race players (n=2004)	Black players (n=1625)	P value
Prolonged QTc interval (%)	0	0	0	0	–
QRS≥140 ms (%)	1 (0.02)	1 (0.04)	0	0	–
PR interval≥400 ms (%)	1 (0.02)	0	0	1 (0.06)	–
Complete LBBB (%)	0	0	0	0	–
≥2 PVCs (%)	3 (0.05)	1 (0.04)	1 (0.05)	1 (0.06)	NS
Mobitz-type 2 AV block (%)	0	0	0	0	–
Third-degree AV block (%)	0	0	0	0	–
WPW pattern (%)	2 (0.03)	2 (0.08)	0	0	–
Brugada type 1 pattern (%)	0	0	0	0	–
Pathological Q waves (%)	0	0	0	0	–
ST-segment depression (%)	7 (0.1)	2 (0.08)	3 (0.1)	2 (0.1)	NS
Epsilon wave (%)	0	0	0	0	–
Abnormal TWI (%)	170 (2.8)	63 (2.5)	58 (2.9)	49 (3.0)	NS
Two borderline criteria					
RAD+complete RBBB (%)	1 (0.02)	1 (0.04)	0	0	–

AV, atrioventricular; LBBB, left bundle branch block; NS, not significant; PVCs, premature ventricular contractions; QTc, corrected QT interval; RAD, right axis deviation; RBBB, right bundle branch block; TWI, T-wave inversion; WPW, Wolff-Parkinson-White.

index exceeding 15 g/m². The third player with slightly reduced myocardial strain and hypertrophy in the basal portion of the interventricular septum on TTE had a normal CMR consistent with 'athlete's heart'.

Among the four players with inferolateral TWI patterns despite normal TTE results, CMR showed specific pathologies: a 30-year-old black player was diagnosed with HCM with a septal thickness of 15 mm and areas of fibrosis (figure 4A); a 24-year-old black player showed myocarditis in the apical segments, demonstrated by late gadolinium enhancement (figure 4B) and a 35-year-old white player showed HCM (online supplemental figure S6A). Additionally, an 18-year-old white athlete was diagnosed with an apical non-compaction cardiomyopathy. He fulfilled the same diagnostic criteria as the previously described case (online supplemental figure S6B).

Interventions and outcomes

In summary, nine athletes (0.1%) were diagnosed with cardiac diseases associated with sudden cardiac death and were subsequently followed for a mean duration of 40.3±29.5 months. Among them, two white athletes with a Wolff-Parkinson-White ECG pattern underwent catheter ablation with successful resolution of ventricular pre-excitation before returning to competitive activities. The player with a bicuspid aortic valve and severe aortic regurgitation underwent valve replacement surgery and later resumed playing football, although at an amateur level.

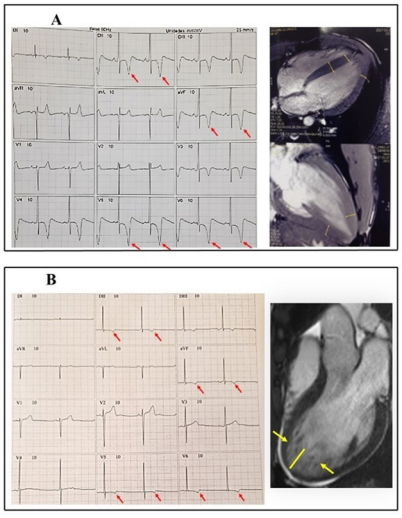

Figure 3 Two athlete ECGs with inferolateral TWI and CMR showing apical hypertrophic cardiomyopathy (A) and non-compaction cardiomyopathy (B). (A) The ECG showed symmetric and deep inferolateral TWI (red arrows). Cardiac magnetic resonance (CMR) imaging showed compatible findings with apical hypertrophic cardiomyopathy. (B)The ECG showed inferolateral TWI (red arrows). CMR showed increased left ventricular myocardial trabeculation (yellow arrows), compatible with non-compaction cardiomyopathy. TWI, T-wave inversion.

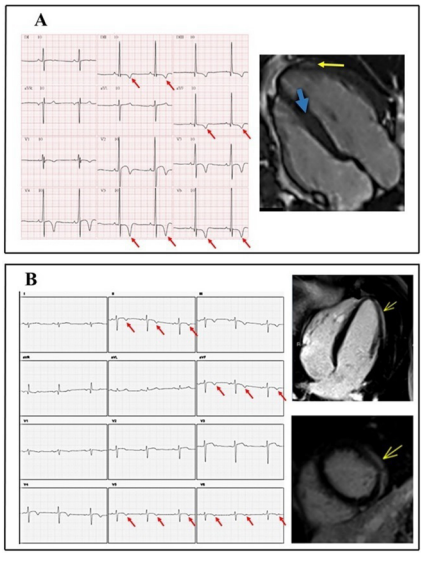

Figure 4 Two athlete ECGs with inferolateral TWI and CMR showing HCM (A) and myocarditis (B). (A) The ECG showed inferolateral TWI (red arrows). CMR imaging showed the presence of asymmetric septal hypertrophy (blue arrow) with signs of myocardial fibrosis (yellow arrow). (B) The ECG showed inferolateral TWI (red arrows). CMR imaging showed late gadolinium enhancement in apical segments (yellow arrows), suggestive of myocarditis. TWI, T-wave inversion.

The two white players with non-compaction cardiomyopathy opted to continue playing professionally, experiencing no adverse events during the study period. The player diagnosed with HCM and areas of fibrosis received advice against participation in competitive football, leading to his decision to end his professional career. The player with apical HCM, showing no signs of fibrosis on the CMR, continued to compete following a shared decision-making process. Notably, genetic testing using new generation sequencing method with a library of 104 genes related to HCM showed no related genetic variants. In another case of HCM, in which an athlete had slight junctional fibrosis detected on the CMR, he continued to compete, with recommended regular CMR follow-up every 6–12 months. Finally, the CMR imaging of a player diagnosed with myocarditis indicated the presence of late gadolinium enhancement in apical segments of the myocardium with systolic function and cavity volumes of both ventricles within normal limits. The athlete was temporarily removed from competitive activities (6 months) and successfully returned to competitive football without experiencing any adverse cardiac events. No potentially lethal ventricular arrhythmias or cases of sudden cardiac arrest occurred in this sample during the study period.

DISCUSSION

To the best of our knowledge, this research marks the first and largest multiethnic sample study to investigate the prevalence of abnormal ECG findings and their association with imaging results in male Brazilian football players.

Due to the growing importance of ethnicity as a potential determinant of cardiovascular changes in athletes, it becomes crucial to investigate and understand these patterns among Brazilian athletes of diverse ethnic backgrounds. Thus, this study sheds light on the unique cardiovascular profiles within this ethnically diverse athletic population. Such investigations are essential for informed decision-making, especially in the context of PPE screening in athletes. Our principal findings indicate that (1) the prevalence of abnormal ECGs in male Brazilian football players was 3%; (2) black players showed a higher prevalence of TWI in V5/V6 than white and mixed-race players; (3) nine athletes (0.1%) were diagnosed with serious cardiac disorders, including HCM, non-compaction cardiomyopathy, Wolff-Parkinson-White pattern, bicuspid aortic valve and severe valvar regurgitation, and myocarditis and (4) in male Brazilian football players with inferolateral TWI on the ECG, a routine TTE with normal results fails to exclude the possibility of underlying pathologic cardiac conditions.

This study found differences according to ethnicity in the prevalence of TWI. Consistent with previous studies,[14–16] we found that black athletes had a higher prevalence of TWI in the inferior, anterior and lateral leads than white athletes. Mixed-race and white players showed no significant differences in TWI occurrence, a novel finding of this study. Furthermore, while the presence of inferior TWI occurred more commonly in black athletes than in white athletes (2.6% vs 1.4%, respectively; p=0.005), black and mixed-race athletes showed no significant differences (2.6% vs 2.0%, respectively; p=0.24). This finding is consistent with results from Malhotra *et al*,[17] indicating a similar prevalence of inferior TWI in mixed-race and black athletes. Among black athletes in our sample, we observed a 2.1% prevalence of TWI in leads V5–V6. Notably, this percentage appears lower when compared with the prevalence of lateral TWI in black Africans, such as elite Ghanaian male football players (approximately 9%),[18] and differs from black athletes in the UK and France, in which the prevalence of lateral TWI is reported to be 4.1%.[5] The reasons for these disparities remain uncertain but may be attributed to ethnic diversity within the highly mixed Brazilian population. Our findings revealed a significantly lower prevalence of anterior TWI preceded by J-point elevation and convex ST-segment elevation in both white (0.4%) and mixed-race athletes (0.3%) compared with black athletes (1.8%). In our study, white and mixed-race athletes with this anterior TWI pattern also had a normal TTE. While few studies suggest that this pattern is normal in mixed-race[17] or white athletes,[19] further long-term longitudinal studies are warranted to confirm this hypothesis.

Imaging studies have shown that black athletes often exhibit greater left ventricular wall thickness on TTE than white players.[5] A large-scale study of competitive athletes revealed a higher prevalence of potentially abnormal TWI in Afro-Caribbean athletes compared with white athletes.[20] Furthermore, some athletes with TWI exhibited cardiac abnormalities linked to sudden cardiac death.[20] We found four male Brazilian players with inferolateral TWI and normal TTE results. However, CMR showed potentially dangerous cardiac conditions. Given these findings, additional CMR testing is recommended to obtain a more comprehensive assessment in athletes with inferolateral TWI, even if TTE results appear normal.

Consistent with our results, a previous study also supports the limitation of TTE in identifying cardiac disorders in athletes displaying inferolateral TWI.[20] Among the 69 athletes with pathological TWI and diagnosed with cardiac diseases, 14 showed normal TTE results at the initial evaluation. Indeed, the International Criteria for ECG interpretation in athletes supports routine CMR imaging for athletes with lateral or inferolateral TWI on ECG.[1]

In our sample, there is a positive association between increasing age and prevalence of abnormal ECG patterns in male Brazilian players. Particularly, older athletes (aged 26–35 years) showed a higher prevalence of abnormal ECGs than did those aged 15–17 years and 18–25 years. These data suggest that the cumulative effect of higher training loads and physical efforts over the years may influence the ECG patterns in male Brazilian players. Consistent with these findings, a study involving 519 National Basketball Association basketball athletes showed that individuals aged 27–39 years had a significantly higher prevalence of abnormal ECG results than those in the 18–22 age group (23% vs 9%; OR: 2.9; 95% CI, 1.6 to 5.4; p<0.001).[21] We also observed that midfielders and forwards showed a higher prevalence of abnormal ECG results than goalkeepers, centre-backs or wing-backs. The increased frequency of repetitive movements between attack and defence in these positions may induce greater cardiovascular adaptations, including left ventricular hypertrophy, thereby potentially increasing susceptibility to TWI. For instance, a study found that midfielders and forwards experience a higher average heart rate during a game than defensive players.[22] Taken together, these hypotheses possibly explain the observed results.

In our study, one athlete displayed a PR interval exceeding 400 ms, while another exhibited a QRS duration surpassing 140 ms. Orchard *et al*,[23] in their research of 1189 elite athletes engaged in over 15 sports in New Zealand, also reported a low prevalence of these occurrences (0.1%). Our study also demonstrates a low prevalence of the Wolff-Parkinson-White ECG pattern in male Brazilian players (0.03%). This is lower than findings in Malhotra *et al*[24] showing a 0.2% prevalence of WPW pattern among 11 168 adolescent football players in the UK.

Overall, 3% of our athletes exhibited an abnormal ECG pattern, and 0.1% manifested cardiac diseases. Comparable findings were noted in studies involving athletes from various sports. For instance, MacLachlan *et al*[25] examined 1208 elite cricket players in England and Wales, identifying abnormal ECG patterns in 3.3% of athletes, with 0.3% diagnosed with a major cardiac condition. Another study of roughly 1200 elite athletes in New Zealand from diverse sports revealed a similar percentage of abnormal ECGs, specifically 3.5%.[23]

Considerations regarding the implementation of the PPE are crucial. Highlighting the success of the Italian PPE programme, which achieved a 90% reduction in mortality among young competitive athletes,[3] another study in Italy involving over 22 000 young individuals (median age: 12 years) with an mean follow-up of 7.5 years underscores the efficacy of repeated cardiovascular assessments.[26] Serial evaluations demonstrated a higher diagnostic yield for cardiovascular diseases at risk of sudden cardiac death compared with a single preventive paediatric screening.[26] Furthermore, another study also conducted in Italy, involving a consecutive series of 15 127 competitive athletes aged 12–18 years, revealed that annual cardiovascular screening increased threefold the diagnostic yield of cardiovascular diseases with the risk of sudden cardiac death compared with a single initial assessment.[27] It is important to highlight that PPE with ECG offers distinct advantages, including earlier detection of cardiac diseases and potentially improved survival outcomes. However, accurately interpreting ECGs in athletes necessitates physicians with expertise in modern athlete-specific ECG interpretation standards and access to relevant cardiology resources. This ensures proper evaluation of any identified ECG abnormalities during the secondary assessment phase.

Recent decades have witnessed refinements in athlete ECG interpretation criteria. However, a critical need remains to address ethnic considerations in these criteria. As highlighted in a recent editorial by Grant *et al*,[28] tackling racial disparities in sports cardiology is essential. Our study adds valuable data to the understanding of ECG findings in a diverse population of Brazilian players.

What are the clinical implications?

The presence of inferolateral TWI on an athlete's ECG may signal a potential pathologic cardiac disease, even when a standard TTE shows no apparent abnormalities. This emphasises the importance of conducting CMR in athletes with inferolateral TWI, regardless of normal findings on TTE.

Strengths and limitations

Our study is strengthened by the large sample size of male Brazilian players which exceeds prior studies with smaller and less diverse cohorts. Inclusion of individuals from different ethnic backgrounds allows for a more comprehensive understanding of ECG findings in Brazilian athletes, a population previously understudied. In this context, as Brazil is currently the leading global exporter of football players, it is important for the international sports medicine community to appreciate the characteristics of ECGs in male Brazilian football players.

It is important to acknowledge several limitations in our study. First, the exclusive focus on football player's warrants caution when generalising to other sports across Brazil. Second, the absence of female athletes in our sample also restricts the broader applicability of our results. We excluded female athletes from this study due to the absence of an equally well-organised screening programme in Brazil. Third, the decision by a club's physicians to avoid CMR evaluations for athletes with inferolateral TWI may have underestimated diagnoses related to pathologic cardiac disease. Thus, it is important to note that our data originate from examinations requested by clubs, introducing a potential selection bias. Fourth, the study exclusively targeted football players aged from 15 to 35 years, which might have underestimated the prevalence of cardiac diseases in players outside this age range. Finally, athlete ethnicity was not self-reported, introducing a potential influence on the results. However, it is important to acknowledge the complexities in self-attributing ethnicity among Brazilians. The classification may vary, especially for individuals with greater financial means and/or fewer traces of African ancestry.[9]

CONCLUSION

In this large and diverse sample of male Brazilian football players, we observed a 3% prevalence of abnormal ECGs. This study found a higher prevalence of TWI in leads V5–V6 in black athletes than in white and mixed-race athletes. Importantly, normal TTE findings in our sample failed to exclude the presence of potentially life-threatening cardiac disease in individuals with inferolateral TWI on ECG, and CMR should be strongly considered in athletes with this markedly abnormal ECG pattern.

Author affiliations
[1]Graduate Program in Cardiology and Cardiovascular Sciences, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil
[2]Exercise Cardiology Research Group (CardioEx), Hospital de Clínicas de Porto Alegre, Porto Alegre, RS, Brazil
[3]Science, Health and Performance Department, Grêmio Foot-Ball Porto Alegrense, Porto Alegre, RS, Brazil
[4]Graduate Program in Epidemiology, Department of Statistics, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil
[5]Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil
[6]Sociedade Esportiva Palmeiras, São Paulo, SP, Brazil
[7]Instituto de Neurologia de Curitiba, Curitiba, PR, Brazil
[8]Cardiofit Campinas, Campinas, SP, Brazil
[9]Universidade Federal do Pará, Belém, PA, Brazil
[10]Clínica Biocardio, Natal, RN, Brazil
[11]Clínica Biocorfit Reabilitação Cardíaca Pulmonar e Metabólica, Goiânia, GO, Brazil
[12]Instituto Nacional de Cardiologia, Rio de Janeiro, RJ, Brazil
[13]Laboratorio de Performance Humana, Universidade Estadual do Rio de Janeiro, Rio de Janeiro, RJ, Brazil
[14]Instituto de Cardiologia de Santa Catarina, Florianópolis, SC, Brazil
[15]Department of Cardiovascular Medicine, Stanford University, Palo Alto, CA, USA
[16]Internal Medicine Department, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil

Collaborators The following are collaborators of B-Pro Foot ECG (Brazilian Professional Football Electrocardiogram): Ivan Zanella Arruda (Brazil), Luiz Fernando Ribeiro de Miranda Mourão (Brazil), José Nairo Júnior (Brazil), Marcelo Machado Arantes (Brazil), Márcio Dornelles (Brazil), Paulo Roberto Schvartzman (Brazil), Carla Tavares Felipe Vieira (Brazil), Rodrigo Otávio Bougleux Alô (Brazil), Valdir Torres (Brazil), Diogo Thadeu Meira (Brazil), Gabriel Faria Isfer Lima (Brazil), Frederico Porto Luciano Coimbra (Brazil), Filipe Cortez Duarte Barbosa (Brazil), Mateus Freitas Teixeira (Brazil), and Pedro Bruno Costa Murara (Brazil). All collaborators of the B-Pro Foot ECG project contributed data to this project.

Contributors Study conception and design: FF, ADdS and RS; data acquisition: FF, ADdS, HA, GDD, LGE, FCOM, FBC, HCdS, FEFG, LGS, AHH and RS; data interpretation: FF, ADdS, VF and RS; statistical analysis: FF and PKZ; manuscript writing: FF, ADdS, PKZ, HA, GDD, LGE, FCOM, FBC, HCdS, FEFG, LGS, FBa, FBr, AHH, VF and RS; critical revision of the manuscript for intellectual content: FF, ADdS, AHH, VF and RS. RS is the guarantor.

Funding This study was partially supported by Hospital de Clínicas de Porto Alegre Research Incentive Fund (FIPE-HCPA), Porto Alegre, Brazil, and by the Coordination for the Improvement of Higher Education-Brazil (CAPES)-Funding Code 001.

such expression remains solely that of the relevant source and is not endorsed by BMJ. Maps are provided without any warranty of any kind, either express or implied.

Competing interests RS is an Established Investigator of the National Council for Scientific and Technological Development (CNPq), Brasília, Brazil.

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 This study involves human participants. This study was approved by the Research Ethics Committee of the Research and Postgraduate Group of Hospital de Clínicas de Porto Alegre, Brazil (GPPG-HCPA; number: 2019-0050). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request.

ORCID iDs
Filipe Ferrari http://orcid.org/0000-0001-6929-8392
Anderson D da Silveira http://orcid.org/0000-0002-0327-3392
Patrícia K Ziegelmann http://orcid.org/0000-0002-2851-2011
Haroldo Aleixo http://orcid.org/0000-0001-6387-6198
Flávia C O Magalhães http://orcid.org/0000-0002-6467-1917
Fernando Bassan http://orcid.org/0000-0002-0179-4661
Fabrício Braga http://orcid.org/0000-0002-7062-1705
Artur H Herdy http://orcid.org/0000-0001-9263-5916
Victor Froelicher http://orcid.org/0000-0001-8831-4853
Ricardo Stein http://orcid.org/0000-0003-2357-5176

REFERENCES

1 Drezner JA, Sharma S, Baggish A, *et al*. International criteria for electrocardiographic interpretation in athletes: consensus statement. *Br J Sports Med* 2017;51:704–31.
2 Palermi S, Cavarretta E, D'Ascenzi F, *et al*. Athlete's heart: a cardiovascular step-by-step multimodality approach. *Rev Cardiovasc Med* 2023;24:151.
3 Corrado D, Basso C, Schiavon M, *et al*. Pre-participation screening of young competitive athletes for prevention of sudden cardiac death. *J Am Coll Cardiol* 2008;52:1981–9.
4 Corrado D, Basso C, Pavei A, *et al*. Trends in sudden cardiovascular death in young competitive athletes after implementation of a preparticipation screening program. *JAMA* 2006;296:1593–601.
5 Papadakis M, Carre F, Kervio G, *et al*. The prevalence, distribution, and clinical outcomes of electrocardiographic repolarization patterns in male athletes of African/Afro-Caribbean origin. *Eur Heart J* 2011;32:2304–13.
6 Confederação Brasileira de Futebol. Available: https://www.cbf.com.br/a-cbf/informes/index/em-alta-cbf-registrou-1-276-clubes-em-2022 [Accessed 8 Dec 2023].
7 Cnn Esportes. Available: https://www.cnnbrasil.com.br/esportes/brasil-e-o-pais-que-mais-exportou-jogadores-de-futebol-em-2022-23-veja-ranking/ [Accessed 10 Dec 2023].
8 Magalhães da Silva T, Sandhya Rani MR, de Oliveira Costa GN, *et al*. The correlation between ancestry and color in two cities of Northeast Brazil with contrasting ethnic compositions. *Eur J Hum Genet* 2015;23:984–9.
9 Osório RG. O Sistema Classificatório de "Cor Ou Raça" Do IBGE. IPEA - Instituto de Pesquisa Econômica Aplicada, 2003:1–53.
10 Lang RM, Bierig M, Devereux RB, *et al*. Recommendations for chamber Quantification: a report from the American Society of Echocardiography's guidelines and standards committee and the chamber quantification writing group, developed in conjunction with the European Association of echocardiography, a branch of the European Society of Cardiology. *J Am Soc Echocardiogr* 2005;18:1440–63.
11 Cerqueira MD, Weissman NJ, Dilsizian V, *et al*. American Heart Association writing group on myocardial Segmentation and registration for cardiac imaging: standardized myocardial Segmentation and nomenclature for Tomographic imaging of the heart: a statement for Healthcare professionals from the cardiac imaging committee of the Council on clinical cardiology of the American Heart Association. *Circulation* 2002;105:539–42.
12 Kawel-Boehm N, Hetzel SJ, Ambale-Venkatesh B, *et al*. "Reference ranges ("normal values") for cardiovascular magnetic resonance (CMR) in adults and children: 2020 update". *J Cardiovasc Magn Reson* 2020;22:87.
13 Mansournia MA, Collins GS, Nielsen RO, *et al*. A checklist for statistical assessment of medical papers (the CHAMP statement): explanation and elaboration. *Br J Sports Med* 2021;55:1009–17.
14 Ozo U, Sharma S. The impact of ethnicity on cardiac adaptation. *Eur Cardiol* 2020;15:e61.
15 Basavarajaiah S, Boraita A, Whyte G, *et al*. Ethnic differences in left ventricular remodeling in highly-trained athletes relevance to differentiating physiologic left ventricular hypertrophy from hypertrophic cardiomyopathy. *J Am Coll Cardiol* 2008;51:2256–62.
16 Malhotra A, Dhutia H, Yeo T-J, *et al*. Accuracy of the 2017 International recommendations for clinicians who interpret adolescent athletes' ECGs: a cohort study of 11 168 British white and black soccer players. *Br J Sports Med* 2020;54:739–45.
17 Malhotra A, Oxborough D, Rao P, *et al*. Defining the normal spectrum of electrocardiographic and left ventricular adaptations in mixed-race male adolescent soccer players. *Circulation* 2021;143:94–6.
18 Pambo P, Adu-Adadey M, Agbodzakey H, *et al*. Electrocardiographic and echocardiographic findings in elite Ghanaian male soccer players. *Clin J Sport Med* 2021;31:e373–9.
19 Calore C, Zorzi A, Sheikh N, *et al*. Electrocardiographic anterior T-wave inversion in athletes of different ethnicities: differential diagnosis between athlete's heart and cardiomyopathy. *Eur Heart J* 2016;37:2515–27.
20 Schnell F, Riding N, O'Hanlon R, *et al*. Recognition and significance of pathological T-wave Inversions in athletes. *Circulation* 2015;131:165–73.
21 Waase MP, Mutharasan RK, Whang W, *et al*. Electrocardiographic findings in national basketball association athletes. *JAMA Cardiol* 2018;3:69–74.
22 Ali A, Farrally M. Recording soccer players' heart rates during matches. *J Sports Sci* 1991;9:183–9.
23 Orchard JJ, Orchard JW, Davis AJ, *et al*. Clinical outcomes of 10 years of cardiac screening in elite New Zealand athletes. *J Sci Med Sport* 2023;26:659–66.
24 Malhotra A, Dhutia H, Finocchiaro G, *et al*. Outcomes of cardiac screening in adolescent soccer players. *N Engl J Med* 2018;379:524–34.
25 MacLachlan H, Dhutia H, Bhatia R, *et al*. Results of a nationally implemented cardiac screening programme in elite cricket players in England and Wales. *J Sci Med Sport* 2022;25:287–92.
26 Sarto P, Zorzi A, Merlo L, *et al*. Value of screening for the risk of sudden cardiac death in young competitive athletes. *Eur Heart J* 2023;44:1084–92.
27 Sarto P, Zorzi A, Merlo L, *et al*. Serial versus single cardiovascular screening of adolescent athletes. *Circulation* 2021;143:1729–31.
28 Grant A, Krishnan S, Chukumerije M, *et al*. Reckoning with race in sports cardiology: a call to action. *Br J Sports Med* 2023;57:956–7.